This report on the ancient shorelines of the Great Lakes Region continues the series of Pictured Rocks National Lakeshore Resource Reports. It summarizes Dr. Blewett's efforts over the 2004 field season studying and interpreting ancient shorelines.

Jim Northup

Superintendent

Pictured Rocks Resource Report

UNDERSTANDING ANCIENT SHORELINES IN THE NATIONAL PARKLANDS OF THE GREAT LAKES

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Introduction

Ever since Louis Agassiz first pondered the craggy outlines of Lake Superior more than a century ago, the abandoned shorelines of the Great Lakes region have intrigued geologists. Early investigators rightly attributed these features to periods of higher lake levels associated with a melting continental glacier during the Ice Age, but only recently has a coherent picture of the complicated series of glacial lakes and the strands they left behind begun to emerge. This report will attempt to provide an understandable, although highly simplified, overview of present concepts regarding these lakes, giving special emphasis to the abandoned shoreline features observable in the National Parks and Lakeshores of the region.

Relict shorelines are common features in Great Lakes national parks. By "relict," we mean landforms such as beach ridges, wave-cut bluffs, sea caves, sand spits, and sea stacks that have been abandoned and are higher than the modern shoreline. Some of these features are now located well inland and can be traced for considerable distances. To the casual visitor, however, their formation and significance are difficult to grasp because of the enormous size of the lakes involved, and our unfamiliarity with the mechanisms. Many visitors also confuse the large-scale changes in lake levels from the Ice Age with the much smaller variations caused by changes in temperature, precipitation, and runoff which characterize the modern Great Lakes from year to year. The latter rarely exceed 3 feet, whereas the former reach into the hundreds of feet. Simplifying the science is not easy, but by understanding just a few major principles, most of the intricacies can be easily understood.

Getting Started…

We'll keep terminology to a minimum, but a few terms are essential. For our purposes, *basin* refers to the elongated depressions in the Earth's crust that hold the present Great Lakes. For example, when we refer to the Superior *basin*, we mean "the hole in the ground" (to put it perhaps too simply) that contains modern Lake Superior. The modern lake, however, is only the latest in a number of water bodies that have occupied this lowland. Because these lakes varied in size, elevation, configuration, and in the location of their outlets, they've been given different names such as Lake Minong and Lake Duluth, yet all formed in the Lake Superior *basin*. Lake *phase* refers to the particular time period during which a lake existed. The Nipissing *phase* of the Great Lakes, for example, occurred between about 4,000 and 6,000 years ago. Such time-dependent terms allow geologists to distinguish between the lake itself and the time during which that water body existed.

We also need to learn how geologists tell time. As you may recall from science class, geologists subdivide the time since the Earth began into large chunks called Eons (Figure 1). Eons are further subdivided into Eras, Eras into Periods, and Periods into Epochs.

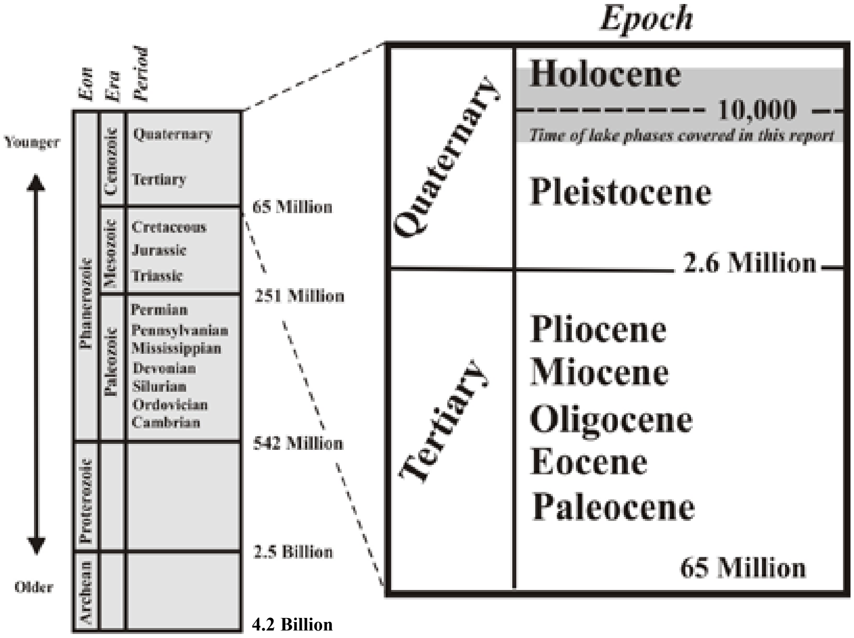


Figure 1. The Geologic Time Scale. Shaded area in Quarternary represents the time of lake phases covered in this report.

Because the Ice Age only dates back a few million years we can ignore most of these and simply concentrate on the Quaternary (qua-TER-na-ry) Period and its two epochs, the Pleistocene and Holocene (Figure 1).

Originally, geologists defined the Pleistocene as the time of the Great Ice Age, and the Holocene as the present warm period that began when the glaciers melted. They envisioned four major glacial episodes within the Pleistocene that were named (from oldest to youngest) the Nebraskan, Kansan, Illinoian, and Wisconsin glaciations. More recent discoveries indicate that the Ice Age began about 2.6 million years ago, possibly as a result of natural perturbations in the Earth's orbit which changed the amounts of solar radiation received during particular seasons. These orbitally-induced climatic changes resulted in cycles of warming and cooling that produced a major glaciation about once every 100,000 years over the succeeding 2.6 million years, or about 20-24 major glaciations in all. Accordingly, the old idea of four glaciations was discarded, but the terms Wisconsin and Illinoian were retained.

By *glaciation* we mean an event during which the ice accumulated in northeastern Canada, advanced southward into the present Great Lakes region, and then completely melted away. Because each succeeding glaciation erased much of the evidence of the preceding one, only the latest advance, called the *Wisconsin*, is of importance to our discussion. The Wisconsin began approximately 79,000 years ago, reached its maximum extent about 23,900 years ago, and had disappeared completely by about 8,000 years ago. All of the lake phases that are described in this report are associated with later stages of the Wisconsin glaciation, or with the Holocene Epoch which immediately followed it.

Geologists can determine the ages of glaciations and ancient shorelines using *radiocarbon dating*. This technique is based on the assumption that all living things contain a small proportion of the radioactive isotope Carbon-14 in their tissue. C-14 is inherently unstable and will decay into the more stable by-product, Nitrogen-14, at a known rate. This rate, called the *half-life* of C-14, is the time it takes for half of the C-14 present to decay into N-14, about 5568 years. When an organism is alive, the amount of C-14 is continually replenished in tissue from the surrounding environment through respiration and intake of nutrients. However, upon death, the C-14 begins to break down at a known rate, acting as a natural clock. If a lucky geologist later stumbles upon the preserved remains of the organism, the

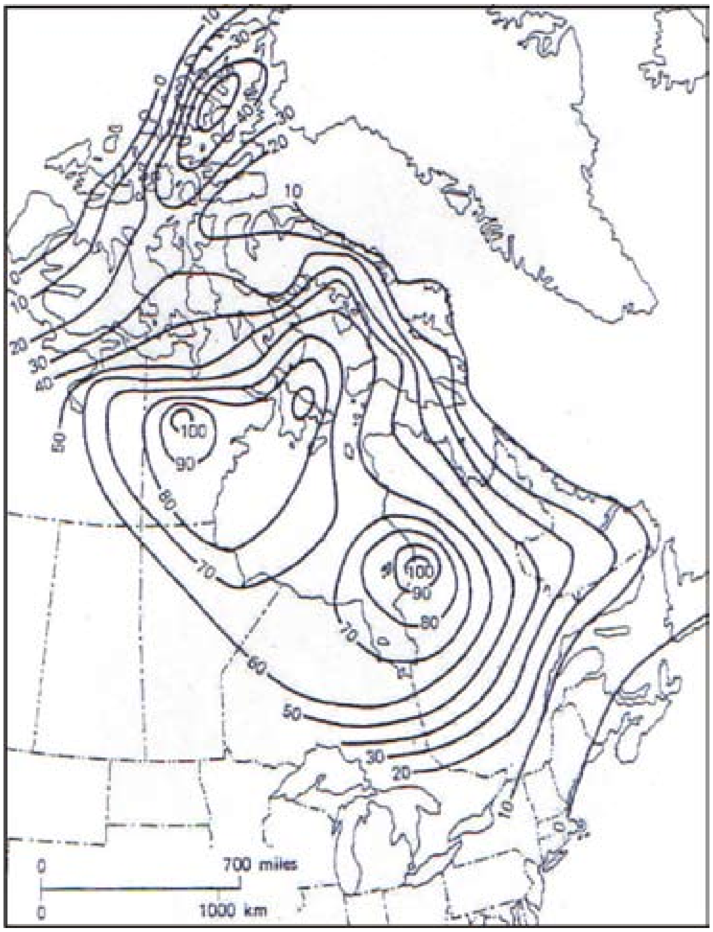


Figure 2. Crustal uplift (in meters) since the melting of the Wisconsin glacier (from Flint, 1971, after J. T. Andrews, unpublished).

