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THE ABANDONED SHORE-LINES

OF

EASTERN WISCONSIN

BY

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The Nipissing beach ridge at Graceport.

PREFACE.

During recent years studies of the late glacial and post-glacial history of the Great Lakes have been carried on more thoroughly and more accurately than ever before. The well organized work of the United States Geological Survey, carried on under the direction of Dr. T. C. Chamberlin by Mr. Frank Leverett, Mr. F. B. Taylor, and Dr. W. C. Alden, supplemented by the work of Dr. A. C. Lane and his associates on the Geological Survey of Michigan, by Mr. H. L. Fairchild and Mr. J. B. Woodworth in New York, and others, has modified and extended previous knowledge on the subject to a remarkable degree. The ice-dam hypothesis of Dr. G. K. Gilbert, at first accepted with hesitation, has been abundantly demonstrated. The extent of successive ice-front lakes and their order of succession has received more careful attention than heretofore, and the time of occupation of the several old outlets has been studied with greater care, while the reconstruction of the extinct water-planes, now in warped or bent positions, forking and diverging, has at last been put on a sound basis, through observation rather than assumption. It may truly be said, however, that a synopsis of the late glacial history of the Great Lakes cannot be properly written until the entire region has been studied with the care which only certain parts have thus far received. The present report is offered as a contribution from Wisconsin.

In an introductory chapter will be found a brief resume of the development of the extinct lakes of the Great Lake region, and of their changes of configuration during the disappearance of the ice sheet and the attendant tiltings of the region. Following this is a more detailed review of previous studies of lakes Algonquin, Nipissing, and Chicago, in which attention is called

to various problems concerned in the history of these lakes, some of them still not wholly solved. The body of the report, however, is contained in the two later chapters, which describe the abandoned shore-lines of eastern Wisconsin and present in full the results of instrumental measurements of altitude. The present work will be found to differ from previous studies of the Great Lakes region mainly in the large amount of data collected within a comparatively small district, and in the accuracy of the measurements,—the wye level being used, rather than the aneroid barometer or the hand level. It is thought that the results of these detailed measurements, embodied in the reconstruction of the water-planes of the extinct lakes Algonquin and Nipissing (Plate XXXVII) fully justify the close attention which was given to this phase of the work.

The study of the shore-lines from Port Washington northward to Washington island and thence around Green Bay to Marinette occupied the greater part of July, August, and September, 1905; this was supplemented later in the fall by work in Kenosha and Racine counties. Most of the distance was traversed on foot; but gasoline fishing boats were used to great advantage in northern Door county, and railroads afforded quick transportation south of Manitowoc and north of the city of Green Bay. While the shore-lines were traced as continuously as practicable in the time allowed, greater value was placed upon a close examination of them at each locality where beaches were found well exposed, and on accurate measurements of altitude of the whole series of beaches by means of the wye level.

In the leveling, photographing and examination of the old shorelines, Mr. W. J. Reed gave valuable assistance. Acknowledgment is here made of kind and helpful counsel from Dr. Chamberlin, Mr. Leverett, Mr. Taylor, Dr. Alden, Dr. Lane and others familiar with the problems of Great Lake history. To Dr. E. A. Birge, the Director of this Survey, the writer is indebted for repeated favors and encouragement.

A typewritten copy of the report was submitted and accepted as a thesis for the degree of Doctor of Philosophy at Harvard University in May 1906.

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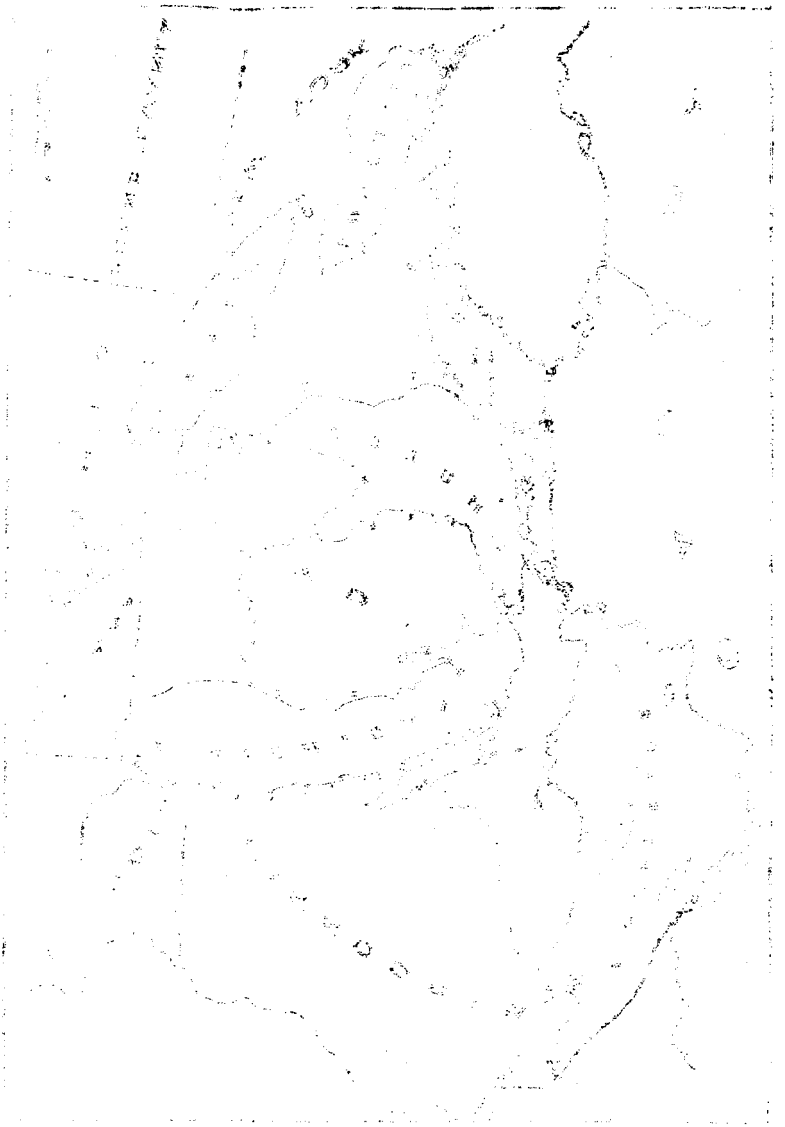

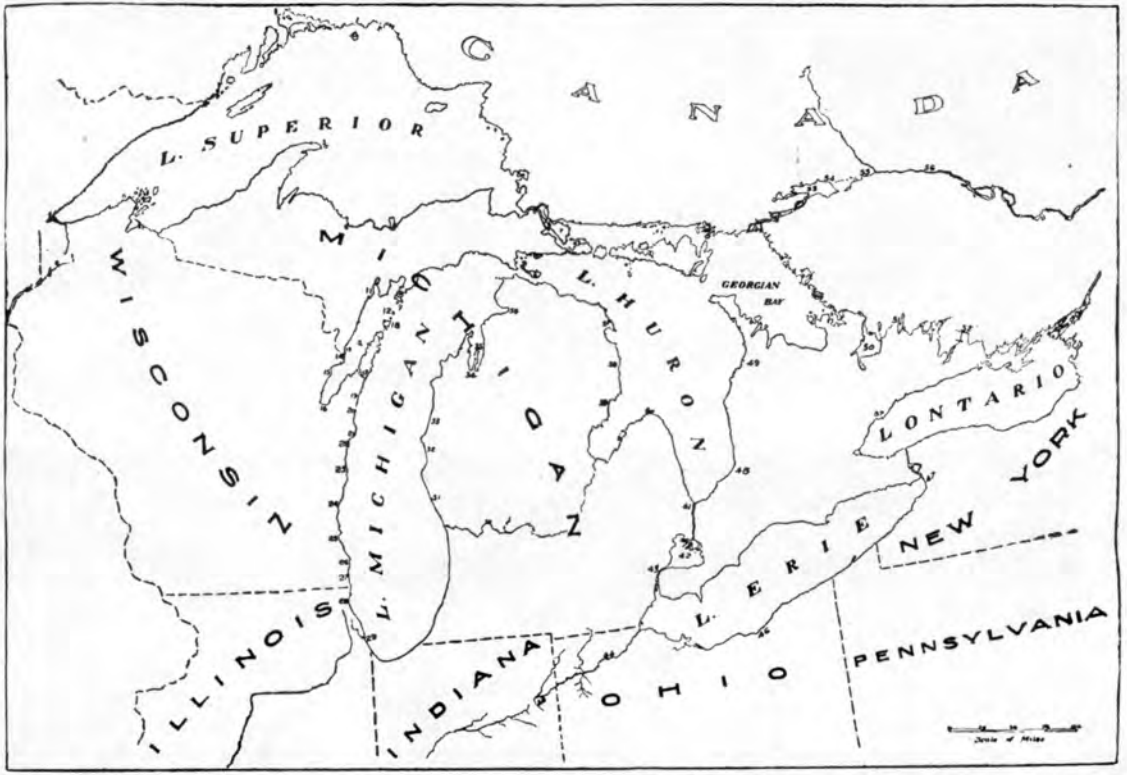

Location map of the region about the Great Lakes. 1, Duluth. 2, St. Croix River. 3, Keweenaw Pt. 4, Port Arthur. 5, Marquette. 6, Sault Ste. Marie. 7, Drummond I. 8, Bois Blanc I. 9, Mackinac I. 10, Garden Peninsula. 11, Escanaba. 12, St. Martin's I. 13, Menominee. 14, Marinette. 15, Oconto. 16, Green Bay. 17, Sturgeon Bay. 18, Washington I. 19, Algoma. 20, Kewaunee. 21, Two Rivers. 22, Manitowoc. 23, Sheboygan. 24, Port Washington. 25, Milwaukee. 26, Racine. 27, Kenosha. 28, Waukegan. 29, Chicago. 30, Grand Rapids. 31, Whitehall. 32, Ludington. 33, Manistee. 34, Traverse City. 35, Grand Traverse Bay. 36, Petoskey. 37, Alpena. 38, Harrisville. 39, Tawas City. 40, Pt. aux Barques. 41, Port Huron. 42, Lake St. Clair. 43, Detroit. 44, Defiance. 45, Fort Wayne. 46, Cleveland. 47, Buffalo. 48, Great Bend. 49, Southampton. 50, Lake Simcoe. 51, Balsam Lake. 52, Trent River. 53, Lake Nipissing. 54, North Bay. 55, Mattawa River. 56, Ottawa River. 57, Toronto.

THE ABANDONED SHORE LINES OF EASTERN WISCONSIN.

CHAPTER I.

INTRODUCTION.

As one of the eight states which border on the great Laurentian lakes, Wisconsin possesses a share of the records of the still greater lakes of late glacial time. The northwest corner of the state, near the south Superior shore, contains a large series of abandoned high level shore-lines which have as yet received little attention; but from studies on the north Superior shore, in the upper peninsula of Michigan, and elsewhere, it is known that these old shore-lines mark out the successive boundaries of an ancestral line of lakes Duluth, Algonquin, and Nipissing. The eastern part of the state, where it borders on Lake Michigan and Green Bay, holds a similar record of extinct high-level lakes. To be sure, this record has been marred and in many places totally destroyed by natural processes, during the scores of centuries which have elapsed since Lake Michigan took its present form, but enough fragments of the earlier lakes of the Michigan basin—lakes Chicago, Algonquin, and Nipissing—remain to furnish interesting material for a study of the genealogy of Lake Michigan.

Since two of these extinct lakes, Algonquin and Nipissing, were not confined to the Michigan basin, but in turn overspread the combined areas of Superior, Michigan, and Huron, and since their history is complicated by a long series of earth move-

ments which affected not only Wisconsin but nearly the whole of the Great Lake region, the abandoned shore-lines must be studied in the light of similar knowledge from neighboring states and from the Canadian shores. A review of the history of the extinct lakes, in brief outline, may serve as an introduction to the more complex matters set forth in later chapters.

OUTLINE OF THE HISTORY OF THE EXTINCT LAKES.

During the late Wisconsin stage of glaciation the Great Lake region was deeply buried beneath the great ice sheet. The influence of the several lake basins on the thickness of the ice and consequently on the velocity of its motion was expressed in the lobate border of the glacier, especially when the ice sheet diminished until definite tongues or lobes appeared not only in the main lake basins, Superior, Michigan, and Erie, but also in the secondary basins like Green Bay and Saginaw Bay. The slow uncovering of the southern and western ends of the lake basins, by the melting back of the ice border, gave birth to three ice-front lakes, Duluth, Chicago, and Maumee, blockaded on one side by the great ice dam and overflowing at the three lowest cols in the rims of the three basins.

Lake Chicago, in its early stages a crescent-shaped lake rimming the Michigan lobe, found its outlet southwestward into the Illinois river across a col near Chicago, at first at a height of 60 feet above Lake Michigan, but gradually reduced by the erosion of the river. Lake Maumee, the crescentic lake at the western end of the Erie basin, had its outlet first across the divide at Fort Wayne into the Wabash river. The two maps in Fig. 1 show two successive stages of the retreating ice front and the expanding lakes Chicago and Maumee.

While Lake Chicago stood at the 60-foot or "Glenwood" level, there seems to have been a readvance of the ice sheet as far south as the Milwaukee district; for gravel deposits, thought by Dr. W. C. Alden to belong to the Glenwood stage of Lake Chicago are exposed in the lake cliffs near Milwaukee, beneath ice-laid and water-laid red clay and about 60 feet above Lake Michigan. This readvance seems not to mark the close of the Glenwood stage, however; for a few fragmentary beach ridges were

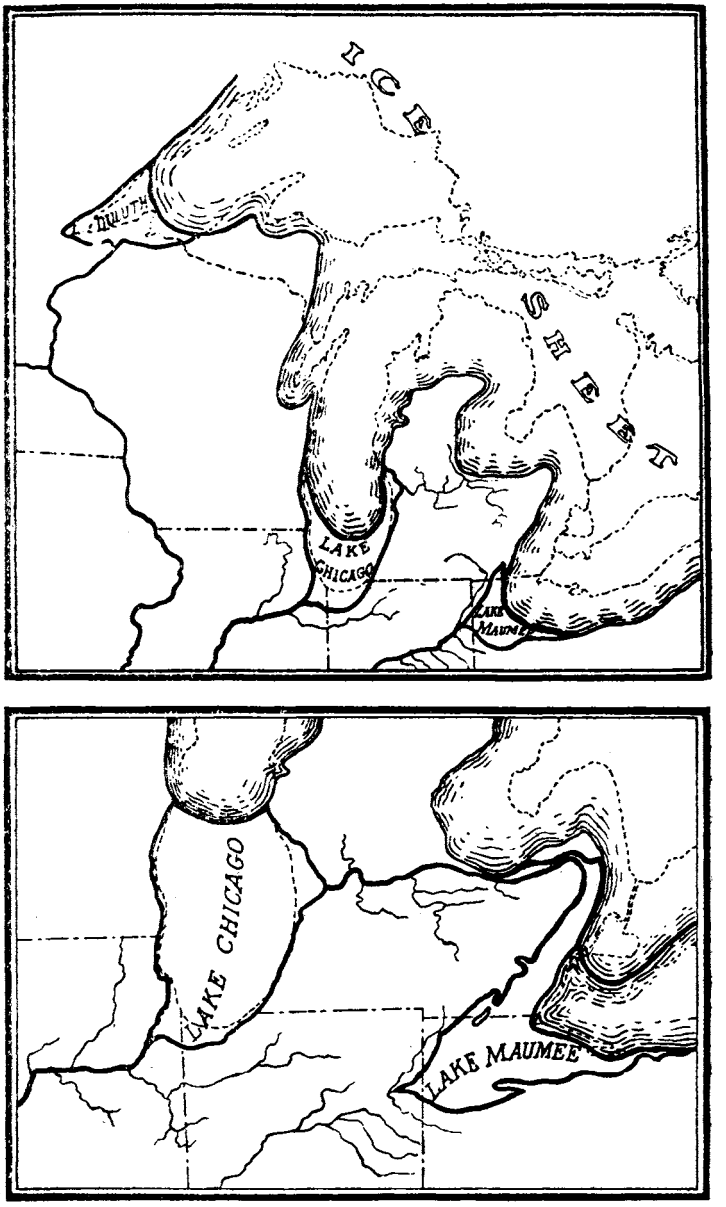

Fig. 1.—Sketch maps showing two successive stages of the ice-front lakes. (Taylor and Leverett.)

found farther north by the writer, in Ozaukee and Sheboygan counties, at the 60-foot level. It is not known that the Glenwood readvance was attended by any change of level of Lake Chicago. In the lower part of Fig. 1 is shown the supposed outline of the lakes near the close of the Glenwood stage.

As the outlet was deepened, the lake fell to a 40-foot or "Calumet" stage. How far the ice withdrew during this stage is unknown—possibly far enough to open the straits of Mackinac and a low pass to the northeast; for there are evidences of a stage of emergence along the Wisconsin, Illinois, and Michigan shores which occurred before the next lower beach, at a 25-foot level, was formed. The evidences referred to are peat and buried stumps (below the beach gravels of the 25-foot stage) near Chicago, and elsewhere,* and deeply cut river channels now drowned to a depth of nearly 50 feet, on the east side of Lake Michigan.†

Before the lake water came to rest at a 25-foot level there was evidently a readvance of the ice as far south as Manistee, Michigan, and Manitowoc, Wisconsin, which obliterated both the 60- and 40-foot shore-lines north of that latitude and formed a strong moraine. The level of Lake Chicago seems to have fallen to the 25-foot or "Toleston" stage before the ice withdrew from this Manistee moraine, since no higher beach is found north of it, in Wisconsin.

While Lake Chicago was expanding northward in the Michigan basin, Lake Maumee also expanded in the Erie basin, and found a lower outlet across the "thumb" of Michigan, at Imlay, to the border of the Saginaw lobe and thence down the Grand River to Lake Chicago. (See Fig. 1, lower map.) With various changes in configuration, as the ice front shifted and at times readvanced, as the lakes of Saginaw Bay and the Erie basin coalesced, or as new outlets were found, the waters of the Huron, Erie, Ontario, and Saginaw basins formed an ancestral series of

* "The North American Lakes considered as Chronometers of Post Glacial Time," by Edmund Andrews. Chi. Acad. Sci. Trans. II.

"The Illinois Glacial Lobe" by Frank Leverett. Monograph 37. U. S. Geol. Sur. pp. 440–447.

† Leverett, loc. cit.

lakes, from which the main line of discharge was the Grand River, until they merged to form a single great Lake Warren which overspread all of Lake Erie, the southern part of Lake Huron and Saginaw Bay and the southern part of the Ontario basin.

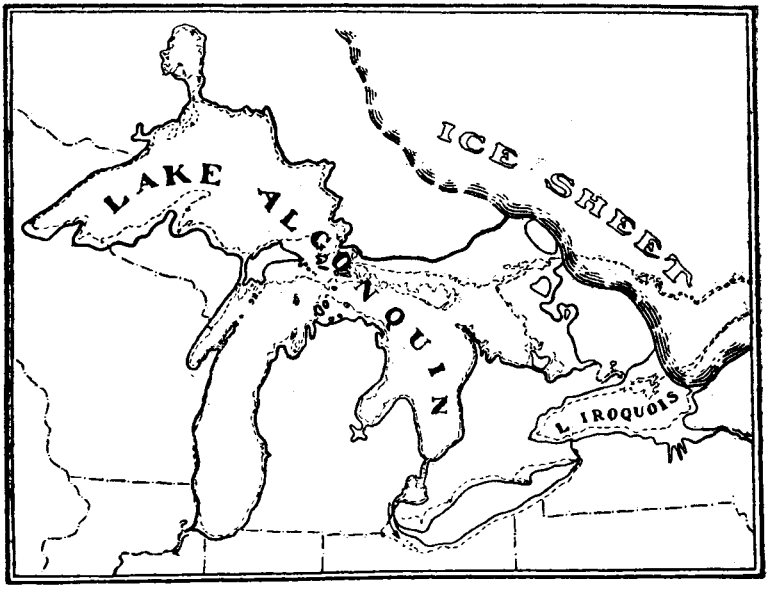

Fig. 2.—Lakes Algoquin and Iroquois. (Taylor and Leverett.)

The outlet down the Grand River was abandoned on the uncovering of a lower pass in New York, at the head of the Mohawk valley. Marked changes in configuration of the eastern lakes resulted, while changes equally great took place in the upper lake region, where the ice now withdrew so far as to allow the waters of the Michigan and Huron basins to coalesce. The combined result of these changes was the dismemberment of Lake Warren, the birth of Lake Iroquois in the Ontario basin, the extinction of the separate lakes Duluth and Chicago, and the formation of a great Lake Algonquin.

Lake Algonquin seems from the first to have had an outlet southward past Port Huron, along the present line of discharge of the upper lakes. It will be shown in a later chapter that the

Chicago outlet probably served, also, as an outlet for Lake Algonquin in its highest stages. Another possible outlet may have been eastward along the line of the Trent River, in Ontario, to Lake Iroquois. The northeastern part of the region at that time stood much lower than at present, and the great lake would have discharged in that direction, into the Mattawa and Ottawa valleys if these had not been buried by the ice sheet. Figure 2 shows in a very diagrammatic way the outline of Lake Algonquin. The position of the ice-front, especially northeast of Lake Superior, is largely theoretical.

While Lake Algonquin was in existence, there were repeated tiltings of the land, by which the northeastern part of the region was raised with respect to the southwestern part. The uplifts seem to express the unburdening of the crust from beneath the weight of the great ice sheet. By these movements the shores of Lake Algonquin were raised above the level of the Port Huron and Chicago outlets, successive planes were warped, and the shore-lines all around the lake, within the area affected by the mevements, came to have southward slanting positions. Meanwhile the Port Huron outlet seems to have been lowered several feet, and the Chicago outlet practically abandoned. The spillways that served as distributary outlets for the lake at these stages are clearly exhibited near St. Clair, Michigan, and elsewhere along the St. Clair and Detroit Rivers. Possibly a still lower outlet was found to the eastward when the ice sheet withdrew beyond the valley of the Trent River.

The next great event in the history of the lakes seems to have been the opening of the low pass east of North Bay Ontario (at the east end of Lake Nipissing) by which Lake Algonquin was drained down to a lower level and the Port Huron outlet was abandoned. Recent studies by Taylor, as yet unpublished, make it seem likely that this fall in level was very considerable, amounting to several hundred feet. The discharge was thus shifted from one end of the lake to the other. The three lakes at this stage, closely resembling Lakes Superior, Michigan, and Huron, have been called the "Nipissing Great Lakes." The region near the ice front stood so low at this time that the sea reached far up the St. Lawrence and Ottawa valleys and invaded Lake Champlain and the valley of the Hudson River.

Meanwhile, the rivers flowing into the shrunken Great Lakes cut their valleys deeply, in adjustment to the low base-level.

Continued upheavals in the northeast following the receding ice front raised the Nipissing outlet higher and higher until it stood as high as the deserted pass at Port Huron, and at the same time the lake waters (everywhere south of the Nipissing outlet) must have risen on the shores, drowning the tributary valleys and spilling over into the Erie basin. A "two outlet"

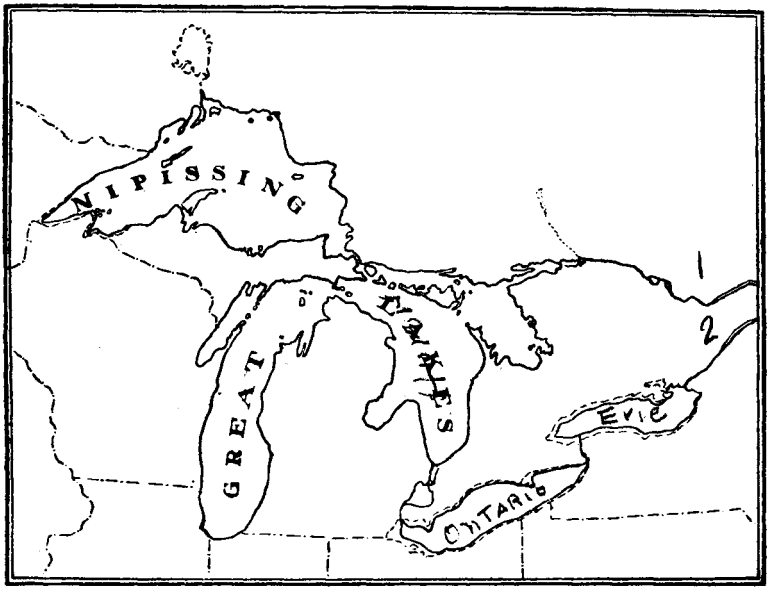

Fig. 3.—The Nipissing Great Lakes at the close of the Nipissing stage. (Modified from Taylor.)

stage was thus established, as shown by the map, Figure 3. Uplifts were resumed, lifting the Nipissing pass gradually above the plane of the lakes so that only one line of discharge was retained, past Port Huron. The Nipissing shore-lines (at least in the northern part of the region, where uplifts occurred) were tilted, and the already inclined planes of extinct Lake Algonquin were bent still more.

The deepening and widening of the Port Huron channel, since its final occupancy by the outlet, have caused a general lowering of the lakes below the Nipissing plane; meanwhile fluctua-

tions in rainfall have caused minor oscillations in level amounting to several feet. Gilbert has found indications that slow differential uplift is still going on; but observations by Taylor, Lane, and others in Michigan, and by the present writer in Wisconsin, suggest rather that recent movements are restricted to the northern and eastern part of the Great Lake region.

CHAPTER II.

HISTORICAL REVIEW.

EARLIER STUDIES.

Before the Great Lake region had been penetrated by the white man the old beach ridges were familiar to the Indians, who used them as convenient lines of travel from place to place. Early in the settlement of the lake region, the nature of the ridges and terraces was recognized, and mentioned in narratives of travel.

The conspicuous beach ridges near Lake Erie and Lake Ontario were among the first to receive careful study, by geologists of the early state surveys. In Ohio, Colonel Charles Whittlesey, in 1838-1839, reported a line of beaches skirting Lake Erie at a maximum distance of five miles and an altitude of 90-120 feet above the lake.*

In Michigan a corresponding shore-line north of Lake Erie and the Maumee River was traced for sixty miles by Bela Hubbard, and described by him in the Annual Report of the Geological Survey of Michigan for 1840.†

In western New York, Lardner Vanuxem and James Hall recognized an abandoned shore-line in a great ridge near the Ontario shore, which was followed many miles by the "Ridge Road." Hall's first report‡ briefly describes this ridge, and

*Geological Survey of Ohio, 2nd Annual Report, 1838, p. 55.

†Geological Survey of Michigan, 3rd Annual Report, 1840, p. 104.

‡New York Geological Survey, 2nd Annual Report, 1838, p. 310.

his final report on the "fourth district" in 1843* devotes a whole chapter to "Lake Ridges," which are compared to certain long barrier beaches on the shores of Massachusetts Bay. D. D. Owen found the ridges in northern Indiana in 1837-1838.

Meanwhile, one Mr. Roy, a civil engineer who was engaged in surveying routes for canals and railroads across the province of Ontario, collected much accurate information regarding the altitudes of beaches and terraces on the Canadian side. Roy gave an account of his studies before the Geological Society of London in 1837. In June, 1841, while Sir Charles Lyell was on his first visit to the United States, he joined Mr. Roy on a trip across the old shore-lines near Toronto. Eleven distinct terraces were crossed, of which the highest stands 680 feet above sea level. The impression which this noted English geologist received is thus expressed in his own words: " with the exception of the parallel roads or shelves in Glen Roy, and some neighboring glens of the Western Highlands on Scotland, I never saw so remarkable an example of banks, terraces, and accumulations of stratified gravel, sand, and clay maintaining, over wide areas, so perfect a horizontality, as in this district north of Toronto."† Lyell also visited the "lake ridges" at Cleveland.

Much thought was given by these early geologists to the probable geography of the region while the shore-lines were being built. A comparison of the known altitudes of beaches with the altitudes of the low passes through the rim of the Laurentian drainage basin (at Portage, Wis., to the Wisconsin River; at Chicago, to the Des Plaines and Illinois Rivers; at Lockport, N. Y. at the head of the Mohawk valley) led to a belief in a general submergence of the Great Lake region and the Mississippi valley beneath the sea, whereby there was continuous water conection from the Gulf of Mexico to the St. Lawrence. Whether the land was uplifted evenly or unevenly at the close of this period was a matter of disagreement. Whittlesey was among the first to observe that the beach ridges are seen to change in altitude when followed for long distances; and he ascribed this to

* Natural History of New York, part IV, Geology of the 4th District, 1843, pp. 348–358.

† Travels in North America in 1841–1842, with geological observations on the United States, Canada, and Nova Scotia. 1845, vol. 2, p. 106.

uneven upheaval of the land. Lyell suggested, however, that the discordance of altitude might have been original, as a result of the various conditions under which reefs and beach ridges were built. W. W. Mather presented the early views in an interesting way in his final report on the Geology of the First District of New York,* alluding to the Lake Michigan basin in the following words,† "It is probable that communication also existed between Lake Michigan and the Illinois River, but we lack data to give *certainty* to it; because the beaches, if they exist, have not been described, or their elevation given; and we are not certain that the *amount* of elevation that that part of the country has experienced at that epoch, is the *same* as that around Lake Erie. If, however, we *suppose* it to be the *same,* it is probable that a *great volume of water* passed between Milwaukee and the south end of Lake Michigan, the lowest point of depression being near Chicago, and elevated only seventeen feet above the lake, or five hundred and ninety-five feet above the ocean, and would give a depth of water in the lowest point of seventy-six to seventy-seven feet, between the Gulf of Mexico and the St. Lawrence." Difficulty is felt in accounting for the currents which flowed through the Mohawk, Champlain and Hudson valleys during this submergence; but Mather ingeniously suggests that "the Gulf Stream caused a flow into lakes Michigan and Erie from the Gulf of Mexico" and out through the Mohawk and Hudson valleys, drifting clay in a uniform direction, and depositing it along the straits.‡ A sudden uplift of the St. Lawrence basin above the sea is supposed to have sent strong currents southward down the Hudson valley, choking parts of it with gravel and bowlders. As signs of this recent uplift Mather refers to faults traversing clays and gravels near Newburg on the Hudson, and to slight faults in the bed rock at several localities, by which smoothed and striated rock surfaces have been dislocated. The uplift is thought to have been nearly even, with "little relative change of height."§

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*Op. cit., 152–158.

†Ibid. 154–155.

‡Ibid. p. 155.

§Ibid. p. 157.

Reference may next be made to work done by I. A. Lapham, who as a resident of Milwaukee and a scientist of great activity was for many years devoted to scientific researches of local interest. A paper written by Lapham in 1847 for the American Journal of Science,* which describes certain lacustrine deposits overlying the drift, contains one of the earliest references to the stratified laustrine clays and sands of the Milwaukee district. Aside from the recognition of this sort of evidence of former lacustrine conditions, and of its relation to the low beach ridges of Lake Erie, Lapham's paper affords one of the earliest and most clearly stated accounts of shore action and its effects on the topography of the eastern Wisconsin shore. The building of beach terraces by shore drift against a pier is demonstrated by observation; and attention is called to a peculiar instance of severing or intercision of the lower part of a river valley by the retreat of the lake cliffs,—a case which will be fully discussed in the next chapter.

The reports of the Foster and Whitney survey of the Lake Superior Land District in 1850-1851† contain much that is of interest concerning the old shore-lines of the south shore of Lake Superior and the north end of Lake Michigan. One of the assistants on this survey was Edward Desor, a fellow countryman and associate of Louis Agassiz, who came to the Great Lake country fresh from glacial studies in Europe and a few years' experience on the United States Coast Survey, by reason of which he was peculiarly qualified to observe and interpret the abandoned shore-lines of the glaciated area. In Chapters VIII and IX of Part I, under "The Drift" Desor explains the origin of characteristic features of shore topography, and with much keenness of insight discusses the local absence of certain old shore-lines, and its significance. He points out that old terraces are often

* "On the existence of certain Lacustrine Deposits in the vicinity of the Great Lakes, usually confounded with the Drift." Amer. Jour. Sci., 2nd series, vol. 3, pp. 90–94, 1847.

