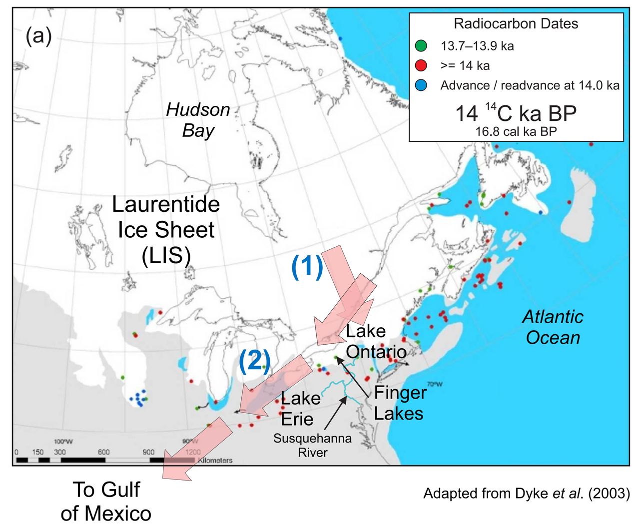
Geological Survey of Canada
Open File 8181

LINKING SUBGLACIAL MELTWATER THROUGH THE EASTERN GREAT LAKES, ONTARIO AND NEW YORK (AT THE TIME OF THE ATLANTIC HEINRICH 1 EVENT) WITH A MELTWATER FLOOD IN THE GULF OF MEXICO ABOUT 13.5 ka (16.2 cal ka)

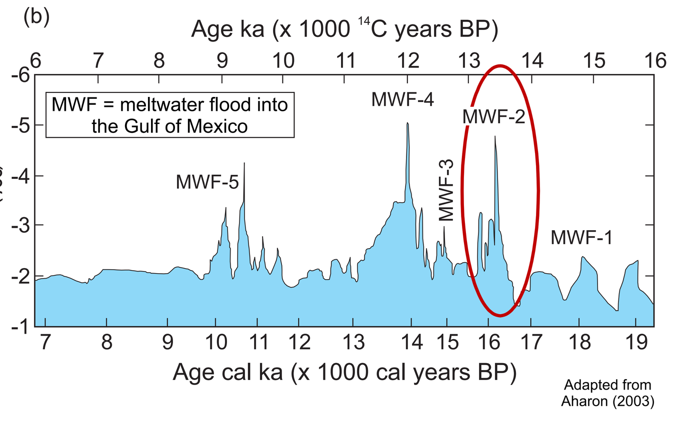
C.F.M. Lewis[1] and B.J. Todd[1]

1. Overview: H1 ice sheet instability induces subglacial meltwater flows

This poster presents a scenario about 13.5 ^{14}C (16.2 cal) ka connecting inferred subglacial meltwater flows west-southwest (WSW) through Lake Ontario and eastern Lake Erie followed by westward transport in glacial lakes to the Gulf of Mexico via Mississippi River valley (a). This meltwater flow through the eastern and southern Great Lakes basins is considered to be a source or partial source for a major influx of meltwater to the Gulf of Mexico about 13.6–13.4 ^{14}C ka identified as MWF-2 (b). The subglacial floods are considered in the context of Laurentide Ice Sheet (LIS) instability, possibly induced by the loss of buttressing support for the eastern margin of the ice shelf between Baffin–Labrador and Greenland during the Heinrich 1 event about 14–13 ^{14}C (17–15.5 cal) ka (c) (Alvarez-Solas *et al.* 2011).



Adapted from Dyke *et al.* (2003)



