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Comment on "Alternative routing of Lake Agassiz overflow during the Younger Dryas: New dates, paleotopography, and a re-evaluation" by Teller et al. (2005)

1. Introduction

The Teller et al. (2005) paper is of great interest to us and we agree that there is uncertainty about the chronology of hypothesized eastern outlet drainage (Fisher and Lowell, 2005; Fisher et al., 2005a, b; Lowell et al., in press) and thus its potential role in abrupt climate change. First, we note a resurgence of interest in this topic. Wally Broecker, seeking to understand the nature of the field evidence upon which the pattern of meltwater routing is developed, suggested two trips: to the eastern, and then to the other Lake Agassiz outlets. Flights over the southern outlet on the second trip revealed strandlines merging with a well-developed spillway, and in northern Alberta and Saskatchewan (the northwestern outlet), strandlines and boulder gravels lie at the head and within the large Clearwater–Athabasca spillway. As noted by Teller et al. (2005), no such field evidence was found along a suggested pathway for an eastern outlet (K on Fig. 1 of Teller et al., 2005). These preliminary observations made it evident that Upham's (1895) 'probable hypothesis', that water drained from Lake Agassiz eastward into the Superior Basin, had not been adequately tested prior to publication of several papers reconstructing the drainage routing across this region (e.g., Licciardi et al., 1999; Mann et al., 1999; Leverington et al., 2000; Leverington and Teller, 2003; Teller and Leverington, 2004).

To clarify the evolving status on this topic, we comment on the three main points of Teller et al. (2005): (1) the age of deglaciation in the Thunder Bay region; (2) events in the Fort McMurray region; and (3) the possibility of readvances in the Thunder Bay and Fort McMurray regions.

2. Age of deglaciaton in the Thunder Bay region

For climate change issues, it is important to distinguish between testing the existence of an eastern outlet, and testing if any eastern outlet passed meltwater at the right time to trigger the Younger Dryas. At the core of this point is the assumption that no drainage could have occurred until deglaciation (subglacial lateral drainage has not been formally suggested). Because prior reports did not elaborate on the basis for deglaciation age assignments but rather depended upon a series of works leading to the Dyke et al. (2003) reconstructions, it may be informative to explore some of the details upon which age assignments in Teller et al. (2005) are made.

A key event is a drop in water level marked by a sequence of beaches in the main Lake Agassiz basin (Upham, 1895) attributed to opening of an eastern drainage outlet. We were unaware of any dates in the literature from the upper Agassiz strandlines, until we read about the "scant number of dates on the oldest beaches in the Agassiz basin" (p. 1892). Perhaps Teller et al. (2005) could list those dates on the oldest beaches. Until these can be assessed, it is difficult to make any chronological connection to opening of an eastern, or any alternative drainage pathway.

Developing their arguments, Teller et al. (2005) suggest that the evidence for sufficient ice margin retreat allowing eastern drainage at the onset of the Younger Dryas are two basal radiocarbon dates (10,850 ± 100, WIS-1379 and 11,110 ± 100, WIS-1327 ^{14}C BP) on bulk sediment from clay gyttja and clay from Rattle Lake (Björck, 1985). This lake lies outside the trace of the so-called Eagle–Finlayson–Brule Moraines. The gyttja dated consisted of <6% organic matter, and of that, ~20–25% of the organic matter was carbonate as determined by LOI analysis (Björck, 1985; Björck pers. comm., 2005), thus casting doubt on the reliability of these dates. Curiously, caution of these carbonate-rich bulk dates was not drawn out in the Teller et al. (2005) paper, even when they carefully made this distinction when rejecting dates from their Table 1. In addition, because this site lies outside the moraine complex, the moraines are younger than the Rattle Lake age. A glacier standing along the Eagle–Finlayson–Brule Moraines would block the proposed drainage route out the Kaministikwia Valley, regardless of the rebound model employed. Without more accurate chronologic control on the Eagle–Finlayson, Steep Rock and Brule Moraines, little can be said about potential Younger Dryas out flow.