†Report on the geology and topography of a portion of the Lake Superior land district, in the state of Michigan, Part I. Copper Lands. 31st Congress, Exec. Doc. No. 69, 1850. and Geology of the Lake Superior land district, Part II. Senate Exec. Doc. No. 4. 1851.

absent not only on account of the sheltered position of the shore and consequent weakness of attack of waves, but frequently because of extreme exposure of the shore, enabling the waves of the lake during later, lower stages to cut back rapidly and wash away terraces of the higher stages. Desor seems to have been the first American geologist to state this principle with proper emphasis. He is careful to show how the absence of terraces in some places and their presences in others may lead to the mistake of concluding that a single bluff at the shore represents the work of but a single stage of the lake, whereas bluffs of higher stages may have been washed away by more recent erosion. In Part II Desor gives a detailed description of the old shore-lines of Mackinac Island, with an illustrative view, a sketch map and three cross-sections of the terraces. At the steep southern side of the island a series of conspicuous terraces marks "a gigantic staircase," a record of successive levels of submergence; while at the more gently sloping northern end beach ridges occur at corresponding altitudes. The highest shore-line reported stood 147 feet above Lake Michigan on Mackinac island and 130 feet near Gros Cap, west of the straits (by no means the highest shore-line, according to more recent studies, however). Desor expresses some surprise at the apparent absence of this high shore-line along the northern border of Lake Michigan and Green Bay, as well as at discordances between the altitudes of the terraces at different localities; but says:* "the difficulty might, however, be met by supposing that the upheaval which raised the terraces of Mackinac to their actual height did not operate to the same extent west of the island. At any rate, this circumstance is in itself a proof that the change could not have been brought about by a mere lowering of the water; but that they must at all events be referred to a gradual, but unequal, rise in the land." It is thought that there are two distinct series of shore-lines represented; a higher series which is marked by the great terraces, and a lower series marked by beaches. Various forms peculiar to shore topography, hitherto not well understood, are carefully described: "river belts" or bars built by shore drift so as to hold

*Op. cit. Part II. p. 254.

the lower part of a stream in a deflected course parallel to the shore; hooked spits; and dunes, which seem never before to have been observed on the shores of inland tideless bodies of water.

A short paper by Whittlesey in the same chapter* gives an account of old beaches at the north end of Lake Michigan and in Green Bay, and is followed by a valuable chapter on observed fluctuation of level of the lakes.† It is recorded that at a stage of high water in 1838 the lake rose nearly six feet above low-water mark. Such fluctuations as these can be traced to variations in rainfall during a series of years. Whittlesey makes particular mention of a shore-line which stands about 18 feet above the lake at many places near the northern end of Green Bay. On the western side of St. Martin's Island a scrap of old beach deposit was found at 14 feet on a shelf of a retreating cliff of white limestone; and on the northeast side of Pottawatomee (Washington) Island a similar deposit 18 feet above the lake. The conclusion is reached that the 18-foot shore-line so uniform in height around these shores, marks a single water-plane of considerable importance. The trees growing on it compel a minimum estimate of several centuries for the time since this shore-line was built. Fluctuation in lake level, with changes of rainfall, are regarded as sufficient cause; but thought inapplicable in the present case, because Lakes Erie and Superior do not seem to share the 18-foot shore-line. Whittlesey thinks, therefore, that it represents the lowering of Lakes Michigan and Huron by the deepening and widening of the outlet at Port Huron, which is cut across sand and drift, while the rocky outlet channels of Superior and Erie were not cut down so far. The close correspondence between Whittlesey's views of the significance of the 18-foot beach on Pottawatomee Island and that reached in the present report will be brought out in a later chapter.

A paper by Whittlesey "On the Fresh Water Glacial Drift of the Northwestern States," written in 1864‡ makes brief report of terraces and beaches of the northern and eastern Wis-

* Ibid. pp. 270–273.

† Ibid. pp. 319–339.

‡ Smithsonian Contributions to Knowledge, 197, 1866.

consin shores, including what is perhaps the earliest mention of ancient beaches around the south end of Lake Michigan and Green Bay. The series of beaches is again explained by the "settling away" of the lakes as their outlets were worn down.

In 1867 a brief account of the abandoned beaches of the Chicago district was prepared by Dr. H. M. Bannister for the Geological Survey of Illinois.* It is here recognized that Lake Michigan was at least 40 feet higher at the close of the glacial period and had its outlet past Chicago, along the line of the Illinois-Mississippi canal. The presence of buried peat beds and fossil shells of existing fresh-water species in the lower beach ridges was given some attention.

A paper by Dr. Edmund Andrews on "The North American Lakes considered as Chronometers of Post Glacial Time,"† published in 1870 gave the subject of the extinct Lake Michigan more elaborate treatment, although Andrews' chief purpose was to estimate the duration of post-glacial time by means of comparative measurements of (a) the average rate of erosion along the present shore, (b) the width of the sub-aqueous platform which has been cut at the present level, (c) the amount and direction of transportation of drifting sand, and (d) the amount of sand in the beach ridges. Three extinct stages of the lake were distinguished by means of three separate beach ridges which were built out from three bluffs farther north. The highest beach at 52 feet is thought to correspond to the highest beach west of Lake Huron and around Lake Erie, and to have been greatly deformed by differential uplift. The courses of the three beaches around the southern end of Lake Michigan are shown on a map, extending northward through Wisconsin to a point beyond Racine. The highest beach, said to be uniformly 52 feet above the lake on the west side is thought to correspond to a 21-foot beach on the east side, and to the highest beach around the southern and western sides of Lake Huron and Lake Erie. It is therefore supposed that this beach has been "thrown into sinuous form" by

* Geological Survey of Illisois. Vol. 3. Geology and Paleontology, pp. 239–257. "Cook County." 1868.

† In the transactions of the Chicago Academy of Sciences, vol. 2, pp. 1–23.

"flexures of the strata of the continent since the beach was laid down." Andrews thus made the mistake which Desor had sought to prevent, twenty years before. The highest beach is thought to have been reached twice by the waters of the lake, these two high stages being separated by an interval of emergence and the deposition of a peat bed down to within a few feet of the present lake. The second beach (formed after the final drop from the stage) is placed at 30–35 feet and the lowest at about 25 feet. Low ridges below the highest beach ridge, and below the 25-foot ridge are regarded as subaqueous bars or reefs, while occasional ridges on the outer slope of the 35-foot beach are thought to have been cast up during the lowering of level of the waters.

The surface geology of eastern Wisconsin was studied in considerable detail for the first time between 1873 and 1877, by T. C. Chamberlin, as geologist and later Director of the State Survey. In his "Geology of Wisconsin,"* Chamberlin describes four beach formations. One of these is a stratified deposit of sand and gravel observed in the neighborhood of Milwaukee, where it is overlain by a deposit of red clay. Another, called "Beach Formation D" is said to be marked on its inland border by a ridge of gravel and sand, which in Racine and Kenosha Counties varies in altitude from 40 to 80 feet above Lake Michigan. A terrace rarely more than 15 feet above the lake is briefly described as appearing for a few miles on the lake shore just north of Milwaukee, again along the shore between Port Washington and Sheboygan, again near Centerville, again just north of Ahnapee (Algoma) "in sharp and rigid outline" and continuing without essential interruption to the vicinity of Sturgeon Bay" where the bluff behind it becomes 75 feet high. From Sturgeon Bay this terrace is said to continue interruptedly northward through Door County as a beach ridge, to "Death's Door." On the western side of the peninsula, the old shore-line is often interrupted by rocky promontories, and marked by conspicuous chip-stone bars at Ephraim, Fish Creek, Egg Harbor, and elsewhere. On this side of the peninsula the shore-lines are much higher than before. Rock cliffs and terraces also are re-

* Geology of Wisconsin, Survey of 1873–1877, vol. 2, pp. 219–229.

ported here. "Near Green Bay there is an inconspicuous beach ridge formed of worn chip-stone, first appearing on the bay shore and extending a few rods, when it is replaced by a well-defined terrace of red clay, which extends southward nearly parallel to the shore for about two miles, when it is in turn replaced by a low, flat, sandy ridge, which may be traced around the extremity of the bay and northward along the western side to Menominee and beyond." The beach ridge north of Sturgeon bay rises to 44 feet at Sec. 9, T. 33, R. 29 E. (not far from the northeastern extremity of the peninsula). On the west side of Door county the gravel ridge is said to be about 40 feet above the lakes at Hedgehog Harbor; 65 feet at Sister Bay; 53 feet at Eagle Harbor; 50 feet at Egg Harbor; and 55 feet at Fish Creek. "The elevation becomes less again toward the southern extremity of Green Bay."* Two and sometimes three well-defined ridges are said to occur between the highest beach and the lake. All these topographic forms and the red clay deposits are regarded as evidences of several advances and retirements of the waters of the lake which occurred at a time of general depression of the Great Lake region at the close of the glacial period.

LATER STUDIES.

In all this early work, difficulty was felt in accounting for the depth of submergence, which at the very highest levels seemed to have been by fresh water rather than by the sea. Gilbert's study of the old lake records of the Maumee valley, west of Lake Erie, in the early '70's, brought him to the front as the demonstrator of the ice dam hypothesis, hitherto not fully appreciated. Accepting the ice sheet as a barrier for Lake Maumee, Gilbert proceeded farther and after an examination of the beaches south of Lake Ontario and of the Mohawk valley confidently expressed the view that the shore-lines mark an extinct lake which was held up by the ice dam to a level considerably above the sea, overflowing down the Mohawk valley to the Hudson.

*Ibid. p. 229.

Meanwhile, in the early '80's Warren Upham had begun those extensive studies in the Red River valley of Minnesota, Dakota, Manitoba, and Saskatchewan, which were finally embodied in his monograph on "Glacial Lake Agassiz,"—a classic in geologic literature.* In this work, the connection between successive stages of lake level and successive terminal moraines, and the consequent inferences regarding the function of the ice sheet as a great northern barrier to the lake are convincingly presented. Upham's discovery of the fan-like splitting of beaches, produced by differential uplifts of the northern position of the lake while the ice was retreating, deserves more than mention here, for it has been confirmed many times in the Great Lake region, and finds graphic illustration in Plate XXXVII of the present report. The highest or "Herman" shore-lines, followed by Upham for a distance of 140 miles, was found to split, fan-fashion, into seven distinct ridges, the higher ones terminating farther south than the lower. Taking the whole group of beaches in Lake Agassiz, which at the southern end of the lake are five in number, it is found that they are increased northward by divergence and splitting to seventeen distinct shore-lines.

While Gilbert and Upham accepted the ice-dam hypothesis in its broadest significace thus early, other investigators, accepting it for the Lake Maumee and for others of the smaller extinct lakes, hesitated to apply it to those great sheets of water which covered several of the Great Lake basins. Among these, J. W. Spencer was the most outspoken in his disbelief in the ability of the ice sheet to act as a barrier for such vast bodies of water. Working at first in the province of Ontario, on the northern shore of the same extinct lake whose beaches Gilbert was tracing in western New York, Spencer came to the conclusion that this "Lake Iroquois" was nothing less than a great inland gulf, approximately at sea level, but fresh because of the considerable drainage into it. The ice-dam hypothesis to him seemed visionary, based on assumptions, with no support from facts. He did not at first accept the phenomena in the Mohawk valley as evidences of an outlet river. The same explanation—that of inland gulfs—was applied by him to "Lake Warren" or

* U. S. Geological Survey, Monograph 25, 1895.

"Warren Water," (as he named the extinct lake which overspread Lakes Erie and Huron and parts of adjoining lake basins) and to its successor, "Lake Algonquin." The change in configuration and extent of successive lakes was thought by Spencer to depend wholly on differential uplifts in the northeast, which turned the gulfs into lakes, the straits into outlets, and continuing, caused the abandonment of certain outlets in favor of others. Three probable outlets were under examination at this time, for Lake Algonquin: that at Port Huron, along the present line of discharge; one across Balsam Lake at Kirkfield, Ont., and down the Trent River*—discovered by Spencer and soon discarded by him (to be again brought into consideration by Gilbert); and the low pass east of Lake Nipissing, between North Bay and the head of the Mattawa valley, first pointed out by Gilbert in 1890† and later studied in detail by Taylor.

In 1886 Frank Leverett began a study of the old lake beaches near the head of Lake Michigan, which was continued interruptedly for ten years, and published in final form in his monograph on "The Illinois Glacial Lobe."‡

Earlier reports by Leverett were printed in the Transactions of the Wisconsin Academy of Sciences§ and in a bulletin of the Chicago Academy of Sciences.¶ The lake which occupied the south end of the Michigan Basin was named by Leverett "Lake Chicago," and its three shore-lines (formerly recognized by Andrews) were named the "Glenwood" (55 foot), the "Calumet" (35 foot), and the "Tolleston" (25 foot) beaches. Although altitudes at different points along these beaches were somewhat discordant, no proof of other than a horizontal position of the Lake Chicago water-planes was found. The beaches were not

*For the location of this supposed outlet, see Fig. 2, and the index map—Plate 3.

†Sixth Annual Report of the Commissioners of the State Reservation at Niagara, p. 72. 1890.

‡U. S. Geol. Survey, Monograph 38, 1899.

§"Raised beaches of Lake Michigan." Wis. Acad. Sci. Transactions, vol. 7, pp. 177–192. 1883.

¶"The Pleistocene Features and Deposits of the Chicago Area." Chi. Acad. Sci. Bulletin No. 2. 1897.

traced north of the Wisconsin line by Leverett; but on the basis of Chamberlin's observations it was thought that they continued at least as far as Racine.

The name "Lake Algonquin" was first used in 1888 by J. W. Spencer* to designate the sheet of water which overspread the basins of Superior, Michigan, and Huron after the dismemberment of Lake Warren. The shore-line which constitutes the record of this lake was named the "Algonquin beach," and the outlet by which the lake was thought to have discharged through the Trent valley in Ontario has been called the "Algonquin river." Spencer had spent the field season of 1887–1888 in exploration and study of the Algonquin beach in the province of Ontario around the eastern borders of Lake Huron and Georgian Bay, and had suggested the appropriate name "Algonquin" after the tribe of Indians who once used the raised beaches near Georgian Bay for trails.

In 1891 Spencer published an interesting paper entitiled "Deformation of the Algonquin Beach, and Birth of Lake Huron,"† in which the course of this shore-line east of Lake Huron and Georgian Bay and its slanting attitude are described in detail. At the same time, information is given regarding the associated shore-lines which stand both above and below the Algonquin. It is significantly stated that "upon surveying, the beaches are all found to rise in altitude toward the north and east with a slightly increasing divergence between the ridges in the same direction."‡

In many places about Georgian Bay the Algonquin beach is said to be "broken up into a series of prominent ridgelets, the lowest being, where developed, as much as 28 feet below the upper." Spencer recognized further that "these rates of higher differential uplift [of the Algonquin and two higher beaches calculated at 1.71, 1.50 and 1.33 feet per mile] are reduced at their more southern extensions, but increased to two

* "Notes on the origin and history of the Great Lakes of North America." (Abstract). Am. Assoc. Adv. Sci., Proc., vol. 37, pp. 197–199. 1889.

† Am. Journ. Sci., vol. 141, pp. 12–21. 1891.

‡ Ibid. p. 19.

feet, or somewhat more, at their more northern,"* reaching even 4.1 feet per mile north of Lake Simcoe.† These observations are of great importance in showing that (1) the uplift of the land which raised the shore-lines was differential in amount, being greater in the north so as to tilt the Algonquin and other beaches towards the south; (2) in each case the shore-line is tilted more steeply in the northern part of the region than in the southern, showing that the movement was in effect not a simple plane tilting but a warping of the surface; (3) each shore-line has been tilted more steeply than the one next below it, and less steeply than that next above. This indicates that the tilting movements were going on during the formation of the shore lines instead of wholly at the close of the history of the series. The average rate of tilt on the east side of Lake Huron, from the south end of the lake northward to Southampton was estimated by Spencer to be 1.33 feet per mile; but this estimate involves the assumption that the Algonquin water-plane south of Spencer's southermost ordinate (Grand Bend) continues to descend and is submerged 20 feet at Port Huron, an assumption which has more recently been found incorrect. The tilt rate if computed from Spencer's actual measurements, between Grand Bend (602 feet, above sea level) and Southampton (714 feet), a distance of 90 miles in a north-northeast direction, is 1.24 feet per mile. North and east of Southampton, on the southern shore of Georgian Bay, the rate of steepest ascent was found to be about 3 feet per mile in a direction N. 20° E. East of Georgian bay, in the Lake Simcoe region, the mean rise was estimated at 4.1 feet per mile, in a direction N. 25° E. The course of the Algonquin beach north of Kirkfield, between Lake Simcoe and Lake Nipissing was not continuously followed; but a gravel ridge at Burk's Falls, about 1,171 feet above sea level was thought by Spencer to mark the northern extension of the shore. It was further estimated that the beach would stand 600–700 feet above the bottom of the pass east of Lake Nipissing (707 feet above the sea).

Spencer takes the view that there was no ice-dam across the Nipissing pass (and several other low passes between the lakes

* Ibid. p. 15.

† Ibid. p. 16.

and Hudson's Bay) but that the pass was occupied at first by a deep strait connecting an inland "Warren Gulf" with the ocean; by repeated uplifts this inland gulf was raised above sea level to form a lake; the Nipissing pass was occupied as an outlet during successive stages until it was finally lifted higher than the pass at Port Huron, and the lakes overflowed the southern rim of the Huron basin into Lake Erie. This view of continental warping without ice-dams was urged again by Spencer in a paper before the Geological Society of America in December, 1890.*

Assuming that the tilt of the Algonquin shore-line in the Lake Michigan basin is comparable to that in Lake Huron, Spencer estimated a submergence of the Algonquin water-plane 290 feet below Lake Michigan at its head. At Mackinac Island, at the northern end of Lake Michigan, a shore terrace at 190 feet was regarded as a mark of the Algonquin water-plane.—"Accordingly tilting in the Michigan basins has amounted since the Algonquin episode, to about 430 feet in 300 miles, or a little more. This approximation is close upon the mean rate of uplift measured east of Lake Huron."† This conclusion of submergence of the Algonquin beach near the southern end of Lake Michigan, like the similar conclusion of submergence in the Huron basin, was drawn on insufficient evidence, as previously remarked.

Spencer furthermore advanced the idea that the Algonquin water-plane in the western part of the Superior basin had been submerged by recent backing of the waters,—an indication of this tilt being imagined in "the open bays behind the bars, which cut off Fond du Lac, at Duluth."‡ Regarding the supposed overflow of Lake Algonquin via Balsam Lake and the Trent River, emphasized in the earlier paper,§ Spencer considers the pass too shallow to have drained Lake Algonquin after its very highest stages. The Nipissing pass stands much farther below the Algonquin water-plane.

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* "Post Pliocene subsidence versus glacial dams." Geol. Soc. Am. Bull. vol. 2, pp. 465–476.

† Am. Jour. Sci., 3rd series, vol. 41, pp. 18–19. 1891.

‡ Loc. cit.

§ Amer. Assoc. Adv. Sci., Proc., vol. 37, pp. 197–199, 1889.

While Spencer was still studying the Algonquin beach about Lake Huron, Frank B. Taylor, in the autumns of 1890 and 1891 carefully examined the old shore-lines near the northern extremity of lower Michigan and on Macinac Island, and published on account of them in the American Journal of Science.* The "Algonquin beach" of Spencer was recognized in a well-built series of parallel stony ridges on Mackinac Island, the lowest 170 feet and the highest 205 feet above Lake Michigan. Taylor showed satisfactorily that the 205-foot beach marks the highest level of submergence in the northern end of the Michigan basin. At Petoskey a heavy shore-line (probably the same) was found at 100 feet and at Traverse City an old delta at about 80 feet. Other kinds of evidence, such as the upper limit of worked-over drift and the altitude below which streams follow curiously deflected courses were presented by Taylor to prove that the Algonquin shore is the highest one in the Lake Michigan basin, and that Lake Warren did not extend so far westward. Although he accepted the idea of ice-dams for the higher beaches of the Erie and Ontario basins, Taylor at this time favored the view that Lake Algonquin was an inland gulf at sea level, as suggested by such facts as marine species of crustaceans in Lake Superior, whale fossils in gravel near Lake Champlain, and marine clays 520 feet above the sea at Montreal.

In the summer and fall of 1893 in company with Dr. F. S. Pierce of Philadelphia, Taylor followed the shore-lines rapidly through northeastern Wisconsin from Manitowoc around Green Bay and into the upper peninsula of Michigan, reconnoitering the south shore of Lake Superior from Duluth to Sault Sainte Marie, and the Canadian coast north of North Channel from the Sault east to Lake Nipissing, and thence south to Lake Simcoe. The results of this long excursion are set forth in four papers.†

* Am. Jour. Sci., 3rd series, vol. 43, pp. 210–218. 1892.

† "The Ancient Strait at Nipissing." Geol. Soc. Am., Bull., vol. 5, pp. 620–626. 1894.

"A Reconnaissance of the Abandoned Shore lines of Green Bay." Am. Geol., vol. 13, pp. 316–327. 1894.

"A Reconnaissance of the Abandoned Shore lines of the south coast of Lake Superior." Am. Geol., vol. 13, pp. 365–383. 1894.

"The Limit of Post-Glacial Submergence in the Highlands east of Georgian Bay." Am. Geol., vol. 14, pp. 273–289. 1894.

In the Green Bay region efforts were directed chiefly to finding the highest shore-line. Nothing of importance was seen south of Kewaunee, although Sheboygan, Manitowoc, and Two Rivers were visited. The general report for this stretch of shore was absence of old shore-lines due either to a cutting back of the cliffs at the present level or to a submerged position of the Algonquin water-plane. At Kewaunee evidences of a shore-line about 15 feet above Lake Michigan were noted,—but their importance somewhat overdrawn. At Sturgeon Bay a well-built beach, recognized as the highest of the series, was followed in several directions, and found to stand about 35 feet above the lake. Lower beach ridges were observed but not continuously traced nor levelled. Lack of time prevented any exploration of the long Door County peninsula north of Sturgeon Bay, or of the exposed Washington Island, although the importance of that part of the coast was realized at the time and commented on in the paper.* At Green Bay several low sand ridges were found, but none rising above 20 feet. On the west shore of Green Bay—a broad flat stretch of cedar swamps—no definite beaches were seen, although delta-like deposits of sand and gravel cut by the railroad at Suamico, Oconto and Peshtigo seemed to represent higher levels. North of the Wisconsin-Michigan line, however, distinct beaches were found and measured by aneroid as follows: Birch Creek station (6 miles north of Menominee) 48 feet; Burnt Bluff 123 feet; South Bay hill (near Fayette) 133 feet; Cook's Mills 168 feet. From these measurements Taylor concluded that the highest shore-line in the upper peninsula slants southward from Cook's mills at a rate of over 2 feet per mile (measured in a due north-south direction) to Birch Creek, beyond which it declines more slowly, at about 8 inches to the mile to Two Rivers, where it was estimated to pass under Lake Michigan. In so far as the northern portion of this beach is concerned the conclusion regarding the tilt rate in the upper peninsula has been abundantly confirmed by later studies; it is also certain that south of Birch Creek the tilt rate decreases markedly; but there is now reason to think that

*Am. Geol., vol. 13, p. 327.

the highest shore-line becomes horizontal before reaching the level of Lake Michigan.

On the south coast of Lake Superior, Taylor found the highest shore-line well marked at several places; but on account of the rough and thickly wooded character of the country it was not practicable to follow it at all continuously. Between Duluth and Marquette this shore-line is found to rise from 1,134 to 1,190 feet above sea level. East of Marquette the highest shore stands at a considerably lower altitude,—1,014 feet on the Canadian side, according to accurate measurements by Dr. A. C. Lawson.* Taylor nevertheless correlated the highest beach at the Sault with those between Marquette and Duluth, merely remarking that the topmost beach west of Marquette "is rather higher than would be expected when compared with other parts of the highest shore-line in the same basin,"—i. e. at the east end of the lake and around Green Bay. The true cause of this anomalous condition was recognized by Taylor a few years later when he discarded the theory of marine submergence in favor of the ice-dam theory. An apparent discrepancy between Taylor's observations on the south shore of Superior and Lawson's on the north shore was also accounted for by Taylor after the ice-dam theory was accepted. The close accordance of the highest water-plane in the Superior basin with the col at the head of the St. Croix valley is remarked in Taylor's paper, but not given much importance. The idea of marine submergence, with inland connection by several straits across the height of land north of Lake Superior, and perhaps also south of the Great Lakes, was uppermost in Taylor's mind at this time.

Evidences of submergence at lower levels were also observed, but especially the "Nipissing" shore-line, which stands never more than 50 feet above the lake and which on account of its accessibility and remarkable strength of development was traced rather continuously in the eastern part of Lake Superior from Portage Lake canal to the Sault, and thence eastward along the

*"Sketch of the coastal topography of the north side of Lake Superior, with special reference to the abandoned strands of Lake Warren." Minnesota Geol. & Nat. Hist. Sur., 20th Ann. Rept., pp. 181–289. 1893.

Canadian shore to Lake Nipissing. Sharply cut terraces and bluffs are characteristic of this Nipissing shore-line; but at each large bay it takes the form of a great barrier ridge, built by the shore drift. Lake Autrain, Lake Independence, Pine Lake, Lac la Belle, and others occupy the hollows behind these old barriers. Taylor places the Nipissing beach 20 feet above Lake Superior at L'Anse, 40 feet at Keweenaw Point, and 25 feet at Marquette. The discordance of altitudes was regarded as systematic, indicating a southwestward slant which would bring the shoreline below the level of Lake Superior near Duluth. The correlation of these fragments of shore-line into a single water-plane might now be questioned. At Sault Ste. Marie a strongly cut terrace 50 feet above the level of Lake Superior was continuously traced through the strait and found on St. Joseph's and Sugar Islands. Along the Canadian shores from the Sault eastward to Lake Nipissing strong beaches were seen at levels which seemed to indicate a uniform rise of the Nipissing shore to an altitude of 743 feet (above the sea) at North Bay, nearly a hundred feet higher than the "Nipissing" beach at Sault Ste. Marie.

This 743-foot shore-line is strongly developed on the north side of the pass between Lake Nipissing and Trout Lake (the source of the Mattawa River), and its evident connection with the use of the pass as an outlet for the Great Lake waters led to the application of the name "Nipissing" beach.* At higher levels fragments of several strong shore-lines were found and measured, and the unexpected discovery was made that the highest beaches on the south side of the pass (at South River and Sundridge) are decidedly lower than the highest on the north side, although still farther north (from North Bay to Cartier) the uppermost beach indicates again a northward rise. While it is easier to explain the drop in level of the shore-lines at the Nipissing pass by the removal of an ice-dam and the abandonment of the original level for one considerably lower, that view was not expressed by Taylor at this time; for he continued to favor the theory of Spencer that at the highest stage the Algon-

*Recent studies by Taylor place the Nipissing beach at 700 feet (not 743 feet), at the North Bay pass.

quin waters were at sea level and were connected with the submerged St. Lawrence valley and Hudson's Bay by several deep straits. The strait across the Nipissing pass was estimated by Taylor to have been at least 500 feet deep and 25 miles wide. Other straits were supposed to have crossed the northern height of land near Lakes Abitibi, Nipigon, Kenogami, and Missinabi.

The region east of Georgian Bay, between Lake Nipissing and Lake Simcoe is described in Taylor's fifth paper* as very irregular in topography, involving the presence of many islands and long narrow straits during the stages of submergence. The shore-lines were nevertheless discovered at many places along the line of the Grand Trunk Railway, and measurements obtained on them. The rate of inclination between ordinates (in a north-south direction) is as follows:

South River to Sundridge	about 3 feet per mile.
Sundridge to Huntsville	6 feet 2 inches.
Huntsville to Bracebridge	1 foot 2 inches.
Bracebridge to Orilla	¼ foot.

The ordinate at Bracebridge is regarded as poorly determined; but even this cannot take from the figures the suspicion of imperfect correlation, since it involves so very unsystematic a tilt rate from place to place.

Excursions were also made by Taylor in the fall of 1893 to critical localities in the vicinity of the Straits of Mackinac, the full results of which were published in his sixth paper, "The Munuscong Islands."† These are a small group of hills, formerly islands in Lake Algonquin, lying seven miles north of Hessel, and fourteen miles north of Mackinac. The highest Algonquin shore-line was found here at about 280 above lake Michigan.

In his paper on "The Second Lake Algonquin," in 1895‡, Taylor reviewed the data previously collected concerning the lower or "Nipissing" beach of Lake Algonquin; then consider-

* Am. Geol., vol. 14, pp. 273–289. 1894.

† Am. Geol., vol. 15, pp. 24–33. 1895.

‡ Am. Geol., vol. 15, pp 100–120 and 162–179. 1895.

ing at length the attitude of the deformed Nipissing water-plane and entering upon many theoretical considerations, he drew conclusions regarding successive movements which have deformed the beaches and shifted the outlets. The problems of lake history in this form become decidedly complex, and involved in the assumption of a drowned position of the Algonquin water-planes at the southern ends of Lakes Huron and Michigan, regions then not thoroughly investigated. The considerations of this paper are largely theoretical. Beginning with the supposed early submergence beneath the sea, the history of deformation of the higher beaches of Lake Algonquin is briefly reviewed. Following recent statements by Spencer, the idea of the use of the Trent River valley as an outlet is given up. The paper proceeds to a detailed consideration of the dependence of water-planes upon shifting outlets, and an application of simple principles is made to the observed and assumed facts, whereby a series of earth movements is worked out as follows: A slight tilt towards the south brought the Nipissing pass at North Bay up to and above the level of the pass at Port Huron. Lake Algonquin at once commenced to overflow into Lake Erie; the Nipissing beach was raised, while the Nipissing pass was abandoned. These movements continued for some time, at a uniform and slow rate, raising each successive water-plane to a southward slanting position, the hinge line being an east-west line through the Port Huron outlet. The evidence of these movements is found in a series of beaches along the south Superior shore, below the Nipissing. Meanwhile the lake waters at the southern end of the Michigan basin are thought to have risen on the coast, drowning the Nipissing plane; and the waters in the Superior basin to have become separated by the Sault barrier. Then a second uplift is deduced which tilted the water-planes towards the southwest, thereby deforming the raised beaches so that their direction of maximum ascent became N. 27° E., raising the outlet of Lake Erie so as to flood not only that basin but also the southern part of Lake Huron, drowning the water-planes at the head of Lake Michigan still more, and backing the waters into the Lake Superior beasin so as to drown the earlier hypothetical "Sault beach."

Taylor speaks of the beaches in the Michigan basin in these

words: "The upper beach [Algonquin] ....descends gradually southward on both sides of Lake Michigan and lies only 50 to 75 feet above the Nipissing beach where the latter was last seen toward the south. The declivity of the upper beach grows less towards the south and it there forms a plane nearly parallel with that of the Nipissing. Possibly the earlier observations of Dr. Andrews and Mr. Bannister carry the identity of some of these beaches farther south, but although I have not yet seen their papers, it seems improbable that such is the case. For, as stated in the third paper, the upper beach passes under Lake Michigan on the west side at Two Rivers. On the east side it is estimated to pass under the lake at a point about sixty or seventy miles south of Traverse City, probably near Ludington or Pentwater. The higher levels described by these observers and Mr. Leverett at points farther south certainly have no extension in the north. They are probably fragmentary and mark the shores of a lake of the glacial recession which had its outlet at Chicago. It is estimated that the Nipissing beach passes under the present lake at points about thirty miles north of Menominee and fifteen miles north of Traverse City. Neither the Nipissing nor the upper beach, therefore, has any connection with the Chicago outlet unless they change the attitude of their planes southward in a very exceptional manner."*

In "The Nipissing Beach on the north Superior Shore,"† Taylor sought to identfy the Nipissing plane from among a large series of accurate measurements made in 1893 by A. C. Lawson. A particularly strong shore-line, thought to be the Nipissing, is found at many places on the north shore, reaching at the most northerly point a height of 100 feet above the lake. This suggests that the inclination of the Nipissing plane across Lake Superior is no greater than along the southern shore, in spite of the fact that the plane east of Sault Ste. Marie to North Bay, is more inclined than farther south. The isobases

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*Op. cit. pp. 107–108. That the beaches do change the attitude of their planes southward, in both the Lake Huron and the Lake Michigan basins, has since been demonstrated by Taylor himself, by others working in Michigan, and by the present writer in Wisconsin.