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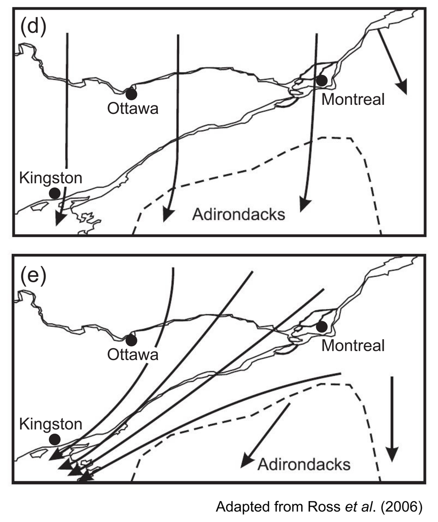
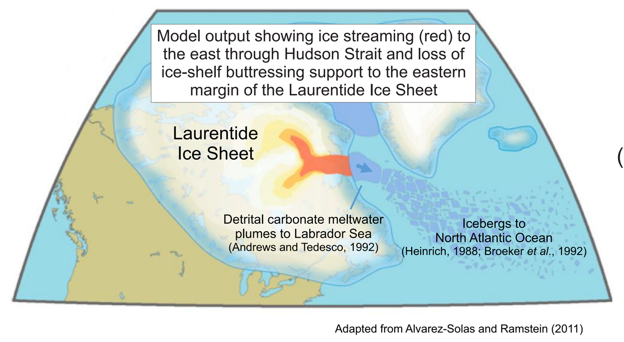
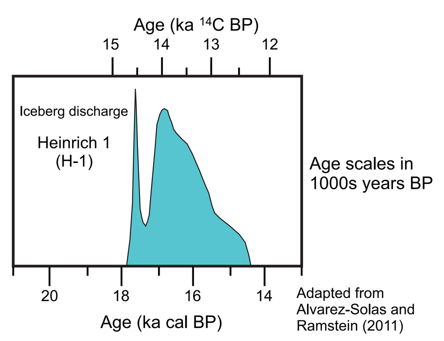


Adapted from Ross *et al.* (2006)

We infer that instability in the LIS induced catastrophic ice and meltwater flows from regional subglacial lakes (Shoemaker 1991, 1999), including subglacial water in Lake Ontario basin (Livingstone *et al.* 2013, Sharpe and Russell 2016). The meltwater first passed southward (1) through a N–S oriented drumlin field (Panel 2) to deposit sediment in the Finger Lakes basin as found by Mullins *et al.* (1996). Subsequently, the meltwater and ice flows switched from a N–S direction (1 in a, above) to a WSW direction (2 in a, above) (Shaw and Gilbert, 1990). This change in direction is consistent with glacier dynamics in the upstream Upper St. Lawrence region where southward flows (d) were found to have switched to a southwestward direction (e) with subglacial meltwater flows through the Montreal–Ottawa–Kingston region (Ross *et al.* 2006).

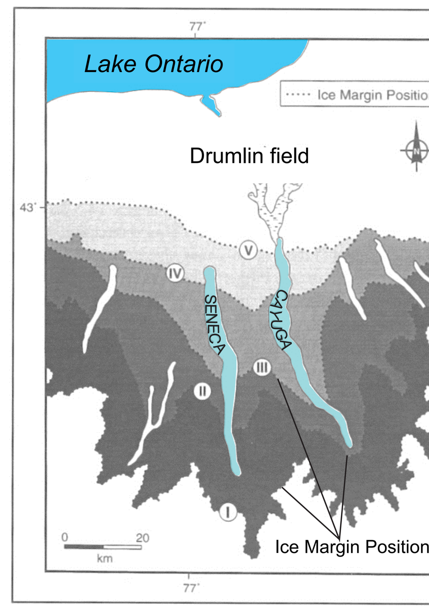


Adapted from Alvarez-Solas and Ramstein (2011)

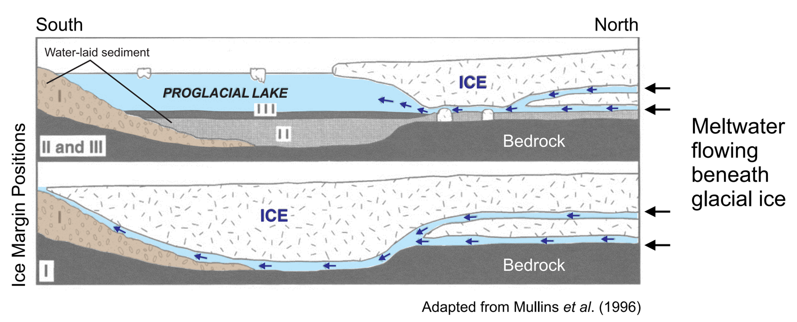


Adapted from Alvarez-Solas and Ramstein (2011)

