Quaternary Research 71 (2009) 397–408

Contents lists available at ScienceDirect

Quaternary Research

journal homepage: www.elsevier.com/locate/yqres

Paleohydrology of the upper Laurentian Great Lakes from the late glacial to early Holocene

Andy Breckenridge [a,*], Thomas C. Johnson [b]

[a] Department of Geology, Mercyhurst College, 501 E. 38th Street, Erie, PA 16546, USA
[b] Large Lakes Observatory and Department of Geological Sciences, University of Minnesota Duluth, Duluth, MN 55812, USA

ARTICLE INFO

Article history:
Received 22 December 2006
Available online 5 March 2009

Keywords:
Great Lakes
Lake Superior
Lake Huron
Lake Michigan
Oxygen isotopes
Lake Agassiz
Paleohydrology

ABSTRACT

Between 10,500 and 9000 cal yr BP, $\delta^{18}O$ values of benthic ostracodes within glaciolacustrine varves from Lake Superior range from −18 to −22‰ PDB. In contrast, coeval ostracode and bivalve records from the Lake Huron and Lake Michigan basins are characterized by extreme $\delta^{18}O$ variations, ranging from values that reflect a source that is primarily glacial (~−20‰ PDB) to much higher values characteristic of a regional meteoric source (~−5‰ PDB). Re-evaluated age models for the Huron and Michigan records yield a more consistent $\delta^{18}O$ stratigraphy. The striking feature of these records is a sharp drop in $\delta^{18}O$ values between 9400 and 9000 cal yr BP. In the Huron basin, this low $\delta^{18}O$ excursion was ascribed to the late Stanley lowstand, and in the Lake Michigan basin to Lake Agassiz flooding. Catastrophic flooding from Lake Agassiz is likely, but a second possibility is that the low $\delta^{18}O$ excursion records the switching of overflow from the Lake Superior basin from an undocumented northern outlet back into the Great Lakes basin. Quantifying freshwater fluxes for this system remains difficult because the benthic ostracodes in the glaciolacustrine varves of Lake Superior and Lake Agassiz may not record the average $\delta^{18}O$ value of surface water.

Introduction

Determining freshwater flux to the St. Lawrence Seaway and Arctic Ocean during Laurentide ice sheet (LIS) retreat is important because this freshwater is hypothesized to have disrupted North Atlantic deep water (NADW) formation, initiating rapid climatic cooling events, including the Younger Dryas, Pre-Boreal oscillation (PBO), and 8200 cal yr BP event (Johnson and McClure, 1976; Broecker et al., 1989; Barber et al., 1999; Licciardi et al., 1999; Clarke et al., 2001; Fisher et al., 2002). Ocean circulation models predict that freshwater inputs can disrupt NADW, but the models are sensitive to the magnitude and duration of the discharge (Manabe and Stouffer, 1995, 1997; Rahmstorf, 1995, 2000; Fanning and Weaver, 1997; Renssen et al., 2001). Continuous sediment deposition in the Laurentian Great Lakes should provide a valuable record of freshwater discharge to the St. Lawrence Seaway; during some periods this discharge included overflow from Glacial Lake Agassiz, a proglacial lake within the Hudson Bay watershed (Fig. 1). At times Lake Agassiz overflow is hypothesized to have been catastrophic, characterized by floods lasting 1 to 3 yr (Teller et al., 2002). Only annually resolvable sediment records can test the existence of such floods, and these records exist in the Laurentian Great Lakes.

The recognition of Lake Agassiz water within sediment records from the Great Lakes remains disputed, largely because the $\delta^{18}O$ value of Lake Agassiz overflow is uncertain. Because the $\delta^{18}O$ value of water within the Huron and Michigan basins is relatively high when Agassiz water is presumed to have flowed through the Great Lakes (including the Younger Dryas and a later period between 10,600 and 9000 cal yr BP), major flows of freshwater from Lake Agassiz did not occur if the $\delta^{18}O$ value of Lake Agassiz overflow approached that of glacial meltwater, ~−30‰ SMOW (Moore et al., 2000). In contrast, others have suggested that Lake Agassiz surface waters were dominated by meteoric precipitation and were evaporatively enriched, and therefore overflow had high $\delta^{18}O$ values (Lewis et al., 1994; Buhay and Betcher, 1998; Birks et al., 2007).