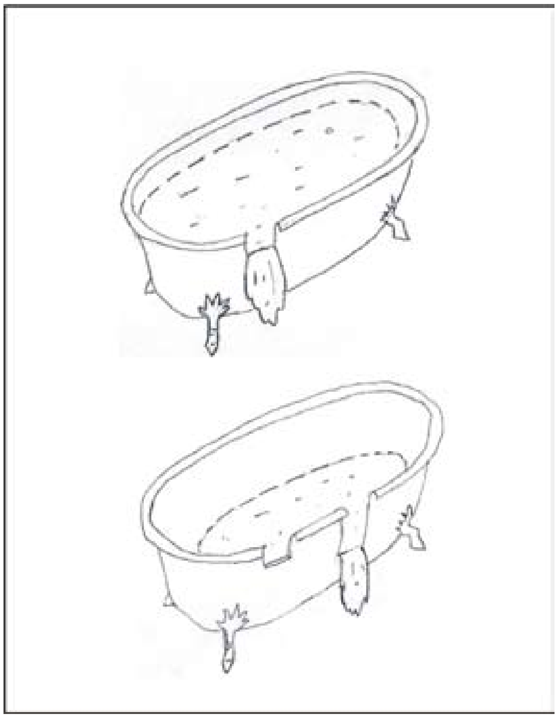


Figure 3. A notch cut in the side of a bathtub determines the water level in the tub. The lower the notch, the lower the water level. Each of the Great Lakes basins has its own set of notches, called "outlets."

ratio of C-14 to the total carbon in the sample can be measured and an age determined. In the Great Lakes region, wood is the material most often dated by geologists. Advancing glaciers often buried forests under thick mantles of glacial sediment (called *till*) and the wood can be sampled and dated to determine the time of burial. Along ancient shorelines, wood and other organic material often filled the low swales between beach ridges and were covered by sand dunes and preserved.

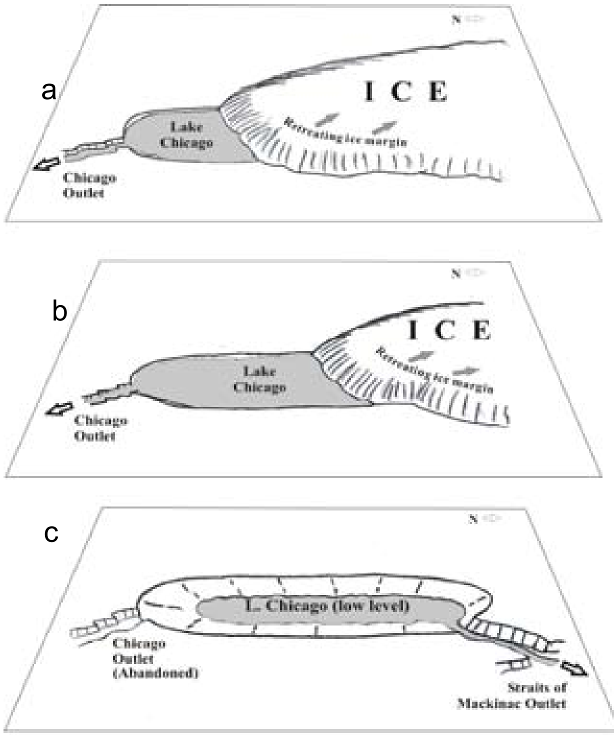
More recently, a new technique called Optically Stimulated Luminescence (OSL) allows geologists to actually determine when a geologic surface was last exposed to the sun's rays. The details are beyond the scope of this report, but the technique is especially well-suited to dating stabilized sand dunes, which often mark old shorelines.

Factors affecting lake levels

The most important factors influencing lake level history are rebound of the Earth's crust, glacial margin fluctuations, drainage outlet location, and overall configuration of the basin. Each is explained below.

Crustal rebound: Contrary to our own experience, the Earth's crust is not solid and unchanging, but extremely sensitive to internal and external influences. For example, when Lake Mead was allowed to fill behind Hoover Dam in Nevada, the weight of the water caused the crust to subside 12 mm. If a large reservoir has this effect, imagine the consequences of a continental-sized glacier a mile thick! Scientists estimate that the Earth's crust was depressed nearly 1000 feet in parts of northeastern Canada where the ice was thickest. As the ice melted, however, the weight was gradually reduced, and the crust began to rise or "rebound" in response, much like the response of a foam chair cushion after a person gets up. The amount of rebound is directly related to the thickness of the ice at any particular spot-- the thicker the ice, the greater the amount. In the case of the Laurentide ice sheet (the name given to the continental glacier that occupied northeastern North America), the ice was centered on the Hudson Bay region and became progressively thinner in all directions from its center. Thus, the amount of rebound that occurred at the glacier's periphery in, say, central Illinois, was much less than the amount around Hudson Bay. Accordingly, as one moves northward across the Great Lakes region, the amount of crustal rebound that has occurred progressively increases, reaching a maximum near Hudson Bay (Figure 2). This effect is enormously important in understanding lake level history, as we shall soon see.

Ice marginal retreat and uncovering lower outlets: Prior to glaciation, today's lake basins were probably broad river lowlands developed upon areas of weak rock. Glaciers advancing in broad tongues southward from Canada took the path of least resistance and followed these lowlands, grinding, plucking, and excavating deep troughs along the axes of the pre-existing river valleys. Each time the glacier returned, it took a



Figures 4a, b, and c. With retreat of the glacial margin, the Straits of Mackinac outlet was uncovered, causing Lake Chicago to abandon the Chicago outlet and drop to a much lower level.

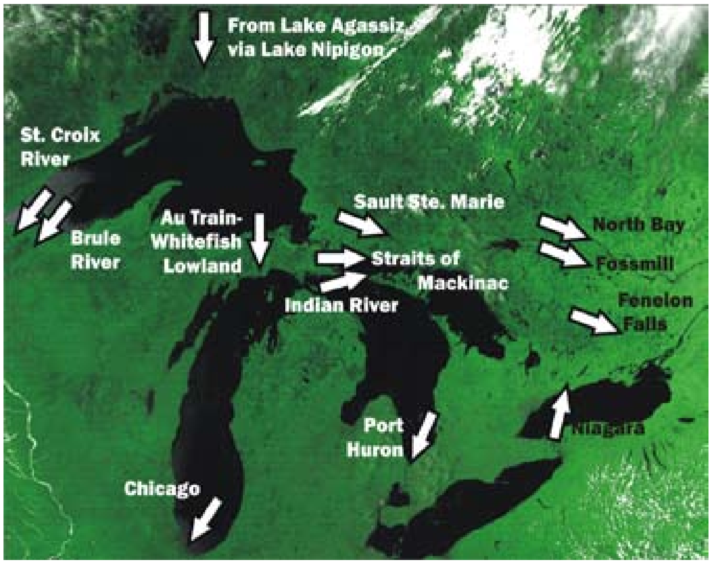


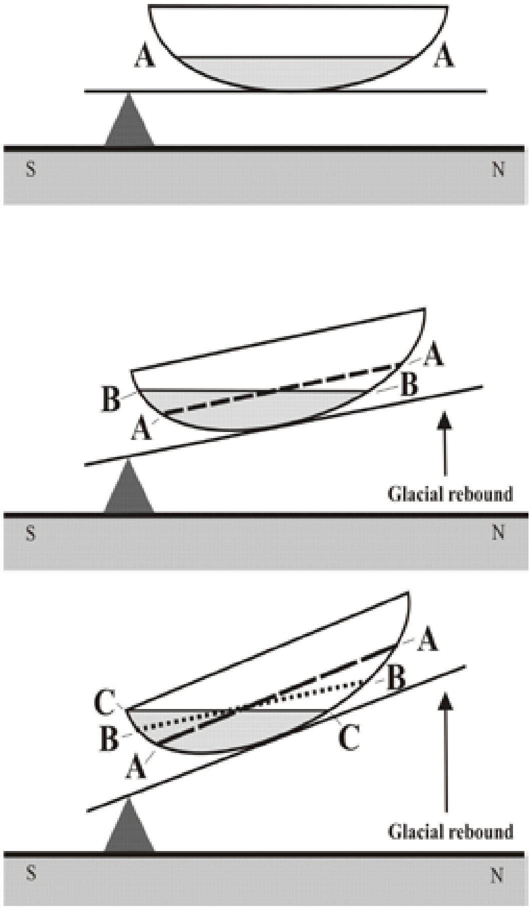
Figure 5. Principal outlets of the Great Lakes.

similar path, carving the basins ever deeper. By the beginning of the Wisconsin glaciation, it's likely that the rough configurations of today's Great Lakes basins were already in place. This situation is especially important to lake history because, as the ice margin retreated northward across the region for the last time, meltwater collected in these deep depressions as they were uncovered by the ice, forming what geologists call pro-glacial lakes. These lakes expanded northward with the margin.

With continued melting, the level of the lake would rise until it was higher than the rim of land surrounding the basin, causing it to overflow at the lowest point along the rim. Geologists call these low spots "outlets" and their elevation often controlled the level of the associated lake. The analogy is a bathtub in which a notch has been cut into the side (Figure 3, top). The water would drain down to the level of the notch, but no farther. Even if water were slowly added to the tub from the faucet, the notch would continue to control the water level in the tub. If a deeper notch were cut (Figure 3, bottom), the tub level would drain to the new lower level, and so on. Like multiple notches in the side of a tub, each of the Great Lakes basins has its own set of outlets at varying elevations.

When outlets undergo crustal rebound, the situation becomes much more interesting. We'll use Lake Michigan to illustrate the point. It so happens that the principal outlets of the Lake Michigan basin are found at either the northern or southern ends (Figure 5). The southern outlet is called the Chicago outlet because of its proximity to that city. The present Straits of Mackinac mark the northernmost outlet. Imagine the situation as the ice margin retreated northward along the axis of the Lake Michigan basin (Figure 4). In the south, a lake of ever increasing size was formed in front of the ice as the glacier melted, spilling southward through the Chicago outlet (Figure 4a, b). Eventually, however, the ice uncovered the Straits of Mackinac. This outlet was at a very low elevation, much lower than the Chicago outlet, because the crust in the Mackinac region had not yet rebounded, whereas the crust near Chicago already had begun to do so and was continuing to rise higher. Thus, the lake in the Lake Michigan basin spilled out through the Straits of Mackinac (a much lower notch in the tub), causing the water level in the basin to drop dramatically (Figure 4c). With time, as the Mackinac area rebounded, this northern outlet began to rise, causing water levels in the Lake Michigan to rise. It continued to rise until the waters began to slosh back southward towards Chicago, eventually reopening the southern outlet.