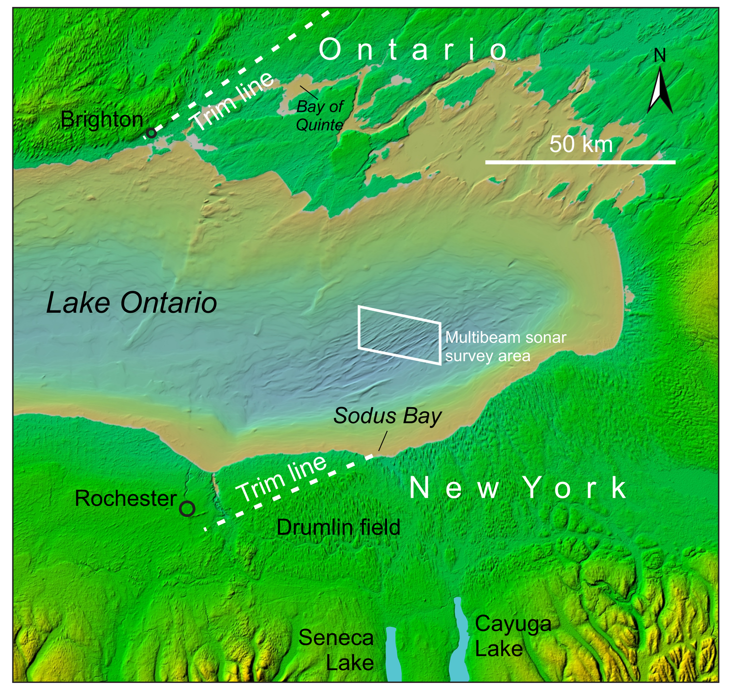
2. Flows of ice and meltwater switch from S to WSW



In the Finger Lakes area, New York, south of a large drumlin field, Mullins *et al.* (1996) found thick accumulations of water-laid sediment which they dated between 14.4 and 13.9 ka (17.5 and 16.8 cal). They suggested that these accumulations were deposited from meltwater flows moving southward beneath the LIS at the time of the Heinrich 1 event. The south-flowing meltwater through the Finger Lakes continued to the Atlantic Ocean via the Susquehanna River.

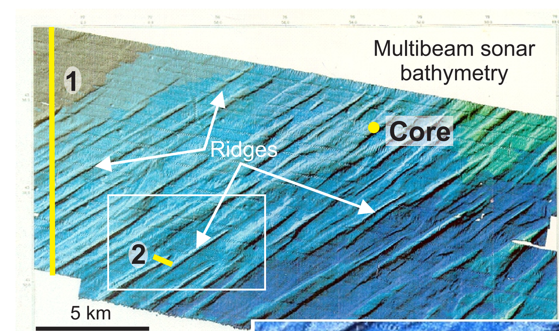


Adapted from Mullins *et al.* (1996)

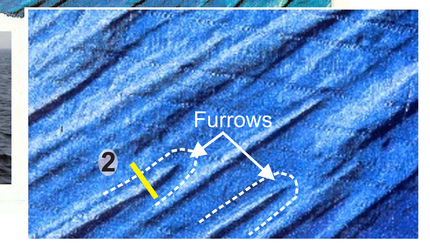


We infer the N to S ice and water flows began to respond more sensitively to lower ground including the axial trend of the eastern Lake Ontario basin as the ice cover was thinned, probably by erosion of its underside as a result of fast meltwater movement. The meltwater and ice flows then switched to a WSW direction, removing N–S oriented features in the basin between WSW-trending trim lines from Sodus Bay to 11–12 km inland of Rochester, New York, on its south side, and from Bay of Quinte past Brighton, Ontario, on its north side.

3. Drumlins in eastern Lake Ontario formed by WSW flows



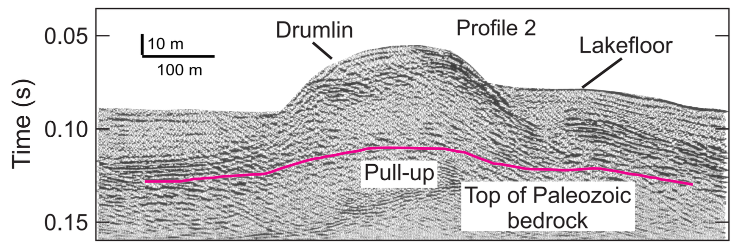

CSS *Frederick G. Creed*



Bathymetric ridges with the same WSW trend as the trim lines in panel 2 are evident in the contoured hydrographic charts for the deepest part of the Rochester Basin in eastern Lake Ontario. It is these WSW ridges or drumlins and downstream features for which we have new data and interpretation.