We appreciate that obtaining terrestrial macrofossils for radiocarbon dating is challenging from lake cores, but we question the usefulness of the dates from the new cores. Firstly, it is not clear whether the new radiocarbon dates listed in Table 1 of Teller et al. (2005) are corrected or not for $\partial^{13}C$, or what the $\partial^{13}C$ and LOI values for the gyttja

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dates are. Secondly, a critical assessment of the dates from the six cores collected reveals that the oldest reliable one is 8155±46 ^{14}C BP (AA-58455) from Devils Crater rim, because it is the oldest wood date. Without the ∂^{13}C data, it is unknown whether the older ages from gyttja or fine vegetation contain old carbonate (cf., Karrow and Geddes, 1987). Perhaps then, the best evidence for deglaciation in the study area is shortly before 10,000 ^{14}C BP based on wood (9990±360 ^{14}C BP, GX-11407) from an exposure along the Kaministikwia River, inside the Marks Moraine, just west of Thunder Bay. The lack of any radiocarbon dates older than 10,000 ^{14}C BP in the region is most simply explained by a deglaciation younger than previously hypothesized; a conclusion Teller et al. (2005) suggest but then later question (see Section 4). Therefore their own chronology data and new paleogeographic reconstructions of strandlines projected into the region (Fig. 5 of Teller et al., 2005), imply that the Herman through Tintah strandlines postdate the Younger Dryas, i.e., <10,000 ^{14}C BP. We would argue that without better ice margin chronologies, paleogeographic reconstructions of lake stages, and any implications drawn from such reconstructions, are premature.

3. Events in the Fort McMurray region

As an alternative to an eastward route, Teller et al. (2005) consider a northwestern route through the Clearwater–Athabasca spillway near Fort McMurray, Alberta. Three points about this region merit clarification: (1) the statement advocating additional research at the head of the Clearwater spillway; (2) the stratigraphy of the flood gravel; and (3) the relevance of the new infinite date.

On page 1900, Teller et al. (2005) state that more research is necessary on the deglacial chronology associated with the Clearwater spillway to evaluate two older ages (11,100±150 ^{14}C BP [GSC-4807] from Long Lake and 10,600±120 ^{14}C BP [GSC-4821]) reported by Anderson and Lewis (1992). Long Lake occupies a scour depression into Canadian Shield bedrock at the head of the spillway (Fig. 6 of Fisher and Souch, 1998), therefore basal dates from this lake provide minimum estimates of spillway abandonment. Although more work might be undertaken, we are puzzled why Teller et al. (2005) make no reference to some additional data of which they are aware. For example, beyond the work by Fisher and Souch (1998) who collected a near identical replicate stratigraphy from Long Lake that yielded a younger 9120±50 ^{14}C BP (Beta-104544) age from wood fragments rather than the previous date on bulk gyttja (Anderson and Lewis, 1992), additional results appear in Fisher (2003a) and Fisher (in press). Although the latter is not yet published, Dr. Teller is co-editor for the special issue in which this will appear. In this paper, Fisher (in press) report four additional radiocarbon dates to conclude that the spillway was abandoned by ~9400 ^{14}C BP, with no evidence found for an earlier flood. It is also important to note that older (pre-Late Wisconsin aged) wood is present on the landscape, and that bulk dates, even those not contaminated by carbonate, can be contaminated with older wood fragments (cf., Waterson et al., 2005). Thus, pinpointing the timing of deglaciation has many complicating factors.

Teller et al. (2005) imply that the wood used to establish the 9900 ^{14}C BP age for a northwest outlet flood is from well above the base of the flood gravel in the Athabasca River Valley. In order to correctly interpret the significance of radiocarbon dates, it is critical to know from where the dated material comes. The dates 10,310±290 (GX-5301-II), 10,015±320 (GX-5036-I) and 9860±230 (GX-5031-I) ^{14}C BP are on wood, and 9410±240 (GX-5032) ^{14}C BP is on peat, all from the original Syncrude mine property (Fig. 1) supplied by Neil O'Donnell (pers. comm., 1988) and reported in Smith and Fisher (1993) from the upper scoured zone of the spillway. The second group of dates: 9910±190 (GSC-4302) and 9710±130 (AECV-1183C) ^{14}C BP are from wood in deltaic deposits of glacial Lake