Obviously, as with our example above, the shape and orientation of the major lake basins, along with the relative locations of their outlets helped control the lake sequence. Figure 5 shows the major outlets for the Superior, Michigan, Huron, and Erie basins. Because water levels in the Lake Michigan and Huron basins were often confluent (as they are today), these two lakes typically were controlled by outlets east of Georgian Bay in Ontario (Fossmill, Fenelon Falls, North Bay



Figures 6a, b, and c. Diagram illustrating the effect of rebound on the pattern of shorelines produced in a lake basin (after Larsen, 1987).

outlets, Figure 5). As these outlets rebounded, water sloshed southward towards Chicago or the present outlet at Port Huron. Details of the lake sequence are described in a later section.

Shoreline Patterns—Rebound and the Bathtub Revisited

How does rebound affect the pattern of ancient shorelines in a particular basin? The answer can be illustrated by placing our bathtub on a fulcrum, so that one side can be lifted up, mimicking the effects of rebound. We'll assume that our basin is oriented north-south, so that in figures 6a-6c, north is to the right and south is to the left. Because rebound increases the farther north you go in this region, we will progressively "lift" the right side of the bathtub as time goes on to see what happens to the position of the shorelines over time. The actual situation is more complicated than this, but it serves to illustrate the point. Before rebound commences, the shorelines of our lake are found at the positions shown by line "A." As the area rebounds, "A" rises in the north and sinks in the south, and a new lake is formed at level "B" (Figure 6b). The process continues with lake "C" (Figure 6c). Eventually, rebound slows and lake levels stabilize.

Notice that shorelines "A" and "B" are preserved on the north side of the basin, whereas these same shorelines are submerged beneath the lake on the southern end in Figure 6c. This situation is analogous to a coffee cup as we raise it to our lips. As we tip the cup, the coffee floods the side of the cup closest to us, while it falls along the opposite side. This simple model can be applied to both the Lake Michigan and Lake Superior basins (with some important modifications), and explains why relict shorelines are the most numerous and well-developed along the northern coasts of Lakes Michigan and Superior, as at Pukaswa National Park in Ontario.

Other Factors

Two additional factors affecting lake levels include changes in meltwater volume and the erosion of outlets. As glaciers melt, the volume of meltwater they release varies depending on temperature, precipitation, humidity, glacier surface area, and other factors. During periods of rapid melting, large volumes of meltwater would have been discharged into the adjacent basins, raising lake levels. Conversely, during times of slower melting, lake levels may have dropped. These changes could have occurred seasonally or over longer time periods. Because these adjustments to lake level were often short-lived, little time existed to produce well-developed shorelines, and geologists have been hard-pressed to verify this effect with any reliability. More certain is the effect that meltwater had on the erosion of outlets. Some, such as the one at Chicago, were initially cut into loose, easily eroded glacial sediments (gravel, sand, silt, and clay), which produced a lake at that particular level. As erosion of the outlet bottom proceeded, the lake began to drop until water eventually encountered the resistant bedrock lying beneath the glacial sediments, and the elevation of the lake stabilized.

All of these factors are responsible for the relict shorelines we see today, but they often combine in complicated ways that defy simple explanation. Accordingly, the history presented below is highly simplified, but hopefully gives a general understanding of the main events recognized by glacial geologists. Because the principal national parklands of the Great Lakes are found only along Lakes Michigan and Superior, we will focus on these basins during our discussion. The Lake Huron basin is included because it was often confluent with the Lake Michigan basin and its outlets were critical in controlling levels in the Lake Michigan basin.

The lake sequence in the Lake Michigan-Huron basins

The accepted chronology of events in the Lake Michigan basin has changed radically over the last few decades with advances in our understanding of rebound and intensified efforts at determining the age of shorelines using radiocarbon dating. Scientists are still debating the details, but a general consensus is beginning to emerge. We'll begin by cataloguing the various shorelines present, and then review the history as currently known.

Recognized shorelines

Geologists have long recognized three conspicuous ancient shorelines above modern lake level in the southwestern part of the Lake Michigan basin (Figure 7a): the Glenwood level at 640 feet (195 m), the Calumet level at 620 feet (189 m), and the Toleston level at 600-605 feet (183-184 m). These shorelines are horizontal, or nearly so, and were first described in northwestern Indiana and adjacent Illinois just west of Indiana Dunes National Lakeshore. These three features can be traced northward to about the latitude of Manistee, Michigan. North of this line, a number of separate shorelines rise in elevation, as shown in Figure 7a, and some were assumed (though never confirmed) to be the northward extensions of the Glenwood, Calumet, and Toleston beaches. This situation – horizontal shorelines in the southern part of the basin, tilted shorelines in the north – led to the concept of the "hinge line." That is, shorelines in the south did not experience rebound, whereas north of Manistee,

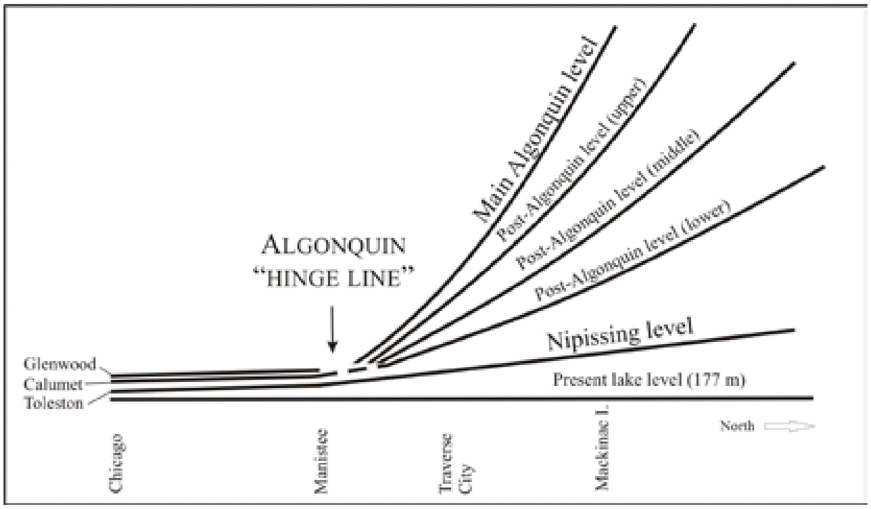


Figure 7a. Traditional interpretation of shorelines in the Lake Michigan basin (after Larsen, 1987).

these same shorelines were elevated due to rebound, with Manistee marking the "hinge" between the two. More recent work has brought the hinge line concept into question. Most geologists now suspect that these northern shorelines actually plunge beneath present lake level at Manistee, similar to our coffee-cup analogy shown in Figure 6, and that they are not related to the shorelines farther south. Figure 7b shows two famous examples of raised shorelines in the northern part of the basin at Mackinac Island. If all this sounds complicated, it is, but a review of the sequence of events should provide clarification.

Sequence of events

Our story begins approximately 16,000 years ago, as the margin of the Wisconsin glacier retreated into the Lake Michigan basin (Figure 8a). Meltwater collected in the basin between the ice margin and the southern rim of the depression, eventually spilling out through the Chicago outlet. Geologists refer to this proglacial lake as Lake Chicago, and its shoreline, at least initially, stood at the Glenwood level. Lake Chicago expanded northward with the retreating ice margin until outlets near the Straits of Mackinac were uncovered about 15,500 years ago. These outlets were much lower than the Chicago outlet, and Lake Chicago quickly drained through the Mackinac straits, forming a very low level lake that geologists call the Intra-Glenwood low level (Figure 8b). Any shorelines associated with this lake would lie well below the present lake surface. Their presence has been confirmed by analysis of lake bottom sediments.

At this point the continental ice sheet, as if to cover its retreat, began a series of short-lived marginal readvances superimposed on the overall pattern of ice wastage. These fluctuations may have been caused by the internal physics of the collapsing ice sheet, climatic cooling, or a combination of factors. In the first of these pulses, called the Port Huron advance, the ice readvanced into the Lake Michigan basin, reaching as far south as Muskeegon. This advance closed the outlet