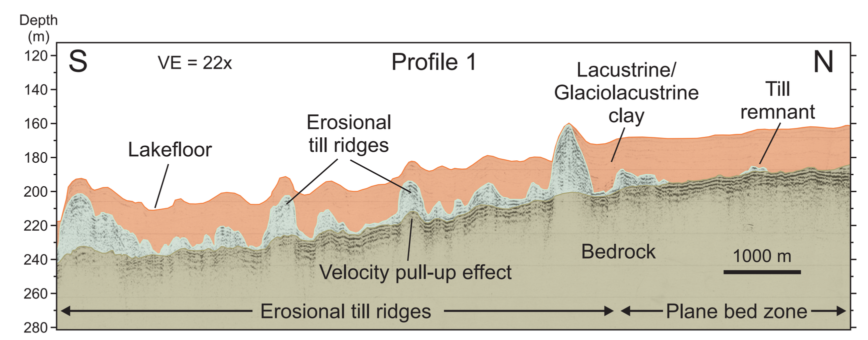
To advance understanding of the ridges, we conducted a multibeam sonar bathymetric survey over 265 km^2 of the Rochester Basin, using a Kongsberg EM1000 sonar system mounted on the survey vessel CSS *Frederick G. Creed* (Mayer *et al.* 1994).

The resulting bathymetric image clearly reveals narrow ridges of finite length, commonly ranging from 1 to 10 km. We interpret these features as buried drumlins as did Hutchinson *et al.* (1993) and implied by Shaw and Gilbert (1990). Notable details of the buried drumlins are horseshoe-shaped furrows that bend around their upstream NE-facing noses and parallel their sides. If these drumlins were exposed to high-velocity meltwater flows, the furrows might be the result of scouring by horizontal vortices in a turbulent flow under the ice sheet (Shaw 1989,1994, 2002).



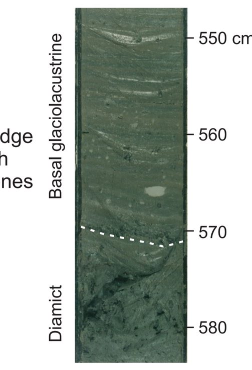
Processed seismic profile:
- Frequency filtering
- Deconvolution
- Trace mix
- Migration
- Velocity modeling

Profile 2 across a drumlin in the SW sector of the multibeam survey area (left) was processed to clarify reflector surfaces and to provide information about the seismic velocity of the ridge-forming material (Coflin *et al.*, 2016). At 2200 m/s the ridge material velocity is definitely faster than that in the overlying silty clay lacustrine sediments which is ~1500 m/s, and slower than typical bedrock velocities in southern Ontario which range from 4000 m/s to 6000 m/s (Hobson, 1960). The bedrock reflector is flat beneath the till ridge; its apparent upward curvature, called velocity pull-up, results from the faster travel time of seismic wave energy in diamict than in the surrounding lacustrine sediment. The diamict velocity is similar to that of the Valley Heads Moraine south of the Finger Lakes, New York (Mullins *et al.*, 1996) and the subglacial Newmarket Till in southern Ontario (Pugin *et al.* 1999), deposited prior to the WSW flows described here. This ridge and others like it are clearly composed of till, not bedrock as interpreted by Thomas *et al.* (1993) and Kerr and Eyles (2007).



Profile 1 reveals the internal structure of sediments along the western margin of the multibeam area (top left). The strong reflector sloping down from N to S is the smooth continuous bedrock surface. (Irregularities are mainly velocity pull-up artefacts beneath till deposits as explained for Profile 2). Prominent ridges of till up to 25 m high, as well as some thin remnants of till, rest on bedrock and are draped by lacustrine sediments up to 20 m thick. Because of significant attenuation of seismic wave energy in diamict sediments, the bedrock surface is not well detected beneath the thicker till ridges.