No summary of Great Lakes paleohydrology includes records from Lake Superior, despite the fact that Lake Agassiz water flowed through the Lake Superior basin before cascading into the Lake Huron basin (Figs. 1, 2). This study describes new $\delta^{18}O$ records from the Lake Superior basin that date after 10,700 cal yr BP (see Breckenridge, 2007) and correlates these records to those from the Lake Huron and Michigan basins. There is no dispute that Lake Agassiz water overflowed into the upper Great Lakes basins during this time. At times this overflow is predicted to have been catastrophic, reaching magnitudes similar to those predicted for the Younger Dryas (Teller and Leverington, 2004).

A summary of the late glacial history of the upper Laurentian Great Lakes

During much of the Younger Dryas, water in the Lake Huron, Michigan, and Superior basins was confluent, forming the Main

* Corresponding author. Fax: +1 814 824 3297.
E-mail addresses: abreckenridge@mercyhurst.edu (A. Breckenridge), tcj@d.umn.edu (T.C. Johnson).

0033-5894/$ – see front matter © 2009 University of Washington. All rights reserved.
doi:10.1016/j.yqres.2009.01.003

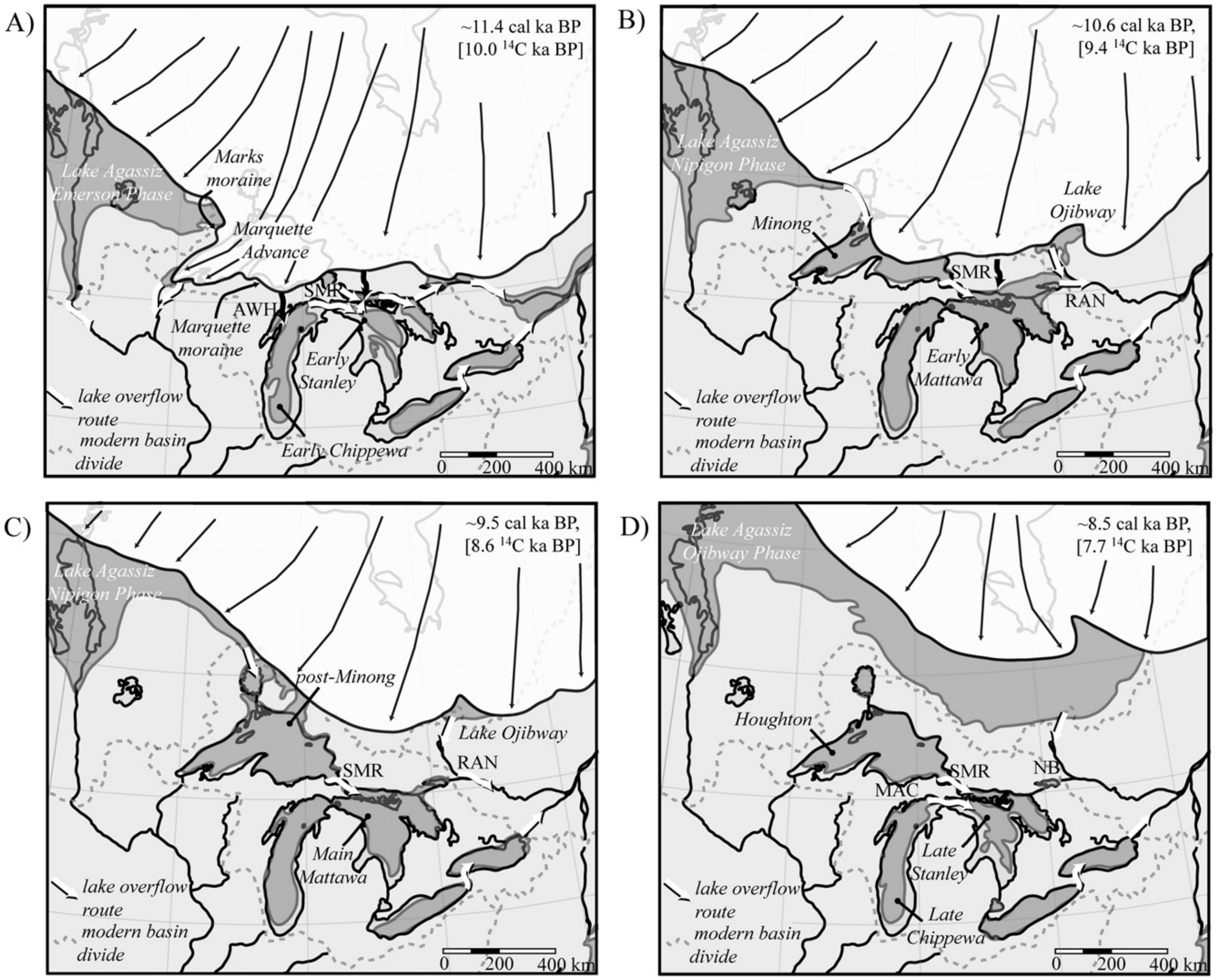

Figure 1. Great Lakes paleogeography, adapted from Lewis and Anderson (1989), Lewis et al. (1994), and Dyke et al. (2003). Outlets: AWH, Au Train–Whitefish channel, SMR: St. Mary's River channel (Sault Ste Marie), RAN: Rankin constriction on the Ottawa River, NB: North Bay, MAC: Mackinac Straits.

Algonquin highstand. Lake levels dropped when LIS retreat opened an outlet to the Ottawa River valley, ca. 11,400 cal yr BP (Fig. 1A) (Lewis and Anderson, 1989). This period is roughly coincident or just prior to advance of the Superior ice lobe to the Marks and Marquette moraines in the Superior basin, which would have closed an eastern Agassiz outlet if one existed at this time (Lowell et al., 1999, 2005; Teller et al., 2005; Fisher and Lowell, 2006). The drop in lake levels from the main Algonquin created separate lakes in the Huron, Michigan, and Superior basins: the Chippewa lowstand in Michigan, the early Stanley lowstand in Huron, and pro-glacial lakes in the Superior basin divided by the Superior Lobe (Farrand and Drexler, 1985; Hansel et al., 1985; Rea et al., 1994a,b). With subsequent ice retreat, overflow from the Superior basin was directed