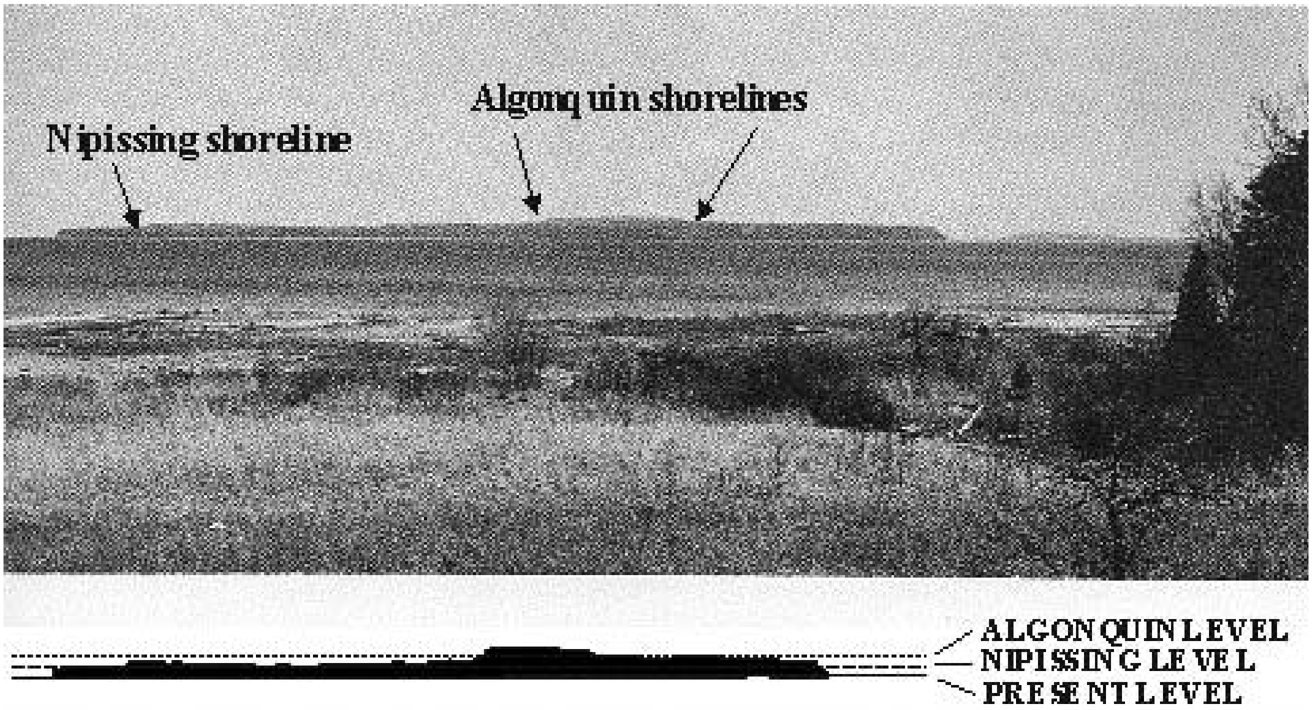
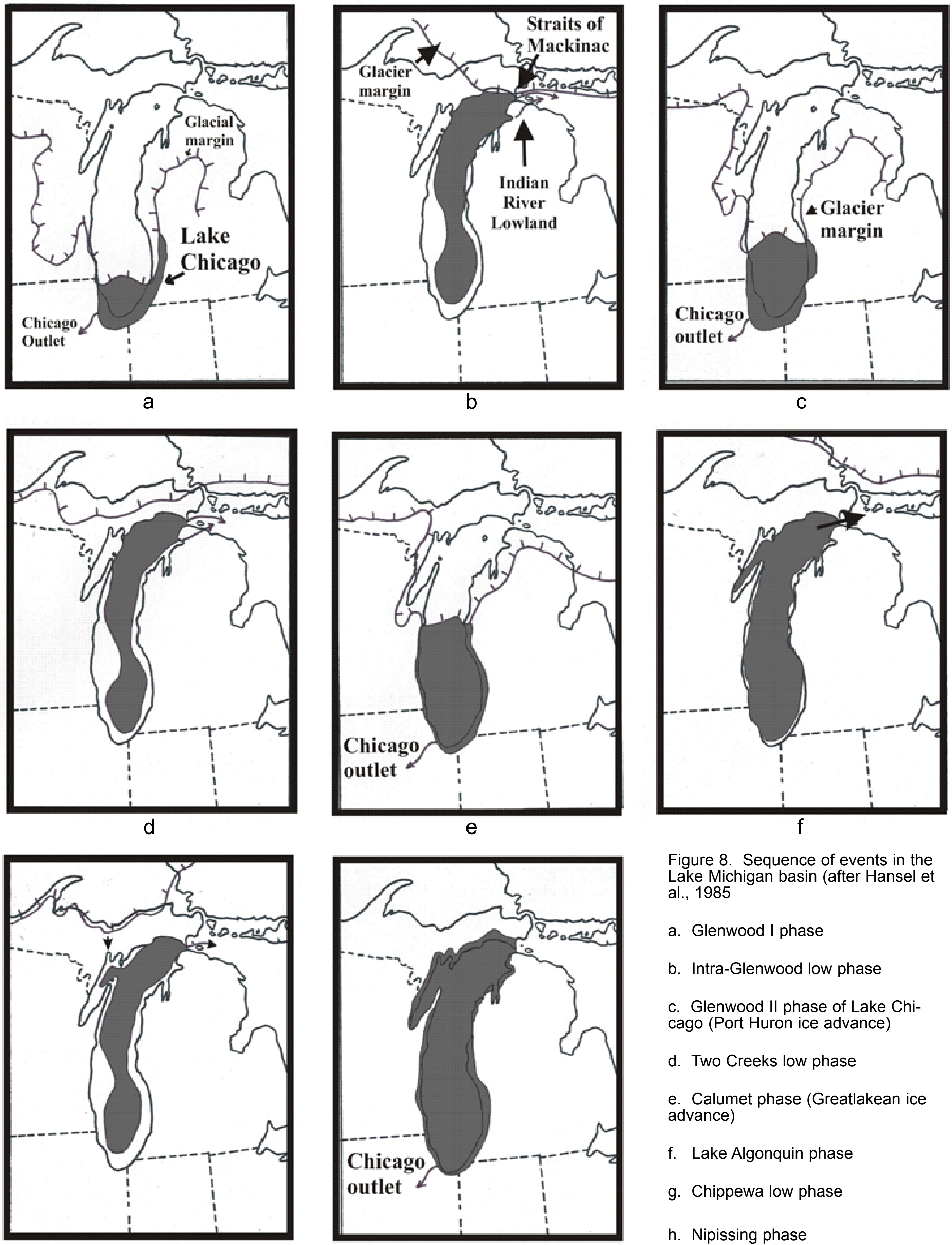


Figure 7b. Raised shorelines at Mackinac Island (after Dorr and Eschman, 1971).



a b c

d e f

g h

Figure 8. Sequence of events in the Lake Michigan basin (after Hansel et al., 1985

a. Glenwood I phase

b. Intra-Glenwood low phase

c. Glenwood II phase of Lake Chicago (Port Huron ice advance)

d. Two Creeks low phase

e. Calumet phase (Greatlakean ice advance)

f. Lake Algonquin phase

g. Chippewa low phase

h. Nipissing phase

at the Mackinac Straits, dammed water once again in the southern part of the basin, and caused the Glenwood level of Lake Chicago (with its outlet at Chicago) to be re-established. This lake is often referred to as the Glenwood II level of Lake Chicago; the roman numeral II means that this was the second lake to form along the previously established Glenwood shoreline (Figure 8c).

The ice margin then retreated north of the Straits again, uncovering lower outlets at the Straits of Mackinac, and initiating another low level phase, the Two Creeks low phase of Lake Chicago (Figure 8d). This retreat was followed by the Greatlakean ice advance approximately 14,000 years ago, which reached as far south as Two Rivers, Wisconsin. The Mackinac straits were covered once again, water was dammed in the southern part of the Lake Michigan basin, and the Chicago outlet was re-established. This time, however, the lake formed at the lower Calumet level, possibly due to erosion of the Chicago outlet (Figure 8e).

Finally (yes, finally!) the ice margin retreated across the Lake Michigan basin for the last time. This allowed lakes in the Superior, Huron, and Michigan basins to coalesce into a single lake common to all three basins approximately 13,000 years ago. Geologists have named this lake Lake Algonquin and it likely drained through the Fenelon Falls outlet located east of Georgian Bay in Ontario (Figures 5, 8f). With continued ice-marginal retreat across northern Ontario, even lower outlets were opened and Lake Algonquin dropped precipitously through a series of lower shorelines collectively referred to as the "Post-Algonquin group," finally bottoming out at a very low level lake named Lake Chippewa in the Lake Michigan basin. The outlet for this low level lake was at North Bay in northern Ontario (Figures 5, 8g).

Over the next 4500 years, uplift of the North Bay outlet due to rebound caused lake levels in the Lake Michigan-Huron basin to rise until they reached the previously abandoned outlets at Port Huron and Chicago. Geologists call this rise in lake level the Nipissing transgression, and it eventually resulted in the establishment of Lake Nipissing in the Michigan, Huron, and Superior basins between about 4000 and 6000 years ago (Figure 8h), with an outlet at Port Huron and possibly Chicago. This lake was established at the level of the Toleston shoreline in the southern part of the Lake Michigan basin.

These different names for the same shoreline may seem confusing. Originally, the Toleston was thought to be a level of Lake Chicago. Radiocarbon dates on driftwood and other organic material associated with this beach indicate that this shoreline instead relates to Lake Nipissing. Whether this shoreline was reoccupied several times during the history of the Lake Michigan basin is still debated by geologists. Because the name "Toleston" has been around for so long, geologists retain the name, but now interpret the shoreline (at least in part) as a Nipissing feature. This strandline can be traced northward at progressively higher elevations into Michigan's Upper Peninsula on the north shore of the Lake Michigan basin (Figure 7a).

Closely associated with the Nipissing, but lower in altitude, is another, fainter, shoreline named the Algoma, which records a drop in lake level from the Nipissing level approximately 4000 years ago. Until recently, geologists assumed that the level of Lake Nipissing was controlled by the Chicago and Port Huron outlets, and that subsequent erosion of these outlets caused a drop to the level of Lake Algoma. More recent work indicates that changes in precipitation and climate, along with subtle adjustments of the outlet channels to increases in water volume, may be responsible for explaining the Nipissing and Algoma high lake levels. In this sense, these Holocene water bodies behaved much more like the present Great Lakes, in which levels fluctuate based on rainfall and runoff generated by subtle annual variations in climate, although the Nipissing and Algoma fluctuations were much more pronounced. Eventually, climatic variations along with gradual erosion of the Port Huron outlet, allowed the lakes to drop to their present elevation, initiating modern Lake Michigan.