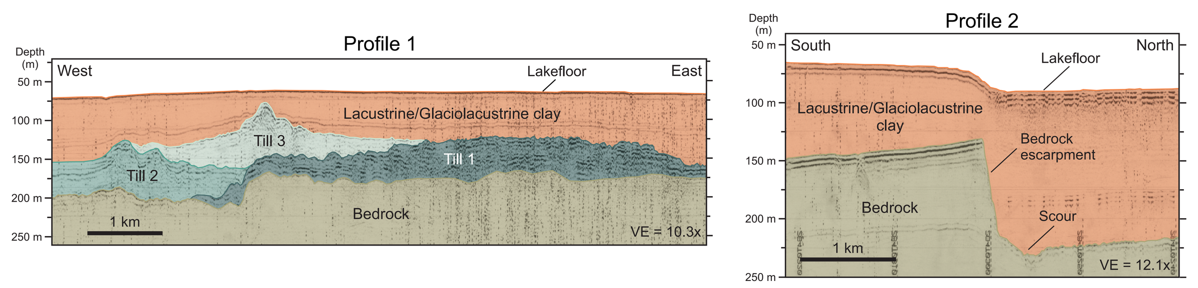
A piston core from a ridge top in the northeastern part of the multibeam survey area (see map top left) confirms that the ridge is composed of a stony diamict overlain at 571 cm core depth with laminated basal glaciolacustrine clay containing dropstones and rip-up clasts.

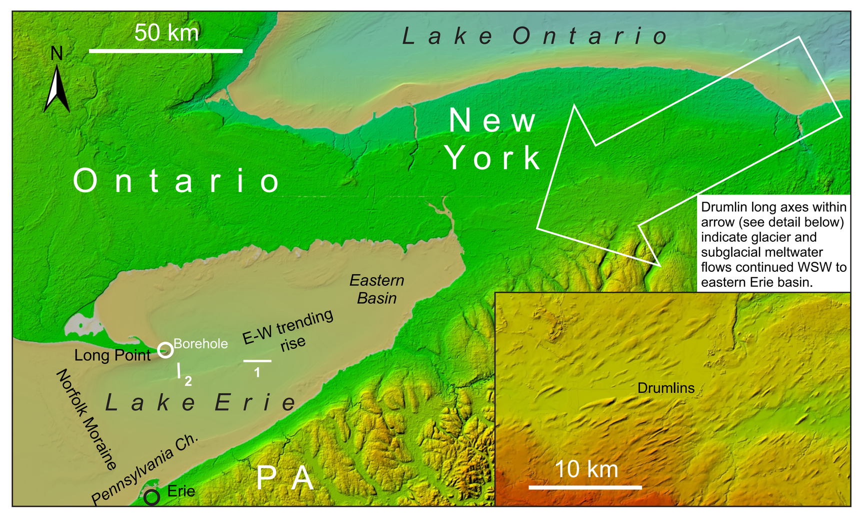


4. Flows continue to the Erie basin and erode till

Drumlins with long axes in the same WSW orientation as in Lake Ontario are evident south of the lake in a 10 m digital elevation model, suggesting that the glacier and subglacial meltwater flows continued toward eastern Lake Erie.

The eastern basin of Lake Erie is terminated at its western margin by the Norfolk Moraine. The present basin lake floor is divided by a distinct E–W trending 15-m rise, reflecting a much larger bedrock escarpment below (the northern eroded edge of the Devonian Marcellus Shale Formation). Long Point is a Holocene spit and was not present at the time of the subglacial flows.