† Am. Geol., vol. 15, pp. 304–314. 1895.

for the Nipissing plane, therefore, on the Canadian side, seem not to run parallel to those across Huron and northern Michigan, but to diverge from them west of and to the Sault.*

A letter from Taylor in the American Geologist for April 1896,† clears up many of the hitherto disputed points of Great Lake history. Taylor had spent the preceding summer visiting critical portions of the region, with much profit. Of chief significance was his discovery that the passes through the height of land north of the Great Lakes are not marked by shore-lines, and seem therefore not to have been straits at any time. The highest beach near each of these passes lies well below the Algonquin water plane (as produced from its position farther south). "To my mind the disproof of the northward straits from Lake Superior greatly weakens the marine hypothesis, and it strengthens the glacial hypothesis correspondingly."‡ Led in this way to discard the theory of marine submergence, theory were cleared away by the ice-dam hypothesis; for example, a sudden break in the old water-plane at Petosky, and the correlation of the highest beach at Marquette with that of Green Bay, despite a surprising steepening of the tilt rate which it involved. "The interval of distance [between the northern coast of Green Bay, and Marquette] was too great for the inference of continuity. I entertain no doubt now that the beach at the former place was made after the withdrawal of an ice dam which held up the water at the latter."§ The "easy possibility" of an ice-dam for Lake Algonquin became apparent after a visit to the Ottawa River.

Certain changes in nomenclature of beaches and lakes now be-

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*Taylor's more recent studies, placing the Nipissing beach at 700 feet (instead of 743 feet) east of Lake Nipissing, lead to the conclusion that the isobases of deformation of the Nipissing plane maintain a parallel direction across the whole district, even to the North Bay pass. The Nipissing water-plane has been evenly tipped rather than warped.

†"Preliminary notes on studies of the Great Lakes made in 1895." Am. Geol., vol. 17, pp. 253–257. 1896.

‡Ibid. 256.

§Loc. cit.

came desirable. The first and second Algonquin lakes became respectively "Lake Algonquin" as originally used by Spencer and the "Nipissing Great lakes;" and the corresponding shore-lines were now termed the "Algonquin" and Nipissing" shore-lines. These two great strongly developed strands are the only ones which mark critical stages for the whole area of the three upper basins. A traverse of the Michigan shores shows that "the beaches of Lake Warren do not extend north beyond Alpena, Michigan, if indeed they reach that place,"* though they were found on the west side of Saginaw bay. The outlet of Lake Warren was "westward through the Pewamo channel into the Michigan glacial lake, and this emptied through Chicago. But Lake Warren never extended around the northern side of Michigan, nor did it ever include any part of the Superior basin." On the north coast of Lake Superior, the Nipissing beach was easily identified, and found to rise from 61 feet above the lake at Port Arthur to 115 feet at Peninsula Harbor. Thus the slanting attitude of Lawson's lower beaches was established for the first time by observation. Taylor found no evidence, however, of similar tilting in the highest beach on the Canadian shore. The Nipissing beach was followed eastward from the Sault half way to North Bay. A full report of this study on the north Superior shore was published later, in 1897.†

Regarding the relation of the Algonquin and Nipissing shorelines to those near the south end of Lake Michigan. Taylor wrote:

"The higher beaches of the western end of the Superior basin have no extension south over the Green bay area nor do any of the beaches which connect with the Chicago outlet reach as far north as Escanaba. My own observations seem conclusive on these points. Neither the Algonquin nor the Nipissing beaches have any connection with the Chicago outlet, nor do either of them extend to the Erie basin. Both pass to, or a little below, the head of the St. Clair River."‡

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*Ibid. 257.

†"Notes on the abandoned beaches of the north coast of Lake Superior." Am. Geol., vol. 20, pp. 111–128. 1897.

‡Am. Geol., vol. 17, p. 257.

These statements about the beaches in the southern parts of Lakes Michigan and Huron, since disproved by Taylor and others, seemed to be justified by an exploration of the coasts of the lower peninsula of Michigan, from Saginaw Bay past Mackinac to Manistee, where Taylor reports that "both the Algonquin and Nipissing beaches were found developed in fine form, and both were traced with substantial continuity from their nodal points on the east coast northward and upward to the strait, and then southward and downward to their nodal points on the west coast."* The Algonquin water-plane was thought to pass under Lake Huron a few miles south of Harrisville, and under Lake Michigan near Old Mission Point, in Grand Traverse Bay. The altitudes previously conjectured are reported to have been confirmed in all but two or three instances.

Now that a general agreement had been reached among workers on Great Lake history regarding the ice-dam theory, as against that of marine submergence, attention was turned to other points. The extent of Lake Warren was discussed by Taylor and Upham,† the latter maintaining that Lake Warren entered the Michigan and Superior basins, although Taylor's examination of the beaches around the borders of Michigan had led him to the opposite conclusion. The complete independence of the Algonquin and Nipissing planes and the distinctness of their shore-lines was repeatedly emphasized by Taylor, the Nipissing being described as a shore line of mature development, stronger and more conspicuous than the Algonquin.

In a report on his examination of the Nipissing pass,‡ Taylor gives additional evidence to show the abnormal drop in level of the highest beach in this district, and again accounts for it by differential warping near the pass. The problem of the date of opening of the Nipissing pass by the breaking of the ice-dam, —whether it was before or after the deformation of the Algonquin plane, is discussed at some length, but without arriving at a positive conclusion.

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*Ibid. 254.

†In correspondence in the American Geologist.

‡"Notes on the Quaternary geology of the Mattawa and Ottawa valley." Amer. Geol., vol. 18, pp. 108–120. 1896.

Attention was also directed once more in 1895 to the Kirkfield or Trent River pass, the line of drainage which had been discovered by Spencer, at first thought by him to drain Lake Algonquin, and called the "Algonquin River." Spencer had soon discarded the idea, because it did not harmonize with his later views of general marine submergence. Gilbert, examining the pass in 1895, reported unmistakable evidences of a powerful stream which had excavated a broad, rock-floored channel in the stretches between neighboring lakes of the Trent Basin.* The marks of this old river do not cease at the Iroquois plane, but can be followed all the way down to Lake Ontario at Trenton. The conclusions which Gilbert drew, therefore, are: "(1) that the Algonquin water was a lake and not a gulf; (2) that during the epoch of the Algonquin River the Niagara drained only the Erie basin; (3) that the waning of the ice sheet opened the upper St. Lawrence valley before it opened the Mattawa valley." A recent discovery of Taylor's of the Algonquin beach a few feet above the level of the lake at Port Huron and Sarnia, coupled with the slanting attitude of the old water-plane, and with this study of the Algonquin River, led Gilbert to infer that "the outlet of Lake Algonquin was diverted by terrestrial deformation from Kirkfield to Port Huron" and that the ice front withdrew from the St. Lawrence valley and Lake Iroquois disappeared before the deformation and the shifting of the outlet.

In 1896 Gilbert carried on careful investigations to determine the present stability of the Great Lake region, and reached the conclusion that differential uplifts similar to those which deformed the Algonquin and Nipissing water-planes are still going on. This view had been expressed as early as 1869 by G. R. Stuntz, a land surveyor at work near the western end of Lake Superior, who saw there indications of recent rising of the lake upon the land, in the drowning of the mouths of rivers now partly filled by swamp deposits, and in the disappearance of rapids on the St. Louis river west of Duluth.† The work of

* "The Algonquin River." (Abstract) Am. Geol., vol. 18, p. 231.

† "On some recent Geological Changes in Northeastern Wisconsin." Am. Assoc. Adv. Sci., Proc., vol. 18, pp. 205–210. 1870.

Gilbert and Spencer on the deformed planes of Iroquois and Algonquin had raised the question whether the deformation of the shore-lines is really finished or still in progress. The tilting of the Nipissing plane in the distance between North Bay and Port Huron (points originally on the plane) had been found to amount to 140 feet; and this deformation was produced within about 5,000 years, according to estimates of the time required to cut the upper gorge of Niagara. Since such earth movements are gradual, 5,000 years seemed none too long a time for so pronounced a deformation; thus the likelihood of present movements was emphasized;. Several points on the shores of the great lakes were selected by Gilbert; viz. Escanaba, Milwaukee, and Port Austin, on the upper lakes; and Cleveland, Port Colborne, Charlotte and Sackett's Harbor on Lakes Erie and Ontario. After careful elimination of irregularities of lake level due to wind, tides, etc., the present height of bench marks at each of these stations above the present lake-plane was determined with great accuracy. These measurements were then compared with similar measurements taken in earlier years (1876 for the three stations on the Michigan–Huron water-plane); and a small but definite increase in height of the more northerly points over the southern points was found in every case. Assuming that the tilting affecting the whole region equally (that is, that it is a uniform plane tilting) and that the tilting is greatest in a direction S. 27° W., and measuring the distances between the stations in that direction, it was found that the four independent pairs of measurements between the seven stations agree very closely, in determining a deformation amounting to 0.42 feet per 100 miles per century. The possibility of errors from various causes, affecting measurements of such slight absolute value was fully seen, as well as the uncertainty in the assumptions regarding the nature of the tilting; but the remarkable harmony between the independent computations argues for the approximate correctness of the results. This study has been of unusual popular interest, because it suggests that in time the Port Huron outlet may be lifted as high as the old outlet at Chicago, causing the great lakes to flow into the Mississippi, and Niagara to diminish in volume and finally run dry.

Upham published his views on the history of the Great Lakes again in the American Geologist for Sept. 1896.* He persists in the opinion that Lake Warren overspread Lakes Michigan and Superior and had its outlet past Chicago, "attaining an area nearly equal to that of the contemporaneous Lake Agassiz."† Lake Algonquin is thought to have drained into Lake Iroquois past Port Huron and the "river Erie" in the floor of the present shallow Erie basin. The use of the Nipissing pass as an outlet for the lake for any considerable period is disputed, it being thought that the uplifts had brought this pass nearly or quite up to the water-plane of Lake Algonquin before the dam broke. The Canadian geologists, Robert Bell and A. E. Barlow, are quoted as saying that they find no evidence of a great river in the Mattawa and Ottawa valleys.

In the summer of 1896, Taylor completed a study begun by Gilbert on the beaches, outlets and moraines of the southeastern part of Michigan. Five well defined outlets were examined, by which Lake Warren had at different stages drained westward across the "thumb" of Michigan to the Grand River and Lake Chicago.‡ The independence of Lake Warren and the early lake of the Michigan basin was thus supported by a new line of evidence. The demarkation of successive ice-dams by water-laid moraines was carefully worked out, and the successive changes of outlet and configuration of an ancestral line of lakes, Maumee, Saginaw, Whittlesey, and Warren. In the autumn of the same year, Taylor examined once more the valley of the Nipissing–Mattawa River, finding in it ancient rapids, cataracts, and bowlder pavements which testify to the occupancy of the valley for a considerable length of time by a strong river.§

One of the most widely read accounts of the post-glacial

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* "Origin and age of the Laurentian Lakes and of Niagara Falls." Am. Geol., vol. 18, pp. 169–177. 1896.

† Ibid. p. 172.

‡ Correlation of the Erie-Huron beaches with outlets and moraines in southeastern Michigan." Geol. Soc. Am., Bull., vol. 8, pp. 31–58. 1897.

§ "The Nipissing-Mattawa River the outlet of the Nipissing Great Lakes." Am. Geol., vol. 20. Correspondence, pp. 65–66. 1897.

history of the Great Lakes in Taylor's paper in the "Studies in Indiana Geography."* This states the conclusions reached up to 1897, without going into detail as regards the facts on which the conclusions are based. Briefly, this is the history: Lake Warren and Lake Chicago were contemporaneous for a long time, the former discharging westward through the Grand River into the latter. At last, with the retreat of the ice front in New York state, the Mohawk pass was opened; Lake Warren fell below its former outlet and was dismembered, with a strait across the ridge at Port Huron. At about the same time the Superior and Michigan basins were opened and united with Huron to form Lake Algonquin, with its outlet at Port Huron. Some time after this, the Niagara ridge rose above water and separated Lake Erie from glacial Lake Iroquois. Taylor's map of Lake Algonquin† shows the water-plane dipping under Lake Michigan to a depth of about 100 feet at Chicago. The retreat of the ice front so as to uncover Balsam Lake opened the Trent valley pass, and the level of Lake Algonquin sank (probably only a slight amount) to the new outlet. Differential uplifts were going on, so that in time the Trent pass was raised above the Port Huron pass and the outlet shifted to the south again. These uplifts continued to raise the beaches to a slanting position, while a tongue of the ice sheet maintained a dam across the lower pass east of Lake Nipissing. At last this dam broke, the new pass opened and a new outlet was found at the northeast corner of the great lake; but the fall in level was probably slow and of slight amount, because the earth movements had brought the Nipissing pass up nearly to the Algonquin water-plane. A considerable time before Lake Algonquin fell, Lake Iroquois had been drained off by the retreat of the ice front from the Adirondack region. The falling of the waters to the Nipissing pass dismembered the lake into the "Nipissing Great Lakes," of shape similar to Superior, Michigan, and Huron. The long duration of this stage is shown by the strength of cliffs, bay barriers and lagoon lakes.

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* "A short history of the Great Lakes." Chapter 10; in "Studies in Indiana Geography," edited by C. R. Dryer. 1897.

† Reproduced in its general outlines (but modified in this particular) in Fig. 2.

The Nipissing plane rises towards the northeast, like the Algonquin, but with remarkable uniformity, and at the rate of 7 inches to the mile. It is thought to pass under Lake Michigan to a depth of 100 feet at Chicago, under Lake Huron to 40 feet at Port Huron, and under Lake Superior to 25 feet at Duluth. The uplift of the Nipissing pass brought it finally to the level of the Port Huron pass, and the outlet southward to Lake Erie was revived. The occupation of different outlets at the different stages is thought to be recorded in the dimensions of different parts of the Niagara gorge. The narrow shallow gorge, three quarters of a mile long, from the railroad bridge to the Whirlpool basin was cut while the Nipissing pass drained the great lakes; the wider gorge above the railroad bridges to the falls, two and a fifth miles long, was cut after the outlet was shifted from the Nipissing pass to Port Huron. An estimate of the time taken to cut the upper section of the Niagara gorge, based on the modern rate of recession of Niagara, places the abandonment of the Nipissing pass at least 2,700 years ago.

Continued investigation by Taylor and Leverett around the Huron and Erie basins, from 1897 to 1900, resulted in an elaborate reconstruction of the successive positions of the ice front along ice-laid and water-laid moraines, and of the determination of the outline of the lakes at each stage. An account of this work, and an answer to certain criticisms by Spencer, who still held to the hypothesis of marine submergence, was given by Taylor in the American Geologist for 1899;* and has been greatly amplified, and embodied in Leverett's monograph on "The Glacial Formations and Drainage Features of the Erie and Ohio Basins."†

RECENT WORK IN WISCONSIN AND MICHIGAN.

Work done under the direction of the Geological Survey of Michigan in the last six or seven years by Dr. A. C. Lane, Mr. F. B. Taylor, Dr. C. H. Gordon, the late Prof. I. C. Russell, and others, together with work now being carried on by Mr. Leverett

*"The great ice dams of Lakes Maumee, Whittlesey, and Warren." Am. Geol., vol. 24, pp. 6–38. 1899.

† U. S. Geol. Surv., Monograph 41. 1902.

for the U. S. Geological Survey, has greatly extended the knowledge of old shore-lines in that state. Important parts of this work are still unpublished, but of that already in print reference must here be made to the report on Huron County, by Lane,* and a more recent one by Russell, on the surface geology of the north shore of Lake Michigan.†

Lane's report on Huron County (the end of the "thumb" of Michigan) is of particular significance to the present study because that area corresponds to a critical portion of the eastern Wisconsin shore, where the reconstruction of the Algonquin and Nipissing water-planes is difficult. In Huron County, the Algonquin beach was found by Lane at a height of about 25 feet above the lake. On the eastern side of the thumb it is marked by cliffs, except where for a few miles it has been destroyed by recent cutting. On the west side of the thumb where the slopes are gentle, it is marked by dunes and marsh flats. Below the Algonquin beach four lower crests are frequently seen; but one which is particularly well formed and persistent at 14 feet, which may be the Nipissing beach. A reference‡ to river terraces which seem to correspond to the beaches, recording successive lake levels, is of special interest, as a recognition of a principle which is emphasized in the present report on eastern Wisconsin. The Nipissing plane had formerly been thought to pass under Lake Huron north of Huron county. Lane argues for the presence of the Nipissing plane above the lake instead of below it; the rivers, where they enter the lake show no recent drowning, and seem never to have been adjusted to a lower base level than the present one. Following the method of Dr. Andrews,§ Lane estimates the date of the old lake stages. Lake Algonquin seems to have come into existence 4,000 years ago. A chart showing the fluctuations in level of the lakes from 1800 to 1900 (based on Whittlesey's data, and on the reports of the Lake Survey) is of great interest in showing in a graphic way the

* Mich. Geol. Surv., vol. 7, part II. "Geological Report on Huron County, Michigan." 1900.

† "A Geological Reconnaissance along the north shore of Lakes Huron and Michigan." Geol. Surv. Mich., Ann. Rept. 1904, pp. 83–112.

‡ In a foot note on page 76.

§ In his paper of 1870. Op. cit.

monthly and annual fluctuations as well as the greater changes of level which occupy periods of a number of years' duration. The highest water level, in 1838, was approximately six feet higher than the stages of low water in 1811 and 1896. The rainfall line, on the same diagram, brings out a manifest causal connection.

Russell's report of 1904* confirms Taylor's observations on the Algonquin and Nipissing shore-lines around the north end of Green Bay and Lake Michigan, giving a more detailed description of these beaches and terraces, with several new measurements of altitude of the deformed water-planes. The northeastward rise of the Algonquin plane, here averaging 2 feet per mile, but increasing towards the north, is confirmed; likewise the presence of several well defined shore-lines below the Algonquin and above the Nipissing. The latter is most strongly marked of all. It is said to be tilted, also, but not so strongly as those above it. "The planes of both the Algonquin and the Nipissing beaches, in the region about the north shore of Lake Michigan, . . . are inclined downward from the northeast toward the southwest, the former at the rate of about two feet per mile and the latter 6½ inches per mile. At these rates of inclination the two beaches should coincide in the region about Menominee. The country on the west side of Green Bay between Escanaba and Menominee for a distance of five or six miles inland, is low, sandy and swamps covered with dense vegetation. It has not been examined in detail and only the position of the highest beach present and that at only a few localities, has been well determined. Precisely at what locality the two beaches referred to came together is not known.

"To the south of Menominee, the Nipissing beach as represented on a map published by Taylor, passes below the level of Lake Michigan, but observations made by Frank Leverett, as yet only in part recorded, seem to indicate that more tilting has occurred to the northward of a northwest and southeast line drawn through Lake St. Clair and the vicinity of Menominee, than to the south of such a line, and that the Algonquin and Nipissing beaches coincide in the southern half of the Lake

* Op. cit.

Michigan basin, their combined records being a well defined beach about 15 feet above the present water level."*

These statements indicate some of the unsettled problems which are now engaging the attention of those engaged in the study of shore-lines near Lake Michigan. In the present report on the abandoned shore-lines of eastern Wisconsin some light will be shed on the behavior of the Algonquin and Nipissing planes, on the west side of the Michigan basin.

In recent years the Chicago district, formerly investigated by Leverett, has been studied by Dr. W. C. Alden, in preparation of the Chicago Folio.† A brief resumé of what is known concerning the beaches of Lake Chicago near the head of Lake Michigan is there given. Still more recently Alden has carried this study farther north, into Wisconsin, in his preparation of a report of "The Delavan Lobe‡ and of the Milwaukee folio.§ The terrace mentioned by Chamberlin in 1877 as occurring between Port Washington and Sheboygan has been followed by Alden as far as the northern boundary of the Port Washington sheet (near Belgium), and traces of a higher terrace and beach, thought to be the Calumet, have been recognized. From the Illinois line, the Toleston beach has been found to extend as far north as Kenosha, the Calumet to Racine, and the Glenwood to a few miles beyond Wind Point. Beyond that locality the Glenwood is thought to be represented in part by gravels and sands which are covered by a red clay formation, as if the ice had overrun the beach deposits in Glenwood times during a temporary re-advance. Near Fox Point a 15-foot terrace, supposed to be Toleston, was found. The two terraces north of Port Washington were provisionally referred to the Toleston and Calumet stages of Lake Chicago. No beach at Glenwood level was found north of the Wind Point termination.

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*Op. cit. pp. 92–93.

† Geologic Atlas of the United States. Chicago Folio, No. 81, U. S. Geol. Surv. 1902.

‡ "The Delavan lobe of the Lake Michigan glacier of the Wisconsin stage of glaciation and associated phenomena." U. S. Geol. Surv. Prof. Paper No. 34, 1904.

§ Geologic Atlas of the United States. Milwaukee Special Folio, No. 140, U. S. Geol. Surv., 1906.

PROBLEMS UNDER CONSIDERATION.

The problems which were kept in mind by the present writer during the season's field work are naturally grouped around the history of the three lakes, Chicago, Algonquin, and Nipissing.

(A) How far north could each of the Lake Chicago beaches be traced? Alden had apparently found the end of the Glenwood beach beneath the red clay of the Milwaukee district; but the northern limits of the Calumet and Toleston shore-lines had not been determined, on the west side of Lake Michigan. On the east side, Leverett and Taylor had traced the Calumet northward to its probable end at Manistee, Mich. (opposite Manitowoc, Wis.).

Are these Lake Chicago beaches tilted? Previous studies seemed to indicate that they were not.

(B) How far south do the Lake Algonquin beaches extend? The Door county peninsula offered an exceptional field for collecting evidence on this point, as Taylor suggested in 1893; yet no one had visited it since the existence of Lake Algonquin and Lake Nipissing had first been recognized. The Algonquin beaches were found by Taylor only at Green Bay, Sturgeon Bay, and Kewaunee.

How steeply are the Algonquin beaches tilted? Does the inclination decrease, south of Sturgeon Bay, as the latest observations of Leverett, Taylor, and others in Michigan would indicate? or does the Algonquin beach continue to slant southward at the two-foot-per-mile rate until it dips under the lake at Two Rivers? If the inclination of the water-plane does decrease, do the Algonquin shore-lines become horizontal as far north as Two Rivers, and continue southward around the head of Lake Michigan at a height greater than has been supposed? Is the "Algonquin" thus perhaps the northward extension of the "Toleston" beach of Lake Chicago? This would involve, of course, the use of the "Chicago outlet" as an outlet for Lake Algonquin.

(C) Does the Nipissing shore-line appear in Wisconsin at all? or does it gradually descend southward to a 10- or 15-foot level, and becoming horizontal encircle the head of Lake Michigon, as the later work of Leverett and Taylor might suggest?

In that case, do the Algonquin and Nipissing planes coincide in the southern part of the basin or does the Nipissing plane overlap the Algonquin, or does the Algonquin become horizontal above the Nipissing plane and the two shore-lines encircle the head of the lake as separate beaches?

CONCLUSIONS REACHED.

Before presenting the detailed evidence these questions may be briefly answered.

(A) The 60-foot and 40-foot beaches of Lake Chicago seem to extend as far north as Sheboygan. It seems probable that the more northerly portions of them were obliterated by the advance of the ice to the Manistee moraine. These higher beaches seem to have suffered little or no tilting.

(B) The Lake Algonquin beaches seem to extend southward through Wisconsin with rapidly diminishing inclination south of Sturgeon Bay, becoming horizontal near Two Rivers, and encircling the southern half of Lake Michigan as the "Toleston" beach. This makes the Chicago outlet an outlet for Lake Algonquin at its highest stage.

(C) The Nipissing water-plane seems to stand nearly horizontal along the whole Wisconsin shore,—absolutely horizontal, and 10 or 15 feet above the lake, south of Manitowoc.


WASHINGTON I.
DEATH'S DOOR
Hedgehog I.
Ellison Bay
Sister Bay
Newport
Rowleys Bay
Appleport
North Bay
Ephraim
Fish Creek
Egg Harbor
Bailey's Har.
Jacksonport
Cave Pt
Whitefish Bay
Sturgeon Bay
Sawyer
Gracefort
Peshtigo
Marinette
MARINETTE
OCONTO
Oconto
Pensaukee
GREEN BAY
Brookside
Little Suamico
Big Suamico
Brussels
Dykesville
Clay Banks
Foscoro
Algoma
Green Bay
Bay Settlement
Rostok
Kewaunee
BROWN
KEWAUNEE
Two Creeks
Two Rivers
Manitowoc
MANITOWOC
Centreville
SHEBOYGAN
Sheboygan
Oostburg
Belgium
Port Washington
OZAUKEE
Fox Pt.
MILWAUKEE
Milwaukee
Wind Pt.
Racine
RACINE
KENOSHA
Kenosha
LAKE MICHIGAN
N
MAP
OF
EASTERN WISCONSIN
Showing the Location of
Preserved Fragments
Of the Shore Lines of
the Extinct Lakes.
0 6 12 18 24 30
SCALE OF MILES
LEGEND
Lake Chicago Shore Line
Lake Algonquin " "
Lake Nipissing " "
Dunes

CHAPTER III.

DESCRIPTION OF THE OLD SHORE-LINES IN EASTERN WISCONSIN.

THE DISTRICT SOUTH OF THE STATE LINE.

South of the Wisconsin line, in Illinois, the beaches of Lake Chicago have been traced by Andrews, Alden, Leverett, and others. Three stages marked by three distinct shore-lines, are usually discriminated; the Glenwood or 60-foot, the Calumet or 40-foot, and the Toleston or 20-foot beaches. From the Chicago district these beach ridges run northward to the lake shore, where they are successively cut off by the present lake cliff at Evanston, Gross Point, and Winnetka. The Glenwood shore-line passes into a high cut bluff and terrace, however, at Winnetka, a short distance before it reaches the lake. Appearing again at Waukegan, these beaches run northward past Zion City, reaching the Wisconsin state line about a mile inland from the present lake, and just west of the Chicago and Northwestern railway. Since the attitude of these Lake Chicago shore-lines, whether horizontal or tilted, has an important bearing on the correlation of the fragments, separated as they are by a twenty-five mile gap between Winnetka and Waukegan, and by much longer stretches in Wisconsin, where the present lake has destroyed previous lake records, it is profitable to consider briefly what is already known of the Glenwood, Calumet, and Toleston water-planes in Illinois.

The Glenwood stage was recognized by Andrews as complex, indicating several successive levels. Later, Leverett published measurements of the height of this beach at ten localities in Illinois. At Glenwood, the type locality, the beach ridge stands at 636 feet above sea level, or 55 feet above Lake Michigan. When compared with other measurements, this seems to register the highest level of the lake in Glenwood times. Below it are ridges at many places which mark successive lowerings of the lake while the Chicago outlet was being cut down; and these extend the Glenwood series down to about 627 feet, or 46 feet above the lake, only a few feet higher than the Calumet stage. In the district between Waukegan and the Wisconsin line, also, the highest beach shows a complex structure. Three miles north of Waukegan it is 47 feet above Lake Michigan; west of Beach station its three crests are 46–49 feet; at Zion City two parallel ridges stand at 53 feet; and at the state line the beach is a few feet higher. Further study may demonstrate a tilting of this beach and of the lower shore-lines of Lake Chicago; but at the present time there seems scarcely to be sufficient reason to suppose that any considerable tilting has occurred in this part of the basin of Lake Michigan since the Glenwood stage, particularly as beach ridges at about 60 feet have been found farther north, in Racine and Sheboygan counties. The same statement applies to the Calumet and Toleston beaches, with certain exceptions which will be noted.

KENOSHA AND RACINE COUNTIES.

Facing the lake just west of the tracks of the Chicago and Northwestern railway where it crosses the Wisconsin state boundary is a conspicuous bluff and terrace which has been referred to the Toleston stage of Lake Chicago. (Plate V, Fig. 1.) It is plainly seen from the railroad train all the way from Waukegan, Illinois, northward to this point. In the whole stretch of several miles the terrace at the base of this bluff is never so high as 20 feet and usually but 13 or 14 feet above the lake. At the state line, leveling from the railroad places it at 594 feet, or 13 feet above Lake Michigan. This is ten feet lower than the crest of the Toleston beach ridge at Evan-

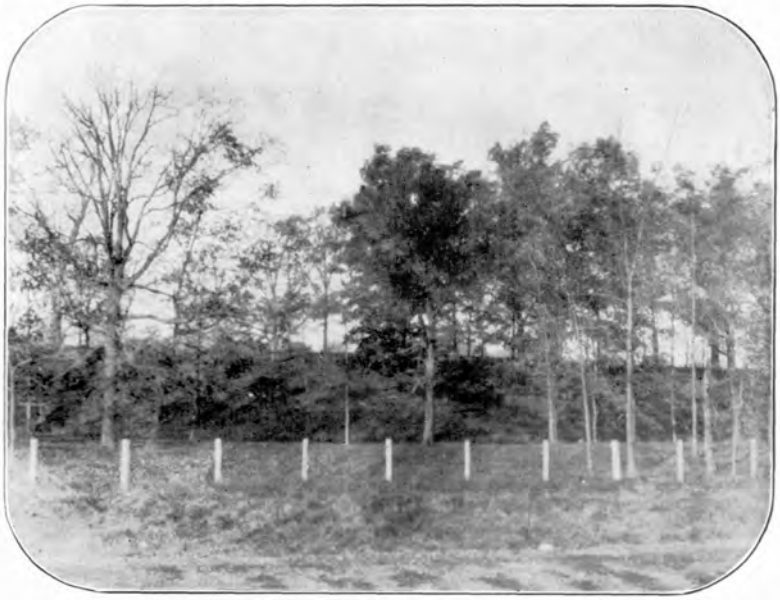


Fig. 1. Bluff of the Nipissing or 14-foot stage, near the Illinois state line.

Fig. 2. Termination of the Glenwood beach, north of Wind Point.

ston, Illinois, on the campus at Northwestern University, the nearest point south of Waukegan where shore-lines as low as this are preserved. It seems likely, therefore, that this 13–14 foot terrace and bluff corresponds rather to certain beach ridges of the Chicago district which stand below the main Toleston beach, in a closely set series ranging in altitude from 10 to 15 feet above the lake. The absence of any record of the Toleston stage at the State line is then explained by the mere presence of the bluff, which records a recession of the shore-line so far inland during the 14-foot stage that it destroyed the Toleston beach and developed a bluff nearly twenty feet high. The idea that this marks the water-plane of Lake Nipissing may here be suggested, to await more thorough statement in a later chapter.

On the brink of the Nipissing(?) bluff at the State line there seems to be a faint ridge at an altitude of 35 feet above the lake, half cut away by the retreat of the cliff. Farther south more distinct fragments of a beach ridge between 35 and 40 feet have been preserved, where the later cliff recession has not gone on so far. It seems reasonable to suppose that this is the Calumet beach, as other observers have stated. A short distance farther on, at the State line, a gentle slope leads up to the highest beach ridge, presumably the Glenwood, which here has a variable altitude of 53 to 58 feet. This beach ridge is followed for a short distance by the road to Kenosha, but soon swings off to the northwest. Not far west of the road at the State line is another ridge which stands about ten feet higher than the Glenwood beach and contains some stratified materials, but so far as could be judged this is one of those local glaciolacustrine deposits which seem to have formed in pools or along temporary stream courses before the ice had wholly uncovered this corner of the Glenwood lake.

Fig. 4.—Profile at the Illinois state line.

The diagram (Fig. 4) shows the old shore-lines as they appear in profile at the State line. East of the railroad a broad marsh containing a large number of low sand ridges extends out to the

present lake shore. It is probable that the outermost of these beach ridges record merely fluctuations in level of the present lake dependent on rainfall; others probably mark stages of lowering from the 14-foot plane to the Lake Michigan level as the outlet at Port Huron has been gradually cut down.

