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Oxygen-isotope variations in post-glacial Lake Ontario

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ABSTRACT

The role of glacial meltwater input to the Atlantic Ocean in triggering the Younger Dryas (YD) cooling event has been the subject of controversy in recent literature. Lake Ontario is ideally situated to test for possible meltwater passage from upstream glacial lakes and the Laurentide Ice Sheet (LIS) to the Atlantic Ocean via the lower Great Lakes. Here, we use the oxygen-isotope compositions of ostracode valves and clam shells from three Lake Ontario sediment cores to identify glacial meltwater contributions to ancient Lake Ontario since the retreat of the LIS (~16,500 cal [13,300 ^{14}C] BP). Differences in mineralogy and sediment grain size are also used to identify changes in the hydrologic regime. The average lakewater $\delta^{18}O$ of −17.5‰ (determined from ostracode compositions) indicates a significant contribution from glacial meltwater. Upon LIS retreat from the St. Lawrence lowlands, ancient Lake Ontario (glacial Lake Iroquois) lakewater $\delta^{18}O$ increased to −12‰ largely because of the loss of low-^{18}O glacial meltwater input. A subsequent decrease in lakewater $\delta^{18}O$ (from −12 to −14‰), accompanied by a median sediment grain size increase to 9 μm, indicates that post-glacial Lake Ontario received a final pulse of meltwater (~13,000–12,500 cal [11,100–10,500 ^{14}C] BP) before the onset of hydrologic closure. This meltwater pulse, which is also recorded in a previously reported brief freshening of the neighbouring Champlain Valley (Cronin et al., 2012), may have contributed to a weakening of thermohaline circulation in the Atlantic Ocean. After 12,900 cal [11,020 ^{14}C] BP, the meltwater presence in the Ontario basin continued to inhibit entry of Champlain seawater into early Lake Ontario. Opening of the North Bay outlet diverted upper Great Lakes water from the lower Great Lakes causing a period (12,300–8300 cal [10,400–7500 ^{14}C] BP) of hydrologic closure in Lake Ontario (Anderson and Lewis, 2012). This change is demarcated by a shift to higher $\delta^{18}O_{lakewater}$ (~−7‰), driven in part by strong evaporative conditions in the Ontario basin and in part by increasing $\delta^{18}O_{precipitation}$ at this time. The $\delta^{18}O_{lakewater}$ then fluctuated only slightly upon the eventual return of the upper Great Lakes water during the Nipissing phase at 5800 cal [5090 ^{14}C] cal BP (Anderson and Lewis, 2012), after which shelly fauna are no longer preserved in the sediment record.

1. Introduction

The timing and volume of glacial meltwater outbursts from large glacial lakes in North America are crucial to understanding their potential role in initiating and/or enhancing climatic changes such as the Younger Dryas (YD) by disrupting thermohaline circulation (THC) in the Atlantic Ocean. Carlson and Clark (2012) and references therein provide an excellent review of the current understanding of late-glacial North American meltwater hypotheses. In short, Broecker et al. (1989) initially proposed that the YD (12,900 cal (calibrated years) [11,020 ^{14}C (radiocarbon)] BP was triggered by a change in meltwater routing of glacial Lake Agassiz from a southern, Mississippi River outlet to an eastern outlet through the Great Lakes (Fig. 1a). Evidence for eastern drainage of glacial Lake Agassiz at that time has remained elusive, as the opening of a suitable eastern outlet has yet to be established by dating (Clark and Carlson, 2012). There is also a lack of geomorphologic evidence for drainage of glacial Lake Agassiz eastward, such as flood deposits and downcut channels (Teller et al., 2005; Voytek et al., 2012). Northwest drainage of glacial Lake Agassiz to the Arctic Ocean at the start of the YD has also been postulated (Murton et al., 2010; Condron and Winsor, 2012; Fahl and Stein, 2012). A re-evaluation by Clark and Carlson (2012) of the optically stimulated luminescence (OSL) dates provided by

