

# **DEGLACIATION AND HOLOCENE LANDSCAPE EVOLUTION IN EASTERN UPPER MICHIGAN**



## **A Field Guide for the 48<sup>th</sup> Midwest Friends of the Pleistocene Field Conference**

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## **Stop # 11, Au Train**

### **Beach-Ridge Architecture, Lake-Level Change, and Shoreline Behavior in the Au Train Bay Embayment, Au Train, Michigan**

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#### **Introduction**

The Au Train Bay embayment is a recessed area on the southern coastline of Lake Superior (Figure 1 and 2) about 20 km west of Munising, Michigan, and 50 km southeast of Marquette, Michigan. The 5-kilometer-wide embayment opens northward into Lake Superior and is bounded on the east, west, and south by Cambrian sandstone outcrops from 4 to 15 m high (Hamblin, 1958). Au Train Lake is located in the southernmost part of the embayment, and more than 90 continuous and discontinuous beach ridges (linear ridges of sand subparallel to the modern shoreline) arc east-west from one bedrock upland to the other across the embayment. The Au Train River dissects the strandplain of beach ridges as it passes from Au Train Lake to Lake Superior, dropping about 2.5 m in elevation (186.00 to 183.50 m above sea level). The pattern of the Au Train River channel changes from a meandering channel closer to Au Train Lake to an anastomosing channel closer to Lake Superior. This channel pattern change corresponds to poorly developed wetlands between beach ridges in the meandering part of the embayment to well-developed wetlands in the anastomosing part of the embayment (Figure 2).

The highest topography in the embayment is located north of Au Train Lake; this feature extends up to about 201 m above sea level and stretches to the eastern and western edges of the embayment. Lakeward from this high, topographic elevations in the strandplain decrease, becoming more horizontal, then rising toward Lake Superior. The topography becomes more horizontal and approaches the elevation of modern lake level about 1 km from the modern shoreline. This area is the lowest part of the embayment. The area also corresponds to the approximate location in the embayment where the Au Train River changes channel patterns from meandering to anastomosing and where wetlands become better developed in swales between beach ridges. Topographic elevations rise from about 400 m landward of the modern shoreline toward Lake Superior. The rise toward Lake Superior can be seen at this fieldtrip stop ("A" in Figure 1).

#### **The Modern Shoreline**

We are studying the modern Au Train Bay shoreline to help interpret ancient shoreline deposits preserved in beach ridges. An onshore/offshore profile of the modern beach was surveyed and 22 sediment samples were retrieved from each survey point to study the lateral variations in sediment grain-size and elevation change across the modern shoreline. Sediment samples were sieved using 1/2 phi interval standard sieves, and statistical