The Lake Sequence in the Lake Superior Basin

Events in the Lake Superior basin often operated independently of those in the Lake Michigan and Huron basins because it drained through essentially one outlet, the rapids at Sault Ste Marie, during most of its history. In addition, rebound increased from southwest to northeast across the basin, much like those farther south, but here the outlet at Sault Sainte Marie was located off at the basin's southeastern edge, making its influence on lake levels much more difficult to visualize. In effect, these relationships caused the basin to "pivot" along a northwest-southeast line drawn from the Sault to Pigeon River on the Minnesota-Ontario boundary (Figure 9). Shorelines to the north and east of this line were raised progressively higher by rebound over time, while shorelines to the west and south of this line were submerged. The analogy is to a bathtub in which the drain is located along the side midway between the drain and the foot of the tub. As one end of the tub is raised due to rebound, a familiar pattern of raised and submerged shorelines is developed on either end (Figure 6), with the outlet located at the point where the shorelines converge.

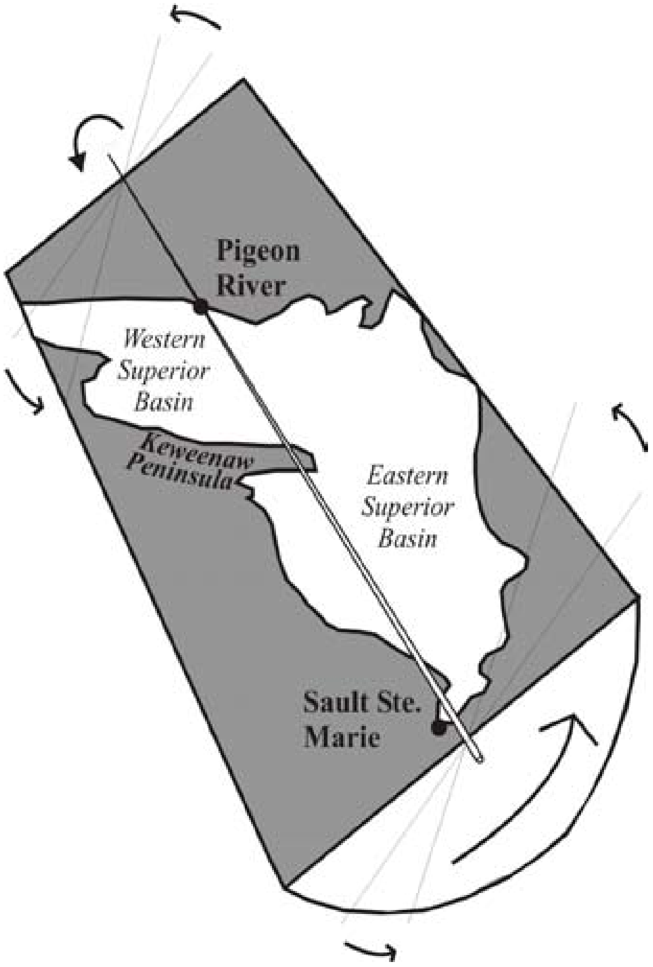


Figure 9. A simplified way to understand relations among Lake Superior basin shorelines, the outlet at Sault Ste. Marie, and glacial rebound. The basin appears to pivot on an axis drawn through Sault Ste. Marie, Michigan and Pigeon River, Minnesota.

Recognized shorelines

The Lake Superior basin can be divided into two parts: the western Superior basin, encompassing that part of the lake west of the Keweenaw Peninsula, and the eastern Superior basin, to the east of the Keweenaw (Figure 9). As long as the ice margin remained south of the tip of the Keweenaw, lakes in the western and eastern parts of the basin remained separate (Figure 11a, b). Today, a number of ancient shorelines exist high above modern lake level in the western part of the basin. The name "glacial Lake Duluth" was proposed for the highest and most prominent of these shorelines visible in the city of Duluth (Figure 10). A slightly lower shoreline, likely associated with a minor retreat of the ice margin, is named "sub-Duluth." Below the Duluth beaches are a series of shorelines named Highbridge, Washburn, Beaver Bay, and Huron Mountain, each representing progressively lower water levels (Figure 10). In the eastern part of the basin, a separate suite of shorelines exist. The most important of these are the Minong, Houghton, Nipissing, and Algoma shorelines. As noted in Figure 9, however, some of these shorelines are only visible northeast of the Sault Sainte Marie-Pigeon River line, the features having been covered by the modern lake southwest of this line. Figure 10 shows the relationship between the western and eastern basin shorelines. Now that a general idea of the existing strandlines has been presented, we'll turn to the lake chronology.

Sequence of events

A number of glacial lakes, including Lake Algonquin, likely occupied the Superior basin during final deglaciation, but the Marquette readvance into the Superior basin at around 11,500 years ago obliterated most of their shorelines. This advance did not reach the Lake Michigan and Huron basins, which is why Lake Superior is handled separately.

Our Lake Superior history begins with the first lakes to emerge as the Marquette ice front began to retreat from the southwestern edge of the basin about 11,400 years ago. Initially, a series of ice marginal lakes were dammed between the bedrock highlands to the south and the ice margin. These lakes spilled westward across the axis of the Bayfield Peninsula and drained via the Brule outlet into the St. Croix River (Figures 5, 11a). Their shorelines are visible today in the vicinity of Apostle Islands National Lakeshore (see final section). With continued retreat, these lakes coalesced to form glacial Lake Duluth, which expanded northward with the wasting ice margin. This lake dropped to a slightly lower level, the sub-Duluth, possibly as a result of downcutting of the Brule outlet, and remained there until deglaciation of the Huron Mountains in Michigan

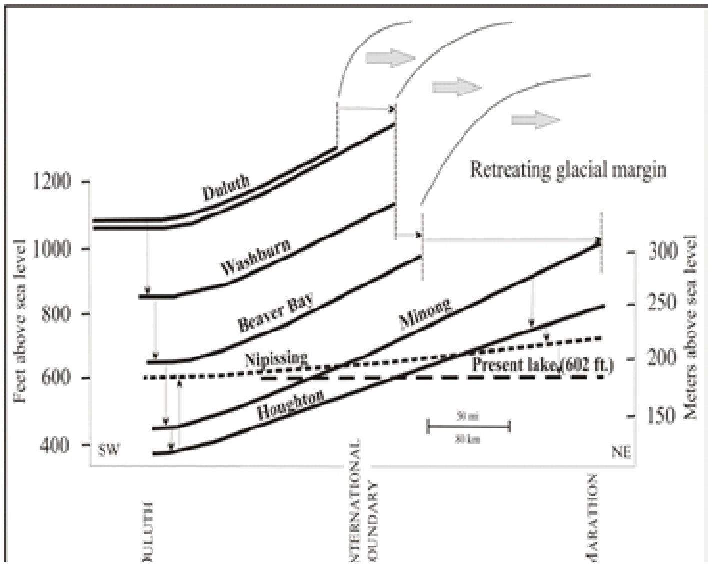


Figure 10. Selected shorelines recognized in the Lake Superior basin (after Farrand and Drexler, 1985; Highbridge, Huron Mountain, and Algoma shorelines not shown).

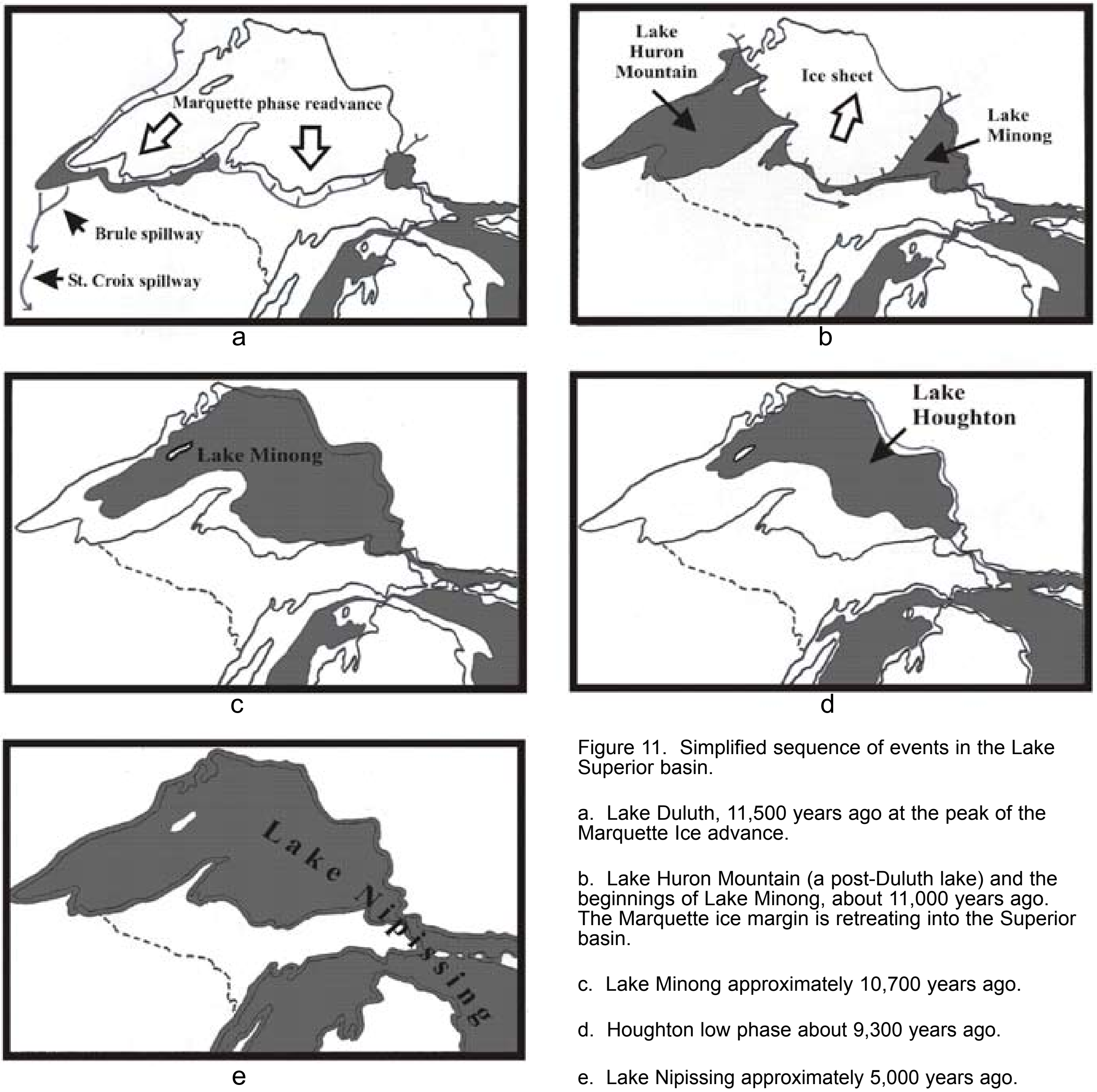


Figure 11. Simplified sequence of events in the Lake Superior basin.