through the St. Mary's River to the Lake Huron basin by around 10,600 cal yr BP (Fig. 1B). Rebound of northern outlets in the Huron and Michigan basins created rising lake levels (Figs. 1B, C). In Lake Michigan sediments, this lowstand (Chippewa) created a coarse-grained horizon. In shallower water this horizon is an unconformity, which decreases in age to the south due to the transgression (Colman et al., 1994a,b).

Lake Agassiz overflow is predicted to have entered the Lake Superior basin, and therefore the Lake Huron basin (early Lake Stanley), at around 10,600 cal yr BP [~9300–9500 ^{14}C yr BP] (Fig. 1B) (Mann et al., 1997; Teller et al., 2000; Fisher, 2003). Seismic surveys and sediment cores document oscillating lake levels in the Lake Huron basin following early Lake Stanley (Moore et al., 1994; Rea et al., 1994a,b). Levels oscillate between three lowstands (the early, middle, and late Stanley), punctuated by two highstands (the main and late Mattawa). The middle Stanley lowstand may have been controlled at least in part by the shutting on and off of Lake Agassiz overflow due to ice readvance over the Lake Agassiz outlets into the Superior basin (Lewis and Anderson, 1989; Lewis et al., 1994; Thorleifson, 1996). The Mattawa highstands project far above Stanley levels. The main Mattawa highstand ends with the late Stanley lowstand ca. 8800 cal yr BP (Lewis et al., 2007), which coincides with the end of both glacial meltwater and Lake Agassiz overflow into the Great Lakes basin, dated at 8800–9200 cal yr BP (Fig. 1D) (Bajc et al., 1997; Breckenridge et al., 2004). During the late Stanley lowstand, the Lake Michigan and Huron basins were disconnected. Black iron sulfide (FeS) bands, attributed to low oxygen levels and higher organic matter inputs, characterize the sediments during this phase (Odegaard et al., 2003). Estimates of freshwater flux by Moore et al. (2000) that are based on the δ^{18}O records (discussed below) suggest freshwater flow increased during the late Stanley lowstand.

The late glacial δ^{18}O records of the Huron, Michigan and Agassiz basins

Contemporaneous oxygen isotope records have been published from Lakes Winnipeg (a remnant of Lake Agassiz), Michigan, and Huron (Figs. 2, 3). Every record spans several lake phases, but all records are labeled and referenced according to the modern lake from