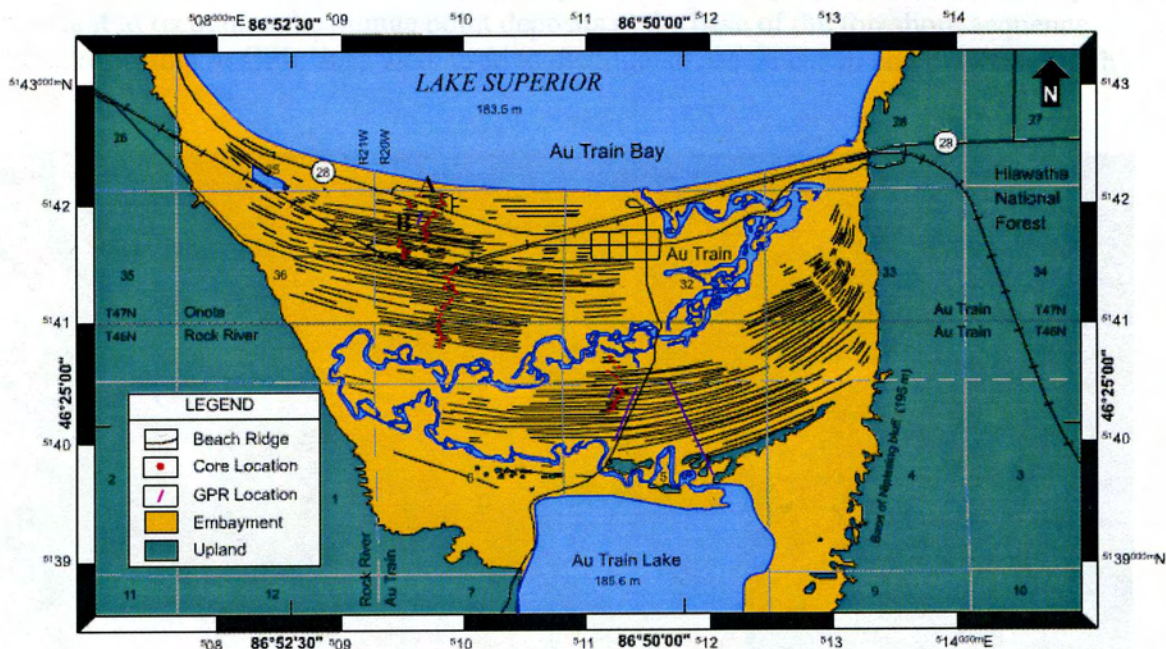


**Figure 1. Map of the AuTrain Bay embayment on the southern coast of Lake Superior. This northward-opening embayment contains more than 90 shore-parallel beach ridges north of Au Train Lake. The lakeward sides of 81 beach-ridge crests were cored (red dots) to determine the maximum elevation of the lake when each beach ridge formed. Several ground penetrating radar profiles were collected over beach ridges throughout the embayment (purple lines) to study beach-ridge architecture. The fieldtrip stop location is labeled “A”; the GPR profile in Figure 4 is labeled “B.”**

parameters were calculated using the method of moments (Figure 3). Dune, foreshore, and upper shoreface sediments all show lateral grain-size patterns, however, they also show sedimentary structure patterns that can be used to differentiate them vertically in core. Foreshore sediments have a coarser mean grain size and the coarsest one-percentile (C1%) compared with adjacent facies. At the plunge point (the base of the swash zone where waves break and rush up the beach face) there is a sharp coarsening in mean grain size and C1% and a sharp change in sorting towards more poorly sorted sediment. Note that the plunge point occurs at or very near still water level. Recognizing this deposit in ancient coastal deposits can pinpoint the elevation of lake level when the ancient deposits accumulated.

### Beach-Ridge Architecture

Two methods were used to study the internal architecture of beach ridges: vibracoring and ground penetrating radar (GPR). Vibracoring provides a direct measurement of sediment at one location through each beach ridge, while GPR provides an indirect view of sedimentary sequences between vibracore locations and across beach ridges. Sedimentary structures and grain-size statistical results from vibracores were used to distinguish three

sedimentary facies – dune, foreshore, and upper shoreface deposits. As noted above, it is important to recognize the plunge point deposits at the base of the foreshore sequence. Strong reflectors in GPR lines were used to distinguish sequences in and between beach ridges.



**Figure 2. Air photograph of the Au Train Bay embayment. Beach-ridge crests normally are tree-covered and darker in color than adjacent swales, except in areas where swales are submerged by water. Several well-developed wetlands have formed in swales in the northwestern part of the embayment and are shown as linear black features on the air photograph. The channel pattern of the Au Train River changes from meandering closer to Au Train Lake to anastomosing closer to Lake Superior.**

We collected 81 vibracores in the Au Train Bay embayment using 3-inch aluminum irrigation tubing, a 5 HP engine and vibrator head mounted in a clamp, and a 15-ft mobile tripod. The vibracores were extracted with winch hoists. Vibracores were collected lakeward of the beach ridge crest where there is a change in slope between the lakeward dune slope and the adjacent swale. This position allowed us to recover foreshore deposits at their highest elevation without collecting large amounts of dune sand. Moreover, the wet conditions at these locations, where the water table approaches the ground surface, improves vibracore penetration and recovery. The depth of penetration for vibracores ranged from 2 to 5 m and consistently shows dune deposits overlying foreshore sediments that, in turn, overlay upper shoreface deposits. None of the vibracores reached depths sufficient to penetrate lower shoreface deposits.