a. Lake Duluth, 11,500 years ago at the peak of the Marquette Ice advance.

b. Lake Huron Mountain (a post-Duluth lake) and the beginnings of Lake Minong, about 11,000 years ago. The Marquette ice margin is retreating into the Superior basin.

c. Lake Minong approximately 10,700 years ago.

d. Houghton low phase about 9,300 years ago.

e. Lake Nipissing approximately 5,000 years ago.

allowed the lake to find lower outlets to the east. The lake then rapidly drained through a cascading series of lower lake levels, represented by the Highbridge, Washburn, Beaver Bay, and Huron Mountain (Figure 11b) shorelines.

Meanwhile, a different lake, named Lake Minong, occupied the now rapidly deglaciating southeastern end of the basin near Sault Sainte Marie by about 11,400 years ago. The ice margin still remained along the southern shore of Michigan's Upper Peninsula in the vicinity of Pictured Rocks National Lakeshore, however, and the lowest of the post Duluth lakes drained along the edge of the ice through this area into an expanding Lake Minong (Figure 11b, c). Retreat of the ice margin from the area of Pictured Rocks allowed the two lakes to merge and form a single expanded lake at the level of Lake Minong, with its outlet at Sault Sainte Marie. With final deglaciation 11,000 years ago, Lake Minong expanded across the entire basin, becoming the first post-glacial ancestor of Lake Superior (Figure 11 c). Due to rebound, Minong shorelines today are found northeastward of the Sault Sainte Marie-Pigeon River line mentioned previously. Southwest of this line they are submerged below modern lake level, except for the easternmost parts of Michigan's Upper Peninsula. Interestingly, shorelines related to Lake Minong, if projected southeastward toward the Sault, are 120 ft above the present outlet at Sault Sainte Marie. This means that the controlling outlet at Sault Sainte

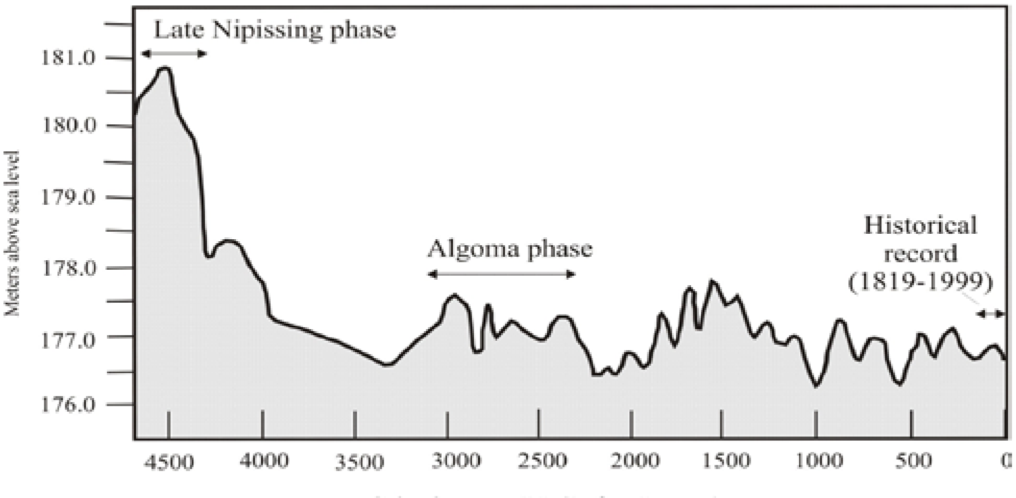


Figure 12a. Smoothed long-term lake levels in the Lake Michigan basin (from Baedke and Thompson, 2000).

Marie must have been 120 ft above its present elevation at the time Lake Minong existed. To explain this difference, geologists have proposed that the Sault Sainte Marie area was likely covered by a thick accumulation of glacial material (called “drift” by geologists, and consisting of mixtures of loose boulders, sand, silt and clay) that originally controlled the outlet of Lake Minong at the higher level. Until recently, geologists were at a loss to explain how this drift was removed to allow Lake Minong to drop to lower levels. Researchers working in Canada may have provided the answer.

It seems that about the same time that Lake Minong existed, a vast glacial lake, Lake Agassiz, covered parts of Saskatchewan, Manitoba, Ontario, Minnesota, North Dakota, and South Dakota. Modern Lake Winnipeg in Manitoba is a remnant of this lake. Detailed work on Lake Agassiz’s shorelines, deposits, and outlet channels by various workers indicate that Lake Agassiz drained into the Lake Superior basin, perhaps in huge floods, sometime during the Minong phase. If so, this flood of water from Lake Agassiz could have swept away the drift dam at the Sault, causing Lake Minong to drop to the level of the now denuded outlet. Whatever the cause, abundant evidence indicates that Lake Minong did drop over the succeeding several hundred years, eventually reaching a low level lake called the Houghton Low (Figure 11d). This lake was controlled by the now eroded outlet at the Sault, which apparently was developed on bedrock after the higher drift dam had been swept away.

At the same time, the Nipissing transition was causing lakes in the Lake Michigan-Huron basin to rise higher and higher. Eventually these rising waters reached the level of Sault Sainte Marie, and Lake Nipissing expanded into the Lake Superior basin, erasing many of the Houghton low features, and building new shorelines. At this time the Sault would have been a strait, much like the present Straits of Mackinac, connecting Lakes Huron and Superior (Figure 11e). Following the Nipissing maximum, lake levels fell throughout the Great Lakes region, possibly due to climatic factors. The Algoma level mentioned previously was common to all three basins (Superior, Lake Michigan, and Huron) but by approximately 2500 years ago the rebounding outlet at Sault Sainte Marie raised water levels in the Lake Superior basin higher than those in the Michigan and Huron basins, creating modern Lake Superior. Initially, Lake Superior was slightly higher than present, at a level geologists call the Sault level. Climatic changes, erosion of the outlet at Sault Sainte Marie, or both may have led to a slight drop to the present level.

The modern Great Lakes

Levels of the modern Great Lakes continue to fluctuate annually, but within a range much reduced from the mid-Holocene. Lake level gauges, emplaced

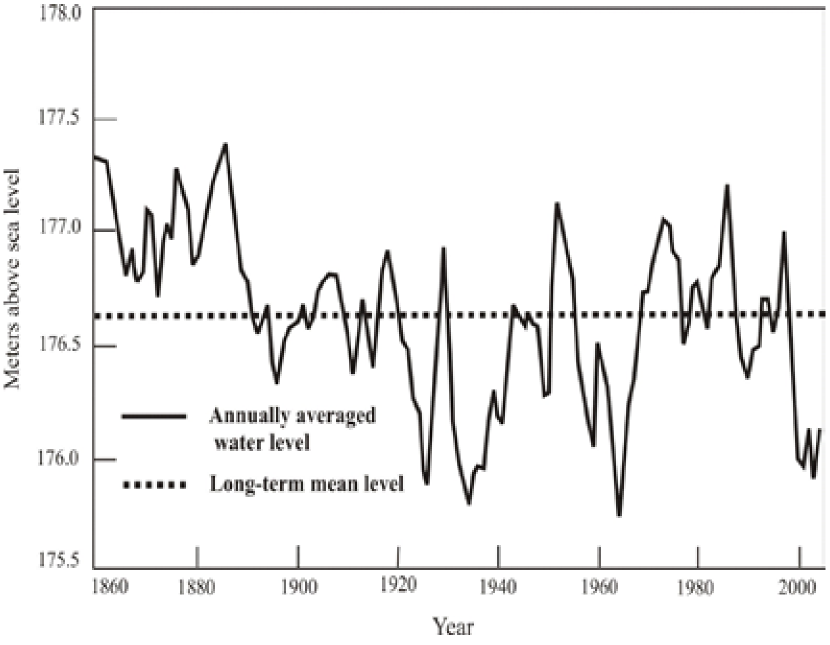


Figure 12b. Historic water levels of Lakes Michigan and Huron based on lake level gauges.

Figure 13. Dune associated with the Toleston level of Lake Chicago, Indiana Dunes National Lakeshore.

in the 1850s, continue to measure changes in water levels and provide an unbroken record of lake fluctuations spanning more than 150 years (Figure 12b). They indicate that Lake Michigan levels typically range about one foot (high vs. low) from the long-term average and have never exceeded more than 7 feet during the period of record. Geologists from the Indiana Geological Survey have been able to extend this record back in time by carefully measuring the altitude of old shorelines along the Lake Michigan basin, and then dating the shoreline using radiocarbon techniques. These data are then graphed to produce a curve of former water levels (Figure 12a). In analyzing the data, scientists were surprised to find that Lake Michigan undergoes a 150 year lake level cycle, in which levels broadly rise and then fall over this time frame. The data suggest that the relatively recent high lake levels of 1986 may have marked the crest of the cycle and that lake levels will continue to fall over the next 75 years. Data from beaches along Lake Superior show a similar pattern, although the fluctuation signal is weaker and determining the length of the cycle is much more difficult.

