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Radiocarbon Dating of Basal Peats Supports Separation of Lake Superior from Lakes Michigan-Huron about 1250 years ago

Shi-Yong Yu[a,*], Steven M. Colman[a], Glenn A. Milne[b]

[a] Large Lakes Observatory, University of Minnesota Duluth, 2205 E 5th Street, Duluth, MN 55812, USA
[b] Department of Earth Sciences, University of Ottawa, 140 Louis Pasteur, Ottawa, Ontario, Canada K1N 6N5

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ABSTRACT

Lake Superior represents an important component of the aquatic ecosystem in North America. Along its south shore, ongoing lake-level rise, accelerated erosion, and wetland loss are major environmental concerns to coastal communities. A better prediction of the future of this shore requires placing the instrumental lake-level records in a geological context. However, our knowledge of the late-Holocene history of the world's largest freshwater body remains fragmentary. Here we present a sedimentary record of late-Holocene relative lake-level changes by dating transgressive basal peats resting directly on a sandy substrate along a bathymetric gradient in Bark Bay Slough, Wisconsin. Our record shows a moderate lake-level rise at 1.4 ± 0.2 mm/yr from about 2200 to 1250 cal yr BP as a result of relatively slow differential uplift of Bark Bay relative to the controlling outlet at Port Huron. The rise accelerated to 2.3 ± 0.2 mm/yr at about 1250 cal yr BP when Sault Ste. Marie emerged as the controlling outlet, thereby separating Superior from Lakes Michigan–Huron and giving rise to the modern hydrographic regime of the upper Great Lakes. The timing of this event in our record is about 1000 yr later than that estimated in most previous studies, but our data complement and confirm the younger age of lake separation inferred using a different methodology. Our results not only provide pertinent information for hydrological regulation, navigation operation, and infrastructural design in the upper Great Lakes, but also provide insight into freshwater wetland succession on flooded coasts.

1. Introduction

Large lakes are an important part of the aquatic environment, and they have been increasingly viewed as inland seas with regard to their immense ecological, economical, and recreational values. The Laurentian Great Lakes are some of the best examples of these freshwater seas. These lakes, including the connecting channels, are a chain of water bodies formed by differential glacial erosion of Precambrian and Paleozoic rocks, draining the middle of the continent and providing a waterway for commercial transportation. Of the five lakes, Superior, Huron, and Michigan are the three largest (Fig. 1A). Today, Lakes Michigan and Huron are connected through the Straits of Mackinac, forming a single hydrological system with a lake level of 176 m against the International Great Lakes Datum 1985 (IGLD 85), while Lake Superior, elevated by about 7 m above the others, is connected by the short St. Marys River. The ongoing accelerated erosion along the south shore of Lake Superior due to submergence has raised concerns about the safety of infrastructure and property (Swenson et al., 2006). Therefore, there is a practical need to place instrumental lake-level data in a geological context to provide stakeholders and policymakers with reliable information about the long-term rate of relative lake-level (RLL) rise and its potential threats.

Lake-level changes in these three upper Great Lakes are primarily controlled by glacial isostatic deformation of the crust, which has governed the location and elevation of lake outlets (Farrand and Drexler, 1985; Clark et al., 1994). The retreat of the Laurentide Ice Sheet from the Michigan and Huron basins by about 11,000 ^{14}C yr BP gave rise to Lake Algonquin, a large proglacial lake draining eastward through the Kirkfield outlet (Eschman and Karrow, 1985; Hansel et al., 1985). Following the ice-sheet retreat, Lake Minong emerged in the southeastern part of the Superior basin, and a lower outlet at North Bay opened at about 10,200 ^{14}C yr BP (Karrow, 2004; Kor et al., 2012), which drained Lake Algonquin and led to a hydrological separation of the upper Great Lakes. As the ice sheet retreated further north, Lake Minong expanded to the entire Superior basin by about 9500 ^{14}C yr BP (Farrand and Drexler, 1985). Failure of a sandy end-moraine dam at about 9300 cal yr BP lowered the lake-level by ca. 45 m, causing a flood to the North Atlantic routed through the Lake-Huron–North Bay–Ottawa River–St. Lawrence River valleys (Yu et al., 2010).