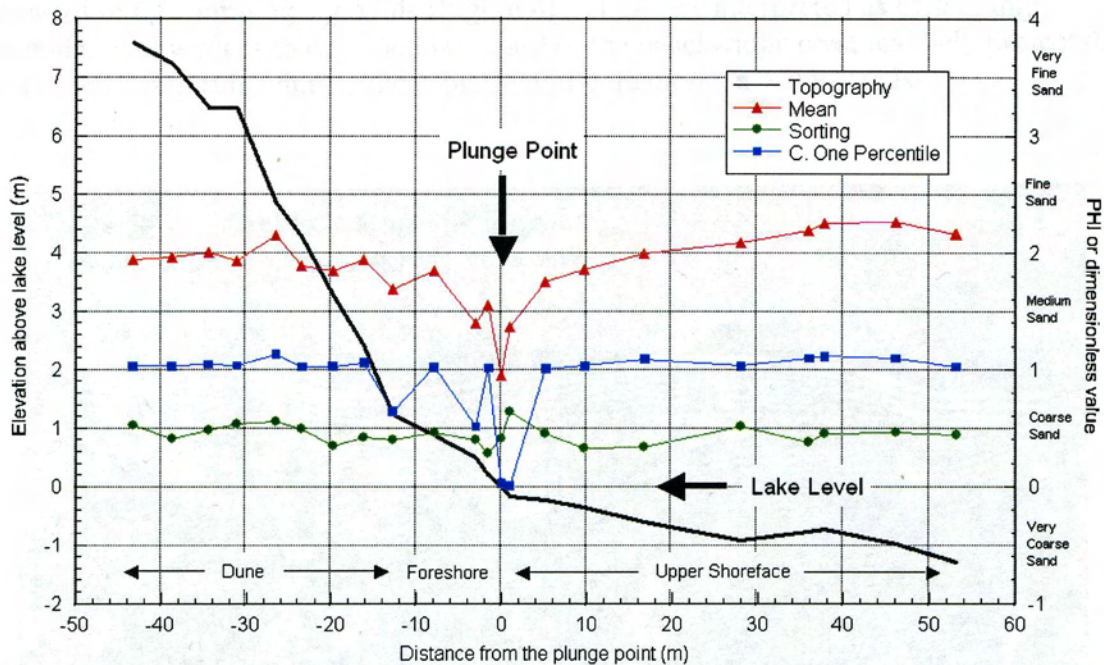


**Figure 3. Onshore-offshore topography and grain-size trends across the modern beach, over the plunge point (land/water interface) and into the upper shoreface at Au Train Bay, Michigan. A steep topographic profile on the landward part of the transect suggests that the modern shoreline is eroding. Sharp changes in grain-size trends at the plunge point indicate the base of the foreshore and is a good approximation of the water level. Foreshore sediment is coarser-grained, more poorly sorted, and has a coarser C1% than adjacent sediment lakeward (upper shoreface deposits) and landward (dune deposits).**

Several GPR lines crossing dozens of beach ridges were collected at Au Train Bay. Details within beach ridges were resolved by using 250-megahertz antennae. The depth of penetration through beach ridges was between 5 and 8 m and the minimum resolution was about 30 cm. We used the data from vibracores to calibrate the GPR lines and determine a representative velocity for the sediment. Determining the velocity is important in calculating depths to the reflectors. All GPR lines were corrected for topography so that a more representative dip of the reflectors could be observed.

Several strong reflectors emerge from the GPR lines projected through beach ridges (location "B" in Figure 1, Figure 4). Most of the reflectors are lakeward-dipping or horizontal and show differences in intensity above and below the water table because of the large contrast between saturated and unsaturated sediment. The lowermost strong reflector in the profile (Figure 4) extends from near the base of the profile below the beach-ridge crest and then rises to the ground surface in the next landward adjacent swale. We interpret this surface to be a ravinement surface formed during a rise in water level. Above this, several strong reflectors take the shape of a climbing sigmoidal pattern (Figure 4). We interpret these climbing sigmoids to be the core of the beach ridge that was formed during the final

stages of a water level rise. Several other sigmoidal features follow strong reflectors lakeward of the climbing sigmoids (Figure 4). These are interpreted as offlapping progradational wedges that formed lakeward of the beach-ridge crest and help protect the core of the beach ridge during the subsequent fluctuations in water levels.

