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Paleoproductivity and organic matter sources in Late Quaternary Lake Ontario

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ABSTRACT

We have examined $\delta^{13}C$ of ostracode valves and clam shells, carbon and nitrogen mass accumulation rates (C- and N-MAR), atomic C/N and $\delta^{13}C_{OM}$ from Lake Ontario since ~16,000 cal BP to evaluate the impacts of the Laurentide Ice Sheet (LIS) and regional paleohydrology on primary lacustrine productivity and sources of OM. Samples were obtained from piston cores from each of the Niagara, Mississauga and Rochester basins, which geographically span Lake Ontario from west to east.

During the glacial period, variations in inputs directly from the LIS versus up-stream glacial Lake Algonquin and (or) ancient Lake Erie controlled the DIC pool in ancestral Lake Ontario. Cold and dry conditions limited primary productivity in the Ontario basin (low C/N ~7.5). Increased contributions of glacial meltwater from glacial Lake Algonquin during the latter stages of deglaciation provided a uniform supply of DIC to ancestral Lake Ontario and other lakes then occupying the Huron and Erie basins, stabilizing the $\delta^{13}C_{DIC}$ pool at ~−4‰ (VPDB).

Upon hydrologic closure of early Lake Ontario at the onset of post-glacial conditions (12,300 cal BP), a growing divergence between the $\delta^{13}C$ of ostracode valves (decreases to −6‰) and clam shells (increases to +1‰) indicates differences in summer versus spring DIC pools. The end of glacial meltwater input to early Lake Ontario also made it possible to detect changes in primary lacustrine productivity using the isotopic and C/N proxies. Increasing $\delta^{13}C_{OM}$ (from ~−29 to −27.5‰) and low C/N (<10) during post-glacial times across Lake Ontario generally support rising primary lacustrine productivity during hydrologic closure and following return to overflow conditions after 8300 cal BP.

1. Introduction

Variations in lacustrine productivity and sources of OM to Lake Ontario provide clues as to how the lake responded to changes in paleohydrology and proximity to the Laurentide Ice Sheet (LIS). Given the detailed water-level history of Lake Ontario proposed by Anderson and Lewis (2012) and knowledge of regional glacial history (Larson and Schaetzel, 2001), sediments obtained from Lake Ontario offer a unique opportunity to assess the responses of traditional proxies (organic carbon (OC) and total nitrogen (TN) mass accumulation rates (C- and N-MAR), carbon/nitrogen ratios (C/N), carbon isotopic compositions of bulk OM ($\delta^{13}C_{OM}$) and biogenic carbonate) to these changing conditions.

In previous work, McFadden et al. (2004) and (2005) examined the changes in vegetation and aquatic productivity for the eastern portion (Rochester basin) of Lake Ontario from 10,000 cal BP to 1850 AD. Using OC, TN, C/N and $\delta^{13}C_{OM}$, they demonstrated that the Holocene Thermal Maximum (HTM; 9400 to 5300 cal BP) was the warmest and wettest period of the Holocene. Their proxy record also recorded the interruption of regional warming by two cold periods: the '8.2 ka' event and the Nipissing phase (Lake Ontario) (6800 to 5000 cal BP). McFadden et al. (2005) also noted that from 5300 cal BP to 1850 AD (Neoglacial), the region was cooler and drier, but climatically less variable than the HTM.

Silliman et al. (1996) also used C/N and $\delta^{13}C_{OM}$ to describe OM delivery to the Rochester basin in eastern Lake Ontario. They concluded from generally low C/N (<10) that lacustrine algae dominated postglacial OM in Lake Ontario sediments. Saying that, increases in C/N from 4 to 9 upcore represent greater proportions of terrestrial OM entering the lake, even though lacustrine algae was the dominant source. Silliman et al. (1996) were unable to discriminate between lacustrine algae and C_3 land plants based on the measured $\delta^{13}C_{OM}$ (−28.0 to −25.5‰).