Dry climate also affected the Great Lakes levels, in the Superior basin (Boyd et al., 2012) and in the Huron basin during the early to mid-Holocene when excessive evaporation drew levels down

* Corresponding author. Tel.: +1 218 726 6055; fax: +1 218 726 6979.
E-mail address: syu@d.umn.edu (S.-Y. Yu).

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below outlets except for short periods of meltwater overflow from upstream glacial lake basins (Lewis et al., 2008; Lewis and Anderson, 2012). Once adequate water supply was restored for lakes to overflow, differential uplift of North Bay led to a confluence of the upper Great Lakes at about 7500 ^{14}C yr BP (Farrand and Drexler, 1985) and a widespread lake-level rise (i.e. the Nipissing transgression) culminating at ca. 4500 cal yr BP (Farrand and Drexler, 1985; Thompson et al., 2011; Fisher et al., 2012). Lake-level control eventually was transferred to the pre-existing spillways at Chicago and Port Huron (Larsen, 1985), and then downcutting of the Port Huron outlet gradually lowered the Nipissing lake level while basins of the upper Great Lakes continued to rise isostatically (Baedke and Thompson, 2000; Thompson et al., 2011). Finally, isostatic uplift of a bedrock sill at Sault Ste. Marie resulted in a separation of Lake Superior from Lakes Michigan–Huron at a time estimated to be about 2200 ^{14}C yr BP (Farrand, 1962; Larsen, 1994; Johnston et al., 2004).

The timing of separation of Lake Superior from Lakes Michigan–Huron remains uncertain. For example, modeling of isostatic uplift at the Sault Ste. Marie and Port Huron outlets suggest that the separation may have occurred as early as 3500 ^{14}C yr BP (Clark et al., 2012). However, in a study of a beach ridge sequence to the west of Grand Traverse Bay, Michigan, Johnston et al. (2007) recognized a break of beach ridge formation in the standplain sequence and they suggested that the onset of lake-level control in the Superior basin by the Sault Ste. Marie outlet might be closer to about 1200 cal yr BP. Recent beach-ridge work with more detailed age controls appears to support the late timing of this event (Johnston et al., 2012).

The separation of Lake Superior from Lakes Michigan–Huron resulted in a contrasting spatial pattern of relative lake-level change in the Superior basin due to differential isostatic uplift (Mainville and Craymer, 2005). Specifically, the Superior basin is now divided by a zero isobase running approximately from Sault Ste. Marie northwestward across the lake to Thunder Bay, Ontario. Lake level to the south and west of the zero isobase shows a relative rise (2.6–2.7 mm/yr), while lake level to the north and east of the zero isobase shows a relative fall (Fig. 1B). This situation has occurred only when Sault Ste. Marie emerged and began to function as a mid-basin controlling outlet.

The timing of lake separation can be determined from reconstructing RLL changes. Existing Holocene lake-level records rely heavily on the radiocarbon dating of swales between beach ridges (Johnston et al., 2000, 2001, 2004, 2007). However, these ages only provide a minimum constraint on the formation of the beach ridges. Although the optically stimulated luminescence (OSL) method can provide a direct age for beach ridges (Argyilan et al., 2005; Johnston et al., 2012), hiatuses in some strandplain records of beach ridge formation may hinder estimation of the precise timing of the separation event. Unlike the beach-ridge approach that reveals RLL fall on emergent coasts, here we reconstruct past RLL rise by dating basal peats deposited at increasing elevations during transgression of the lake with an aim to improve constraints on the timing of lake separation and isostatic land motion.