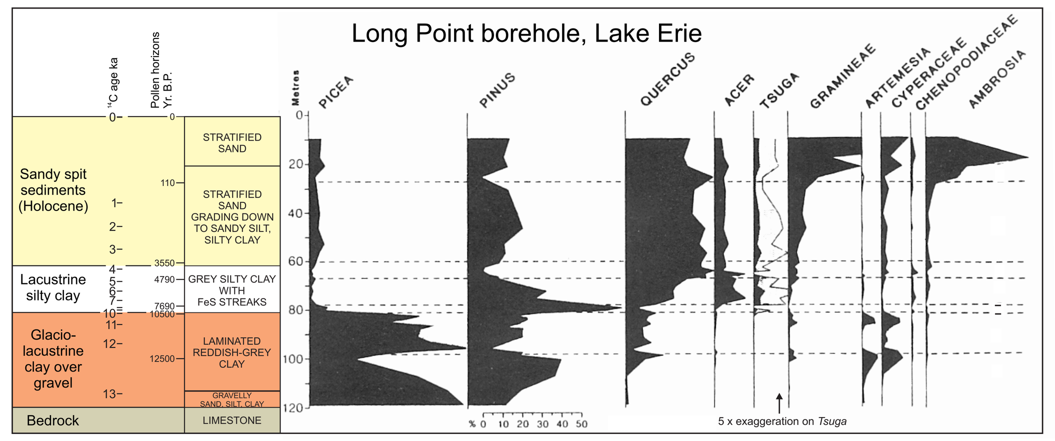


A W–E seismic profile (above left) in the Eastern Basin of Lake Erie reveals a reflective basal till (Till 1) and subsequent tills (Tills 2, 3) atop the eastern crest of the escarpment, suggesting the ice cover was possibly pinned on this elevated part of the basin while meltwater and sediment moved subglacially and southwestward across the basin to the Norfolk Moraine, the ice sheet margin at 13.5 (16.2 cal) ka (Dyke *et al.*, 2003). Coherent internal reflections within the tills may indicate glaciofluvial sediment.

A S–N seismic profile (above right) near Long Point shows the large 75 m high bedrock escarpment that underlies the 15 m rise in the lake floor. A trough in the bedrock reflector at the escarpment base suggests enhanced erosion by concentrated movement of sediment-charged horizontal meltwater vortices in turbulent flow. Till is absent, though remnants of till and coarse sediment are present elsewhere in the basin, and fine-grained glaciolacustrine and lacustrine sediments, indicated by the seismically transparent basin fill, rest on bedrock. The till of the deep Eastern Basin was largely removed whereas several till sheets are known to the west in the Central Basin.

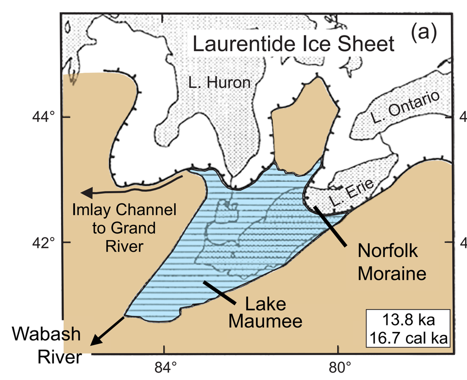
A borehole at Long Point, Ontario, penetrated spit sands over lacustrine and glaciolacustrine sediment over basal sand and gravel lying directly on bedrock. Pollen from the core correlates to onshore ^{14}C-dated records and the age scale at left of the pollen diagram (at right) shows that the removal of till and onset of glaciolacustrine sedimentation occurred prior to 13 (15.5 cal) ka.

Glacial and subglacial sediments likely would have accumulated near the ice margin on the cross-lake Norfolk Moraine. Strong flows may have breached the moraine and initiated formation of the Pennsylvania Channel. Excess meltwater and suspended sediment would have continued to flow westward into the Maumee or Arkona proglacial lakes (see panel 5), between approximately 13.9 and 13.4 (16.8 and 16.1 cal) ka.



Analyst: T.W. Anderson
Adapted from Lewis and Anderson (1992)

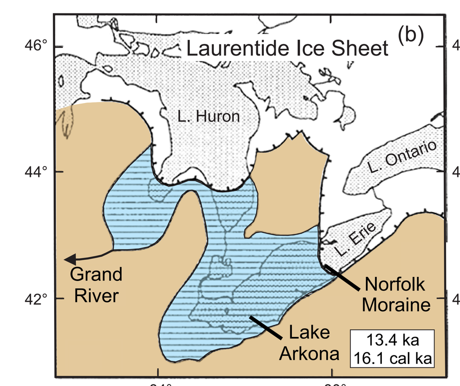
5. Drainage to the Gulf of Mexico



The enhanced WSW subglacial meltwater flows entered glacial lakes, first Maumee in the central and western Erie basins (a), then Arkona which expanded into southern Huron basin (b) (Calkin and Feenstra, 1985). These flows likely increased lake levels and outflows which probably contributed to erosion and enlargement of their downstream valleys, the Wabash River in Indiana (Fraser and Bleuer, 1988) and Grand River in Michigan (Kehew, 1993). These valleys conveyed drainage to the Mississippi River valley via the Ohio River valley, or via the Lake Michigan basin (Lake Chicago) to the Illinois River valley.