Schelske et al. (1988), Schelske and Hodell (1991) and Hodell and Schelske (1998) used similar proxies to assess the changes in lacustrine productivity recorded in more recent sediments (>1850 AD) of the Rochester basin (Lake Ontario). They observed that OC, TN and $\delta^{13}C_{OM}$ paleoproductivity proxies matched reasonably well with data for sediment traps (Hodell and Schelske, 1998). Hodell and Schelske (1998) noted that diagenetic reduction in the mass of accumulating OC in the oxic pore water zone did not affect $\delta^{13}C_{OM}$.

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We build on these previous studies by: (i) expanding sampling coverage to the western (Niagara) and central (Mississauga) basins of Lake Ontario; (ii) extending the time interval considered to ~16,000 cal BP, and (iii) using the $\delta^{13}C$ values of biogenic carbonates as a proxy for DIC isotopic composition (Decrouy et al., 2011). We compare C-MAR, N-MAR, C/N, $\delta^{13}C_{OM}$ and $\delta^{13}C_{DIC}$ to the lake level curve of Anderson and Lewis (2012) to assess the effects of paleohydrology on lacustrine productivity and OM sources, and test for differential regional responses to hydrologic inputs and outputs from west to east across Lake Ontario. Sampling of older sediments, in particular, allows the evaluation of the relationship between DIC isotopic compositions, on one hand, and changes in lacustrine productivity and OM sources during advance and retreat of the LIS, and high- (glacial Lake Iroquois) and low- (hydrologic closure) water stands, on the other hand.

2. Materials and methods

Three piston cores were collected from Lake Ontario, Canada (Fig. 1) during July 15–17, 2008 by the captain and crew of the Canadian Coast Guard Ship (CCGS) *Limnos*: Core 1334, Niagara basin; Core 1335, Mississauga basin; and Core 1336, Rochester basin (Fig. 2). The cores were cut into ~1 m sections onboard and stored in a refrigerator prior to delivery to the University of Rhode Island, where they were halved longitudinally and their visible characteristics noted (color, consistency, grain size, sedimentary structures including laminations; Hladyniuk, 2014). Sediment color was described according to Munsell Color (2000). The cores were then shipped to the University of Western Ontario where they were stored at 4 °C.

The age–depth model (Fig. 3) was anchored using three accelerator mass spectrometer (AMS) radiocarbon dates of terrestrial macro-fossils and clam shells (Table 1). All radiocarbon dates were converted to calibrated ages using INTCAL09 (Reimer et al., 2009). Additional information used to construct the age–depth model included pollen stratigraphy (Carmichael et al., 1990; McAndrews, 1994; Pippert et al., 1996), seismic stratigraphy (Hutchinson et al., 1993), magnetic properties (Carmichael et al., 1990) and previously reported radiocarbon dates (Schroeder and Bada, 1978; Silliman et al., 1996; Anderson and Lewis, 2012) (Table 2). These data were combined to produce a non-Bayesian, linear interpolated age–depth model using the computer program CLAM (Blaauw, 2010), which provides a probabilistic age range for each depth.

A total of 219 ten-cm sections were extracted from the sampling half of the piston cores. The samples were wet-sieved using cold tap water and a combination of four sieve pans (1.00 mm, 500 μm, 250 μm, 125 μm) to recover ostracodes and clams; visible organic matter was also collected when observed on rare occasion. Air-dried fossil material was transferred into Petri dishes, where the biogenic carbonates were identified, ostracodes retained on sieves >250 μm were counted, and clams and individual ostracode species isolated for isotopic analysis. Two species of ostracodes were identified in all three cores, *Candona subtriangulata* and *Fabaeformiscandona caudata*; only adult ostracodes were counted in the abundance measurements. No evidence of transportation (e.g., broken/pitted valves) was observed microscopically for the ostracodes, and hence they are considered to represent in situ deposition. Freshwater clams from the *Pisidium* genus were also present in several intervals.