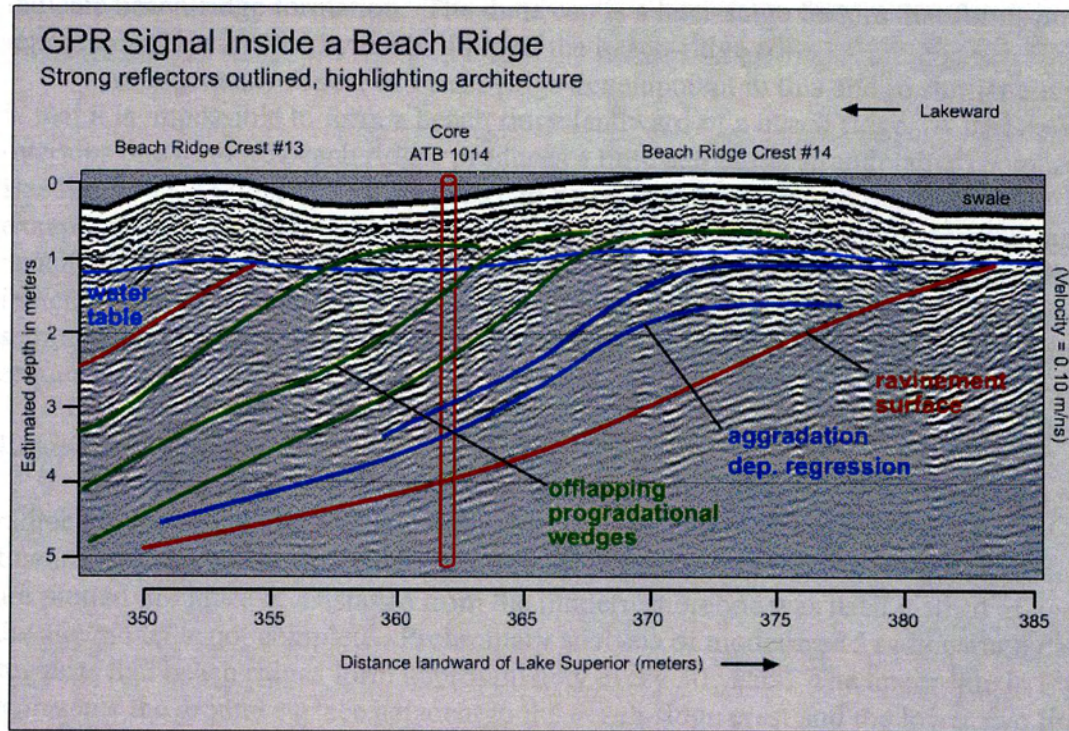


**Figure 4.** A ground penetrating radar profile across the fourteenth beach ridge landward of the modern shoreline in the lakeward part of the Au Train Bay embayment ("B" in Figure 1). Several strong reflectors were traced to define important sequences inside a beach ridge. The lowermost concave-upward strong reflector at the base of the profile is interpreted as a ravinement surface. Vertically building sigmoids, defined by strong reflectors, underneath the crest of the beach ridge represent the core of the beach ridge. Several fairly strong lakeward-dipping reflectors form sigmoidal patterns lakeward of the beach-ridge crest and represent offlapping progradational wedges.

Vibrocoring and GPR results provide us with the means to develop conceptual models of shoreline development and behavior and ultimately help us understand the processes that create a beach ridge. Beach ridges are a product of lake-level fluctuations in areas of positive littoral sediment supply (Thompson and Baedke, 1995). Their internal architecture provides information on past lake-level elevations and shoreline behavior in response to water-level change. Foreshore deposits are water-laid sediments that accumulate in nearshore coastal environments and form the core of a beach ridge. The core of the beach ridge starts to develop in the final stages of lake-level rise, as the rate of rise decreases near an absolute

high water-level elevation (Thompson and Baedke, 1995). The core of the beach ridge, therefore, marks punctuated high stands in lake level. Beach ridges grow lakeward during a subsequent lake-level fall by adding littoral sediment to the foreshore from the upper shoreface. Dune sands are transported onshore from the foreshore by winds that subsequently cap the core of the beach ridge. Vegetation on top of the ridges help accumulate and stabilize dune sands. Many studies focus on the growth of the dune cap to indicate beach-ridge formation. The dune cap is a later-stage feature that forms on a slight topographic rise created by the buildup of the beach-ridge core.

An irrefutable aspect of beach-ridge development in this and in similar environments is that it is impossible to form a beach ridge landward of a beach ridge. A lake-level rise that overtops one or more beach ridges produces a time gap in the strandplain (Thompson and Baedke, 1997). Often these time gaps can be recognized by beach ridges having exceptionally large dune caps landward of the time gap or by low-angle truncations between beach ridges at the time gap. A strandplain of beach ridges is a chronosequence that indicates long-term patterns of shoreline behavior in response to changes in lake level and sediment supply. In a sense, strandplains of beach ridges are horizontal stratigraphic sequences.