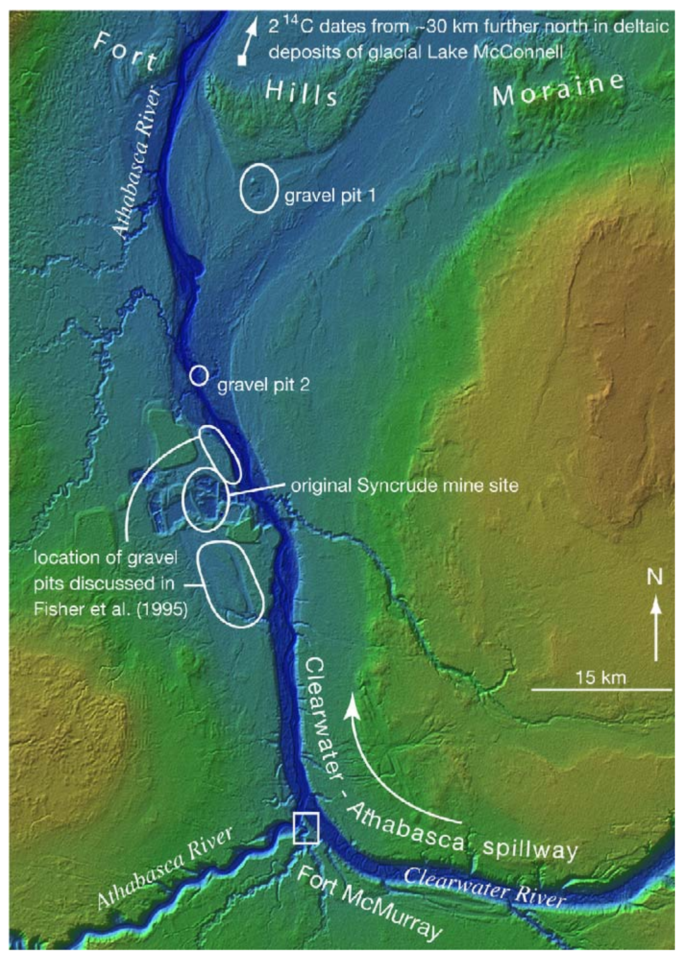

Fig. 1. Digital elevation model of the Clearwater–Athabasca Spillway in northeastern Alberta. The spillway fed a delta building into glacial Lake McConnell, which starts just north of the Fort Hills Moraine. Note location of gravel pits 1 and 2 both visited in September 2003 and that presumably contain the 'lithologically different gravel' (Fig. 2) mentioned in Teller et al. (2005). The greater-than wood date is from gravel pit 1. DEM is based on SRTM 90 m data.

McConnell (Rhine and Smith, 1988; Smith and Fisher, 1993; Fisher and Smith, 1994) (Fig. 1). The reported age of 9900 ^{14}C BP for the northwestern outlet flood was an average of these six dates (rounded up from 9869 ^{14}C BP, Smith and Fisher, 1993). Teller et al. (2005) state that there is more gravel and sand below the dated unit based on ground penetrating radar (GPR) transects reported by Fisher et al. (1995). However, the precise location and stratigraphy of these radiocarbon dates from flood gravel on the original Syncrude property has never been published. Thus, Teller et al. (2005) cannot know that there is more gravel and sand below the dated unit. The GPR sites discussed by Fisher et al. (1995) were from gravel pits *adjacent* to the original Syncrude site (Fig. 1; and Fig. 1B of Fisher et al., 1995).

The second trip to view the Agassiz outlets was to the Fort McMurray region in September 2003. As part of that tour, a short ($<$90 min) visit, led by T.G. Fisher, was made in another gravel pit ~30 km north of the pits discussed by Fisher et al. (1995) at the distal end of the spillway, just south of the Fort Hills Moraine (gravel pit 1, Fig. 1). A second, much shorter stop was at another gravel pit further south (gravel pit 2, Fig. 1). From reading Teller et al. (2005) we learned of a 'lithologically different gravel' (Fig. 2), although from which gravel pit the observation was made was not provided. The 'lithologically different gravel', from which no data or observations were presented, and of which no photograph was provided, is then implicated as 'reflecting an earlier outburst from Lake Agassiz' (p. 1900). Thus, the gravel providing this new radiocarbon age of $>$45,810 (Beta-193988) on wood from gravel pit 1 is not sufficiently documented to allow one to "argue that the scouring was not complete" (p. 1901), or to provide insights about the timing of the flood. In short, Teller et al. (2005) suggest that a greater-than date from

Fig. 2. Flood gravel exposed at gravel pit 1 just south of the Fort Hills Moraine (Fig. 1). It is uncertain if this is the 'lithologically different gravel' of Teller et al. (2005). White arrows indicate blocks of Cretaceous oil sand, the presence of which indicates fluvial scour was into bedrock up flow of this deposit. Jim Teller for scale.

undocumented gravel, viewed on a short field-trip stop, can be used as adequate evidence for an outburst flood at the beginning of the Younger Dryas.