All stable isotope results are presented using the conventional δ-notation relative to the Vienna PDB standard (VPDB) (Coplen, 1996) for carbon:

$$\delta = \left[\left(R_{sample}/R_{standard}\right)-1\right](\text{in ‰})$$

where R_{sample} and $R_{standard} = {}^{13}C/{}^{12}C$ for carbon, in the sample and standard, respectively. All measurements were made in the Laboratory for Stable Isotope Science (LSIS) at the University of Western Ontario, London, Ontario, Canada.

For each carbonate analysis, approximately 0.05 mg of powdered carbonate was utilized (five to six ostracode valves depending on their individual weight; typically, two to three small clam shell fragments). Only undamaged, adult ostracode valves were analyzed to ensure

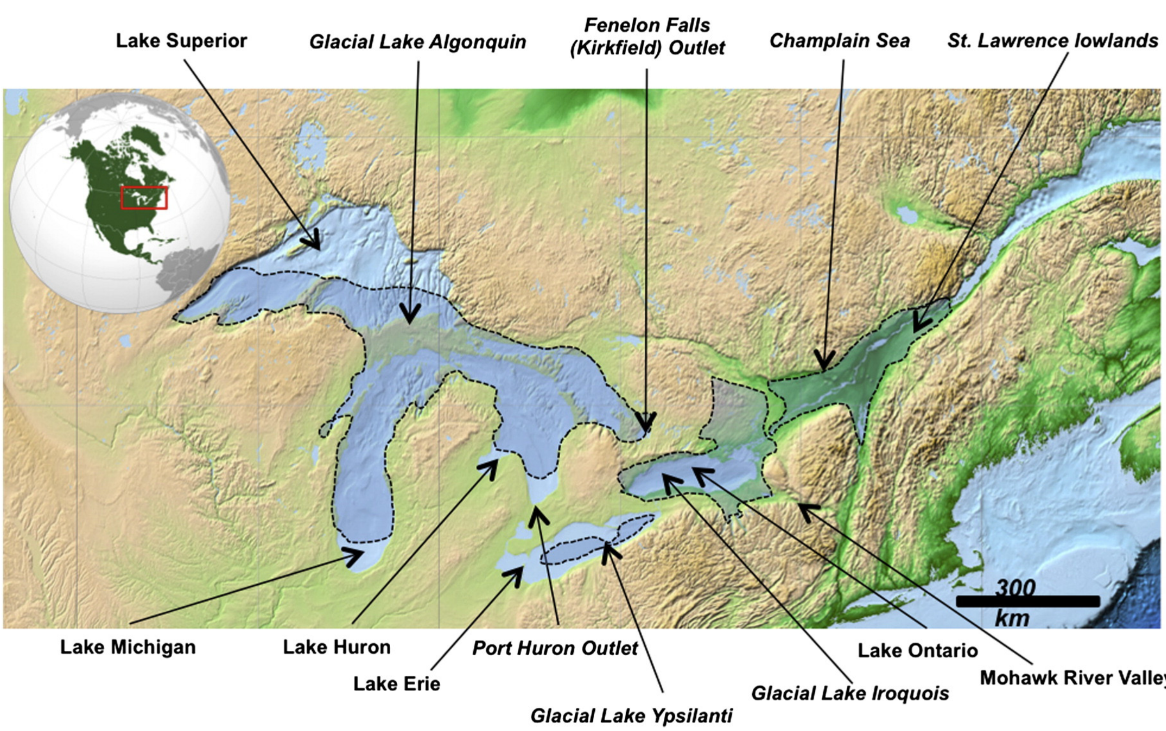

Fig. 1. Digital elevation model (DEM) of the Great Lakes basin, indicating important locations and meltwater outlets.
Figure modified from the National Oceanic and Atmospheric Administration data center website (http://ngdc.noaa.gov/mgg/dem/). Inset map of North America adapted from Wikimedia website (http://commons.wikimedia.org).