### **Lake-Level Change**

By systematically collecting foreshore sediments in vibracores from beach ridges and radiocarbon dating basal wetland sediments, a hydrograph of past relative lake-level fluctuations can be constructed. Data from 81 vibracores in the Au Train Bay embayment are plotted in Figure 5. Distance from the modern shoreline was used instead of age because the age model is not complete. Preliminary analysis of modeling 15 radiocarbon dates suggests that beach ridges form approximately every 30 years. The upper line in Figure 5 represents the ground surface adjacent to the beach-ridge crest and the lower two lines represent the upper and lower boundaries of the foreshore deposits. The thickness of the foreshore sequence is a rough approximation of wave climate (wave height, setup, etc.) during foreshore accumulation. The lowermost line is the base of the foreshore sequence (plunge point) and can be used to interpret relative water-level changes throughout time. Water-level change and vertical ground-movement (namely, isostatic rebound) are both integrated in this graph. Isostatic rebound can only be removed from these data by comparing other sites that have experienced similar water-level changes as this site throughout time. Because we have not yet removed isostatic rebound from the Au Train data, we refer to water-level change throughout time at this site as "relative" water-level change. Across the Au Train Bay strandplain, basal foreshore elevations indicate that relative water-level elevations followed a long-term pattern of a fall followed by a rise. The change from the fall to the rise may be related to the separation of Lake Superior from Lakes Michigan and Huron when the outlet at Sault Ste. Marie began regulating lake levels in the Superior Basin. A shorter-term pattern of rise and fall occurs every four to six beach ridges and may correspond to 160-year water-level fluctuations observed in strandplains in Lake Michigan. The removal of isostatic rebound may show additional patterns between the patterns previously mentioned. Several of these may be associated with shifts in the direction of the Au Train River and related to several long-term patterns of lake-level fluctuation, changes in littoral drift, and paleoclimate.

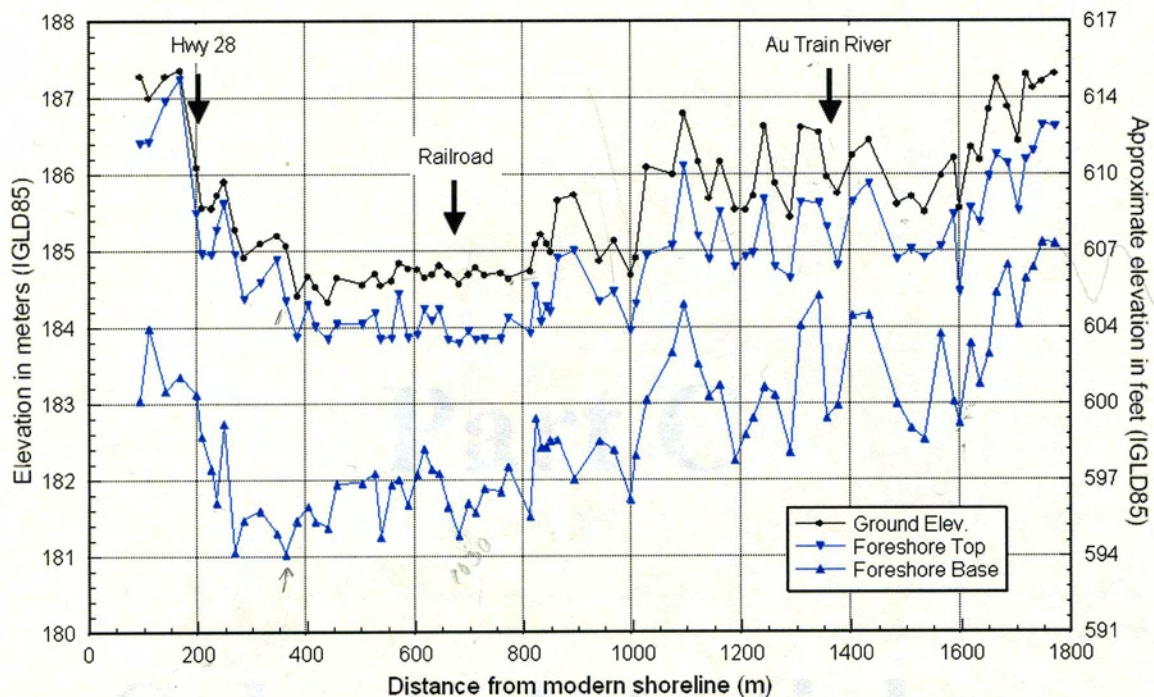


**Figure 5.** The elevation of the ground surface and the upper and lower limits of foreshore sediment versus distance from the modern shoreline for each of the 81 cores collected in Au Train Bay, Michigan. The lower line represents the boundary between foreshore and upper shoreface sediment and approximates the elevation of the lake during beach-ridge formation. These measured elevations are unique to the Au Train Bay study site, because they record localized differential vertical movement from the time the beach ridge formed to present, as well as the elevation of the lake when the beach ridge formed. The middle line represents the boundary between dune and foreshore sediment and is used in conjunction with the middle boundary to calculate foreshore thickness. Foreshore thickness is used to estimate wave setup during beach-ridge formation. The uppermost line represents the ground surface at the core location.

## References

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