North of the State line the railroad obliquely ascends the bluff by a long grade, and thence to Kenosha follows slightly higher ground, among indistinct beach ridges and dune ridges of stages which doubtless include the Toleston. The Glenwood beach ridge, which has turned farther inland north of the state line, stands more than a mile west of the railroad at the southern border of section 28. The road to Kenosha at the same section line follows a ridge whose crest is 48 feet above the lake, probably the Calumet ridge judging from its isolated position, although it is a few feet higher than the supposed Calumet beaches both south and north of this point. Possibly there has been some tilting of the Calumet beach; but the presence of a 35–40-foot ridge a few miles farther north argues to the contrary. The greater height at this point may be due to the accumulation or wind-blown sand. The extension of these beaches to Kenosha has been traced by Alden and others. The highest Glenwood beach lies about a mile and a half west of the city, as can be seen from the contours on the Racine sheet (U. S. Geological Survey). In places the beach gives way to a terrace and low bluff of till.

North of Kenosha the Glenwood ridge has been traced somewhat interruptedly past Racine to the shore four miles beyond Wind Point, where it is cut off by the lake. Levels run from the railroad westward along the Kenosha-Racine county line fix three closely set crests of the prominent Glenwood ridge at 53, 54, and 56 feet above Lake Michigan. The termination of this ridge north of Wind Point is shown in Plate V, Fig. 2. The Calumet beach ridge from Kenosha northward to the county line lies usually just west of the railroad, with an altitude of 38–42 feet, determined by leveling in three places. Its off-shore sand deposits reach eastward to the lake, where they appear at the top of the freshly cut till bluffs continuously as far as Racine. Andrews and more recently Alden have traced the Calumet beach across Wind Point at some distance back of the present

cliffs. Beyond Wind Point there is a stretch of fifty miles before the Glenwood and the Calumet beaches reappear, north of Port Washington.

PECULIAR TOPOGRAPHY AT KENOSHA.

In the northern part of the city of Kenosha is a district exhibiting several topographic features which have a peculiar interest, in connection with the study of lake shore processes. Reference to the Racine sheet will discover Pike River, which cuts across a till ridge half way between Kenosha and Racine, flowing eastward beyond the Glenwood beach about a mile to Berryville, and there, within three-quarters of a mile of the lake, turning abruptly southward and flowing for three miles more in a well defined valley until it finally reaches Lake Michigan near the Kenosha city limits. The lower course of Pike river is a clear case of stream deflection during the drawing down of the lake level and the advance of the shore-line. For a portion of this distance the river runs behind a broad Calumet beach ridge, following the axis of an old lagoon or protected swamp; but it soon crosses the Calumet shore-line obliquely near the railroad and persists in a deflected southward course, reaching the lake just where the Toleston beach ridge seems to have been before it was mostly cut away by the waves. The deflection of this part of the stream appears to have been accomplished without the formation of any barrier reefs or bars, but by continual shifting of the mouth of the river by southward shore currents while the lake was falling from the Calumet to the Toleston water-plane. The same lowering of base-level caused the river to cut down a sharply defined valley to a depth appropriate to the present lake. Deflections like this are by no means uncommon along both the ancient and the modern shores of Lake Michigan and the other Great Lakes. They are the rule rather than the exception, in that part of eastern Wisconsin where shore topography has been preserved. Cases will be cited later where an abandoned beach bar which controlled the course of a stream, causing it to cut a valley parallel to the shore and close to it, while the lake was sawing back a line of cliffs on the outer side of the abandoned bar, has

caused the development of a peculiar elongated terrace which for lack of a better term I have called a "bar terrace." (See pages 64–65.)

Another process which is on exhibition at Kenosha to an unusual degree is cliff recession. Under the attack of the waves a steep line of clay bluffs is being cut back at an extraordinarily rapid rate. During each storm the waves saw horizontally into the red clay, while blocks of the compact but unconsolidated material tumble off into the lake from vertical or overhanging cliffs, supplying the waves with material for the construction of beaches. It is a remarkable fact, however, that the platform below the cliffs at the water's edge is hardly concealed with gravel or sand, but swept nearly clean, so rapidly is the debris transported. At three gaps in the line of cliffs, where the coastal slope is low, beaches are accumulating; and at these points the beach gravel is being shoveled into carts and railroad cars in great quantities. As this process of artificial stripping has been going on at this locality for many years, it suggests one reason for a local rate of cliff recession much faster than the average. There are certainly other reasons, however, for a similar local activity of cliff cutting is found at several points on the eastern Wisconsin shore where artificial conditions do not enter into the problem. It is known, moreover, that the cliffs at Kenosha were rapidly retreating as early as 1847, before the beach gravels were stripped off to any extent. Perhaps local instances of rapid cutting like this may depend on certain favorable conditions of exposure or configuration of the lake platform, whereby the action of waves and shore currents is stimulated.

As a result of the combined process of stream deflection, valley excavation along the deflected course, and rapid recession of the shore cliffs at the lowered level of the lake, a peculiar change of drainage has occurred near the mouth of Pike River. The Racine sheet shows a lagoon or bayou at Kenosha, where the Life Saving station stands, which lies directly in line with the course of Pike River; but is separated from it by the retreating lake cliffs for a distance of three-quarters of a mile. It can easily be demonstrated that this bayou was formerly the mouth of Pike River, and that the lake has severed it from the upper

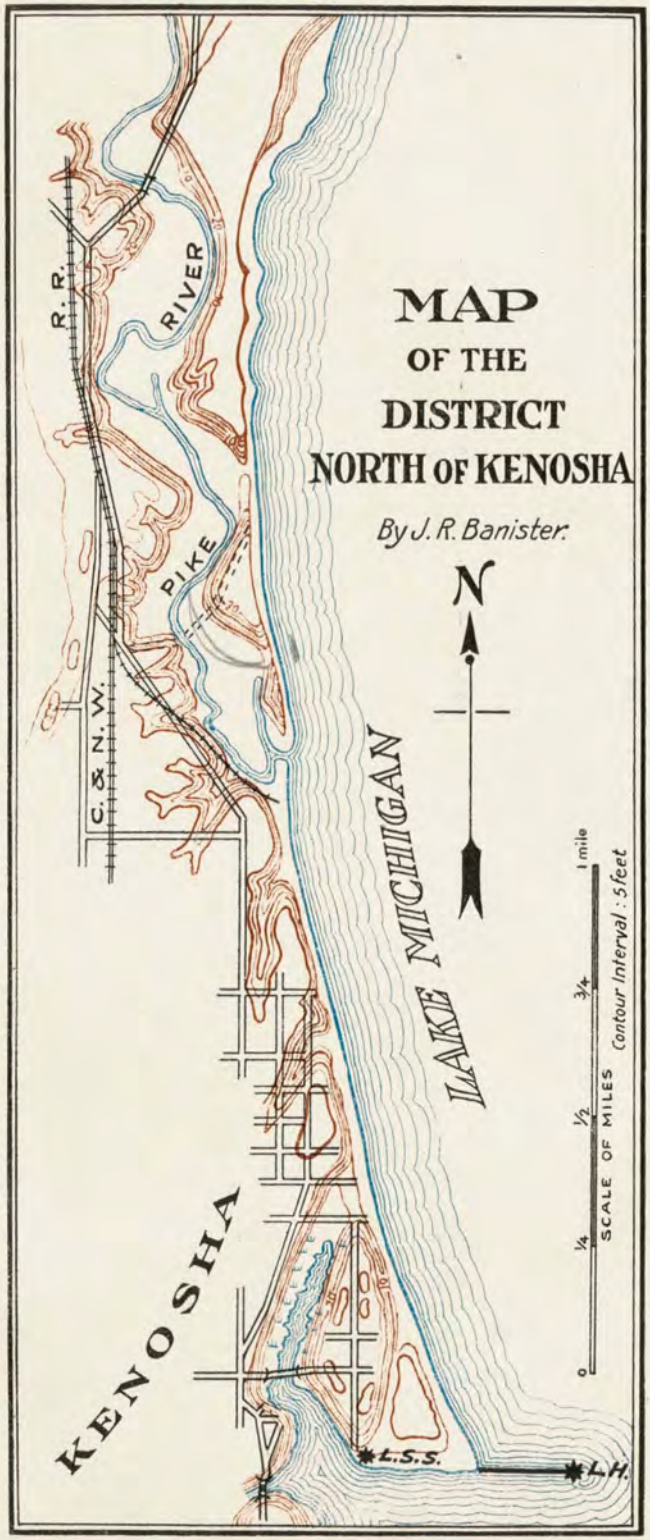

MAP
OF THE
DISTRICT
NORTH OF KENOSHA
By J. R. Banister.
N
R. R.
RIVER
PIKE
C. & N. W.
LAKE MICHIGAN
KENOSHA
L.S.S.
L.H.
SCALE OF MILES
0
¼
½
¾
1 mile
Contour Interval: 5 feet

Fig. 1. Mouth of Pike River, near Kenosha.

Fig. 2. View northward from the mouth of Pike River, showing the nearest breach.

part of the river by cutting a breach through the eastern wall of the valley and capturing the river at a point over half a mile above its mouth. Not only is this fact recognized by old residents of Kenosha who have observed the retreat of the cliffs for years and have heard stories of the condition of the shore in the days of settlement of the region; but it was concisely stated by I. A. Lapham as early as 1847, in a paper printed in the American Journal of Science.* "At Southport, thirty-five miles south of Milwaukee, the bend of a stream has been carried away, so that its valley presents three openings to the lake, as represented in the figure . . . where the dotted line represents the ancient state of things and the black lines the modern."

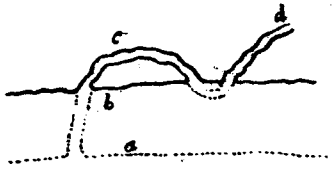


Fig. 5.—The mouth of Pike river (from Lapham's paper). a, Ancient coast; b, present coast; c, bayou; d, river.

It is not known when the severing or intercision of Pike river took place; but a comparison of the present maps with those made in the early days should show considerable change in topography due to cliff recession, by which the distance between the lagoon and the active mouth of the river has increased. The most interesting feature, perhaps, is the repetition of early stages of the same process at two points just north of the present river mouth, where in comparatively recent times the lake has eaten back into two sharp bends of the Pike River valley, opening out a wide breach at each place, which threatens a new intercision, with the production of another severed bayou. The contour map (Plate VI prepared by Mr. J. R. Banister, of Northwestern University) shows the topography much more faithfully than the less detailed Racine sheet. It is noticeable that the bayou valley is much narrower than the valley still oc-

* Am. Jour. Sci., 2nd Series, vol. 3, p. 92. 1847.

cupied by the river. This may be accounted for by lateral plantation along the river banks since the bayou was cut off; for the river is today actively trimming its banks. Plate VII shows the two crescentiform hills which remain between the lake and the river and are separated by three openings where the lake has broken through. At the most northerly of these breaches in December, 1905, the storm waves were running over the top of the beach and washing gravel and sand across the flood plain to the side of the river itself, forming a water connection through the breach. The actual intercision of the river will probably be postponed until the lake-shore has been cut back nearly or quite to the opposite side of the valley, crowding the river back until its flow is obstructed by the beach; but at any time before this stage is reached the river may break through the beach during a flood, and finding a shorter course to the lake, maintain it.

Three minor features incidental to the process of rapid cliff recession are worthy of notice. (1) At each breach the retreat of the beach ridge exposes a thin deposit of peat, underlain by limonite conglomerate, the flood plain deposits of the valley across which the beach is being pushed. (2) In the valley of a former tributary to Pike River, which now runs directly to the lake just south of the river near the trolley station, the little intermittent stream has sunk a sharply defined valley two or three feet below the general valley floor, a delicate index to the recent lowering of its local base-level from Pike River to the lake. (3) A short distance north of the northernmost beach (as the map shows very distinctly) several typical cuspate forelands are developed in the lee of a broad beach terrace built by the southerly shore drift. One of these is seen in Plate VIII, Fig. 2, as well as the terrace which lies north of it, and whose border is itself thrown into cusps of smaller dimensions. A line of breaking waves not far off-shore indicates that a submerged sand reef extends southward from the terrace parallel to the shore. Perhaps the cusps are due to eddying currents between the shore and the strong southward-flowing current, which is here directed somewhat off-shore by a headland at the northern end of the broad terrace. The terrace is in that case the result of filling

Fig. 1. Freshly cut cliff north of Pike River, showing both of the gaps cut by the lake.

Fig. 2. Cuspate foreland and broad terrace, north of Pike River.

in of the quiet water back of the headland by eddying currents, laden with shore drift. Figure 6 suggests this condition.

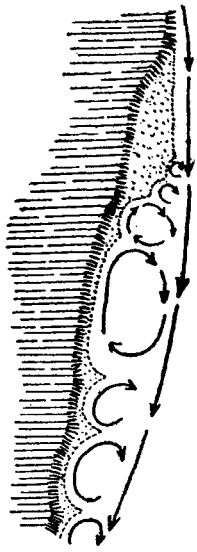


Fig. 6—Sketch map of cuspate foreland north of Kenosha, showing the supposed eddies in the shore current.

THE MILWAUKEE DISTRICT.

Between the termination of the Glenwood beach near Wind Point and Port Washington the active retreat of the clay bluffs has removed almost all the old shore records. In the freshly cut cliffs of the Milwaukee district a complex structure of laminated clays, till, and stratified sands and gravels is extensively exposed. This group of formations has recently received exhaustive study by Alden, in preparation of the Milwaukee Folio* When complete, the section from the lake upwards is; (a) blue bowlder clay, the late Wisconsin till, which sometimes overlies a deposit of laminated and contorted red clays; (b) perfectly stratified sands and gravels of variable thickness and composition, which have an average height of 55 feet above the lake, but locally reach up to 80 feet; (c) burying the gravels and sands, a deposit of red clay, usually finely laminated below and unstratified bowlder-clay above. Alden suggests that the

* Geol. Atlas of the United States, Milwaukee Special Folio, No. 140, U. S. Geol. Surv. 1906.

buried gravels are Glenwood lake deposits, which were covered by red clay during a re-advance of the ice,—probably before the close of the Glenwood stage, because beach ridges at an altitude of 60 feet occur superposed on the red clay deposits in the southern part of Sheboygan county. (See pages 54–55 of this bulletin). The red clay seems to be in part lacustrine (including bowlder clay dropped from icebergs) and in part ice-laid, indicating conditions of variable deposition along the front of an advancing ice sheet. The conspicuous red color of the clay, which does not extend south of the Milwaukee district, may, it is thought, be due to the introduction of red sediment from the iron-ore region of the Lake Superior basin at some time in the late stages of glaciation.

The following description of a conspicuous wave-cut terrace and bluff at Fox Point is quoted from the text of the Milwaukee Folio. "On the north shore of Whitefish Bay, and extending a fraction of a mile within the bounds of the Milwaukee district, is an excellent example of an ancient cliff and wave-cut terrace, probably formed at the Toleston stage of Lake Chicago. This terrace, which is continuous for one and a half miles northward to Fox Point and for a mile north of this point has escaped the complete destruction which other phenomena suffered. This terrace has a width of ten to forty rods. From a level of a few feet above the present beach it rises gradually westward to the foot of the bluff, where it has an elevation of 15 to 20 feet above the present lake level." Without precise measurement of this Fox point terrace it seems fair to assume that like the other prominent fragments of shore lines below 20 feet along this part of the Lake Michigan shore, it registers a water plane of about 14 or 15 feet altitude which stands about ten feet lower than the Toleston beach at Evanston, Illinois, and may reasonably be distinguished from the Toleston for this reason, as well as because of its remarkably strong development.

PORT WASHINGTON TO SHEBOYGAN.

About five miles north of Port Washington the high cliffs of red clay which face the lake for many miles beyond Fox Point suddenly give place to a turf-covered bluff with a poorly formed but definite bench at its base, 25 feet wide, and 14 feet above the

lake. This runs for 300 yards along the lake shore, back of the present beach. Behind it the old bluff rises some 65 feet above the lake. This imperfect strip of terrace, somewhat hidden by woods, is the first trace of old shore line to be found north of Fox Point.

A little farther on, the fresh clay bluffs, about 50 feet high, are again replaced by an old bluff and shore terrace of a 14-foot stage. This terrace, at first narrow, soon broadens out until the old bluff stands a hundred yards back from the shore. Although from a distance the outline of this bluff, which is 45 feet high and moderately steep, is sharply defined, a nearer view discloses imperfections in its form; it is blurred by ancient and modern landslides and worn by frequent ravines from which small cones or fans have been washed forward upon the terrace, raising its level; moreover the terrace is veneered with wind-drifted sand. Low bars of gravel, running along the

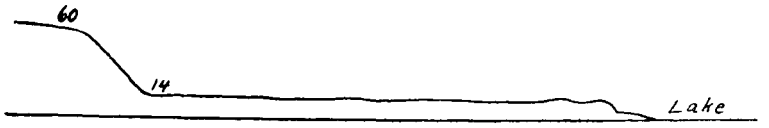


Fig. 7.—Profile of the shore, five miles north of Port Washington.

terrace, close to the present beach, with their crests 10 feet higher than the lake, may be either off-shore subaqueous bars of the 14 foot stage, or beaches of a slightly lower level of the lake.

About a mile north of the place where the 14-foot terrace first appeared, the old bluff is replaced by a second terrace and bluff, marking apparently a much higher stage. It is not nearly as well developed as the lower shore-line. The upper terrace, which Alden has suggested is possibly the Calumet or 40-foot shore-line of Lake Chicago, is generally, in this locality, a vague sloping platform, hardly sandy or gravelly in composition, with a doubtful bluff behind it. On the east-west road south of the quarry east of Belgium (section 25) the double profile may be seen, as in Fig. 8; but neither higher nor lower

terrace is sharply defined. The heights, therefore, 17 and 49 feet respectively, can only be approximate.

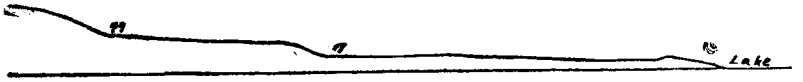


Fig. 8—Profile south of the quarry, near Belgium.

Two miles farther north (on the east-west road along the north side of section 14) the upper of the two shore-lines becomes more definite and takes the form of two low bars of gravel, the higher a short but well formed gravel ridge near the road corner, 60 feet above the lake, and the lower a very flat bar at 48 feet, hardly more than a flattening of the long lakeward slope of the highest beach. The 14-foot shore-line on this road is marked by a low but unmistakable bluff, beyond which a broad terrace with low sand ridges reaches to the present shore.

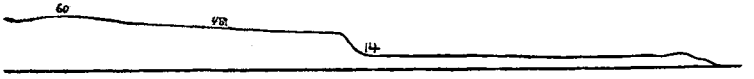


Fig. 9.—Profile a mile north of Belgium.

Although the 14-foot shore-line is easily traced northward for several miles, along the base of a steep bluff thirty feet high, the higher beaches soon become lost in gravel deposits, whose form, if originally characteristic of littoral origin, is too poorly preserved to be detected. And so on, past Amsterdam, the old shore-lines may be followed, the lower with ease, the higher with difficulty and doubt, until east of Oostburg a distinct series of higher beaches is once more found.

Above the clean-cut little bluff of a 17-foot stage (Plate IX, Fig. 1) lie three closely parallel ridges at about 40 feet above the lake, the middle one (by "wye" level) at 37 feet, with a higher and less regular ridge, perhaps a dune, behind it, and farther west, up the road, a well formed bar at 63 feet, in which freshly opened sand pits show the usual cross-bedded structure of beach gravels. North of this road, these higher beaches soon begin to fade away once more, although occasional ridges and frequent ambiguous gravel deposits seem to extend the record

Fig. 1. Nipissing bluff and terrace east of Oostburg.

Fig. 2. Nipissing bluff and terrace at Centerville.

nearly as far as Sheboygan. Even the bluff of the 15-foot stage, heretofore well marked, becomes low and hard to find north of the Oostburg road (in the town of Wilson). But some well-formed gravel and sand-bars which lie somewhat lower, and east of where the bluff is lost, run for a long distance through the woods until they break up into a group of old dunes. These, together with dunes of the present beach, form the backbone of the long strip of unfrequented coast that separates Black River swamp from the lakes. Doubtless many of these dunes date back to the time of the 14-foot stage of the lake, but they are as a rule quite bare and constantly shifting at the present time. On the west side of Black River, occasional low bars, 10 to 15 feet above the lake, are to be seen; but higher beaches are too indistinct to be followed.

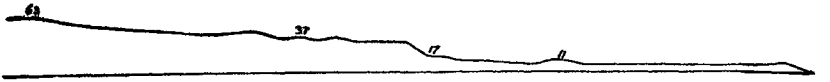


Fig. 10.—Profile east of Oostburg.

The correlation of the shore-lines of Ozaukee and Sheboygan counties with the beaches of Lake Chicago south of Racine is a problem of considerable difficulty. In mapping the Port Washington sheet for the U. S. Geological Survey, Alden doubtfully correlated the upper (49-foot) terrace near Belgium with the Calumet or 40-foot stage of Lake Chicago, and the lower (14-foot) shore-line with the Toleston or 20-foot stage of the same lake. In a later chapter reasons will be given for regarding the 14-foot shore-line as the Nipissing. The higher, less distinct beach ridges undoubtedly belong to Lake Chicago.

SHEBOYGAN.

Although no definite marks of old shore-lines are to be seen near the city, there are extensive plateaus of sand and gravel which seem significant of former high level stages. The northern half of the city is built on one of these deposits, which stands about 60 feet above the lake; and another, south of the city, including Lake View Park, is 40 feet. The sand underlying these flats is usually from five to ten feet thick, and well stratified. They may represent delta-like deposits of the Sheboygan River during a 40- and 60-foot stage.

At the east end of St. Clair St. is a short 40-foot terrace, mentioned by Taylor as possibly part of an old shore-line; but little importance can be placed on it, as artificial grading for houses may have given it the flatness which makes it conspicuous.

Northwest of the city the 60-foot sand deposit passes imperceptibly into a flat upland which the railroad follows to Mosel station. This flat belt is a mile and a half wide, reaching back from the lake cliffs to a gentle but pronounced escarpment. Although it has at first sight the appearance of a 60-foot terrace with a low shore bluff, the absence of any considerable deposit of sand and gravel and of good beach topography makes it of doubtful value in settling the question of the extent of the 60-foot or Glenwood stage of Lake Chicago. As no well marked 60-foot beaches were found north of Oostburg, it is possible that the Glenwood stage of Lake Chicago did not extend beyond Sheboygan.

SHEBOYGAN TO MANITOWOC.

From Sheboygan northward fresh red clay cliffs, from 40 to 60 feet high, face the lake for several miles, until at the old pier at Centerville a 12-foot terrace and turf-covered bluff appear and run inland and northward around the village. From where the terrace first appears at the south end of the village to where it runs out again to the lake is somewhat more than a mile. Were it not for this small fragment of an extinct lake shore, there would be none between Sheboygan and Two Rivers, a distance of about thirty miles. At the north end of the village of Centerville, the steep high bluff appears conspicuously near the shore road, and a broad sandy terrace which is here 14 feet high. (Plate IX, Fig. 2). In the southern part of the village it is significant that the old shore terrace is continuous with a broad terrace that runs up Centerville Creek, an illustration of the dependence of river terraces upon successive lake stages, which is repeated over and over again, along the Wisconsin shore, and which justifies the opinion that most of the ravine terraces, both high and low, indicate approximately old stages of the lake. Such terraces are well displayed along the several large creeks which enter the lake between Centerville and Manitowoc, especially near the mouths of Point River, Point

Creek, and Silver Creek. Although the encroachment of the lake in recent times has left no scrap of shore-line here along the lake border, the ravine terraces abundantly indicate the old stages. Unfortunately it is difficult to confidently recognize whether a certain ravine terrace belongs to a 25- or a 20- or a 15-foot stage; for it is not known how far inland up these slanting terraces the lake has cut since each stage, nor is it known exactly what was the rate of inclination of the old flood plains of which the ravine terraces are mere scraps.

There is opportunity for a large amount of detailed work on these terraces, to determine by many measurements the usual down-valley slant of flood plains of creeks of different sizes, along this coast, and the probable amount of recession of the lake at each locality.

The freshly cut cliffs between Centerville and Manitowoc rise usually from 30 to 60 feet above the lake. Sand frequently occurs at the top, above the red clay formation, but the topography of the upland is never distinctly beach-like; rather is it a low rolling country, as if deposits had been laid down by the melting ice in shallow pools and ill-defined streams. Near Northeim (section 25, Newton) the stratified sands are from three to twenty feet thick, and the topography is decidely hummocky or morainic. About three miles south of Manitowoc the lake cliff is 80 feet high, where the lake is cutting back into a red till ridge, and bowlders are unusually abundant. From that point northward to the city the cliff becomes much lower.

Though this moranic belt was not followed inland, it seems probable that it is the westward continuation of a strong moraine which Leverett has traced through Michigan to Manistee (directly across the lake from Manitowoc) and which marks an important readvance of the ice-border. This readvance probably occurred after the Calumet stage, obliterating the Glenwood and Calumet beaches as far south as Manitowoc and Manistee; for both these shore-lines have been traced nearly up to the moraine, but have not been found north of it.

MANITOWOC.

In the northern part of the city of Manitowoc the retreat of the red clay cliffs has recently been going on with extreme rapid-

ity. The destruction of much property along the shore road and partial consumption of the highway itself has forced the town to take prompt measures to resist the attack of the waves. Long protective breakwaters have been built off-shore and great quantities of brush have been dumped to the base of the cliff where it acts as a sieve to catch the talus of bowlder clay and thus to hinder the waves from loosening and transporting it off-shore. Nowhere along the Wisconsin coast is there a better illustration of the sawing of the lake into the land. The vertical and even overhanging cliffs of red clay are capped by tumbling sods, with occasionally a tottering and dangling fence. At the foot of the cliff is usually a thin narrow pebble beach, hardly concealing a wave-cut bench of red clay, so nearly complete is the transfer of material which falls block by block into the water. In many places, indeed, there is no beach at all, but a narrow red clay shelf, swept bare by the waves. At each storm, during the last few years, the lake has eaten back several feet. At such times the lake for over half a mile off-shore is discolored by red sediment, sweeping northward past Two Rivers. In July, 1905, the road just north of the power house followed the brink of the ragged line of retreating cliffs; a rough breakwater of piles, planks, and rubbish had been built at the base of the bluff and another was being constructed some distance off-shore, enclosing an artificial bay. By the middle of September, in spite of this protection, the bluff had receded several feet, eating back across the road nearly to the trolley track on its western side, the road was closed to travel, and the brush pile below was being daily replenished and strengthened, in hopes of preventing continued destruction. (Plate X.) According to the foreman in charge of work along the highway, the cliff has eaten inland at least 150 feet, in the last three or four years. Such a rapid retreat is extraordinary, as will be seen by comparison with the following statistics, collected by Dr. Andrews in 1868.*

EROSION ON LAKE MICHIGAN SHORE.

Evanston	3.08–16.95 feet per year.
Winnetka	4.05– 6.05
Lake Forest	1.65

* Quoted by Leverett, "The Illinois Glacial Lobe," p. 456.

Rapidly receding cliffs near Manitowoc.

Freshly cut cliffs of red clay, north of Manitowoc. Near the base of the cliff, in the first view, the clay is laminated and contains peat and logs. The second view shows blocks of clay, which have just tumbled from the face of the cliff.

Waukegan	0.00
State Line	16.50
Kenosha	12.00
Racine Point	16.00
Racine	6.00
Milwaukee	6.25
Port Washington	2.30
Sheboygan	6.25
Manitowoc	5.00

Average, Milwaukee to Evanston, 5.28 feet a year.

Still more accurate measurements by Mr. S. G. Knight of Racine, given in full in the "Geology of Wisconsin,"* show that the average rate of retreat in Racine and Kenosha counties between 1836 and 1874 was 3.33 feet per year. In Milwaukee county similar measurements determined a rate of 2.77 feet per year. It is clear, therefore, that the advance of the lake at Manitowoc at the present time, which seems to be at least 40 feet per year, is exceptional.

The continual freshening of the cliff face by the waves affords a rare opportunity to study the structure and composition of the red clay formation,—matters of considerable interest. Near the city, and along the shore north of the power house, the thinly laminated and often highly contorted red and chocolate colored clays are sometimes overlain by buff colored sand, in which cliff swallows have made tunnels for their nests. At one point a peat bed three feet thick forms the upper part of the ten-foot cliff, with laminated clays containing sticks and branches below; in another place a bed of old logs and sticks lies buried beneath fifteen feet of clay, near the base of the cliff. (Plate XI.) A little farther on (in section 16, Manitowoc) a characteristic deposit of red till, full of striated stones and bowlders, comes up from beneath the laminated clays.

TWO RIVERS.

South of the town of Two Rivers the low red clay upland slopes gently toward the shore, and is bordered by a swamp and

*"Geology of Wisconsin," part II., pp. 231–232. 1877.

an outer belt of dunes. It seems likely that these dunes are in part shore deposits of higher stages, worked over by the wind; but no definite beaches were found there.

Northeast of the town this dune belt broadens and forms a wide coastal belt of sand hills, enclosing many acres of swampy woodland, between Two Rivers and the lighthouse.

A mile northeast of town, behind the dunes, an old terrace and bluff of a 17-foot stage appears on the west side of the shore road opposite the ball grounds. This is the first remnant of an abandoned shore-line north of Centerville, 15 miles away. After following the bluff for a short distance, the road passes along a series of beaches of gravel and sand,—two well marked ridges on the western side, rising more than 20 feet above the level of the lake, and lower, flatter beaches on the eastern side, ranging from 10 to 15 feet in altitude. Farther on, near J. Wilsman's house, the beaches attain their best development, the highest rising to 26 feet above the lake, (Plate XII) with an unusually steep back slope, a second ridge at 23 feet, and several lower bars in the fields east of the road. At this point the road

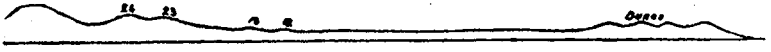


Fig. 11.—Profile two miles north of Two Rivers.

rises to the crest of the highest bar and follows it rather closely until it breaks up into dunes. Behind the 26-foot beach, several rods northwest of Mr. Wilsman's house, higher dune-like ridges of sand may be followed through the woods to Molas Creek, where they join the dunes already mentioned, near the road. These dunes are rather high, rising probably 50 feet above the lake, usually quite irregular in outline, but with occasional ridge-like form that suggests the presence of beaches higher than the 26-foot level. They are no doubt the product of the extinct lake. Whether they belong to a northward extension of the "Calumet" or 40-foot shore of Lake Chicago is a question. It seems natural to associate them rather with the 26-foot beach, which, as will be seen later, is probably the highest "Algonquin" shore-line.

From Molas Creek northward to the lighthouse the shore road passes through a wilderness of sand hills, where deforest-

The twenty-six foot Algonquin beach near Two Rivers.

Fig. 1. Dunes at the lighthouse north of Two Rivers.

Fig. 2. Dunes cut back by the waves.

ing within the last thirty years has allowed the wind to freshen up the dunes into a state of active existence. Along the outer border of the dune belt, north of the lighthouse, the lake is, rapidly cutting back into the sand hills, and exposing their thinly stratified structure, as shown in Plate XIII.

FOREST BED AT TWO CREEKS.

Two miles south of the village of Two Creeks (in section 24) the freshly cut lake cliff showed in July, 1905, a remarkable cross-section of an inter-glacial forest bed. Laminated red clays formed the base of the section, up to two or three feet above the water. Above this, and separating it from a twelve-foot sheet of stony red till was a conspicuous bed of peat, sticks, logs, and large tree-trunks, which unmistakably represent a glaciated forest (Plate XIV). The till immediately above the forest bed, besides containing characteristic subangular striated stones and red clay similar to the clay in the stratified beds below, all absolutely unassorted, was plentifully mixed with broken branches and twigs. In the underlying forest bed the stumps were well preserved, the wood being soft and spongy like rotten rubber, but retaining all the appearance of its original structure. Several logs and stumps lay pointing significantly towards the southwest, the direction in which the ice sheet probably moved at this place. One little stump, however (Plate XIV, Fig. 2), with its ramifying roots firmly fixed in the laminated red clays, stood erect as when it grew there, but it had been broken short off at the top, where the ice sheet, dragging its ground-moraine along had snapped off the top without uprooting the tree. Around each root the red clay was discolered to a light drab, showing the effect of acids derived by decay, in contact with the iron-bearing clays. There was no mistaking the only half- excavated condition of the deposit. Clearly this surficial sheet of red till records a final advance of the ice sheet over a surface of laminated red clays, which here, at least, had been clothed with a forest. The trees were broken and generally overturned by the ice, and buried beneath the twelve-foot sheet of till. The wonder is that so much of the over-ridden forest should be preserved, and at least one stump in it remain erect. Although the steady retreat of the cliffs at this place is doubt-

less continually changing the picture of the cross-section, it seems probable that the same phenomena are to be seen there today.