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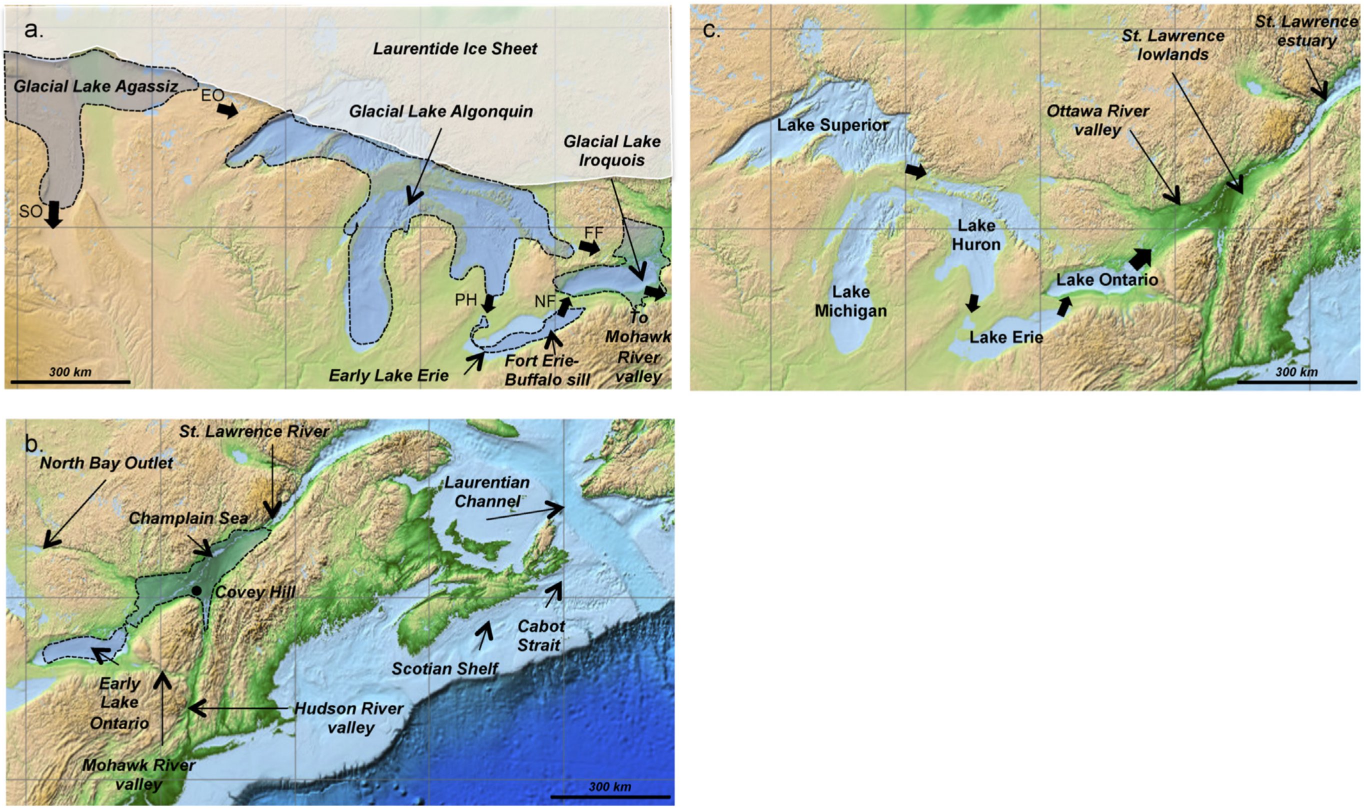