Features related to ancient lake levels in today's parks

Indiana Dunes National Lakeshore—The Toleston, Calumet, and Glenwood beaches of Lake Chicago are especially conspicuous in Indiana Dunes National Lakeshore and are a major focus of interpretive efforts (Figure 13). John Hill of the Indiana Geological Survey has provided an excellent review of where to view these beaches (1987, p.322):

> *Kemil Road from U.S. 20 northward to Lake Michigan transects the three major lake levels occupied by Lake Chicago during the past (15,500) years. The Glenwood beach and dunes can be seen just north of the intersection of U.S. 20 and Kemil Road. Calumet features are evident at the Indiana Dunes National Lakeshore visitor center at Kemil Road and U.S. 12. About half a mile north of U.S. 12, Kemil Road crosses the 605-ft elevation of the Toleston beach and level. In the Kemil Road area, the so-called Toleston beach and level is an undifferentiated sequence of dunes from glacial Lakes…Nipissing and Algoma.*

Many of the lakes and marshes within the lakeshore, such as Long Lake and Cowles Marsh, are formed in low level swales that developed between succeeding beach ridges associated with Lake Chicago. In addition, important evidence supporting the existence of Lake Chippewa comes from deposits buried at the base of Mt. Baldy, a large, active foredune well known to visitors.

Sleeping Bear Dunes National Lakeshore—This park is located only about 25 miles north of Manistee, where many of the principal shorelines in the Lake Michigan basin converge before plunging beneath the modern lake at Manistee (Figure 7a). For this reason, identifying particular shorelines here is difficult, and less is known about ancient shoreline features in Sleeping Bear Dunes than probably any other national parkland in the Great Lakes region.

Nevertheless, scientists recognize at least five conspicuous shorelines here. The highest two at 222-225 m and 198-201m are still the subject of debate. General agreement exists on the lower three and they are assigned, from highest to lowest, to the Main Lake Algonquin phase (189-192 m), the Lake Nipissing phase (184-186 m), and the Lake Algoma phase (179-181 m). A low beach ridge associated with the Main Lake Algonquin shoreline is located just behind the National Lakeshore visitor center in Empire, about 0.2 miles east of the intersection of M-22 and M-72 East. Most

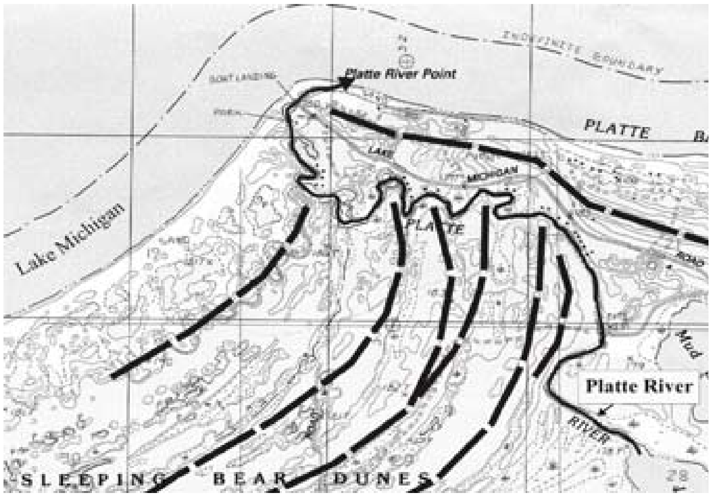


Figure 14. Beach ridges (shown with broken lines) control the meander patterns of Platte River (solid line) in Sleeping Bear Dunes National Lakeshore.

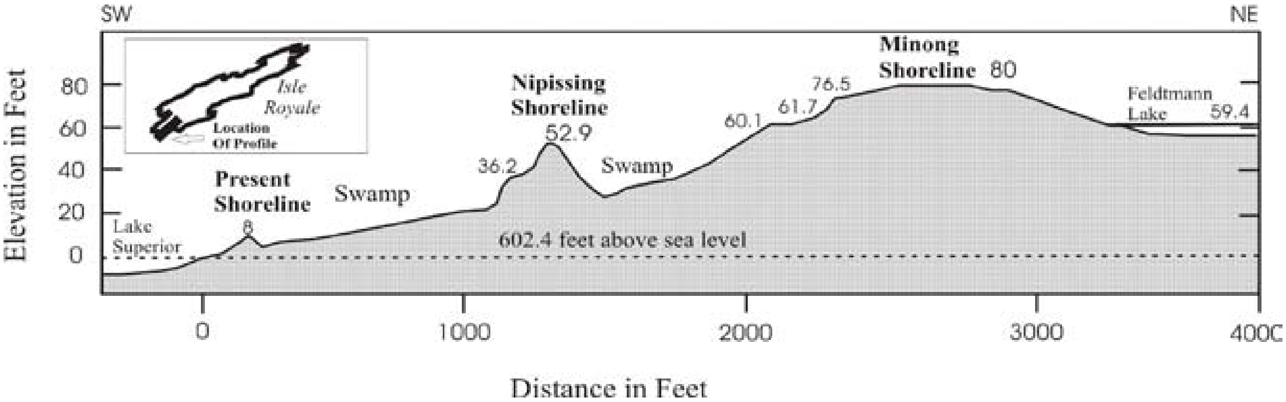


Figure 15. Profile across Nipissing and Minong shorelines between Rainbow Cove and Feldtmann Lake, Isle Royale National Park (after Huber, 1973, and Stanley, 1932). Elevations are in feet above Lake Superior's mean lake level.

of the village of Empire sits on the old Lake Algonquin bottom at an elevation of 188-189 m. Niagara Street, which leads west out of Empire toward the village park on Lake Michigan, descends the Nipissing shore bluff as it enters the park. North and South Bar Lakes originally were embayments of Lake Nipissing. A single Lake Algoma beach is difficult to identify in the park. Instead, a series of beach ridges and intervening swales characterizes the shorezone from the Lake Nipissing shoreline down to the present beach.

These features are conspicuous on aerial photographs and topographic maps (Figure 14) and give a corrugated appearance to the landscape. Their effect is best observed along the lower reaches of the Platte River near Lake Michigan, where the beach ridges help control the river's meander pattern (Figure 14). Just south of the park, the village of Frankfort owes its pleasant situation to an embayment of Lake Nipissing. The base of the surrounding bluffs mark the former storm beach and the downtown is built on old Lake Nipissing lake bottom.

Isle Royale National Park—The Minong shoreline was first identified and named on Isle Royale where it is especially conspicuous. Along with the Nipissing shore, it is the best- developed strandline on Isle Royale, although higher level shorelines associated with the later stages of Lake Duluth may also be present. N. King Huber (1973, p. A12) presents an excellent review of these features:

> *Lake Minong is the earliest of the lake stages for which abandoned beaches and other shoreline evidence can be found along the full length of Isle Royale…Such evidence is most strikingly developed on the west side of the island where the abundance of glacial drift permitted more pronounced development of shoreline features. Beaches from the Nipissing stage are also well developed on Isle Royale, as shown by Nipissing (and Minong) beaches discernible on the aerial photographs of glacial features west of Siskiwit Lake…and by a profile of barrier-bar beaches of the two lake stages between Rainbow Lake and Lake Feldtmann…*
>
> *On the east end of Isle Royale, where glacial debris is limited, and abandoned beaches are less evident, wave-cut features in the bedrock mark old shorelines…Prominent examples are Monument Rock, a stack associated with the Lake Minong shoreline north of Tobin Harbor…and an arch cut through a narrow ridge crest on Amygdaloid Island…, probably associated with the shoreline of the Nipissing stage.*

Figure 15 shows the profile between Rainbow Lake and Lake Feldtmann to which Huber refers. The profiled shorelines can be viewed in the field by observant hikers along the Rainbow Cove Trail between Rainbow Cove and Feldtmann Lake. The trail follows the beach ridge for a short distance.

Apostle Islands National Lakeshore—Most visitors to Apostle Islands experience the park via commercial sight-seeing vessels or private boats. Unfortunately, the high shorelines of Lake Duluth are difficult to observe in profile from a boat because they often left only broad swales in the bedrock rather than distinct

Figure 16. A "notch" in the profile of Michigan Island, Apostle Islands National Lakeshore, representing a storm beach of Lake Nipissing

Figure 17. Oblique aerial photo of Julian Beach and the famous Stockton Island tombolo.

wave-cut notches. Others are obscured by vegetation or traceable only for short distances. The best developed shorelines are located on the Bayfield Peninsula outside the park boundary. Of the Apostle Islands, only Oak Island is high enough (1,081 ft at its highest point) to record the Main Lake Duluth shoreline (1,075 ft), and only a very small portion of the island remained above this level. Geologists have identified lower shorelines in the post-Duluth lake sequence on Oak Island down to about 1,000 ft and also between 800 and 900 ft. Bear Island also reaches high enough to record some of these lower level lakes.

The Nipissing shoreline is the most prominent and easily recognized relict beach in Apostle Islands National Lakeshore. On many of the islands (Figure 16) it occurs as a distinct wave-cut "notch" approximately 12 feet above modern lake level. More famous, however, is the *tombolo* that makes up Julian Beach on Stockton Island (Figure 17). A *tombolo* is a sand barrier that connects an island with the mainland, or, as in the case of the Stockton tombolo, to another island. Prior to about 5,000 years ago, the area of Presque Isle point was an island separate from the rest of Stockton Island. Lake currents responding to higher lake levels predating the Algoma phase of Lake Superior washed sand into the protected area separating the two islands. The sand settled to the bottom, building a series of bars which eventually linked the two islands. Falling lake levels, perhaps related to subtle changes in climate, allowed stabilization of the bars by vegetation, forming the modern island. Sand continues to accumulate along the margins of the tombolo, creating a corrugated series of former shorelines and beach ridges that give Julian Beach its distinctive character.