While a similar relation of red till above and laminated red clays below is to be seen in many places, it cannot be said that all the laminated clays are older than all the red till; for between Two Rivers and Manitowoc the thinly stratified red clays distinctly overlie bowldery red till. When, in addition to this lack of simplicity in the relations between ice-laid and water-laid portions of the red clay formation, it is found that peat beds and logs occur not only within the body of the stratified clays (as near Manitowoc) but between the red till and the underlying red clay beds, one can see the complexity of the history of the formation. A natural inference is a series of slight advances and retreats of the ice front in its last stages by which alternating red silt deposits and morainic beds (both derived from the ice) were laid down, and when the newly exposed drift country was freshly yet abundantly clothed with forest growth. The time interval between the deposition of the laminated red-clay beds and the overlying till is of course at least as long as the age of the trees,—possibly twenty years would be a fair minimum estimate. Alden reports red clays underlying the late Wisconsin till near Milwaukee. The Two Creeks forest bed may then record an interval between early and late Wisconsin time; or it may mark the interval between the Calumet stage and the re-advance of the ice sheet to the Manistee moraine.

TWO CREEKS TO KEWAUNEE.

For several miles along the border of Carlton and Kewaunee townships the lake shore is a fresh clay bluff, 20 to 40 feet high at first, but becoming 50, 60 and finally 80 feet high near the town of Kewaunee. As usual this consists not simply of red till, but often of laminated clays, and beds of sand which occur both at the surface and at various horizons in the red clay formation.

The stream terraces which mark every large ravine have their usual value here, in strongly suggesting that old high-level stages of the lake existed in this region, although the old shore-lines themselves have been consumed by Lake Michigan. (Plate XV,

Old forest bed, freshly exposed in the lake cliff near Two Creeks. In the first picture overturned tree-trunks, pointing southwest, are buried beneath 12 feet of red till. In the second is a small stump, which was buried by till during the advance of the glacier, but was not uprooted nor overturned. Its roots are embedded in laminated red clay. In contact with the decayed roots this clay is strongly discolored.

Fig. 1. Valley terraces of a stream south of Kewaunee. These probably record successive stages of the lake.

Fig. 2. Bluff and shore terrace of the Nipissing stage, near Rostok.

Fig.1.) Although it seems impossible, without more detailed study, to establish the identity of these stream terraces with lake stages of known heights, on account of the variable factors which have to be considered (as already mentioned on page 57), the persistence of terraces about 30 feet above the creeks seem to indicate that the lake in this vicinity once stood about thirty feet higher than now. Lower stages are likewise suggested by lower terraces in the ravines.

KEWAUNEE.

Before the construction of the long pier at Kewaunee the high red till cliffs in the southern part of the town near the signal station were rapidly retreating, and within the memory of the townspeople had cut away one-half of the town "commons." Since the pier was built, the accumulation of sand and gravel swept northward by the dominant shore currents and deposited against the south side of the pier has added several acres of flat terrace to the city and has built a semi-protective beach at the base of the red clay bluffs (Plate XVI, Fig. 1). At the town the flats of the Kewaunee river are bordered by a wave-built bar whose crest is five feet above the water. Back of it a deep lagoon marks the original course of the river, where it used to turn northward near the town, following behind the bar and finally cutting across it at the extreme northern end of the beach. This was the natural deflected course of the river due to northward shore currents. It now enters the lake at the pier at the south end of the beach, through an artificial channel. The low marshy flats of the river are remarkably broad and stretch inland for several miles. Comparing this flood-plain with others of the district, it seems to be almost too extensive to be appropriate to normal river work. Some of the oldest inhabitants of the town say that the flats occupy what was formerly a bay, covered by the quiet waters behind the bar. The deposit of muds and silts in the flats are known to be of considerable thickness. It is possible (as Taylor suggested in 1894) that this is an old river valley, cut during a stage of emergence (when the lake waters were drawn down below their present level) and subsequently drowned and filled with river sediment. No direct evidence of such a history, however, was found.

On the north side of the flats near the lake a very irregular terrace of gravels stands about 15 feet above the river. This might be either a poorly preserved river terrace or shore terrace,—perhaps more likely the former considering the protected position in the deep reentrant angle of the shore. A half of a mile northwest of the town the railroad cuts through a long ridge-like deposit of coarse gravels which Taylor spoke of as "probably a true beach," one of "the first positive evidences of post glacial submergence observed on this shore."* This may be a long flat-topped river terrace rather than a beach ridge. Its crest is over 30 feet above the lake.

ROSTOK.

Three miles north of Kewaunee (Section 32, Pierce) the fresh red clay bluffs give way to a finely preserved little fragment of extinct shore topography, about half a mile long. At first there is a terrace of sand and a sharp bluff of a 17-foot

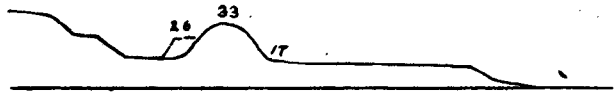


Fig. 12.—Profile near Rostok.

stage, with large bowlders close to its base. (Plate XV, Fig. 2.) The 17-foot terrace extends somewhat interruptedly up a small creek valley near by, where there is also a higher terrace about 35 feet above the lake. Towards the north the lower terrace widens and the old bluff becomes higher; a second creek valley comes out through the old bluff, from behind a long ridge-like terrace, that is 35 feet high and capped by coarse gravel. (Plate XVI, Fig. 3.) The peculiar form of this terrace and the parallelism of the creek valley to the bluff is shown by the sketch map (Fig. 13).

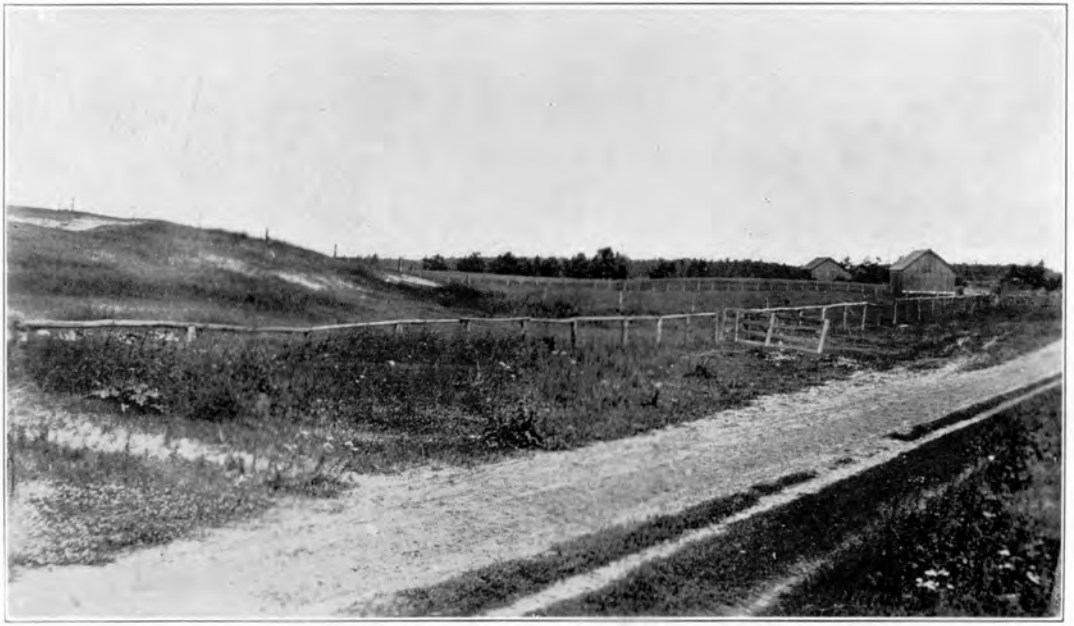
It looks like a clear case of stream deflection behind a shore bar during a 35-foot stage,—a deflected course which it continued to hold after the drop of the lake to the 17-foot stage had given it the power to excavate a steep sided ravine. Long terraces of this sort, where creeks cross old beaches, are not rare in Illinois and Wisconsin. The name "bar terrace" might perhaps be applied to them. In this case, as elsewhere, there

* Am. Geol., vol. 13, p. 319. 1894.

Fig. 1. View northward at Kewaunee, showing the accumulation of shore drift on the south side of the pier.

Fig. 2. Nipissing bluff and terrace near Rostok.

Fig. 3. Bar terrace of a 33-40 foot stage, at Rostok.



Dunes and low sand ridge of the Algonquin (30 foot) shore line near Mr. Paige's house, south of Algoma.

are other creek terraces in the ravine, at lower altitudes. The two shown on the map (20 and 26 feet above the lake, may possibly be scraps of a once continuous flood plain for the creek at the 17-foot stage, in which case the slope of the old flood plain near the mouth was about 6 feet in 800. It may seem strange that the 17-foot shore-line was cut back just as far as the older 35-foot bar and no farther; but the presence of an old beach on the brink of a bluff cut during a lower stage is very common, and possibly due to the checking of cliff recession by the rapid supply of sand from the crest of the bluff. Another strange feature is the path of this creek across the south end of old bar, as if the shore current here, during the 35 foot stage was not towards the north but towards the south. The bar terrace seems to belong to the shore-line of lake Algonquin.

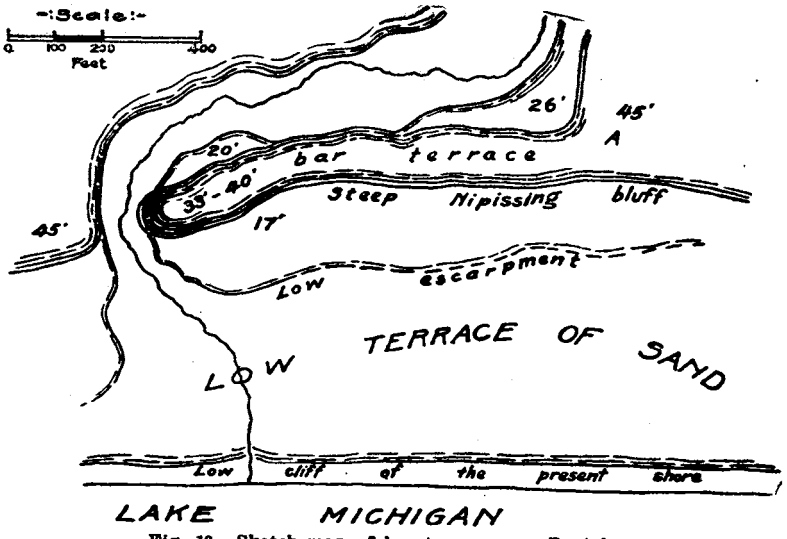


Fig. 13.—Sketch map of bar terrace near Rostok.

Thirty rods north of here the old bluff runs out again to the water and for a distance of three miles red clay cliffs rise steeply to a height of 60 feet. From near the old pier east of Alaska post office, one can look southward to the Rostok shore where the headland notched by the 17-foot stage shows a step-like profile.

ROSTOK TO ALGOMA.

Near C. Dvoreck's house (s. e. corner of sec. 9, Pierce) the old terrace and bluff of the lower stage comes in strongly again and continues for two miles without a break, nearly to Algoma. Although the terrace is usually 17 feet above the lake, it frequently appears to have been eaten away in concave bites at a slightly lower stage (about 9 feet), so that in some places the base of the bluff itself is 9 feet above the lake, and in others the terrace is double, with 17- and 9-foot benches. This 9-foot stage was probably very short lived, for the lake after such a slight drop would rather quickly have cut back its low cliff everywhere to the bluff.

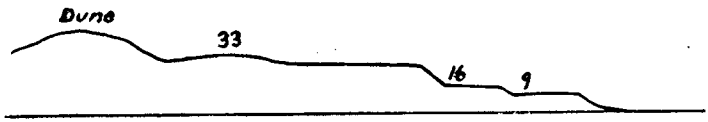


Fig. 14.—Profile near John Paige's house.

A quarter of a mile north of Mr. Dvoreck's, old dunes appear on the brink of the 17-foot bluff, close by the road, and in front of them a gentle but distinct gravel beach probably the Algonquin shore-line, whose crest is about 32-feet above the lake. (Plate XVII.) These run obliquely inland in characteristic fashion, crossing the half-section road near John Paige's house. Beyond a creek which is near here, the crest of the 32-foot beach seems to have been farther east and to have been lost by cliff recession during the 17-foot stage; for the shore road, for over a mile, follows the gentle back slope of a gravel ridge about 38 feet above Lake Michigan, and stratified sands are exposed at the brink of the 16-foot bluff just east of the road. A few old dunes, also, lying near the road at the middle of section 3 vaguely record the 32-foot stage. North of the next section line, however, in Ahnapee township) the lake during the lower stage cut back beyond the higher shore into the red clay upland, producing a high steep bluff of remarkable strength. (Plate XVIII.) The terrace here is usually a 9-foot one, al-

Fig. 1. Looking southward along the Nipissing bluff and terrace, two miles south of Algoma.

Fig. 2. Looking northward along the Nipissing bluff and terrace.

An old headland and terrace of the Nipissing stage, one mile north of Algoma.

though, as explained before, most of the credit for cutting the high bluff belongs to the 17-foot stage, the 9-foot stage having merely stripped off the upper seven or eight feet of the 16-foot terrace and perhaps somewhat freshened the bluff.

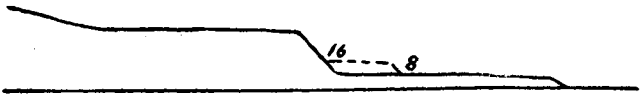


Fig. 15.—Profile two miles south of Algoma.

ALGOMA TO CLAY BANKS.

Most of the city of Algoma is built on a broad terrace-like deposit of gravel and stratified sands, about 20 feet above the lake. It resembles an old delta of the Ahnapee River, in a re-entrant of the lake during the 17-foot stage. On the steep bluffs that enclose this sand flat north and south of the town, are suggestions of both higher and lower terraces; but they are hardly definite enough to deserve further description.

From the railroad station at Algoma one can look north along the clay-bluff shore to a low headland, hardly a mile away, where a small 18-foot terrace forms a clean cut notch in the profile. This is another of the small but valuable scraps of extinct lake records, almost destroyed by the recession of the present shore. It extends hardly 400 yards but affords a good view of the closely packed gravels (Plate XX, Fig. 2) and especially of an old headland of the 17-foot stage which the terrace encircles (Plate XIX, and XX, Fig. 1). It will probably not be many years before this bit of old shore topography will have been wholly destroyed by the waves.

Beyond this place, for half a mile, there are fresh red clay cliffs along the shore; then the old 17-foot terrace and its bluff reappear, running obliquely in from the lake and continuing on with scarcely any interruption for many miles. This display of old shore bluffs surpasses even that south of Algoma, and gives evidence of the extraordinary erosion during the 17-foot stage. Plate XXI shows the view northward along the old clay bluffs of this Nipissing shore-line. A quarter of a mile away, in the middle distance, the old terrace is covered with a sheet

of bare sand, blown inland by the wind from the edge of the newly under-cut terrace.

For some distance the shore road follows the brink of this old bluff. Here and there a small creek valley opening through the bluff, breaks its continuity; the bluff is then replaced by a bar of gravels. But on the whole the high bluffs are remarkably continuous and strong. Out on the old terrace there are commonly two or three low sand ridges, parallel to the base of the bluff, and usually from 2 to 6 feet lower than it. These are perhaps subaqueous offshore bars or reefs, deposited by storm-breakers in shallow water; but I am inclined to regard them rather as true beaches of stages lower than 17 feet.

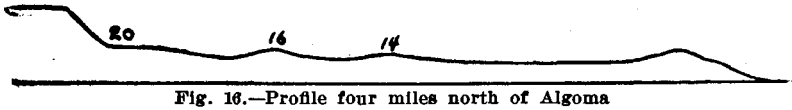


Fig. 16.—Profile four miles north of Algoma

Near the half-section east-west road in section 6 the shore road descends from the bluff to the sandy terrace at its base. Half a mile farther on, at Foscoro post office, on the line between Kewaunee and Door counties, a large creek with broad flood plain and the usual terraces enters the lake through a broad gap in the bluffs. Just beyond here the bluff reappears with its former

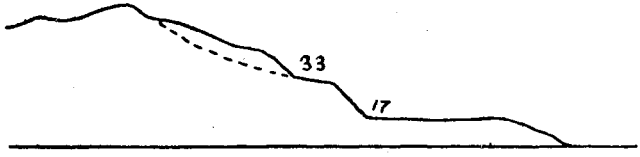


Fig. 17.—Profile near Foscoro.

strength; but associated with it is a scrap of a still higher terrace and bluff, which lies close to the course of a second creek. Judging from its position, this 32-foot terrace might be either an old shore bench or a fragment of a creek terrace, left by the partial recession of the 17-foot (Nipissing) bluff obliquely across the valley of the creek. In either case, although it is but a hundred yards long, rather narrow, and somewhat variable in height, it seems to indicate a lake stage at about 32 feet; and its coincidence with the plane of Lake Algonquin is more fully

Fig. 1. Termination of a bluff and terrace of the Nipissing stage, one mile north of Algoma.

Fig. 2. Gravels of the Nipissing terrace.

Nipissing bluff and terrace, three miles north of Algoma.

appreciated when the measured shore-lines of the region are plotted diagrammatically, as will be shown later. (Plate XXXVII).

Half a mile beyond the creek, the bluff of the 17-foot stage, running through the woods between the road and the lake, has reached its grandest proportions. It is about 80 feet high and steep enough to offer a hard climb. This old bluff is quite comparable to the freshly cut red "clay banks" which rise up 100 feet from the edge of lake Michigan a short distance beyond this point, where the lake has cut away the old shore-line for a short distance. For three miles or more through the village of Clay Banks the old bluffs maintain a height of about 70 feet, being finely displayed near the road, which first runs close to the brink, and then, descending steeply, skirts its base. Nowhere along the eastern Wisconsin shore is there a bluff of more remarkable strength. While traveling along its base or looking down from its crest one is deeply impressed with the work which was accomplished during the 17-foot (or Nipissing) stage,—for at that time the older, higher beach line at about 35 feet was almost totally lost as the bluffs were eaten far back into the red clay uplands. Plate XXII, Fig. 1, shows the lofty bluff, 80 feet high, as it looks from the road. To the left, in a gap in the bluff, a creek terrace marks the higher or 35-foot stage.

CLAY BANKS TO SAWYER.

Beyond Clay Banks village the high bluff continues on the west side of the road for a mile or two with undiminished height, except where a creek valley comes out through it, as in Plate XXII, Fig. 1. At this place, to the right of the barn, the bluff of the 18-foot or Nipissing stage was eaten back across the old valley, exposing a creek terrace which now stands about 35 feet above the lake, and which evidently represents the flood plain of the creek during the Lake Algonquin stage. The terrace below the great bluff does not always mark an 18-foot water level, but frequently 12- or 9-foot levels,—doubtless short, temporary stages of which mention has already been made.

The best example of a 35-foot terrace, however, is found a mile north of the one just mentioned, (in the centre of section

16) where a large creek runs out to the lake. There, a high flood-plain terrace, extending down the valley, merges without a break into a well formed shore terrace of the 35-foot stage. Although this shore terrace disappears a few rods farther north, where the bluff of the lower stage has retreated past it, it soon reappears in a well marked 35-foot terrace shown in Plate XXII, Fig. 2, and rounding an old headland merges into a great barrier ridge of gravel, which extends northward for over a half a mile, midway between the road and the lake. In the photograph the observer is looking southward from near the old headland, on the 35-foot terrace. The cattle are on the terrace; beyond them the lower bluff of the 20-foot stage cuts diagonally across the 35-foot terrace into the high red clay upland, where it runs as a single steep bluff for many rods. In the distance near the houses the high terrace may be seen again, where the 35-foot creek terrace merges with the contemporaneous shore bench.

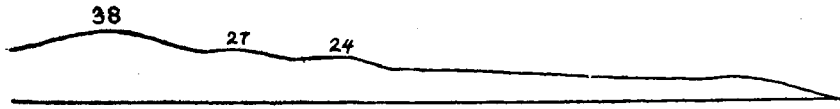


Fig. 18.—Profile near S. Anderson's (section 9, Clay Banks).

The great bar which stretches north from the high bench, with its crest 38 feet above the lake, was evidently formed by strong long-shore currents, sweeping the debris from the cliffs towards the north. This bar bears the record of lower stages as well, for on its front slope are two distinct beach ridges at altitudes of 27 and 24 feet. Below them a peat bog, about 10 feet above the lake, runs out to the shore.

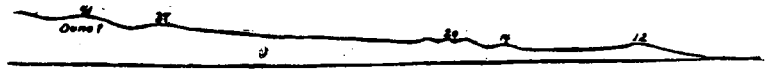


Fig. 19.—Profile in sections 3 and 4 (Clay Banks).

The country just north of here is rather thickly wooded, and the beaches were not traced continuously; but at each east-west road they were found and measured, as shown in the cross section above. The strong beaches at the top of the series bear wit-

Fig. 1. Nipissing bluff near Clay Banks, eighty feet high.

Fig. 2. Algonquin terrace and bluff north of Clay Banks. A short distance beyond the cattle this terrace is cut off by the cliff of the Nipissing stage.

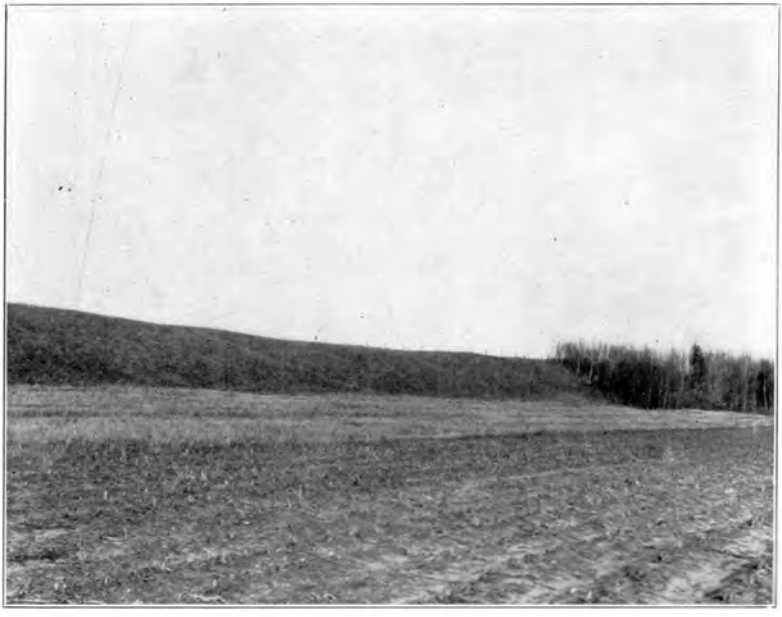


Fig. 1. Straight bluff of the Algonquin stage, two miles east of Sawyer.

Fig. 2. Algonquin beach ridge at Sawyer.

ness to the importance of the 40-foot (Algonquin) stage; but the lower beaches are perhaps even more persistent in their occurrence, although they seem to disagree frequently in height as if they marked several successive planes.

On the east-west road that runs between sections 27 and 34 (Sturgeon Bay), the low beaches near the lake are built of coarse gravel and discoidal chipstone; for here the ground is rocky, with but a very thin covering of glacial drift. The 20-foot beach is especially well marked, and lies 300 yards back from the lake. These low beaches extend northward through the woods, where it is impracticable to map them, and gradually break up into a broad belt of sand dunes which surround the region of the Sturgeon Bay canal. On the same east-west road, the 40-foot beach occurs far inland, over a mile from the lake, near the road corner at Mr. Knuth's house. A broad evergreen swamp east of it is shut in from the lake by a ridge of bedrock and till, and was probably slightly submerged during the 40-foot stage.

From Mr. Knuth's house the road to Sawyer closely follows the 40-foot shore-line,—at first a vague beach, but suddenly turning into a steep bluff and terrace, near the southwest corner of sec. 21. and continuing thus, with occasiosal interruption, past the brick yards. Plate XXIII, Fig. 1, shows a stretch of this bluff near the Sawyer road, where it is remarkably straight. The bluff is cut in compact red clay; the terrace, which is cultivated for cornfields, consists of loose sand and gravel. Beyond the brick yard the cliff gives way to a broad gravel ridge which runs out to the edge of the bay near F. Daniel's house. At this place the lower 20-foot beach is also developed.

A short distance farther west, beyond some very irregular kame topography, a great beach ridge of the 40-foot (Algonquin) stage runs from the railroad crossing along the roadside past the school house and into the town of Sawyer, where its exact position is much obscured by street construction. Plate XXIII, Fig. 2, shows a bend in the Algonquin ridge near the school house at Sawyer, the gentle outer slope on the right, and the steep back slope on the left.

STURGEON BAY AND VICINITY.

Across from Sawyer, in the city of Sturgeon Bay, both the upper and lower beaches which have just been described are strongly developed. The court house and the high school stand on the crest of the highest or 40-foot beach, where it makes a sharp bend from a southwest to a northeast course. The crest of this beach, near the court house, is 36 feet above the bay; but a few rods northeast, where it merges into a cut bluff of till, it is a few feet higher. East of the short till bluff there is no well defined shore-line. A recent cut in the street in front of the court house at the blunt cape or bend, showed well-stratified sand and gravel of all sizes, with occasional beds of flat bowlders. From the high school northeastward the 40-foot shore may be traced interruptedly through the house lots and streets to the northern part of the city, where it is a well-formed bar. It was followed for several miles by Taylor in 1893, and has since been identified by him as the highest shore-line of Lake Algonquin.

A block or two south of the court house, a 23-foot beach extends through the city parallel with the main street. A sand ridge which is lower and less continuous than this one lies closer to the bay, with its crest at 18 feet. Both of these lower beaches disappear towards the southeast near the bay, within the limits of the city.

On the north side of the city, a series of beaches from 12 up to 20 feet is easily found, and may be traced northward for several miles along the shore not far from the road. At Bayside cemetery the Algonquin or 40-foot shore-line, marked by a low bluff, may be seen from the road. The lower beaches have crossed to the west side of the road, and lie halfway between it and the bay. From here northward for more than three miles the shore drive follows closely the 40-foot contour. Occasionally traces of beach topography or of an old bluff appears; but for most of the distance the old shore-line is obscure, —partly, no doubt, from the grading of the road. The low shores are more easily traced through the fields and private grounds along the bay, where the 20-foot beach is usually a bluff and terrace, imperfectly preserved.

Strong development of all the beaches begins beyond the

Bluff and terrace of the Algonquin stage near G. M. Roberts' house, five miles northwest of Sturgeon Bay.

Fig. 1. Algonquin and Nipissing terraces near Dreutzer's quarry, at the mouth of Sturgeon Bay.

Fig. 2. Ridges below the Nipissing bluff, near Dreutzer's quarry.

Laurie stone quarry and continues out to the mouth of the bay. A conspicuous 40 foot terrace and bluff a short distance north of G. R. Robert's house(noted by Taylor in 1893) is shown in Plate XXIV. The coarseness of the material on the beach (large chip-stones and flat bowlders) is characteristic of the beaches of the whole of the Door County peninsula north of the Sturgeon Bay strait, where the drift blanket is thin or locally wanting, and ledges offer plentiful supply of coarse material to the waves. The stony structure of the beaches comes to light still more clearly at Mr. Larr's house, which is built on the crest of the Algonquin bar, near where the shore road descends the stony slope to the edge of the bay. Well rounded discoidal pebbles of white limestone are packed tightly flat-side down into a firm beach ridge. The outer sweep of this 40-foot beach is chopped off sharply by a cut bluff on a 17-foot stage, below which are three low stone ridges at 15, 13 and 11 feet. The photographs in Plate XXV show these beaches from different points of view, near the road. It is possible, perhaps, that the lower ridges are subaqueous bars, not true beaches; but the

Fig. 20.—Profile near Dreutzer's quarry.

coarseness of chipstone in them seems almost too great for such an origin. They seem rather to represent short lived stages, intermediate between the 17-foot stage and the present one. Near Dreutzer's quarry, at the mouth of the bay, the old beaches are destroyed; but around the headland on the Green Bay shore they are again developed, as will be described in a later section.

Along the opposite shore of the bay, between Sawyer and Nasewaupee, thick woods greatly obscure the terraces and beaches. Here and there the bay is bordered by high limestone cliffs which have retreated beyond the 40-foot contour; but along most of the shore the two most important old water lines are visible from across the bay because of horizontal breaks in the wooded slopes. At the entrance of the bay the lighthouse stands on the 20 foot beach. (Plate XXVI, Fig. 1.)

East of Sturgeon Bay on the north side of the strait, between the "Cove" and the head of the canal, a 20-foot bowlder beach of exceptional strength runs through the pastures and woods near Mr. Olson's house. (Plate XXVI, Fig. 2.) Poorly rounded blocks and bowlders, from one to three feet in diameter, are piled up in a steep-sided ridge which stands five feet higher than the ground just behind it and ten feet above that just in front. Fifty feet nearer the bay is a lower ridge, its crest 13 feet up, made of smaller bowlders and gravel. The exceptional size of blocks in the higher ridge and the poorly rounded form suggests that this is not a wave built beach but an ice rampart, crowded up by the expansion of the ice in winter, a process which might be expected to be most efficient right here near the head of the wedge-shaped bay. For size of material this beach ridge seems to have no rival in eastern Wisconsin,—not even on the more exposed Lake Michigan shores.

The 40-foot beach in this district is hard to find, but seemed to be represented by sand dunes and occasional high sand ridges near the unfrequently traveled wood road which leads eastward to the shore through section 14. This road crosses lower bars of sand just before reaching the lake shore, which are doubtless representatives of the 20-foot and lower stages. The lake shore for some distance north and south of the end of this road is low, thickly wooded, and bordered with dunes. No old beaches were discovered two and a half miles farther north, on the east-west road to Lilly Bay.

WHITEFISH BAY AND CAVE POINT.

The low country between Lilly Bay and Whitefish Bay is so swampy and wooded that it did not seem profitable to trace the beaches continuously. The highest shore-line was found in splendid form, however, over a mile inland, near Mr. Roth's house in section 20 (a mile and a half southwest of Whitefish Bay village). A broad, steep-backed gravel ridge, with its crest 41 feet above Lake Michigan can be traced for over half a mile through the pastures towards Whitefish Bay; but this shore-line was not found with certainty near the village, although a coarse gravel beach at 30 feet and a questionable bluff behind it, with its base at 35 feet, were found on the road just west of the

Fig. 1. Lighthouse at the mouth of Sturgeon Bay, on the Nipissing bench.

Fig. 2. Ice-shoved ridge of boulders marking the Nipissing stage at the head of Sturgeon Bay.

Fig. 1. The shore at Cave Point.

Fig 2. The cliffs at Cave Point.

village. The little fishing hamlet stands on a series of low sand bars and dune ridges near the lake, which were built during the lower stages.