Fig. 1. Digital Elevation Models (DEM) of the Great Lakes basin. Important inlets, outlets and other locations are labelled. (a) Great Lakes basin and position of the Laurentide Ice Sheet at ~13,260 cal [11,350 ^{14}C] BP (Dyke, 2004). Glacial Lake Agassiz (Lockhart phase) drained through the southern outlet (SO) (Leverington et al., 2000). Later in the Lockhart phase and during the Moorhead phase, glacial Lake Agassiz is postulated to have switched from a southern outlet (SO) to an eastern outlet (EO) flowing to glacial Lake Algonquin (Teller, 1985). Early glacial Lake Algonquin's outlet was at Port Huron (PH), which allowed water to enter glacial Lake Iroquois through Niagara Falls (NF) from the Erie basin. Later, during the Kirkfield-Algonquin phase (of glacial Lake Algonquin), water reached glacial Lake Iroquois through the Fenelon Falls (FF) outlet (Eschman and Karrow, 1985; Muller and Prest, 1985). Outflow from glacial Lake Iroquois travelled through the Mohawk River valley, eventually reaching the Atlantic Ocean (Donnelly et al., 2005). (b) Following the draining of glacial Lake Iroquois around 12,900 cal [11,900 ^{14}C] BP early Lake Ontario became confluent with the neighbouring Champlain Sea that inundated the St. Lawrence valley (Anderson and Lewis, 2012). (c) Present configuration of the Great Lakes. All figures modified from the National Oceanic and Atmospheric Administration data center website (http://ngdc.noaa.gov/mgg/dem/).

Murton et al. (2010), however, suggests that the minimum age of a northern outlet was ~12,000 cal [10,240 ^{14}C] BP, much later than the onset of the YD. Carlson et al. (2007) used geochemical proxies preserved in foraminifera collected from the outer St. Lawrence estuary (Fig. 1c) to trace freshwater supply to the Atlantic Ocean. These proxies confirmed a freshwater flux into the Atlantic Ocean and Carlson et al. (2007) concluded that an increase in freshwater flux of 0.06 ± 0.02 Sverdrup (Sv) from western Canada (Lake Agassiz) to the St. Lawrence River would have been sufficient to reduce the Atlantic meridional overturning circulation (AMOC). Levac et al. (2015) used microfossils assemblages (foraminifera, diatoms, dinocysts) from cores recovered from the Cabot Strait, Laurentian Channel and Scotian shelf (Fig. 1b) to suggest meltwater drainage via the St. Lawrence River valley to the Atlantic Ocean before/near the onset of the YD. These findings have reignited discussion concerning possible eastward drainage originating from the Great Lakes region.

Other large glacial lakes (Lake Algonquin and Lake Iroquois) also occupied the Great Lakes basin during the period before the YD. Early glacial Lake Algonquin occupied the Huron basin beginning ~13,850 cal [12,000 ^{14}C] BP as ice retreated northward (Fig. 1a) (Eschman and Karrow, 1985). During this time period, there was brief connectivity between the Erie and Huron basins, allowing water to enter glacial Lake Iroquois, which occupied the Ontario Basin at that time (Fig. 1a) (Lewis et al., 1994). Shortly thereafter, glacial Lake Algonquin's water level decreased as water was diverted through the ice-free, isostatically depressed, outlet at Fenelon Falls (Kirkfield-Algonquin phase) and drained directly into the Ontario basin (Fig. 1a) (Eschman and Karrow, 1985; Lewis et al., 2012). As the Fenelon Falls outlet isostatically rebounded above the outlet at Port Huron, glacial Lake Algonquin began to flow southward into the Erie basin, and then onward into glacial Lake Iroquois (Lewis et al., 2012). At ~12,300 cal [10,400 ^{14}C] BP post-glacial Algonquin lakes began draining through a newly open outlet near North Bay, Ontario bypassing the southern Erie and Ontario basins (Fig. 1b) (Lewis et al., 2012). Meltwater routing during the Kirkfield-Algonquin phase (of glacial Lake Algonquin) through glacial Lake Iroquois could have added an additional ~0.1 Sv of freshwater flux to the Atlantic Ocean (Occhietti et al., 2001). Thus, in addition to putative drainage of Lake Agassiz (adding 0.35 Sv of flux; Teller, 1988), contributions from glacial Lake Algonquin and glacial Lake Iroquois could have contributed to suppression of THC and helped to trigger the YD.

Lake Ontario sediments provide a special opportunity to revisit the timing and extent of eastward, glacial meltwater movement that passed through its catchment from various upstream sources (Fig. 1c), especially within the context of the detailed water level history for the Lake Ontario basin presented by Anderson and Lewis (2012). With this objective in mind, we use the oxygen isotopic compositions of ostracodes valves and clam shells, together with