Pictured Rocks National Lakeshore—As mentioned previously, ice lingered in the area of Pictured Rocks long after the southwestern and southeastern parts of the Superior basin were ice free (Figure 11b). By about 11,400 years ago, glacial lakes in the southwestern part of the basin drained along the southern edge of the ice, through the Pictured Rocks area, and into an expanding Lake Minong in the southeastern part of the basin. These drainageways were trapped between the ice margin and higher ground to the south. They also carried enormous loads of sand and gravel, which were dumped along their bottoms. As the ice continued to retreat into the Superior basin, it uncovered a series of progressively lower outlets, and new, lower drainageways formed.

This situation resulted in a stairstep-like series of sand and gravel-floored terraces (called kame terraces by geologists), recording successive drops to lower levels (Figure 18). These features are not shorelines, but they do record the sequence of drainageways that linked the various lakes along the southern margin during the retreat of Marquette ice from the region. Where drift was thin, these channels were cut into bedrock, creating the impressive gorges now occupied by Chapel and Little Chapel Lakes (Fig 19).

These terraces are best viewed at the Sable Falls parking lot near Grand Marais. The parking lot is located on a 720 ft terrace. The hill behind the parking lot is a "riser" up to a 750 ft terrace. The terraces can also be viewed by driving south on County Road H-58 from the Sable Falls parking lot. Early workers misinterpreted these terrace scarps as ancient shorelines. More recent work suggests that the only true ancient shorelines in the park are associated with the Nipissing and Algoma phases.

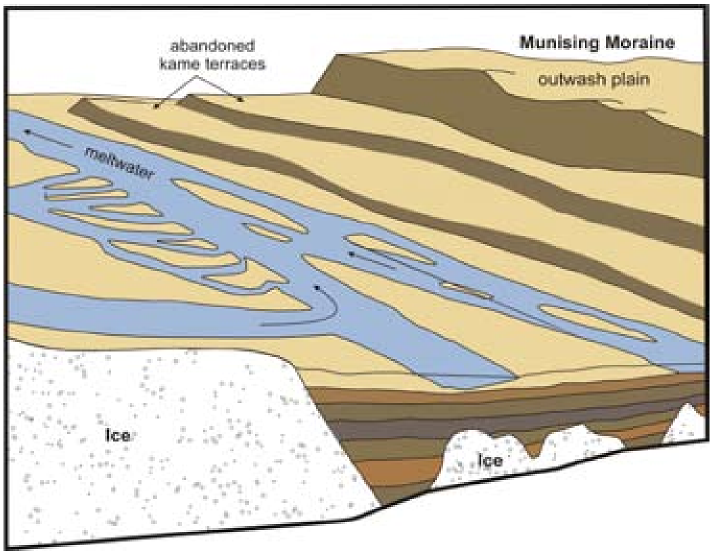


Figure 18. Diagram showing the formation of meltwater terraces near Grand Marais in Pictured Rocks National Lakeshore

The Nipissing shoreline is well defined throughout the park and often seen as a conspicuous “notch” in the shoreline profile about 40 ft above present lake level. This lake had a number of small embayments that are defined by the bluff faces south of the present shoreline along Miner’s Beach, Chapel Beach, and Beaver and Trapper’s Lakes. Miners Castle is often erroneously identified as an ancient shore feature. It is more likely that its configuration is due to weathering and erosion and the peculiarities of the bedrock from which it is made. Chapel Rock is somewhat more ambiguous since its elevation is at or near the Nipissing level and its alcove may have been initiated by the waves of Lake Nipissing. Its present configuration, however, clearly reflects a significant amount of subsequent weathering and erosion. Grand Island, of course, displays one of the finest tombolos in the region between the once main island and its eastern “thumb.” A series of beach ridges between the Nipissing beach and the modern lake are also exhibited along the Sand Point Marsh Trail.

Ancient shore features are best observed in the village of Grand Marais. The steep bluff immediately south of downtown is the Nipissing storm beach. The main part of the village sits on old Nipissing lake bottom. The road from downtown to Coast Guard Point drops down an Algoma shoreline scarp just as it leaves the main part of downtown. The city marina sits at the base of this scarp on old Algoma lake bottom (Figure 20).

Figure 20a and b. Shorelines and terraces in the vicinity of Grand Marais, Michigan, near Pictured Rocks National Lakeshore.

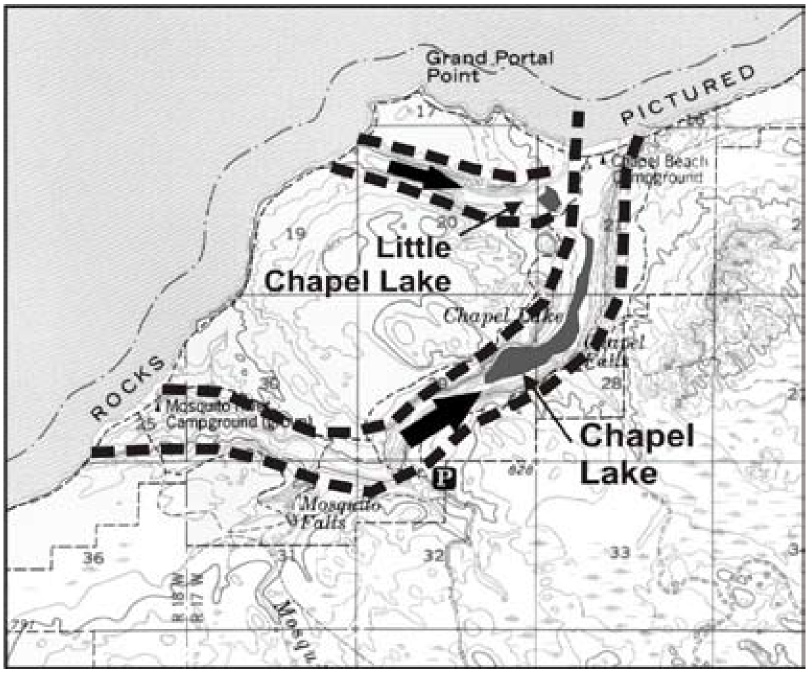


Figure 19. Bedrock channels cut by meltwater in the vicinity of Chapel and Little Chapel Lakes. Arrows show the direction of drainage.

Figure 20a

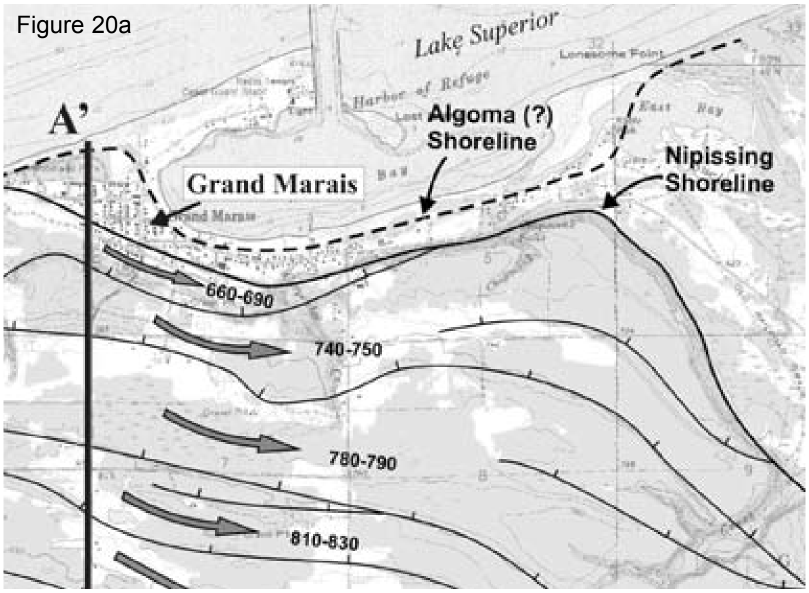
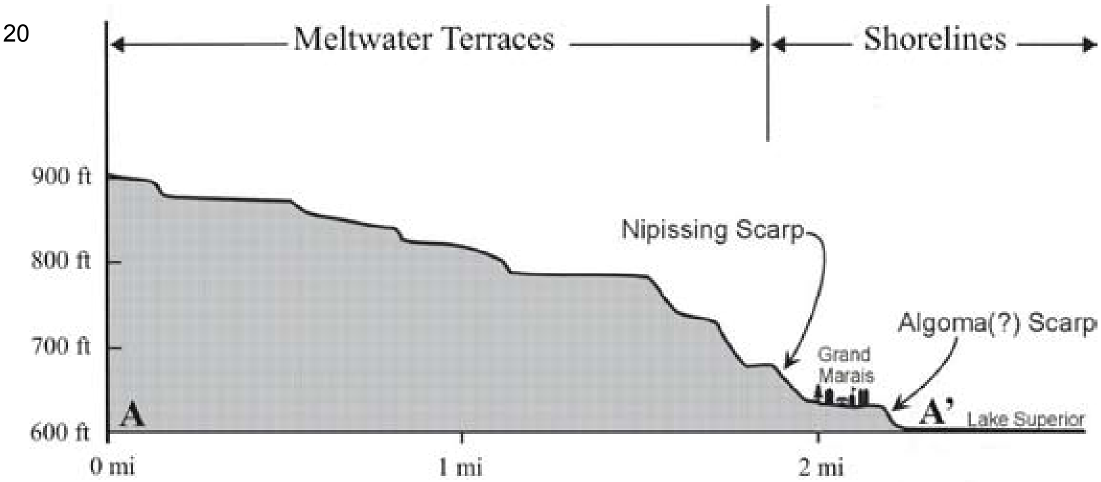


Figure 20



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