North of Whitefish Bay a well forested belt of high dunes separates the present beach from a broad swamp, in which is Clark Lake. East of this lake, a low cape stretches out into Lake Michigan, appropriately named Cave Point. Here are the first well-exposed rock cliffs which one sees in going northward along the west side of Lake Michigan. They are exceedingly picturesque. The flat lying Niagara limestone beds, some hard, some soft, and well cut up by joint cracks, have been torn away irregularly by the storm waves. There are numberless little coves, not infrequently with rectangular outline and vertical walls,—the result of wave-gnawing along joint planes. In many places under-cutting of the beds along the water's edge has left overhanging arches and roofs of limestone; artistic hemlocks, spruces, maples, and white birches overhang the ledges, and wild ducks, startled by one's approach scurry out from under some projecting shelf and around a little promotory, or dive out of sight. Traveling around this shore is slow work; for one must climb up and down, now at the base of the cliffs, where an irregular rock bench is washed by the waves, and now along the brink of the cliffs. through bushes and thickets, with repeated detours around the little coves. A view of the shore from the lake (Plate XXVII, Fig. 1) shows the conspicuous caves, where the waves of every storm are cutting back irregularly, like a horizontal saw, until the overhanging arch of limestone gives way and a great slab of rock falls into the lake, to be gradually broken up and thrown back piece by piece against the cliff. These big prostrate slabs occur every few rods along the shore (Plate XXVII, Fig. 2) with often so fresh a broken surface on the ledge behind them that they seem to have tumbled off during the last storm. Although the recession of these cliffs is probably not so rapid as this would suggest, it is clear that the shore has been eaten back several hundred feet at the present lake stage; for a broad rock shelf runs out from the shore in dangerous reefs. Coarse gravel and cobbles of all sizes have accumulated in protected bays along the shore. At the north side of the cape, near Jacksonport, a cobble and chip-

stone beach is banked up to a height of nearly 8 feet above the water. Evidently there is a strong drift of material along the shore in that direction. In the woods back of Cave Point traces of stone beaches were seen, about 20 feet above the lake, but detailed mapping and leveling was impracticable.

JACKSONPORT.

At Jacksonport there is a fine display of beaches. A wide series of parallel sand ridges, many of them below 15 feet in altitude, passes through the village. Back of these is a bench and a beach of a 19-foot stage, and beyond that two or three ridges and benches, reaching their climax in a stony 50-foot bench and bar which is well exposed in the southern part of the village near the Methodist church (Plate XXVIII, Fig. 1) where the road turns down from the upland to the low terrace. The two profiles in Fig. 21 are drawn at opposite ends of the village, about half a mile apart. Shore-lines of 50-, 34-, and 19-foot stages are prominent among them. The 26- and 28-foot bars in the north end of the town, which lie just off-shore from the 34-foot bench may possibly be subaqueous reefs for that stage.

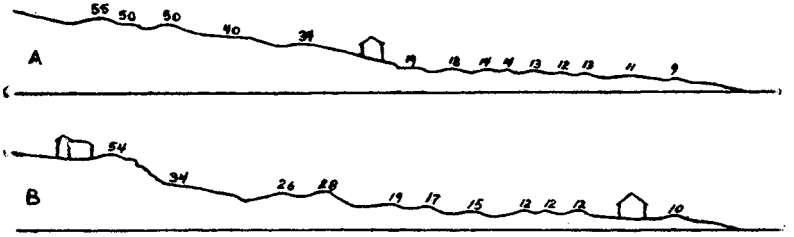


Fig. 21.—Profiles at Jacksonport. (a) South end of the village. (b) Center of the village.

They are made mostly of sand and gravel of moderate size. The abrupt outer slope of the 28-foot bar, steepened into a low bluff for the 19-foot stage, is to be seen in the lower figure in Plate XXVIII. The several sand ridges below 19 feet may likewise be subaqueous reefs of that stage, though it seems more likely that they mark several successive levels of the lake since the 19-foot or Nipissing stage.

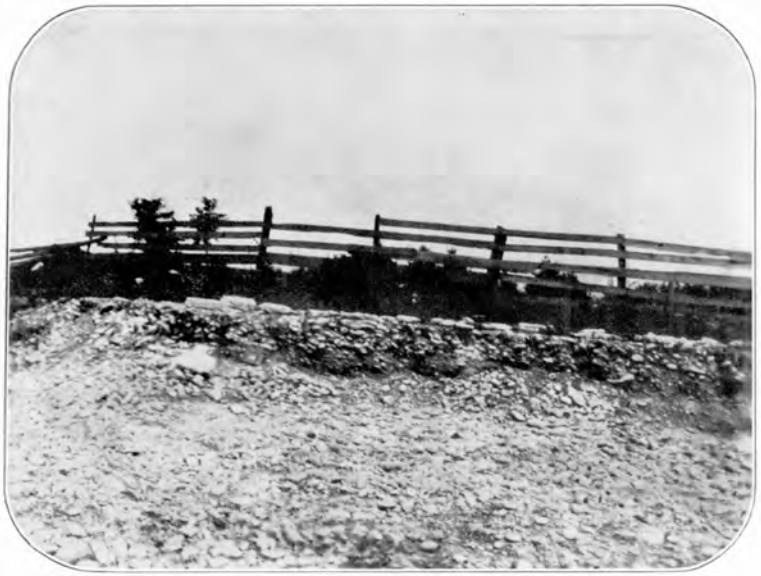


Fig. 1. Highest Algonquin beach at Jacksonport.

Fig. 2. Twenty-eight foot ridge at Jacksonport. The outer slope of the ridge has been steepened by cutting during the Nipissing stage.

Undercut cliffs of the highest Algonquin stage at Bailey's Harbor.

Half a mile north of the village, near where the creek crosses the shore road, there is an ancient Indian burying ground, situated on some of the low sand ridges. The wind has scooped out shallow holes here and there, sweeping the sand away from the old graves, so that bones are plentifully exposed. A few implements and a carved tobacco pipe which seems to have been brought down by the French missionaries from Canada have been found here by Mr. Erskine and others. Perhaps the most common curiosities in these graves are sparkling specimens of silcified *Favosites* ("honeycomb coral") which seem to have been prized and preserved by the Indians.

The 50-foot Algonquin beach, north of Jacksonport, runs inland,—how far, there was not time to determine. It should here be explained that the study of old shore-lines on the peninsula was generally confined to the vicinity of the lake shore, where villages and open country occur, and where leveling on the complete series could be readily accomplished. Between Jacksonport and Bailey's Harbor, therefore, there was no continuous tracing of beaches. Low sand ridges were crossed on the shore road near Kangaroo Lake, but no attempt at detailed study or measurement was made until within a mile of Bailey's Harbor.

BAILEY'S HARBOR.

A large series of beaches, benches, and cliffs runs through this village. The highest Algonquin shore-line is a chipstone bar at 59 feet near the south end of the village, passing northward into a line of overhanging rock cliffs which border the hillside overlooking the town. The old caves and projecting shelves of limestone are characteristic in form as if they were still being cut out by the waves, closely resembling the rocky shore at Cave Point. Weathering since the fall of the lake from this 59-foot plane has torn down slabs here and there, but has by no means obscured the original form of the cliffs, as Plate XXIX shows. In some places the cliffs are vertical joint faces which have their exact counterparts along the lakeshore near Cave Point. Below them a steeply sloping bench of debris leads down to a bench or bar of a 40-foot stage, which seems to have been one of consider-

able importance, judging from the fact that it is marked not only by a heavy stone beach but also in the southern part of the village by a high bedrock cliff and terrace of its own. Lower stone ridges, at about 30 feet, run just east of the 40-foot shore and parallel to it. The town hall stands on one of these. It may be that these are subaqueous reefs for the 40-foot stage, as they do not connect anywhere with a bench or cliff; but they are built of very heavy blocks and cobblestones. Cutting abruptly across these ridges an abrupt cliff of an 18–21-foot stage (evidently the Nipissing) runs close to the west side of the main street. The churches and school house stand on the higher bars close to the brink of the cliff. Half way through the village, near Ed. Westfall's hotel, the cliff passes into a 21-foot stone bar, which can be traced northward parallel to the higher beaches. The profiles in Fig. 22 show the appearance of the series at three different parts of the town.

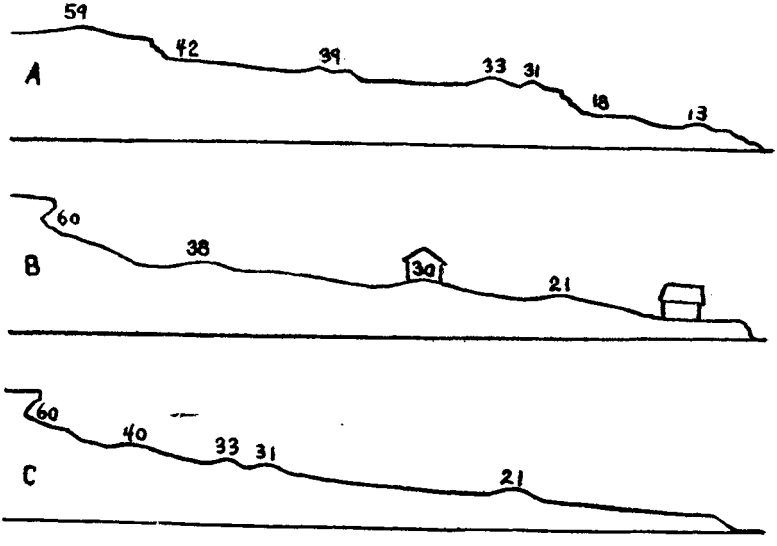


Fig. 22.—Profiles at Bailey's Harbor. A, at south end of village. B, through center of village. C, at north end of village.

At the north end of the village all except the very lowest of the beaches (about 13 feet up) bend a little to the west, near the road to Fish Creek, and run northward into the woods, where it is hard to identify them singly. Half a mile in from the

road, however, there is a clearing where the whole series is exposed,—ridge after ridge of cobblestones, with the highest ridge ending in a circular steep-sided hook. Here at Bailey's Harbor, as in many places on the peninsula, the beach bowlders are mostly composed of large silcified *Halysites,* ("chain coral") and *Favosites* ("honeycomb coral").

A quarter of a mile northeast of the village is a well-marked island of the extinct lake Algonquin, a nearly circular limestone hill which is skirted on the west side by the road past Mr. Appel's house, and on the east side by the road to North Bay. It is plainly seen rising above the woods, as one looks northward from the pier at Bailey's Harbor past the head of the bay. The periphery of the old island is marked almost continuously by steep limestone cliffs in part at least of the 60-foot Algonquin stage, although the shores of lower stages are more completely developed and preserved. The road at Mr. Appel's house follows the base of the cliff of this highest stage. A short distance south one can see from the road the bent hook-like ends of two or three successive bars, in the valley just west of the road. On the southeast side of the island, near the North Bay road, overhanging cliffs of the lower stages overlook several well-formed beach ridges, the extension of which was not traced, for lack of time. On the north side of the island is a very remarkable ridge whose exact nature is not clear. It is over 20 feet high, above the surrounding country, perhaps 60 feet above the lake, very steep on the southwest side, built in part of great bowlders, together with rock debris and earth. It stretches northward in curving fashion for a number of miles. Although its position and association with undoubted beach ridges strongly suggests that it is a bar tying the island to the mainland farther north, its general form and heterogenous composition led to the belief that it is a great esker. This Bailey's Harbor district offers perhaps the best opportunity for detailed study of extinct shore-line topography along the peninsula; for here are unusual irregularities of outline in the old lake, and the exposure to wave action must have been great.

The peninsula northeast of Bailey's Harbor is low and wooded, with hardly a trace of old beaches. Near Mud Bay the shore is almost flat, near lake level. The road to North Bay follows low

sand ridges here and there. Turning north beyond Mud Bay it rises to higher ground without crossing any marked beaches until at Mr. Olson's it descends rapidly to the shore of North Bay.

NORTH BAY.

Between Mr. Olson's house and the summer cottages on the shore of North Bay, well-formed beaches and cliffs of high level stages run through the woods. On the west side of the bay the shore road follows and crosses low sand bars in several places, from 12 to 18 feet above the lake. A belt of low ground runs far into the interior of the peninsula, here, towards Sister Bay. On the east side of North Bay, on William Marshall's large estate, there are a few traces of under-cut cliffs in the woods, but most of the peninsula is low,—far lower than the level of the highest shore-line.

APPLEPORT.

Going up the road which leads due west across the peninsula from the lake to Sister Bay, one crosses a large series of beaches at altitudes of 13, 14, and 23 feet, near Mr. Larson's house; then there is a long gentle rise for nearly half a mile to a broad bar at 50 feet, and finally to a 64-foot bar which lies on the crest of a broad ridge near Mr. Erickson's house. West of this highest beach is a valley over a mile broad—the one already mentioned as running inland from North Bay. Up to the west slope of this valley, near district school No. 2, is a well-formed beach ridge about 68 feet higher than Lake Michigan. Perhaps this was the mainland border during the highest stage of the lake while a reef was being built out along the submerged ridge a mile or more to the east, at nearly the same level.

ROWLEY'S BAY.

At Rowley's Bay the following series of beaches was found: a 7-foot bench close to the road near the saw mill; a 17-foot bar two hundred yards up the road from the last; a 20-foot beach and bluff two hundred yards farther on; a 40-foot double-crested stone bar two hundred yards east of the school house;

Fig. 1. Death's Door bluff. Three great steps or notches in the headland mark stages of Lakes Algonquin and Nipissing.

Fig. 2. Boyer bluff. Three great notches mark three important stages of Lake Algonquin. The Nipissing terrace has been lost by the erosion of the present cliffs.

the highest beach at 72 feet, lying 400 yards west of the school house.

Assuming that the 72-foot beach at this place corresponds to the 68-foot beach west of Appleport, the 59-foot beach at Bailey's Harbor, and the 50-foot beach at Jacksonport, one would expect to find here a beach at about 54 feet, corresponding to the 40-foot shore-line at Bailey's Harbor and the 34-foot beach at Jacksonport; but no ridge was discovered near the Rowley's Bay school house at the appropriate height,—only a long gentle slope leading from the 40-foot beach up to the 70-foot ridge. It is one of the occasional cases where a lake stage of considerable importance is locally unrecorded, possibly because of the gentle inclination of the bed-rock surface.

ROWLEY'S BAY TO WASHINGTON ISLAND.

The depression occupied by Mink River, between Ellison Bay and Rowley's Bay was doubtless a strait during the highest lake stage.

On the cruise north from Rowley's Bay only one stop was made on the Lake Michigan shore, at a pier called Newport. There no high beach was discovered, only some low bars near the shore, about 20 feet above the lake.

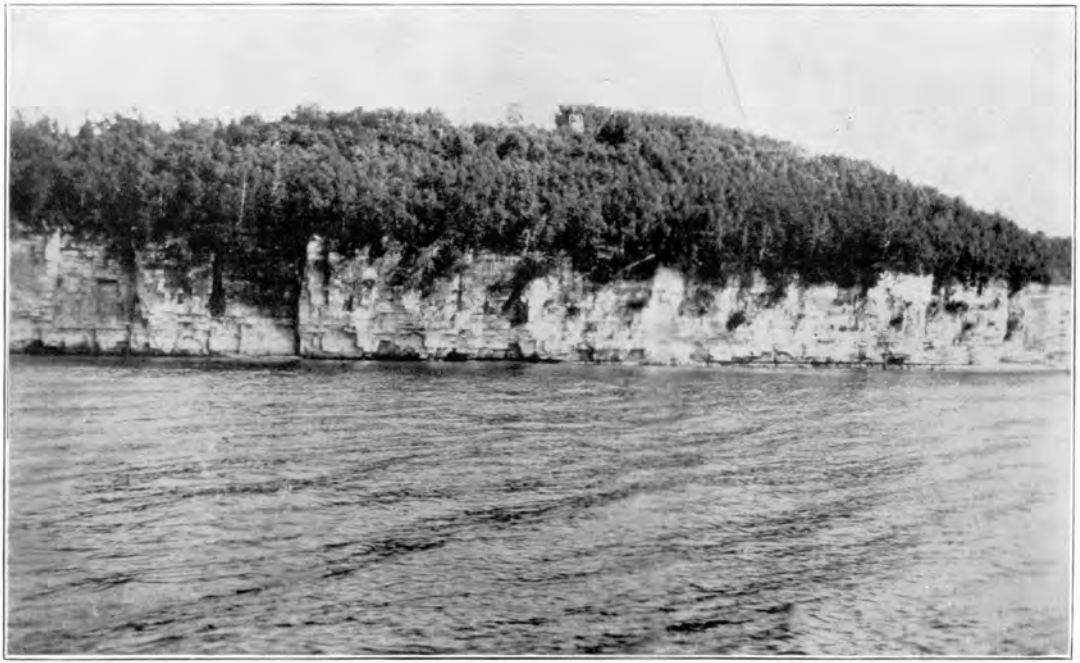
A passing view of the high bluffs at Death's Door (Plate XXX, Fig. 1), the extremity of the peninsula, brought to view an unexpected development of high rock terraces,—gigantic steps on the headlands, so strongly outlined that their wave-cut origin was at first hard to believe. One would be inclined to refer them to structural differences on the bed rock, emphasized by weathering; but closer examination and comparison with the present cliffs left no doubt regarding their true nature. These great step-like notches, which tourists on passing steamers notice on every headland, are the deeply engraved high water marks of an extinct Lake Michigan, or more accurately of Lake Algonquin and Lake Nipissing.

WASHINGTON ISLAND.

On account of its exposed position off the end of the long peninsula between Green Bay and Lake Michigan, and close to

the northern boundary of the state, this large island is a place of vital importance in the study of the beaches of Wisconsin. Since the early '70's, when Chamberlin's geological party explored the thinly settled peninsula, geologists seem never to have visited this island to study its beaches, although the importance of doing so was well recognized by Taylor in 1893, when he wrote, in his paper on the reconnaissance about Green Bay:* "One of the most important points to be determined in this vicinity is the altitude of the highest shore line on Washington Island and on the northern extremity of the peninsula south of 'the door.' These places are not readily accessible, and being under some necessity of economizing our time we were obliged to pass them by." Since this was written the island has been extensively cleared for pastures and fields. Farms cover the hilly interior and fishing piers and sheds are clustered in the bays. Two or three modest little summer hotels at Detroit Harbor and Washington Harbor are gathering in vacation seekers from distant cities, and the place is no longer a difficult one to reach. The shores on the northwest, northeast, and east sides are still heavily wooded with evergreens, and bordered by precipitous white limestone bluffs, famous for their scenic beauty. Plate XXXI shows the northwestern corner of the island, where the bare walls of limestone, cracked by horizontal bedding planes and vertical joints, and exposed by the quarrying action of the waves rise up 40 feet from the water's edge.The clean faces of these cliffs, the tottering pine trees, and the occasional accumulation of blocks below them show emphatically the vigor of the storm waves which roll across Green Bay against the island. Such evidence of work done by the present lake facilitates the conception of deep notching of the same headlands at higher stages. The lower figure in Plate XXX shows the northwest corner of the island again, from the Green Bay side, with three prominent high-level notches, which are approximately 50, 70, and 90 feet above the lake. In Plate XXXII, Fig. 1, a clearing on the densely wooded shore two miles south of the notched headland shows a bench and cliff of a 24-foot stage very conspicuously.

* "A Reconnaissance of the Abandoned Shore lines of Green Bay." Am. Geol., vol. 13, 1894. p. 327.



Cliffs of the present stage at Boyer Bluff.

Fig. 1. Nipissing terrace at the clearing, south of Boyer Bluff.

Fig. 2. Highest Algonquin beach near Detroit Harbor.

This doubtless is the Nipissing beach. The full series of beaches at this place, (hidden by the woods) is shown in Fig. 23.

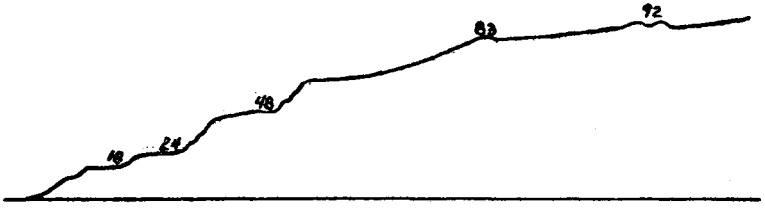


Fig. 23.—Profile at the clearing south of Boyer Bluff.

At Washington Harbor, in the bay on the north side of the island, the beaches are strongly built and the benches deeply cut, in a series shown below in profile. (Fig. 24).

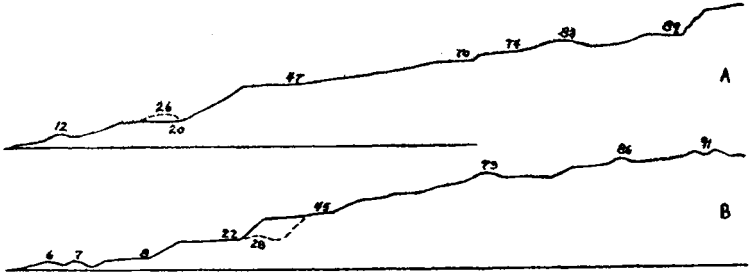


Fig. 24.—Profiles at Washington Harbor. (a) near the "White House." (b) at the head of the bay.

The "White House" stands on a 25-foot stone bar near the base of an abrupt rocky cliff on the 20-foot stage. The road leading from it to the post office follows closely a sloping rock bench at about 50 feet. West of the road, near J. Connell's barn, are benches at 69 and 74 feet, a bar at 83 feet, and highest of all a bench and cliff at about 90. The highest shore-line can be traced southward, crossing the road near the post office as it curves eastward around the head of the bay, and on across the east-west road near J. B. Young's house. It usually has the form of a double crested ridge of chipstone, here 91 feet above Lake Michigan. The complete profie at this point is shown in Fig. 24, A.

At Detroit Harbor, on the south side of Washington Island, the highest beach, a double-crested ridge at 89–91 feet is well

shown near J. G. Richter's house, where it crosses the road just east of the Methodist church (Plate XXXII, Fig. 2), and southeast of here, where it crosses the road at "Idylwood," at a height of 88 feet. At the last mentioned place a double-crested beach ridge crosses the road just below the highest beach, at 78 feet, and a 53-foot bar runs conspicuously through the fields and woods for a long distance to the Methodist church, where it passes into a bench. Nearer the harbor are several distinct beaches from 25 feet down, usually sandy, and in many places (e. g. near the Detroit Harbor post office) so modified by dune action that it is profitless to measure their altitudes.

Fig. 25.—Profile at Detroit Harbor.

OTHER ISLANDS.

The islands between Washington Island and the "Door" are too low to have been above water during the highest stage. On Plum Island a strong beach was found 18 feet above the lake, several at still lower levels, and one in the woods back of the lighthouse which was perhaps 30 feet above the lake.

On Rock Island was found a record of all the beaches, up to the very highest. On its southern side, along the broad path which runs across the island to the lighthouse, beaches were found at 18, 23, 26, and 28 feet; farther on is a sloping bench about 75 feet, and finally a high gravel ridge at 99 feet, marking the highest Algonquin shore-line. At the northern corner of the island, near the lighthouse, the extreme northeastern point of Wisconsin, a limestone cliff rises precipitously 40 feet from the water's edge, and is scaled by a long flight of steps. Part way up the cliff there is a scrap of a rock bench covered with cobbles and gravel at 22 feet, apparently an old shore-line. Back from the brink of the bluffs is a bench at 52 feet, and a short way up the path is a bar at 71 feet and a bench at 75. Beyond this, in a cleared field close to the light-

house, is a terrace about 100 feet above the lake—the highest beach on the eastern Wisconsin shore, and a mark of the earliest stage of Lake Algonquin.

HEDGEHOG HARBOR.

On our return to the Door County peninsula, the notched headland already seen from a distance (Plate XXX, Fig. 1) was found to bear the marks of several stages, shown in the profile below.

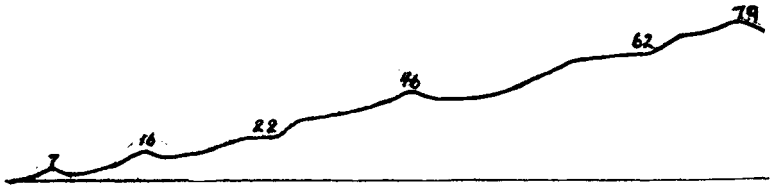


Fig. 28.—Profile at Hedgehog Harbor.

The highest Algonquin beach is here 78 feet above the lake, a heavily built bar of cobblestones. At 62 feet is a cliff and bench of cobbles; at 46 feet a bar with a cliff behind it, at 22 a bench and cliff, and at 16 feet another bar. The crest of the present beach is 7 feet above the water. The shore-lines which show most prominently in the step-like profile of the bluff are the 22 and 46-foot benches; but the highest shore, also, may be dimly made out. Near Hedgehog pier only the lower beaches—one at 18 and one at 27 feet—were found, although search was made on the hills back from the shore to a height of more than eighty feet.

ELLISON BAY TO SISTER BAY.

The depression which runs across the peninsula between Rowley's Bay and Ellison Bay was probably a strait at the highest stage of the lake; but for lack of time no attempt was made to follow the beaches inland. A line of levels from the lake up the hillside near the head of the bay, past Capt. Mike Anderson's hotel, crossed a bench and very conspicuous bluff (30 feet high) of the 19-foot (Nipissing) stage, a faint bar at 41 feet, running under the hotel, and a well formed bar at 66 feet. Be-

yond this to the top of the high hill no well developed beach was seen, although one ambiguous gravel deposit, a few feet higher than the 66 foot beach may mark the true limit of submergence, which might be expected to reach 74 feet here.

Two miles south of Ellison Bay, down an east-west road to the lake, the highest shore-line was seen at C. R. Seaquist's house, a broad 74 foot bench, below which is a series of benches and occasional bars, as shown in Fig. 27.

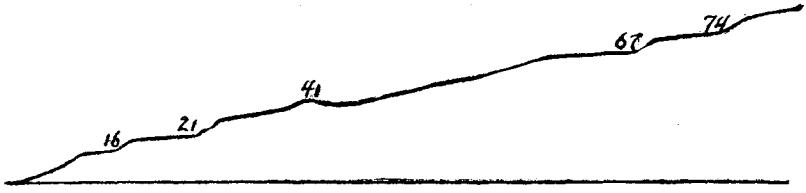


Fig. 27.—Profile near C. R. Seaquist's, south of Ellison Bay.

Half a mile farther south, at the end of another east-west road, beaches are sharply defined at several levels, with the highest, a double-crested cobble ridge by the side of the north-south road, near N. E. Lovstedt's mail box. (Fig. 28.)

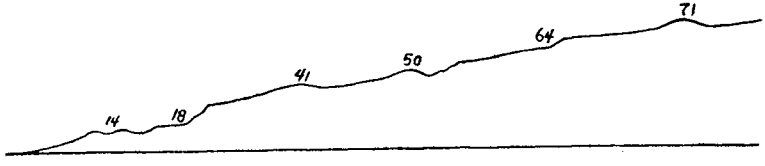


Fig. 28.—Profile near N. E. Lovstedt's, north of Sister Bay.

The Sister Bay road follows this highest Algonquin beach southward for some distance, past Henry Anderson's and Andrew Knutson's houses, coarse gravels showing by the roadside all the way. At Mr. Knutson's the series of beaches is the most complete yet described. (See Fig. 29). Just south of this place, on the outskirts of Sister Bay village, a church stands on

Fig. 29.—Profile near A. Knutson's, north of Sister Bay.

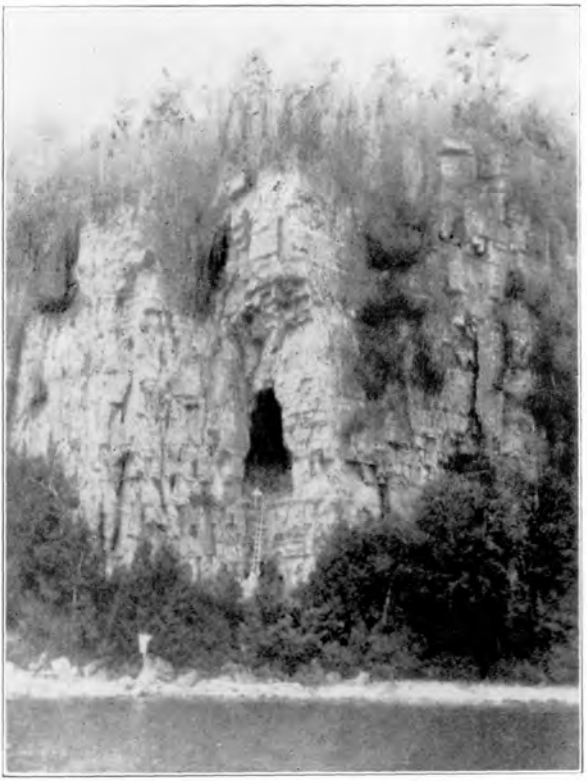


Fig. 1. Cave in the cliffs near Ephraim.

Fig. 2. Lighthouse at Eagle Point, on a rock terrace.

the highest beach. The road descends here to a much lower level, while the high beaches run southeast behind A. Carlson's house.

At Sister Bay post office a 20-foot bench, 47-foot bench, and 66-foot bench were found, the latter finely exposed by the side of the main road to Ephraim, a few rods up the hill from the post office. Behind it at this point is a steep bluff. How far inland this highest Algonquin beach may run has not been determined. There may have been a strait here during this 66-foot stage, across to North Bay.

EPHRAIM.

At Ephraim the marks of several stages of submergence remain in easily accessible places. Back of Hanson's store, halfway between the shore road and the upper road, the 20-foot beach is remarkably developed,— a heavy bar of coarse shingle standing ten feet above the level of the ground, with an unusually steep back slope. Up the hillside east of this, bare ledges and abundant cobbles indicate somewhat vaguely higher stages of the lake. A narrow platform at 35 feet, skirting the base of a low cliff, is followed for several rods by the upper road. North of this place a few rods, where two roads cross, the twin bar of the highest shore-line stands 59–62 feet above the bay.

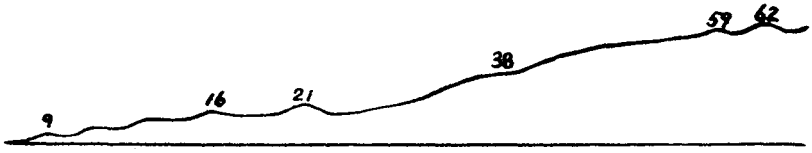


Fig. 30.—Profile at Ephraim.

Across the bay from Ephraim are some picturesque bluffs of limestone shown in Plate XXXIII. In one place a large cave (Fig. 1) reaches in from the cliff face at a height of more than 30 feet above the water. It was probably formed when the lake stood at one of the Algonquin levels, and the waves worked out a chasm at the water's edge.

On a headland just outside the bay a lighthouse stands on one of the high-level rock benches. (Fig. 2).

FISH CREEK.

At Fish Creek the old beaches run through the village, crossing the streets at many places, where coarse gravels are exposed. The lower beaches are well displayed in a pasture on the south side of the shore road, just east of the post office,—especially a coarse ridge of shingle whose crest is 21 feet above the bay. A fairly good series of the higher beaches may be seen by going up

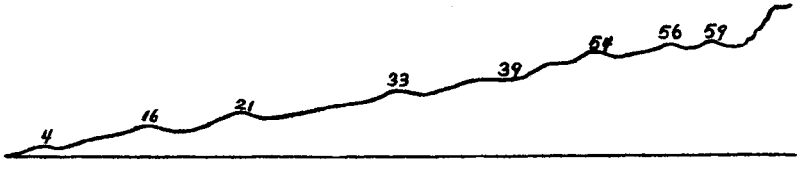


Fig. 31.—Profile at Fish Creek.

the hillside south of the post office. A church on the side street here stands on a faint 33-foot beach with a bench and bluff at a height of 39 feet just back of it. A few rods farther up the slope are two very strong bars which mark the highest level of submergence. Back of them, at Mrs. O. Rowen's house, is the corresponding bench, at 59 feet, and a steep rocky bluff. The series is shown in Fig. 31.

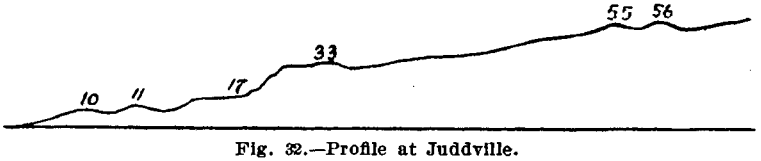


Fig. 32.—Profile at Juddville.

JUDDVILLE.