The enhanced meltwater flows may have contributed also to a distinction between early and late phases (between 17,530 and 15,690 cal BP) of a lake in the middle Illinois River valley near Havana, Illinois (c), recognized by Curry *et al.* (2014).

In the northern lower Mississippi River valley, enhanced river flow likely incised its channel prior to the deposition of the Kennett braided channel belt (16.1–14.4 cal ka) (c). The Kennett braid belt began deposition when meltwater-enhanced Mississippi River flows subsided during subsequent ice recession which caused eastward drainage of meltwater (Rittenour *et al.*, 2007) and lowering of Erie lakes (Lake Ypsilanti).

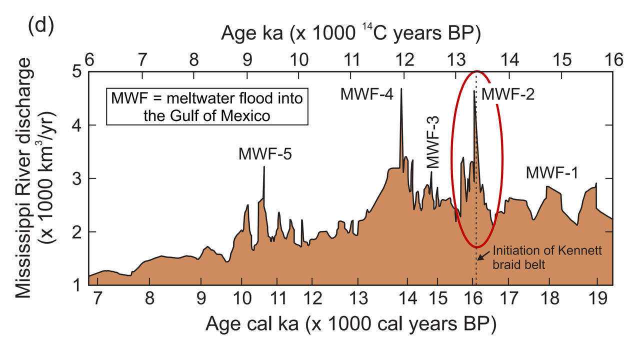


Adapted from Lewis *et al.* (1994) after Barnett (1992)

Base map from NOAA

The enhanced meltwater flux has been detected in Gulf of Mexico cores by the negative δ^{18}O composition of foraminiferal tests as Meltwater Flood 2 by Aharon (2003), who dated the event at 13.6–13.4 (16.4–16.1 cal) ka (1b).

The meltwater flux was inferred as 4600 km^3/year during MWF-2 (d), twice the Mississippi background discharge rate at the time (see red oval at lower right).



Adapted from Aharon (2003)

6. Scenario summary

The events and flows described in this Open File fit a scenario in which Laurentide Ice Sheet (LIS) instability, associated with the H1 event of iceberg discharge to the North Atlantic Ocean, facilitated regional subglacial meltwater flows, first southward, then west-southwestward, leading to rapid transport of meltwater through the eastern Great Lake basins, then southward via the Mississippi River valley to the Gulf of Mexico about 13.6–13.4 (16.4–16.1 cal ka).

At the time of the Atlantic H1 event (~14–13 ka or 17–15.5 cal ka) which initiated widespread instability in the LIS, we suggest meltwater flows discharged southward to deposit sediments in the Finger Lakes basins in New York State beneath the ice. As the ice thinned, meltwater flows and ice switched direction to WSW, consistent with an abrupt switch to SW ice streaming and subglacial meltwater flow through the Montreal–Ottawa–Kingston region upstream of the Lake Ontario basin. In the lake basin, till-cored drumlins were eroded from a basal till sheet by the WSW-moving meltwater and ice.

Similarly oriented WSW drumlins south of central Lake Ontario suggest meltwater flows and ice continued into the eastern Lake Erie basin where previously-deposited till sheets were removed with sediments accumulating in the cross-lake Norfolk Moraine between the base of Long Point, Ontario, and Erie, Pennsylvania. Large flows of sediment-charged meltwater continued westward, possibly initiating a breach in the moraine now known as Pennsylvania Channel. The westward-flowing meltwater through glacial lakes Maumee and/or Arkona likely contributed to higher water levels, larger outflows and erosion of outlet valleys (Wabash River valley in Indiana, and Grand River valley across Michigan into Lake Chicago and the Illinois River valley).

Flows continued by tributaries (Ohio and Illinois River valleys) to the Mississippi drainage possibly adding to meltwater from other sectors of the LIS, contributing to a channel facies or a distinction between early and late phases in a lake in the middle Illinois River valley, and to Mississippi River incision just prior to deposition of the Kennett braided channel belt in the northern lower Mississippi River valley. The meltwater flows discharged to the Gulf of Mexico where they have been detected by highly negative δ^{18}O composition of foraminiferal tests.

Following the meltwater and ice flows, a thinned and weakened ice cover receded and resulted in the onset of eastward-draining Erie and Ontario basin meltwater. The drainage diversion led to low-level Lake Ypsilanti in the Erie basin, and the reduced meltwater flow in the Mississippi River valley induced deposition of the Kennett braid belt.

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