4. Question of readvances

As an alternative to the alternative northwestward drainage, Teller et al., (2005) offer that a readvance of the ice margin during Younger Dryas time buried coarse overflow sediments. They name the Marks Moraine as a key element for the readvance covering hypothesis. Zoltai (1963, 1965) and Burwasser (1977) documented ice-flow directions out of the Lake Superior basin, differences in lithologic character of the drift, and a few exposures where tills appear to incorporate portions of underlying laminated sediments. Indeed Sharp (1953) reported the same relationships further South in Cook County, MN. It is well established that ice flowed out against the northwestern side of the Lake Superior basin. However, where till is exposed, it appears to overlie fine, not coarse, grained sediments as would be expected for the readvance hypothesis.

A second problem is the age of this ice flow. Although it appears to crosscut the southwest regional ice flow pattern, little else can be said about its age. It is commonly correlated to an ice margin on the southern shore of the Lake Superior basin (e.g., Clayton and Moran, 1982) that has most recently been assigned an age of 10,025 $\pm$ 100 ^{14}C BP (Lowell et al., 1999). But a correlation across a major water body (Lake Superior) can be challenging because calving margins have different dynamics than terrestrial margins. And even if that correlation is valid, it does not constrain the geometry of the ice margin during the Younger Dryas. This is critical, as without sufficient retreat of the ice margin at least partway up the Keweenaw Peninsula and off the Upper Peninsula of Michigan, any meltwater that hypothetically was routed eastward out of the Lake Agassiz basin would simply have been deflected back into the Mississippi drainage via any of three possible pathways. Teller et al. (2005) assume that this condition has been met, but a demonstration of that is lacking.

One issue yet to be considered by all those interested in deglaciation of the Superior basin are the seismic profiles from between Isle Royale and the Keweenaw Peninsula showing an off-lapping sequence of major end moraines (Landmesser et al., 1982). These moraines, up to 80 m high, were deposited subaqueously and show systematic retreat with outwash (subaqueous fans) from younger moraines burying older moraines. However, the orientation of these is parallel with moraines west of the Marks Moraine, but perpendicular to the intervening Marks Moraine. Since these moraines show no seismic evidence of being overrun, it is difficult to formulate a reconstruction that accommodates both sets of moraines. On the southern margin of the Lake Superior basin there is chronologic control to reconstruct the ice margin at the end of the Younger Dryas

(~10,000 ^{14}C BP). The lack of evidence to reconstruct ice margins at the start of the Younger Dryas (~11,000 ^{14}C BP) however, identifies future research.

Invoking a glacier margin readvance to hide evidence for a glacial lake drainage event is a potential solution to explain the lack of direct evidence for the drainage. However, we might point out that the hypothesized readvance has regional implications that are not fully considered in Teller et al. (2005).

5. Summary

Documenting relic drainage pathways is challenging. Dates obtained by coring outlet spillway lakes provide age estimates for spillway abandonment (e.g., Fisher, 2003b), but age estimates for spillway initiation are dependent upon knowing the ice margin chronology. To be sure, the water level history in the main Lake Agassiz basin is important to the history of Lake Agassiz, and reconstructions require careful geomorphic, stratigraphic and chronologic analysis. The data from Teller et al. (2005) of six cores and one greater-than radiocarbon date adds little to our understanding of drainage from glacial Lake Agassiz. As pointed out by Karrow (2002), the Lake Agassiz basin is large, the workers few and the reconstructions increasingly complex. Though the drainage of glacial Lake Agassiz has been suggested as a major factor, even a trigger, of abrupt climate change, careful, critical analysis of outlet history and meltwater delivery is required before such a connection can be established.

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Timothy G. Fisher
MS#604, Department of Earth, Ecological and Environmental Sciences, University of Toledo, 2801 West Bancroft Street, Toledo, OH 43606, USA
E-mail address: Timothy.Fisher@UToledo.edu

Thomas V. Lowell
Department of Geology, University of Cincinnati, Cincinnati, OH 45221, USA

Henry M. Loope
MS#604, Department of Earth, Ecological and Environmental Sciences, University of Toledo, 2801 West Bancroft Street, Toledo, OH 43606, USA