Halfway between Fish Creek and Egg Harbor the beaches were found and measured at Juddville, at the foot of two east-west roads, near Kirkland's pier; and a half mile south of it. (See Fig. 32). The highest Algonquin beach was found to be

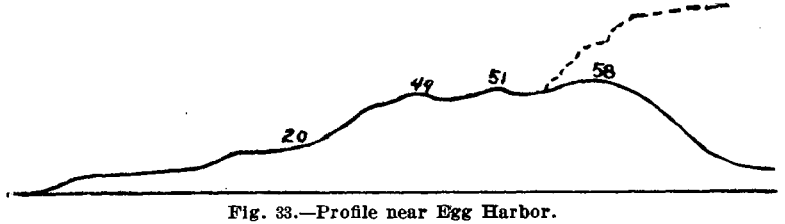
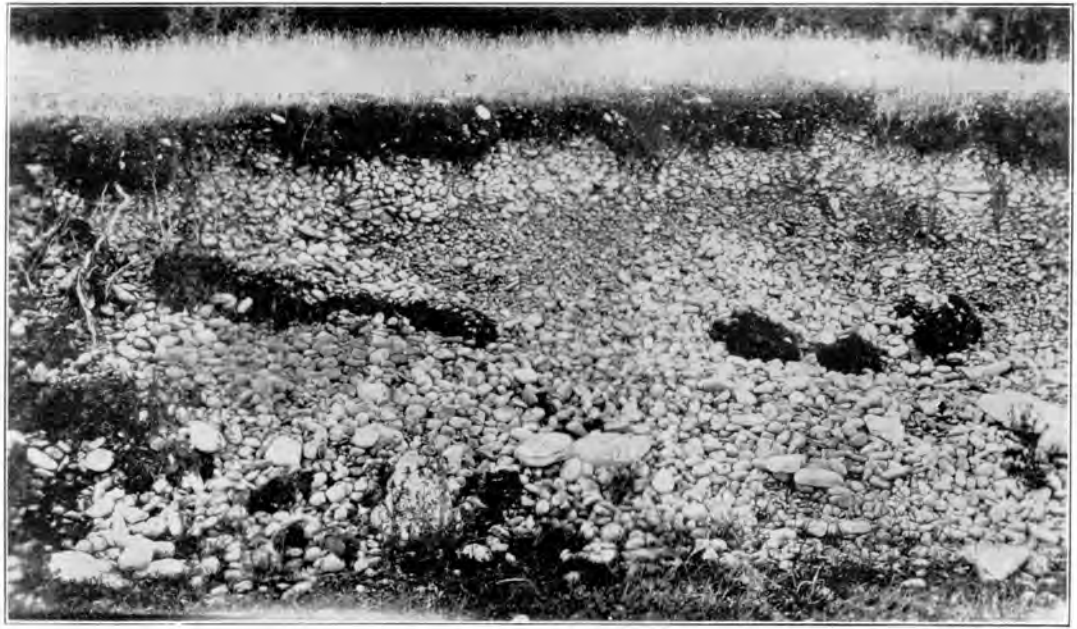


Fig. 33.—Profile near Egg Harbor.



Chip-stone structure of the great barrier ridge at Egg Harbor.

56–58 feet above the lake. Below it are marks of a shore-line at 36–38 feet, with bars a few feet lower, and a strong cliff and bench at 17 feet—doubtless the Nipissing.

EGG HARBOR.

Professor Chamberlin, in his "Geology of Wisconsin" make special mention of a conspicuous beach ridge or bar at a high level, near the head of Egg Harbor. This is probably the most remarkable beach on the Wisconsin shore, a great barrrier bar of coarse chipstone which reaches from the village southward across a broad deep valley for half a mile to some high limestone ledges. The road going south from the village past the schoolhouse follows the crest of this ridge through the woods. On the eastern side of it a steep slope descends to the swampy valley, and on the western side also the ground slops steeply down to the bay. At a clearing by the road, where the great bar connects with the limestone bluff at its south end, the form and structure of it are plainly revealed. The beach like crest, at 58 feet, probably marks a high barrier beach of a 51-foot stage; for the rock bench near by, from which the bar tails out, is but 51 feet up, and a 51-foot beach runs along the ridge just below the actual crest (Fig. 33). The inland slope of the bar is very precipitous, far steeper than ordinary beach slopes; and the lakeward side of the great ridge has been deeply cut into during a 20-foot stage which is marked by a high cliff and bench, a few rods back from the lake. Large borrow pits expose a tightly packed mass of discoidal pebbles of white limestone, nearly all of them between three and six inches in diameter and very well rounded, as if by vigorous wave action (Plate XXXIV). While the unusual size of the ridge and its steep slopes suggest that it is an esker rather than a barrier bar, there is abundant proof of its true nature:—it joins a wave-cut cliff and bench of rock, at precisely the expected level of the highest shore-line; it sweeps around the head of the harbor, where, if anywhere, a barrier would be built; its crest line is quite even; it is made of thoroughly waterworn pebbles and chipstone of nearly uniform size, no erratics whatever being seen in the large pit, and containing hardly any sandy or earthly material; there are distinct beaches on its top and outer slope.

Clearly the whole ridge is a shore embankment, built up in deep water across the head of the bay, from headland to headland, to a height of about seven feet above the water. The limestone cliffs from which the bar tails out have an unusually thin-bedded structure and abundant joint planes, affording favorable supply of rock debris to the waves.

HORSESHOE BAY.

At this place, three miles south of Egg Harbor, the highest Algonquin shore-line is a 49-foot bench, below a rocky bluff. The only lower shore-line which is at all distinct is a broad sandy terrace and bluff of a 15-foot stage.

MONUMENT POINT.

Three miles farther southwest, at Monument Point, a lofty limestone cliff stands half a mile inland; but no certain evidence of its being an old lake bluff was found. In the woods halfway between the cliffs and the lake is a well formed shingle bar at 21 feet, and another close to the lake at 9 feet. From this place southward for several miles no old beaches could be found, although the woods were searched with some care.

GRACEPORT.

This place, which is better known as Thayerport or Podunk, offers the best display of the lower of the extinct shore-lines those which lie below the altitude of twenty feet. The photographs, Plate XXXV and the Frontispiece, show the barrenness of the shore at this place, the heavy structure and the straight alignment of the beach ridges. The crest of the highest of the series, the beach of extinct Lake Nipissing, stands 19 feet above the present lake. The lower ridges are from 10 to 13 feet in altitude. Just north of the barn that is shown in this view, the Nipissing beach ridge terminates in an extraordinary curve,—almost a perfect circle, several rods in diameter. It looks decidedly artificial and might perhaps be the work of the Indians. A similar round-ended hook occurs near Baileys Harbor (see page 79).

Nipissing and lower beach ridges at Graceport.

South of Graceport, except for a few 12–20-foot beach ridges near the shore of the bay, no distinct shore-lines were found; but the high cliffs of limestone which stand some distance back from the shore and parallel to it may be in part the product of wave work at higher levels.

STURGEON BAY TO DYCKESVILLE.

Most of the shore from Sturgeon Bay southwest to the city of Green Bay was examined on a two day's trip in a fishing boat; for this proved to be the most rapid method of work in a country where railroads are absent, distances from towns too great for the best use of horse and carriage, and time too short to traverse the shore on foot, and to use a level at intervals of a few miles. The boat offered a continuous view of the shore; and small piers gave frequent opportunities to land and measure the altitudes of beaches.

For some distance beyond the light house, towards Little Sturgeon Bay, the shore is low and heavily wooded. Marks of the 20-foot stage were seen in places. The first landing was made at Gus Bosman's lime kiln on the shore a short distance west of Little Sturgeon Bay. Just south of this place there are high limestone bluffs which have retreated beyond the old shore-lines; but north of the kiln the bluff becomes much lower, and a shore-line of the 40-foot (Algonquin) stage runs obliquely inland towards the east,—a great bar built of large cobbles and discoidal bowlders of limestone. Near the kiln the beach stone has been extensively taken out and burned for lime, exposing the heavy structure of the beach ridge, whose crest stands 41 feet above the lake. A few rods northeast of the kiln the lower sweep of the 41-foot beach is slightly benched and ridged at the 20-foot level, probably a mark of the Nipissing stage. At a headland a short distance southwest of the kiln the coarse stone beach is again well exposed, resting on the limestone at the top of a freshly cut cliff. From here the beach runs inland to the south, but is never far from the bay shore. At several places it is interrupted by the retreat of the present cliffs, which occasionally rise precipitously for 50 or 75 feet, and have here developed more rapidly because of the weak Cincinnatti shales beneath the limestone near the water's edge.

At G. F. Lovelett's house (section 25, Gardner) there is a strong terrace with beach ridges of the low stages, backed by a steep bluff which has been cut in the outer slope of a great gravel bar of the higher stage. This ridge seems to be an old barrier beach or embankment of Lake Algonquin similar to that at Egg Harbor, built across a broad valley by shore drift towards the south. Its crest, 75 rods north of Mr. Lovelett's house, is 37 feet above the bay; but it declines slightly towards the south to 35 feet, where it is breached by a little stream which drains the enclosed lowland.

South of this place the shore-lines continue southward, back from the shore, for several miles. They were not visited again until a landing was made at a newly built pier (section 4, Union). The highest beach here is a well built shingle ridge, a few rods back from the shore of the bay, and about 35 feet above it. For a short distance this beach ridge is split into two slightly lower ridges, 32 and 33 feet in altitude. A beach of coarse shingle at 18 feet marks the lower stage.

The beaches were picked up again a mile farther south, where the road west from Brussels reaches the shore. A well formed 19-foot ridge crosses the road not far from the bay, and behind it a similar ridge of heavy shingle at 28 feet. This altitude is several feet lower than one would expect, on comparison with other data: but no traces of shore action at higher levels could be found on the gently rising ground east of the 28-foot beach.

For several miles north of Dyckesville, (in Union and Red River) the hillsides along the bay are cleared and farmed; and the steep cut bank and terrace of a 15–20-foot stage is very conspicuous. The absence of higher shore-lines is at once apparent, and due to the fact that in this region of soft shales and glacial drift the lake at its lower stages has cut back more rapidly than in Door County, and thus destroyed the higher shore-lines. At Red River this bank and bench cut in the red till marks a water level not higher than 13 feet, according to careful measurements; but the bench is raised several feet here and there by flat fans swept out by creeks which run down to the bay, and also by the washing down of the clay slope where cultivation has loosened the soil. The bank behind the 13-foot terrace is from fifteen to twenty-five feet high, marking a gen-

eral recession of the soft clay cliffs at this low stage beyond the higher shore-lines of the Algonquin stage. While the weakness of the coast here as contrasted with the solid limestone coast of Door County is doubtless the chief cause of the obliteration of older shore-lines by recession of the later cliffs at lower levels, it may be remembered that the upper (Algonquin) line of beaches is slanting southward more rapidly than the lower (Nipissing) line, causing the vertical interval between them to grow gradually less. For this reason alone, destructive recession at the lower stages would proceed more quickly here than farther north. The greater importance of difference in coast structure, however, is borne out by the fact that the highest of the low (Nipissing) shores has itself been lost by benching at the lower, 13-foot stage.

DYCKESVILLE TO GREEN BAY.

At Dyckesville a distinct sand ridge was found 17 feet above the bay. Its crest is followed a short distance by the shore road. Behind it a long sandy slope runs up to about 26 feet, where there is a steeper slope of red till. No marked shore feature at this higher level could be found.

South of Whitney's bluff no beaches were seen until Point Comfort (just north of Kishkekwanteno) was reached. There a large series of sand ridges was found, at levels as follows: low sand bars at 8 feet, a few rods back from the lake near summer cottages; a 17-foot sand ridge on the private road about 100 rods inland; 19 and 22 feet, other sand ridges near the last mentioned; and at 35–38 feet, a dune ridge of sand, with an uneven crest and a steeper back slope than most true beach ridges. This dune ridge runs for 200 yards or so through the woods and then breaks up into a group of sand hills. Between this place and Kishkekwanteno, among a cluster of cottages, imperfect marks of old lake levels, including one definite bench and bluff of a 12 foot stage, were noted.

At Kishkekwanteno is a stretch of clay banks freshly cut by the waves, rising steeply 60 feet above the bay. A long pier running out to the steamboat landing expresses the shallowness of the shore at this place, where the present lake has evidently

cut back a submerged terrace of considerable width. The fresh bank shows laminated red clays to about 25 feet above the bay, overlain by stratified sands and clays probably of glacio-fluvial origin.

South of Kishkekwanteno the red clay upland declines to levels well below the old lake stages; but well formed shore features are singularly rare. A faint bluff of red clay runs through the fields a short distance east of the shore road through sections 31, 6, 1, and 12, (Scott); and in sec. 1(Scott) the road follows the crest of a pronounced gravel ridge. Evidence of the higher (Algonquin) shore were searched for carefully, but without success.

Au Sable Point is a long spit of sand, built out by shore currents, which sweep the sand southward in great quantities towards the head of the bay. Low dunes have raised the spit considerably above water level. Long Tail Point just across the bay seems to have the same origin.

In section 23, (Scott) the shore road comes suddenly upon a well built bar of cobblestones, whose crest is 17 feet above the bay and 8 feet above the hollow which lies behind it,—an old lagoon which once separated the bar from a steep cut bank. This is the most stony beach found near the head of Green Bay, and was described by Chamberlin in his report of 1877*. The cobble beach together with a sharply defined bluff, along the base of which the road runs for some distance in sections 23 and 22, bears witness to the importance of this Nipissing stage. The old bluff seems to be continuous with a broad ridge of sand in section 33 (Preble), on which runs the main road to Green Bay. Approaching the city one loses this sand ridge, indicating perhaps that it was a spit like Au Sable Point, instead of a continuous beach. In the valleys of streams east of Green Bay (e. g. the one followed by the Green Bay & Western Railroad) in Sec. 33, (Preble) are marked terraces at several levels, which seem to testify to former high-level stages. In one place near the railroad these terraces stand 11, 18, and 37 feet above the creek; the highest of these, being thus about 30 feet above the present flood plain, would probably correspond to a lake stage about 30

* Geology of Wisconsin," vol. 2, p. 229.

feet higher than the present, the Algonquin, whose record seems to be so generally lost in this part of the state.

In the city of Green Bay and on its outskirts low sand ridges indicate that there was active deposition here at the head of the bay during the extinct stages, as at present. The old lake floor between the ridges and the present shore, a smooth deposit of silts, is extensively ditched and cultivated as truck gardens; the larger part of it, however, is so close to present lake level that it is too wet to be occupied. Back towards the interior, southeast of the city, there are irregular gravel deposits in the Fox River valley, which seem to have been shaped by the melting ice sheet and its short lived streams and floods, rather than by shore processes; and to the east of the valley, in sections 45, 33, and 34 (Preble), is a belt of remarkably strong kettle moraine topography which will deserve close attention when the glacial deposits of this part of Wisconsin are given thorough study.

GREEN BAY TO LITTLE SUAMICO.

The road from Green Bay to Duck Creek crosses and follows several stretches of sand ridges, partly beaches, partly dunes, but all apparently within the range of altitude of the Nipissing stage. The Chicago & Northwestern Railway between Green Bay and Big Suamico, passes over many miles of the low lake plain, occupied by truck gardens near Duck Creek, but elsewhere an expanse of unused swamps, covered with second growth.

Just west of the Chicago, Milwaukee & St. Paul Railway, about a mile north of Cormier station, (in Sec. 9, Howard), an east-west road crosses a well marked ridge of gravel and sand whose crest, according to levels from the railroad, stands about 28–29 feet above the bay. This, then, must be the Algonquin beach. (Plate XXXVI, Fig. 1). On the till slopes just west of this ridge no higher traces of water action could be found. A mile and a half farther north (in Sec. 33, Suamico) a cluster of dunes and a beach ridge was seen not far east of the St. Paul Railway; but they seemed to stand at a lower level than the Algonquin. A short distance west of here (in Sec. 33) on the west side of the main road, there are some indications of wave-

cut banks; but they seemed too indefinite to be of much value. At Big Suamico the Northwestern Railway cuts through deposits of gravel and sand which stand about at the Algonquin level (30 feet) but their topography is very irregular. They may represent a poorly developed or modified delta of the river at the highest stage of the lake, as Taylor suggested.*

LITTLE SUAMICO TO OCONTO.

The features described in the last section are typical of the entire stretch of shore from Green Bay to the State boundary at Marinette. The low swampy lake plain stretches inland for a distance of one to six miles, interrupted by low ridges of sand which are often very faint in expression but remarkably continuous, and by occasional groups of dunes. There was little or no erosion by the extinct lake along this shallow coast, but rather continual deposition in the form of beaches and bars. The record of lake stages, therefore, is peculiarly complete, even though it has weak expression.

At Little Suamico in a field a few rods west of the railroad station a faint sand ridge may be traced northeastward through the village and thence for two or three miles in a northerly direction. The State road follows the crest of it for a long distance, whence it is locally known as the "State road ridge." It is about 12 feet above the bay. Although so faint in expression, it stands high enough to offer a dry path across long swampy stretches of ground, and was well known to the lumbermen and early settlers, and doubtless to the Indians. With many slight interruptions and offsets, it is said, this ridge may be followed for a score of miles along the shore. There seem to be ridges also at a 16-foot level, which are closely associated with the 12-foot ridge, and might easily be confused with it. Fragments of these low beaches were seen along the line of the Northwestern railway, at many places (e. g. in sections 27, 22, and 14), but it seemed inadvisable to attempt to trace them continuously through the low country.

A half mile west of the railroad station at Little Suamico are two low but well built sand ridges which run northward, skirt-

* Am. Geol., vol. 13, p. 321. 1894.

Fig. 1. Algonquin beach ridge near Cormier station.

Fig. 2. Algonquin terrace and bluff near Little Suamico.

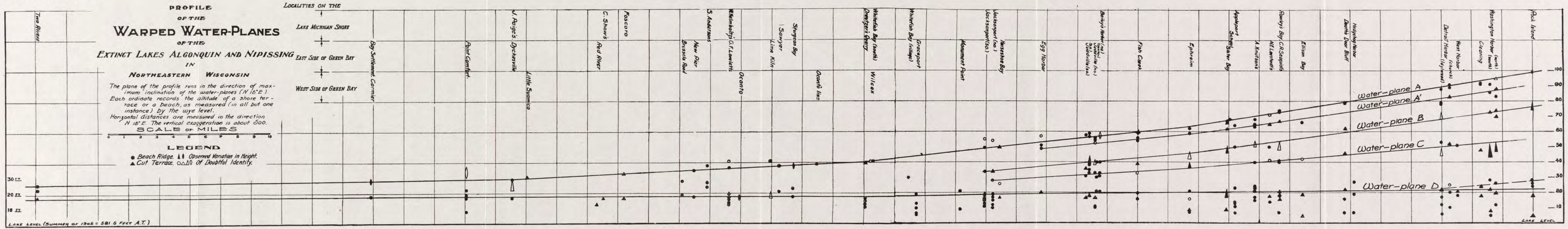
ing the village, and connecting with a cut bank and terrace near the road at the northeast corner of section 13 (Plate XXXVI, Fig. 2). This cut bank is the only one observed along the west side of Green Bay, so uniform has been deposition rather than erosion at all stages. It continues only a few hundred yards before it passes again into a beach ridge, close by the district school. The bluff and bench has not a very sharp outline; for it is cut in sandy drift, and has suffered much blurring by cultivation and rain wash. Leveling from the railroad station showed that the average altitude of the bench and of the crest of the beach ridge is 31 feet above the bay,—just where the Algonquin beach should be, judging from other data. Beyond the school house the old beach seems to fade away; but in section 31 (Pensaukee) two sandy ridges (the lower at J. A. Haskin's house) seem to be beaches or dune ridges of the same series. Just south of Oconto River the railroad cuts through a 16-foot sand ridge once more.

OCONTO TO MARINETTE.

Just north of Oconto station the Northwestern railway cuts through several low sand ridges, which because of their irregular form and uncertain trend seem to be dunes rather than beaches. A mile or so farther north the state road crosses the track, following the crest of a 12–14-foot sand ridge for over a mile. The road then bends slightly (in section 1, Oconto) running due north, and rising rather steeply reaches the crest of a higher beach ridge. This one is quite broad and well defined where the state road crosses the town line; but its topographic expression is not strong. Levels run up from the railroad determined the crest of the ridge to be 39 feet above Lake Michigan.

A mile south of the county line, near Wilcox station, the railroad cuts two ridges of stratified gravels, the higher one being a much more marked topographic feature than any of the beaches seen elsewhere on this stretch of low shore. Inasmuch as this ridge is built of coarse gravels and not far behind a till ridge which is as high if not higher, it seems hard to believe that it is a beach, although it stands (according to hand-level from the railroad) exactly where the Algonquin beach belongs, 41 feet above the bay.

From Wilcox to Peshtigo and Marinette no definite trace of the highest shore-line was found, although search was made for it. In Marinette, particularly, an effort was made to discover old beaches; but aside from a few low and discontnuous sand ridges near the base ball grounds, nothing characteristic was found at the Algonquin level. The nearest place to Marinette where Taylor found the Algonquin beach is Birch Creek, Michigan, 6 miles north of Menominee, where an aneroid measurement placed it at 46 feet. This is over 10 feet too low to agree with the data collected from the Door County peninsula. It is quite likely that a more thorough exploration of the Green Bay-Marinette shore would bring to light many fragments of beaches; because the time spent in this district was necessarily limited, and because without knowing railroad altitudes at that time there was considerable difficulty in judging altitudes when searching for beaches on the broad gently sloping surface. It is certainly true, however, that beaches in this district are both faint and poorly preserved. Enough data was secured to show that conclusions regarding tilting, already deduced from the study on the eastern side of Green Bay are confirmed by the beaches on the western side.


PROFILE
OF THE
WARPED WATER-PLANES
OF THE
EXTINCT LAKES ALGONQUIN AND NIPISSING
IN
NORTHEASTERN WISCONSIN
The plane of the profile runs in the direction of maximum inclination of the water-planes (N 15° E).
Each ordinate records the altitude of a shore terrace or a beach, as measured (in all but one instance) by the wye level.
Horizontal distances are measured in the direction N 15° E. The vertical exaggeration is about 500.
SCALE OF MILES
0 1 2 3 4 5 6 7 8 9 10
LEGEND
Beach Ridge. Observed Variation in Height.
Cut Terrace. Of Doubtful Identity.
LOCALITIES ON THE
LAKE MICHIGAN SHORE
EAST SIDE OF GREEN BAY
WEST SIDE OF GREEN BAY
Two Rivers
Bay Settlement. Cormier
Point Comfort.
J. Paige's. Dyckesville
Little Suamico
C. Shaw's
Red River
Foscoro
Brussels Road
New Pier
S. Andersons
Wilhelmholtz's G. F. Lowlett's
Oconto
Sawyer
Lime Kiln
Sturgeon Bay
Oconto line
Whitefish Bay (south)
Dreutzer's Quarry
Wilcox
Whitefish Bay (village)
Graceport
Monument Point
Jacksonport (no.)
Jacksonport (so.)
Horseshoe Bay
Egg Harbor
Bailey's Harbor (no.)
Juddville (no.)
Juddville (so.)
Fish Creek
Ephraim
Appleport
Sister Bay
A. Knutson's
Rowley's Bay. C. R. Sequist's
N. E. Larsted's
Ellison Bay
Death's Door Bluff
Hedgehog Harbor
Detroit Harbor
West Harbor
Clearing
Washington Harbor (north)
Washington Harbor (south)
Rock Island
Water-plane A
Water-plane A'
Water-plane B
Water-plane C
Water-plane D
30 FT.
20 FT.
10 FT.
100
90
80
70
60
50
40
30
20
10
LAKE LEVEL (SUMMER OF 1905 = 581.5 FEET A.T.)
LAKE LEVEL

CHAPTER IV.

RECONSTRUCTION OF THE WARPED WATER-PLANES.

DETERMINATION OF ALTITUDES.

On the way northward along the shore-lines, altitudes of the beaches or terraces were determined wherever they were found strongly developed. In studying the district between Port Washington and Sheboygan, the aneroid barometer was at first used as a convenient method of determining the heights of beaches; but a week's experience sufficed to show the confusing inaccuracy of it. The instrument was especially erratic near the lake, probably on account of cool lake breezes on the hot summer days. The Locke hand level was therefore used whenever practicable; but in many places the distance between the old shore-lines and the lake, and the varying slopes, frequently covered with underbrush or with grain, made possible errors of five or ten feet in hand-level measurements. Hand-leveling with a rodman was tried in one or two cases; but it proved to be hardly more rapid, and much less accurate, than outright leveling with the wye level. South of Sturgeon Bay, during the first part of the season, most of the measurements were made by hand level; but in the fall many critical localities were revisited and several lines of levels were run with the wye level. North of Sturgeon Bay nearly all the measurements were made with the wye level. On the plotted profile (Plate XXXVII) all the ordinates mark wye level measurements except one at Wilcox, where a sand ridge crosses the railroad. The lake was used as a base for all measurements except those on the west side of Green Bay

and a few in Kenosha county and south of the Illinois line, where bench marks were obtained from railroad profiles through the courtesy of division engineers of the Chicago and Northwestern Railway.

Some error, possibly a foot or two, is involved in estimating the absolute water level of the lake at times when an on-shore wind heaped the waters upon the shore and a strong surf was running. Most of the levels, however, probably need little correction for this reason. The inaccuracy of the leveling itself can hardly amount to more than a foot on the longest traverses, e. g. to the Algonquin beach ridge near Whitefish Bay, a roundabout distance of three miles. In choosing the point to be measured, the crest for a beach ridge was taken as the only determinable datum for the old water-plane, although it is of course recognized that the beach ridge probably stood anywhere from three to six feet above the actual water-plane, according to the configuration of the shore and the exposure to wave action. Where a cut terrace and bluff was measured, the datum is the average height at the base of the bluff, care being taken in each case to avoid places where the terrace has been locally raised a little by flat alluvial fans from ravines or by wind-drifted sand. In cases where both a terrace and a beach ridge were seen connecting laterally, as is usual where an old stream valley causes an interruption in the line of cliffs, the crest of the bar is generally two or three feet higher than the corresponding bench. In the Egg Harbor case (p. 89) the great barrier bar stands six feet higher than the rock terrace from which it tails out. In other cases, however, (e. g. at Little Suamico, p. 97) the terrace and its bar do not differ a foot in altitude. Occasionally a sand ridge shows signs of modification by dune action, in which case little value has been attached to its altitude. In a few cases, also, cliffs and benches are too obscure in form to be significant except when correlated with neighboring benches of distinct form.

The symbols used in the diagram are intended to indicate all these irregularities as well as the probable accuracy of the measurements. Considering the highly exaggerated vertical scale (500 times), the discrepancies between ordinates and inferred water-planes are remarkably few and of small amount.

CONSTRUCTION OF THE PROFILE OF WATER-PLANES.

No plotting of results was done until the east shore of the Door County peninsula had been followed up to the "Door" and around Washington Island. It was then found that the data collected could be reduced to a systematic set of tilted water planes which slant south-southwest, in the direction of the axis of the peninsula. Subsequent leveling on the journey back, on the west side of the peninsula, fulfilled expectation in almost every instance. It was not until after the close of the field season, however, that the altitudes of the beaches on the west side of Green Bay were reduced from the railroad datum to lake level, and the discovery made that the data agree more closely with water-planes slanting more nearly due south than was at first supposed. After experimentation, therefore, the ordinates were plotted with reference to a plane dipping S. 15° W,—the direction of steepest ascent of the shore-lines being not far from N. 15° E. Mr. Leverett had previously come to the same conclusion; i. e. that the direction of steepest tilt of the Algonquin plane is more nearly due south in the Lake Michigan basin than in the Lake Huron basin.*

THE HIGHEST ALGONQUIN WATER-PLANE.

Taylor has identified the 35–40-foot shore-line at Sturgeon Bay and Dreutzer's quarry as the highest of the Algonquin series; and although in his reconnaissance of 1893 he obtained no measure of its altitude farther north in Wisconsin, his aneroid measurements at several places in the upper peninsula of Michigan sufficed to show a northeastward ascent of the water-plane amounting to more than a foot per mile. The scanty observations south of Sturgeon Bay (at Green Bay and Kewaunee) apparently justified his conclusion that the Algonquin plane continues to slant south and dips under the lake near Two Rivers; but much doubt was later thrown on this theoretical conclusion by Taylor's own work on the east side of the lake. This unsettled question of the southward continuance of the Algonquin beach, possibly becoming horizontal above

* Personal communication to the writer. Feb. 12, 1906.

Lake Michigan and continuing southward around the head of the lake, thus involving the use of the Chicago outlet by Lake Algonquin, was naturally the problem of greatest interest in the summer's work. Of nearly as great interest was the possibility that the Nipissing shore-line, in like manner, might become horizontal above the present lake, instead of going under some distance north of Washington Island.

The highest Algonquin shore-line was followed with a good many interruptions the entire length of the Door County peninsula and easily identified on Washington and Rock Islands. Thirty lines of levels, run up from the lake across the highest beach at localities where it was found best developed, together with less accurate hand level measurements which are not shown on the diagram, and some continuous tracing, fully establish this water plane. From the 40-foot terrace at Dreutzer's quarry near Sturgeon Bay to the 95-foot bench at Washington Harbor there is an ascent of 55 feet in a distance of about 40 miles, making an average rate of 1.38 feet per mile; but if this tilted plane (shown in the diagram as "water plane A") is analyzed, the rate is seen to increase from south to north, so that in the last 19 miles from Ephraim to Washington Harbor it is 1.63 feet per mile. The ordinates on which this plane is reconstructed do not vary more than three feet from it; but in three cases the crest of the highest beach deposit is five or six feet too high. One of these is the crest of the great barrier bar at Egg Harbor, which stands six feet above the wave-cut terrace from which it tails out, and which has a distinct beach crest at the same level as the terrace, showing that the barrier bar at this exposed place stood several feet higher than the old lake. At Jacksonport at two places a ridge-like accumulation of only partially rounded stones lies five or six feet above the supposed water-plane, which is here marked by a beach ridge at the expected level. At. Baileys Harbor the old wave-worn cliffs in the northern part of the village furnish a less accurate ordinate than the two beach ridges; but in certain exposed places there is a bench as well as a cliff. There is little difficulty in determining at each place that it marks the upper limit of lake-shore action.

South of Sturgeon Bay the record is far less complete than

out on the peninsula ; for the coast and the hillsides cease to be rocky, and there is only a thick deposit of red clay, in which the recession of cliffs of the lower stages (including the present stage) of the lake has destroyed the higher shore-lines, sometimes only in part, sometimes completely. Near the head of Green Bay the sand ridges have suffered much change of form by the action of wind (e. g. at Point Comfort). This is true of the beach ridges which follow at some distance the low and swampy coast west of Green Bay, where the flatness of the old lake floor, which was shallow for a long distance out, makes the beaches less pronounced in their development than elsewhere. The four measurements obtained by leveling in this district, however, (and the hand-level ordinate at Wilcox) agree closely with the data collected on the two stretches of shore to the east.

The combined measurements around Green Bay, with the few available measurements on the highest beach along the Lake Michigan shore, (at Clay Banks, Algoma, Rostok, and Foscoro) bring the Algonquin water-plane gradually down from 40 feet at Sturgeon Bay to 28 feet near Cormier station, at a contstantly decreasing rate of descent which averages 1.08 feet per mile, but is so diminished towards the south as to be but a fraction of a foot per mile near the head of Green Bay. It seems probable that the Algonquin plane becomes almost horizontal at this height. The presence of a beach ridge at Two Rivers at an altitude of 26 feet above the lake goes far towards confirming this view. The evidence south of Two Rivers is rather obscure, and can be best appreciated after the lower shore-lines of the northeastern district have been considered.

LOWER ALGONQUIN WATER-PLANES.