2. Study area and methods

The semi-enclosed Bark Bay Slough, Wisconsin appears to be an ideal site for reconstructing past lake-level rise along the south shore of Lake Superior (Fig. 1C). Longshore transport of sandy materials led to the development of a spit extending across Bark

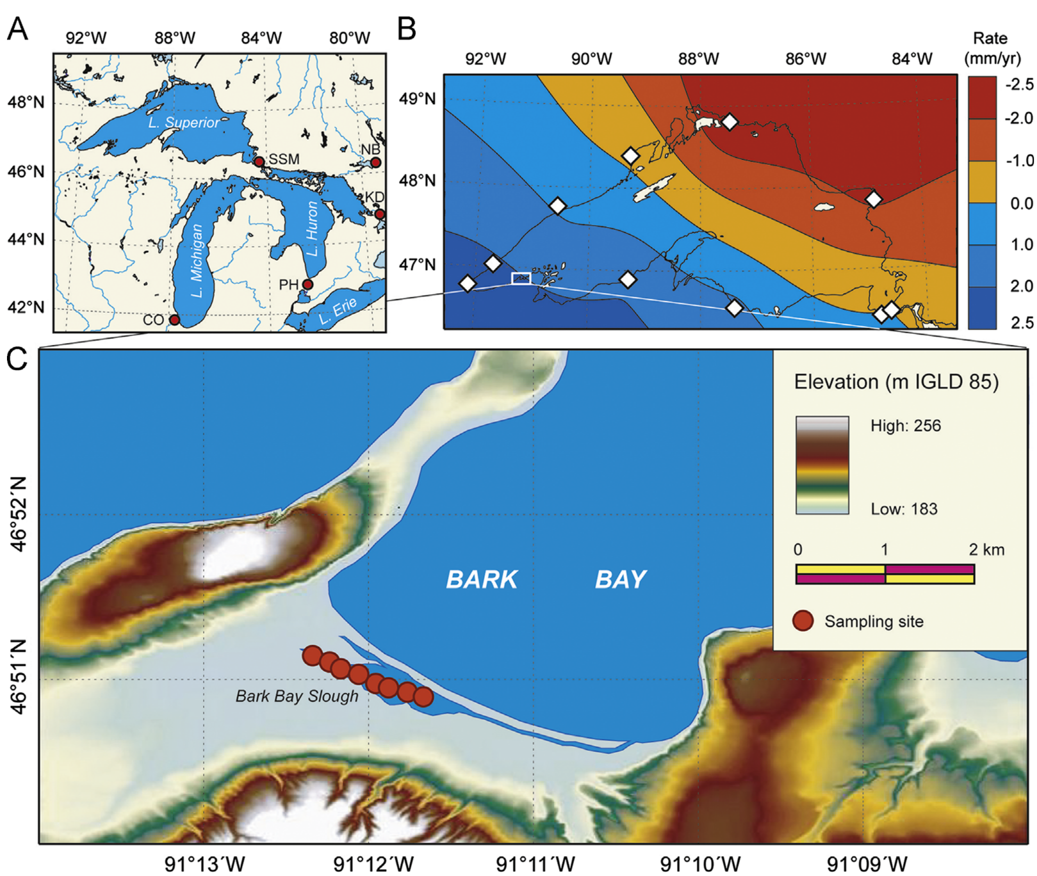

Fig. 1. (A) Map of the upper Laurentian Great Lakes. Filled circles indicate the location of outlets functioning during the Holocene. SSM = Sault Ste. Marie; NB = North Bay; KD = Kirkfield; PH = Port Huron; CO = Chicago. (B) Filled contour map showing the pattern of lake-level changes in the Superior basin defined by historical observations at 10 gauge stations (filled diamonds) around the lake (Mainville and Craymer, 2005). (C) Shaded relief map showing the topographical features of Bark Bay Slough and surrounding area. Core sites (circles) are arranged from west to east as in Fig. 2.