Perhaps the best starting point for the analysis of these lower planes is the line of ordinates near the Death's Door bluff, at the exposed end of the Door County peninsula. A distant veiw of the great headland (Fig. 1, in Plate XXX) shows three deeply cut steps or notches, corresponding to the measured terraces at heights of 22,46, and 62 feet above Lake Michigan. (See Fig. 26). The highest Algonquin shore-line, at 79 feet, is here a beach ridge, hidden by woods. The three water-planes marked

by these great terraces are manifestly stages of more than moderate duration of the lake. The steep bluffs behind each terrace are comparable in height to the present cliffs at the base of the headlands. Distinct records of each of these three stages may therefore be expected elsewhere, at those places where they have not been destroyed. Intermediate stages of shorter duration may of course have been less plainly recorded here, and then destroyed by the recession of one of the conspicuous rock bluffs during a lower stage. Below the 22-foot bench there are no terraces,—merely two beach ridges at 16 and 7 feet. It may be inferred, therefore, that after the 22-foot stage the lake did not stand long at levels above the present. The 7-foot beach ridge is probably a storm beach of the present lake, or one built in recent years during a possible high water stage, like that of 1838. (See p. 39). The 10-foot ridge also may be of no very great age, marking a fluctuation of the lake due to a change in rainfall. The 22-foot bench however, is far too strong to have been cut out in a few years such as the period of high water of 1838.

Referring now to the profiles at Washington Harbor, (Fig. 24) on the similarly exposed northern side of Washington Island, one may quickly see that not only are the three strong planes again well marked, but others occur, which were absent near the Door. The lowest plane is marked in both parts of the village by a bench at 20–22 feet; but a few feet above this is sometimes a ridge of chipstone. Near the pier, the "White House" stands on the 6-foot bench. At the head of the bay, a 28-foot beach ridge, likewise, is preserved for only part of its length; elsewhere the 22-foot terrace lies at the base of a steep bluff. These bars seem therefore to record a stage of comparatively short length. It is noticeable that this lowest terrace is at approximately the same height as at the Door. The next higher stage is marked at Washington Harbor by a broad sloping terrace of nearly bare rock, 44–52 feet above Lake Michigan, which is manifestly a mark of strong wave work, but one on which it is hard to fix accurately the old water-plane. The third plane is marked by rock benches near 70 feet,—about ten feet higher than at the Door. The highest shore-line at Washington Harbor is complex, at both parts of the village where it was examined. It is marked by three benches and a ridge near J. S. Connell's

barn and by a single and a double crested ridge east of the post office. The complexity of this highest stage as it appears on Washington Island and the simplicity of its record near the Door is not hard to understand; for near the Door the 62-foot cliff has receded to the outer edge of the highest or 79-foot beach ridge leaving no chance for beaches of intermediate altitude.

The photograph of Boyer Bluff (Plate XXX, Fig. 2), not far from Washington Harbor, shows that there the 20-foot terrace has been lost by the retreat of the high cliffs which rise perpendicularly from the water's edge. The three higher steps correspond to the 50-, 70- and 90–95-foot stages,—the highest Algonquin being here marked by a terrace. The 20-foot terrace is preserved with strong outline at West Harbor, a few miles south of the point, as Plate XXXII, Fig. 1, shows.

At Detroit Harbor the double character of the highest stage is confirmed by the plotted ordinates. Perhaps the less exposed character of this side of the island may account for a slightly lower beach crest than was anticipated; or it may be that the line of levels from the shore up to Idylwood is a foot or two too low (on account of the difficutly of judging the level of the lake on a day when the waves were running high). None of the shore-lines on this south side of the island are so well marked as at Washington Harbor. The 70-foot terrace, especially, is traced with difficulty. As before, several ridges lie between a strongly cut 20-foot shore- line and the present lake.

In tracing these four or five prominent planes southward, it will be useful to designate them at A, A′, B, C, and D, as has been done in Plate XXXVII. The ordinates harmonize to a remarkable degree with these water planes. The complexity of the highest Algonquin is almost everywhere apparent. At Ellison Bay, where a protected part of the old shore was unfortunately chosen, all shore-lines above the strong 19-foot terrace and bluff are weak, and the two highest shore-lines are not fully marked out. At the three places between here and Sister Bay, the double structure of stage A–A′ is clearly indicated. At Appleport, on the east side of the peninsula, the 64-foot beach lies on the crest of a high ridge of till and bed rock, while the actual highest shore-line, A, is found more than a mile farther west

near the center of the peninsula, at the school house. At Sister Bay fragments of terraces for A and A′ occur, as well as corresponding beach ridges. Fish Creek furnishes one of the best records of the two closely associated water levels, at 55 and 60 feet. The overhanging cliffs at Bailey's Harbor, bordered usually by the sloping terrace of a lower stage, afford only a partial record of the highest Algonquin stage. At Egg Harbor two beach ridges near the crest of the great barrier embankment suggest that the highest shore-line is not a single one. South of Egg Harbor there is no distinct sign of plane A′; which makes it seem probable that it converges to meet plane A somewhere near Whitefish Bay. At Jacksonport a cliff has been cut back to the line of the highest beach, allowing no chance for A′ to be preserved, if it were ever there.

Plane B, which forms the highest notch in the Death's Door Bluff and the 70-foot step at Washington Harbor and Boyer Bluff is elsewhere less sharply recorded than either the highest plane or those below. On the gently sloping hillsides at Detroit Harbor its development as a terrace is naturally obscure. At several places south of the Door the relative indistinctness of this terrace is noticeable, and may indicate a gradual lowering of the waters, during which a sloping terrace rather than a definite one was cut at the base of the rock cliffs. This view is confirmed by the large series of beach ridges and terraces at Bailey's Harbor and Juddville at altitudes intermediate between this plane and the next lower one. The 34-foot bench and beach ridge at Jacksonport undoubtedly lie on this plane. Farther south it seems to be marked by the 30-foot cobble ridge at Whitefish Bay and perhaps by the 27-foot beach at S. Anderson's house (near Clay Banks). The reconstruction of this part of plane B is however uncertain, as the diagram indicates.

Plane C is likewise easily identified at the Door and Washington Island, where it forms one of the great steps, and for about thirty miles south to Jacksonport. It is marked by unmistakable benches and ridges at nearly every point. Its absence at Egg Harbor is explained by the great cut bluff of the next lower stage, which has here worn back the outer slope of the barrier ridge nearly to its crest. South of Jacksonport there is hardly sufficient data to identify it.

The profile (Plate XXXVII) shows a gentle but distinct divergence of these higher water-planes from south to north along the Door County peninsula. The probability of a splitting of A′ from A near Whitefish Bay has already been suggested, on the basis of the slightly decreasing interval between these two planes as they pass from north to south, and the absence of a double record south of Egg Harbor. This divergence probably indicates a slight tilting of this part of the lake basin before the water fell from plane A to A′; the vertical forking of the beaches recording a slight differential uplift which affected merely the district north of Whitefish Bay, lifting it a few feet above its former level. On the other hand it is not impossible that the slight divergence indicates simply the difference in local attraction of the ice sheet at two successive positions. It has been found by computation that the lake surface within sixty miles of the ice front may have slanted upwards 8 inches per mile, and within a few miles of the ice front as steeply as 2 feet per mile.* If, therefore, after its temporary halt, while the shore-line of plane A was being formed, the ice withdrew rapidly to a considerable distance and halted again, the diminished attraction on the water-plane might account for all the divergence between A and A′.

Planes A′ and B seem to be essentially parallel throughout this district; but B and C show a distinct divergence, the interval of more than twenty feet at Washington Island decreasing to less than ten feet at Bailey's Harbor and Jacksonport. This divergence of over ten feet in thirty miles is again within the range of explanation by northward withdrawal of the attractive force of the ice sheet. It is clear, however, that if ice attraction alone was operating at this time (and no uplift going on), *each* plane should slant less steeply than the one next above it: not only should C be more nearly horizontal than B, but B should be flatter than A′. If, therefore, B and A′ are exactly parallel, as the profile (Plate XXXVII) suggests, then ice attraction cannot be the whole explanation; and we must resort to differential uplift, which bent the planes upward while they were being registered by beaches and terraces. With this hypothesis we

* "On the Form and Position of the Sea Level." R. S. Woodward. U. S. Geol. Surv., Bull. 48. 1888.

may suppose that the fifteen foot drop from A′ to B was controlled by the cutting down of the outlet, or the opening of a new one, or possibly by some extraordinary fluctuation in volume of the lakes, while the land stood still; and that A′ and B were uplifted together after B had been recorded and before C was marked out.

The great divergence of planes, however, is between C and D. C slants southward from 54 feet at Washington Island to 30 feet at Jacksonport, while D falls only about six feet in the same distance. The nearly horizontal attitude of this 20-foot plane is very apparent.

The occurrence of beach ridges around Washington Harbor and on Washington Island, a few feet above the Nipissing plane, suggests that a still lower plane of Lake Algonquin rises here from plane D, as indicated on the profile.

THE NIPISSING WATER-PLANE.

At every locality where old beaches were observed (except at the high cliffs at Boyer Bluff) a 20-foot stage was observed to be peculiarly distinct, and its persistence as a nearly horizontal plane was recognized on the journey northward from Sturgeon Bay before any ordinates were plotted, and while the northward ascent of the highest shore-line was being confirmed by each new line of leveling. It is altogether probable that the 18-foot shore-line seen by Whittlesey in 1850 on St. Martin's and Washington islands* is this one. The presence of many beach ridges and occasional benches between the 20-foot shore-line and the lake shows that the drop from the 20-foot stage was very gradual. Nowhere on the Wisconsin shore is this lower series of beaches more plainly exposed than at Graceport, where the photographs in Plates I and XXXV were taken. As the 20-foot beach was traced northward, step by step, to Washington Island with almost no increase in altitude, the conviction gradually grew that it is the Nipissing beach of Taylor, which was traced southward by him in the upper peninsula of Michigan from 45 feet at Mackinac Island to Gladstone and Escanaba, where it stands about 20 feet above the lake, and was at first

*"Geology of the Lake Superior and district," Part II. Senate Exec. Doc. No. 4. 1851 p. 271–272.

supposed to continue southward only a short distance before it dipped under Lake Michigan. Taylor's more recent work in Michigan has suggested that the Nipissing beach extends farther south above the present lake. His acceptance of the strong 20-foot shore-line of Door County as the Nipissing shore-line, in a letter of Sept. 11, 1905,* leaves little doubt as to its identity.

South of Sturgeon Bay in the region of thick glacial drift, in which terrace cutting and bluff recession is rapid, the Nipissing bluffs are wonderfully conspicuous. The long line of abandoned "clay banks" which run southward from the village of that name nearly to Algoma, and again for a few miles beyond, have already been described on pages 67–69. These old bluffs rise at times to a height of eighty feet, and are often as steep as fifty degrees. The significance of this exceptional height deserves careful attention. In the first place, it does not signify necessarily that the lake stood for an exceptionally long time at the level of the Nipissing shore-line for we may suppose that Lake Algonquin had previously cut back a line of cliffs and terrace which stood only eight or ten feet above the Nipissing level, so that the Nipissing waves had only to beat back the low cliffs as far as the old Algonquin shore-line in order to develop such remarkable bluffs as have been left at Clay Banks. What is still more important is the fact (made known by Taylor) that at the close of the Algonquin stage the lake dropped to a very low level (on the opening of the North Bay pass), and that from that time on to the Nipissing or "two outlet" stage the waters repeatedly rose upon the shore (as regional uplifts brought the North Bay pass up to the level of the pass at North Bay) affording most favorable conditions for cliff development and cliff recession. This unique feature,—the *rising* of the lake up to the level of the Nipissing shore-line—when contrasted with the *lowering* of the lake to other stages, accounts for the prevalence and strength of cliffs along the Nipissing shore.

EXTENSION OF WATER-PLANES SOUTH OF TWO RIVERS.

The activity of erosion along the lake shore at the present level, south of Two Rivers, has already been commented on, and its destructive work in cutting away all record of higher stages

*Personal communication to the writer.

for many miles. An exhaustive study of the ravine terraces, in these regions where shore terraces no longer remain, might furnish valuable data for carrying the old water-planes across the vacant stretches with greater certainty. These terraces are significant but not accurately determinative of the Algonquin and Nipissing planes. Two prominent terraces were frequently noticed, at heights appropriate to the two chief water-planes of the area. In some places intermediate terraces suggested intermediate lake levels.

The 12–15-foot terrace and bluff at Centreville, fifteen miles south of Two Rivers seems to represent the Nipissing stage, since it is within a few feet of the altitude of the Nipissing bench at Two Rivers (18 feet above the lake). Whether in the fifteen miles interval the Algonquin water-plane has declined to the Nipissing or not is a difficult question to answer. A tilt rate of a few inches per mile southward from Two Rivers would carry it down to the level of the 15-foot terrace at Centreville. This question will be discussed under the next heading. A more detailed examination of the stream terraces on Point River, Point Creek, and Silver Creek might be of value in separating the Algonquin from the Nipissing plane. Some of the terraces on these streams stand as much as 35 feet above Lake Michigan, and thus suggest an extension of the water-planes of Lake Chicago as far north as this.

In the few miles of abandoned shore-lines which are preserved between Sheboygan and Port Washington the higher beaches (presumably Glenwood and Calumet of Lake Chicago) are weak and obscure as compared with the terrace and bluff of the 15-foot stage. The height of this terrace is substantially uniform from 14 to 16 or 17 feet, but rarely more than 14 feet. This indicates that there is no appreciable inclination of the Nipissing plane between Centreville and Port Washington.

The Fox Point terrace seems to carry the Nipissing plane fifteen miles farther south at essentially the same level (15 to 20 feet as determined by aneroid measurements by Alden). In Racine county the present lake cliffs are everywhere more than twenty feet high, usually much higher, so that there neither the Algonquin nor the Nipissing can be preserved; but at Kenosha the Toleston beach appears at the brink of the lake cliffs

and runs inland interruptedly, at an altitude of 20–25 feet while still lower ridges between the Chicago and Northwestern railway and the lake mark presumably the Nipissing and recent levels.

Before reaching the State line the profile of the abandoned shores has taken the form which characterizes it for most of the distance southward to Waukegan, Illinois. (See Fig. 4). The persistent bluff and terrace of the 13–15-foot stage is a far-stronger record of shore processes than either of the Lake Chicago beach ridges which lie above it, and might at first sight be taken to mark a much more permanent stage of the lake; but as has just been remarked, the bluff seems rather to record the gradual rising of the lake during the uplift of the North Bay outlet.

DEDUCTIONS CONCERNING THE ATTITUDE OF THE WATER-PLANES.

In the plotted profile (Plate XXXVII) no attempt is made to carry the Algonquin planes down to their points of coincidence with each other or with the Nipissing plane. There are not enough data in eastern Wisconsin to warrant so complete a reconstruction. But on the basis of what has been found elsewhere regarding the history of Lake Algonquin and Nipissing, the shifting of the outlets and the differential uplifts, a hypothetical profile may be worked out, which includes those elements of structure that are missing in Plate XXXVII, especially the relation between the Algonquin and the lower planes.

In Huron county, on the "thumb" of Michigan, the Algonquin beach was reported by Lane at 25 feet above Lake Huron, and the Nipissing at 11–14 feet.* Between there and Port Huron there seems to be little if any inclination of the beaches. Taylor and Leverett found the Algonquin beach to be 603–605 feet above sea level at Port Sanilac, or 23–25 feet above Lake Huron (since the altitude of the present lake was taken as 580 feet.) West of Lake Saint Clair the Algonquin shore-line seems to be several feet lower, but this is thought by Taylor to

* Geological Report on Huron County, Michigan, Geol. Surv. Mich., vol. 7, part II, 1906, pp. 75–76; and personal communication from Dr. A. C. Lane, Jan. 6, 1906.

indicate not a differential uplift, but the fall of the plane along the Saint Clair River.*

If the Algonquin and Nipissing planes are horizontal at about 25 feet and 14 feet respectively, at the south end of Lake Huron (showing that there no deformation has affected this part of the region, since the beginning of Algonquin time) then the shore-lines at the southern end of Lake Michigan should also stand horizontal, and at just the same height above the present lake. It has already been mentioned (on p. 101) that the lines of equal deformation run in a direction about 15 degrees south of east (perpendicular to the direction of maximum inclination, which is about 15 degress east of north) Horizontal shore-lines in St. Clair and Sanilac counties (Michigan) would mean, therefor, horizontal shore-lines in eastern Wisconsin, at least as far north as Centreville. So far as the shore fragments described in the present report are determinative, they show essential horizontality of a strong 14-foot shoreline as far northward as Centreville, if not farther. This is probably the Nipissing, because it seems to be continuous northward with the terraces described by Taylor and by Russell in upper Michigan. The close correspondence in level between the Toleston beach ridges at Evanston, Illinois, (24 feet above Lake Michigan) and the highest Algonquin beach ridge at Two Rivers (26 feet) suggests, similarly, that the plane of the Algonquin shore line is horizontal and 25 feet above the lake as far north as Two Rivers.

From these considerations it seems probable that the southern part of the region, including the Port Huron outlet and the southern half of Lake Michigan has been unaffected by any of the earth movements which deformed the central and northern part of the Great Lake region during the existence of Lake Algonquin and its successors. Perhaps the successive deformations of Lake Algonquin, like those described by Upham† for Lake Agassiz progressed northward, following the re-

*Personal communication from Mr. Leverett, Feb. 12, 1906.

† "The elevation progressed from south to north and northeast, like a wave, permanently uplifting successive areas, except so far as the borders of each necessarily shared in the movements of contiguous tracts earlier or later uplifted." Monograph 25. U. S. Geol. Surv., p. 486.

treating ice-front like a wave of uplift. For the sake of simplicity, it will here be assumed that each uplift was uniform over the area affected, tipping rather than warping the area. This distinction is expressed in the profiles in Figure 34, A and B. A consideration of the tipped attitude of the Nipissing plane, as reconstructed by Taylor over an extensive area, gives strength to this view of successive *tipping* rather than *warping* movements.

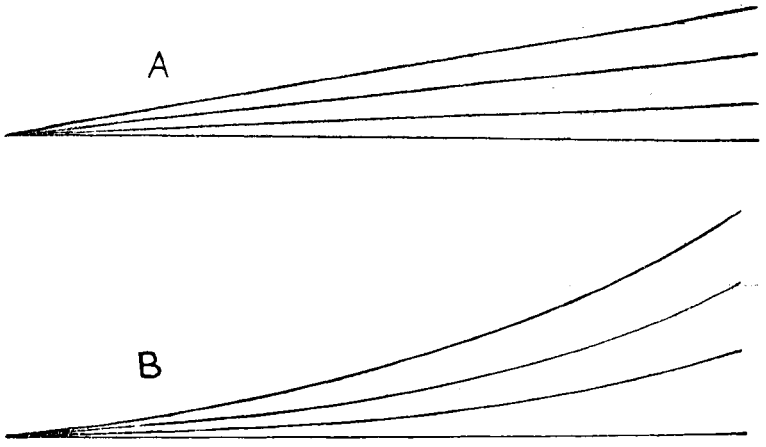


Fig. 34.—Profiles illustrating the fan structure of water-planes, produced by (a) uniform uplifts, and (b) differential uplifts.

In the profile diagram, stage A of Figure 35, the ice front is supposed to have withdrawn a considerable distance north of the Port Huron outlet. Time enough has elapsed for definite beaches and terraces to be marked out around the water-plane. A rapid uplift now occurs in the northern part of the region, and that part of the water plane which lies north of the nodal point "*a*" is tilted towards the south.—Since the node lies north of the Port Huron outlet, the water plane at the south end of the lake (in both the Huron and Michigan basins) is not affected. This uplift may tip the plane north of "*a*" evenly to a slanting

position (Figure 35, B). The rapidity of the uplift (as compared with the rate of shore-form development) is indicated by the absence of intermediate water marks. A horizontal plane (number 2) marks the new lake level. An interval of stability

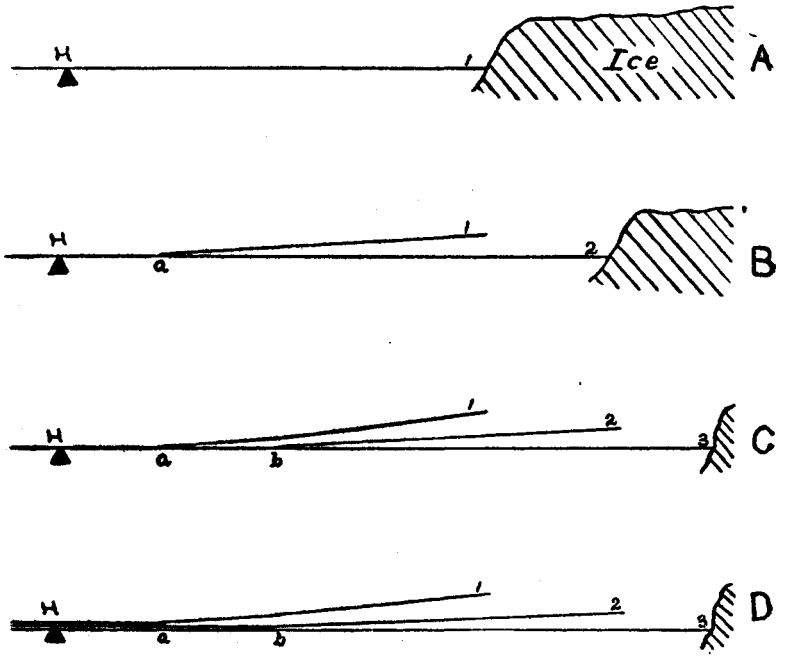


Fig. 35—Profiles showing the development of a fan warped planes by successive uniform uplifts of a zone of deformation which migrates northward with retreating ice front. A, B, C, D, successive stages. H, outlet at Port Huron. A, B, successive nodal points of deformation. 1, 2, 3, successive planes of Lake Algonquin.

now takes place, perhaps while the ice is slowly withdrawing or is at a standstill; and the new plane is registered by terraces and beaches. Suddenly there comes a second uplift, which as before affects the region within a certain distance of the ice front, tilting the northern part of the plane evenly; but failing to change the attitude of the planes south of node "*b*." As a result, the two planes are deformed north of the new node, horizontal plane number 2 being tipped (just as the plane number 1 was tipped before) and the northern part of the inclined plane

number 1 being tilted an additional amount over its former position. So the planes come to have a warped rather than a tipped attitude, since on account of the *northward migration of the zone of deformation* the southern part of the planes are affected by several later uplifts. It is thus possible to produce a series of diverging planes which appear in profile like warped curves, the angles above each node being so low as to escape notice. It is of course possible, on the other hand, that each uplift, instead of being a plane tilting or tipping, is a differential warping, the rate of uplift being more rapid near the ice front than farther south. If so, the lines representing the planes in profile are really curves (like Fig. 36) instead of bent lines.

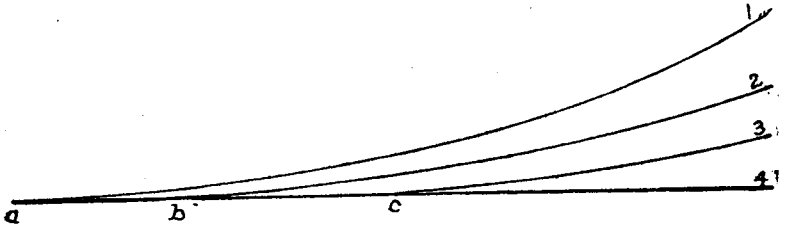


Fig. 36.—Profile of planes warped by differential uplifts of a zone of deformation which moved northward as the ice front withdrew.

In this way, then, the successive planes of Lake Algonquin may have been warped as the ice-front withdrew and while it lingered in the northern part of the Great Lake region, until a feather-like profile was produced. There is reason to suppose however that the outlet was being deepened and widened, all the while, causing the lake level to fall during each stage, and thus separating the planes slightly, as in Fig. 35 D. and Fig. 37.

Next, for the sake of simplicity, we may imagine that no lower outlet for Lake Algonquin than the one at Port Huron was found across Ontario until the Nipissing pass near North Bay was opened. When that occurred the waters necessarily fell below the Port Huron outlet, the plane being lowered an unknown amount to the level of the new outlet. (See Fig. 37.) Meanwhile we may suppose that there was tilting, with the node this time at "*c.*"

A renewal of the upward earth movements in the northern part of the region is thought to have raised the North Bay outlet

higher and higher, causing a corresponding rise of the water-plane throughout the lake basin and submerging the first Nipissing plane more and more deeply. (Fig. 37, lower diagram.) The same movement must have increased the slant of the Algonquin planes in the affected region. As soon as the North Bay outlet had thus been raised to the level of the Port Huron pass, the water-plane of Lake Nipissing south of the node "*c*" coincided with the lowest Algonquin plane, which had been abandoned when the waters fell from the Port Huron to the North Bay level. Thus the horizontal plane of the "Nipissing shore line" (N^2) was produced.

Uplifts continued in the northern part of the region, raising the Nipissing pass above the Port Huron outlet so that the northeastward discharge ceased, deforming the northern part of the Nipissing plane north of the node "*g*," and necessarily increasing the inclination of the Algonquin planes in the same area. Thus we may account for the structure shown in the lower diagram of Fig. 37, which agrees in many ways with what is now known of the actual attitudes of the water-planes.

According to this hypothesis, the Algonquin planes in eastern Wisconsin would slant southward at a repeatedly diminishing rate, becoming horizontal somewhere in the central or southern part of the region, and failing to coincide in just so far as the Port Huron outlet was cut down in the intervals between the deformations. The plane of the Nipissing shore-line, horizontal except in the northern part of the region (north of the node of that deformation which raised the North Bay pass out of water), ought to coincide with the lowest Algonquin plane, where that plane first becomes horizontal (at the nodal point "*c*" in Fig. 37). It is clear also that since the Nipissing plane and the lowest Algonquin plane coincide at the Port Huron outlet, the vertical interval between the highest Algonquin and the Nipissing shore-line at Port Huron measures the deepening of that outlet during the existence of Lake Algonquin. This amounts to only about ten feet (25 minus 14 feet). Subtract this from the interval of 45 feet between the highest and lowest Algonquin shore-lines at Washington Island, and 35 feet is left for the *actual uplift by earth movement*, of Washington Island, during the existence of Lake Algonquin.

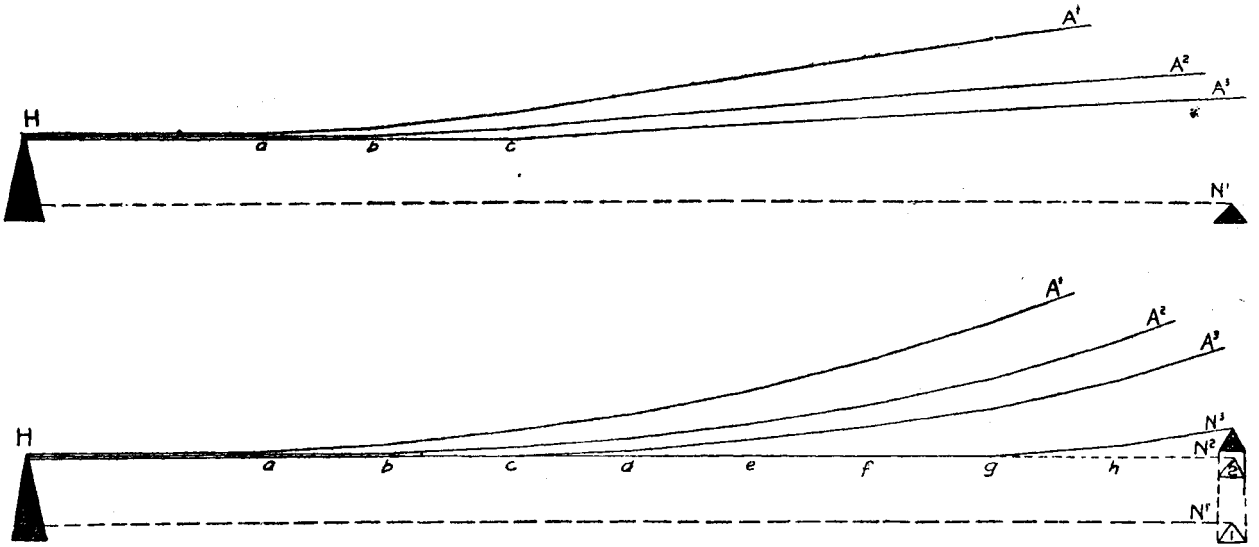


Fig. 87. Profiles illustrating the relation of planes of Lake Nipissing. In the upper figure, the North Bay outlet has just been opened, and the lake has fallen to the low level N^1, leaving the warped Algonquin planes A^1, A^2, and A^3 high and dry. In the lower figure, the effect of raising the North Bay pass up to and above the level of the Port Huron pass is shown. N^2 is the plane of the "Nipissing shore-line," marking the stage when both outlets were active. By later uplifts this has assumed a warped attitude, N^3.

POSTSCRIPT.

During the preparation of the foregoing report, certain investigations have thrown light on some of the problems. Mention may here be made of the more important points brought out.

In the deposits of the 24-foot beach at Evanston, Illinois, a considerable number of small shells was collected by the writer, which confirm the earlier observations of Marcy,* Alden,† and others that the Toleston beaches show abundant signs of life. The shells are all of existing fresh-water types.‡ As no such fossils have been discovered in the 40–60-foot beaches of Lake Chicago, it is inferred that the 24-foot stage was one whose waters were not frigid, as in Lake Chicago, but in which the Chicago district was much more remote from the ice, as was the case in Lake Algonquin. Shells of similar species, but of larger size, were also found in April, 1906, in beach ridges of the Algonquin group (18 feet above the lake) at Huronia beach, near Port Huron; and they have been collected from the Algonquin beach in other parts of eastern Michigan, by C. A. Davis and other members of the Michigan Geological Survey.

In a paper before the Michigan Academy of Sciences, March 30, 1906, Taylor stated that the 743 foot shore-line near North Bay, Ontario, noted in his earlier papers, is not the "Nipissing" shore-line. The strong Nipissing beach, recently recognized by him in that locality, is just 700 feet above the lake. This harmonizes better with measurements of the Nipissing shore-lines elsewhere; and Taylor's observations when all assembled indicate that the plane of the "Nipissing" or "Two outlet"§ stage in the entire northern part of the Great Lake region, is inclined with remarkable uniformity,—not warped, but tipped. This strengthens the view that each of the movements which

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* Geol. Surv. of Illinois, vol. 3, p. 245.

† Chicago Folio, U. S. Geol. Surv. 81.

‡ Identified by Mr. Bryant Walker of Detroit as: *Amnicola limosa* (Say), *Valvata tricarinata* (Say), *Planorbis parvus* (Say), *Pisidium* (3 species).

§ A name proposed by Taylor, to suggest the use of the North Bay and the Port Huron outlets while the water stood at the Nipissing plane.

left the Algonquin planes in warped attitudes, was in itself a *tipping* movement (so far as it affected this part of the Great Lake region) but that on account of the northward migration of the zone of deformation the net result for each of the Algonquin planes was a *warping*. (See Fig. 35 and pages 113–116.)

Taylor had placed the Nipissing shore-line at a 9-foot level, in the southern part of Lake Huron and on the eastern side of Lake Michigan. This is about 5 feet too low to correspond to the strong 14-foot shore-line of southeastern Wisconsin and northern Illinois (here taken to be the Nipissing). In view of the fact that Lane had regarded a strong 11–14-foot shore-line in Huron county as the Nipissing, however, and that Taylor has seen strong shore-lines at 14 feet elsewhere on the western side of Lake Huron, the possibility of a 14-foot level for the Nipissing may be admitted. The strongest shore-line near Port Huron, a cut terrace and bluff near Huronia beach, which was identified by Taylor as the Nipissing beach, was found by Leverett and the writer to be continuous in one place with a beach ridge which stands about 14 feet above Lake Huron. There seems to be at least a probability, therefore, that further study of the lower shore-lines of Michigan will place the Nipissing shore-line at a 14-foot level. The 9-foot terrace would then correspond to those slightly lower stages which quite commonly in eastern Wisconsin (e. g. near Algoma) have obliterated the true Nipissing terrace and thus tended to confuse the record.

Further detailed work on the eastern side of Lake Michigan is much to be desired, in order to fully identify the Algonquin and Nipissing shore-lines in the southern part of Lake Michigan. It is hoped that by such a study it may be fully demonstrated that the Chicago outlet was not only an outlet for the local Lake Chicago but also one of the lines of discharge of the great Lake Algonquin.

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MAP
OF THE
NORTHEASTERN SHORES
OF
-WISCONSIN-

Showing

Altitudes of the Highest Algonquin Shoreline, and the Basis of Construction of a Profile of the Warped Water-planes.

By J. W Goldthwait, 1908

SCALE OF MILES