Pliocene Drainage in Manitoba and Northwestern Ontario, Canada

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ABSTRACT

This study presents the restored Pliocene topography along northerly trending profiles in Manitoba, northwestern Ontario, eastern North Dakota, Minnesota, and western Wisconsin. A top-of-bedrock slope profile of the Red River/Lake Winnipeg/Nelson River and 19 south-trending landscape topographic and top-of-bedrock slope profiles of the region were made from published elevation data. These profiles reveal a clear change in slope and slope direction (flexure) in the top-of-bedrock elevation. The flexure axis trends southeasterly across Manitoba into northwestern Ontario. The profiles were then tilted southerly by lifting the profiles along the southern margin of Hudson Bay to restore remaining glacial isostatic rebound. When imposing a minimum 80 m of isostatic rebound to the Nelson River/Lake Winnipeg/Red River profile, the northern portion of the profile slopes north but the southern portion of the profile slopes south at 0.01%. When imposing a minimum 60 m of isostatic rebound to all 19 top-of-bedrock profiles, the bedrock slopes north to Hudson Bay northeast of the flexure; however, southwest of the flexure, the southern portions of the 19 top-of-bedrock profiles slope south. We interpret the flexure axis to have been the northern divide of the Pliocene Mississippi River basin in Manitoba and northwestern Ontario and the divide that will lie between the north-flowing Nelson River and south-flowing Red River with future glacial isostatic adjustment.

Introduction

The Mississippi River basin margins are the Rocky Mountains on the west and the Appalachian Mountains on the east, with the question being, where was the preglacial Pliocene Mississippi River's northern basin margin? The north-bounding divide of the Pliocene Mississippi River drainage basin has two quite different interpretations. In one interpretation, the northern divide was south of the US-Canada border (Galloway et al. 2011; Carson et al. 2018; Blum 2019), and the alternative is farther north in western and central Canada (fig. 1; Cox et al. 2014; Cupples and Van Arsdale 2014; Lumsden et al. 2016; Kwon and Van Arsdale 2020). Controversy therefore prevails as to the size of the Pliocene Mississippi River basin. Some researchers argue for a smaller Pliocene basin than the modern basin based on sediment provenance in the Gulf of Mexico (Galloway et al. 2011; Carson et al. 2018; Blum 2019), whereas others contend that the Pliocene Mississippi River basin was much larger than today (Cox et al. 2014; Cupples and Van Arsdale 2014; Lumsden et al. 2016; Kwon and Van Arsdale 2020). Cox et al. (2014) believe that the Pliocene Mississippi River drainage basin was ~50% larger than today. They base their conclusion on Pliocene Mississippi River discharge calculated near Memphis, Tennessee, having been 6–8 times the modern Mississippi River discharge, and their interpretation of the Pliocene paleo-drainage mapped by Pugin et al. (2014; fig. 1). The Pliocene Hatfield-Spiritwood River flowed from southwestern Alberta through southern Saskatchewan and southwestern Manitoba (Pugin et al. 2014). In southwestern Manitoba, the Spiritwood valley is 15–20 km wide, is up to 70 m deep, and has no surface expression because it is buried by Quaternary sediments. From Manitoba, the buried Spiritwood valley extends 500 km south across eastern North Dakota (Pugin et al. 2014). Cox et al. (2014) hypothesized that the Hatfield-Spiritwood River flowed south to the ancestral Minnesota River and then into the Mississippi River. In the Cox et al. (2014) and Cupples and Van Arsdale (2014) interpretations, the northern drainage divide

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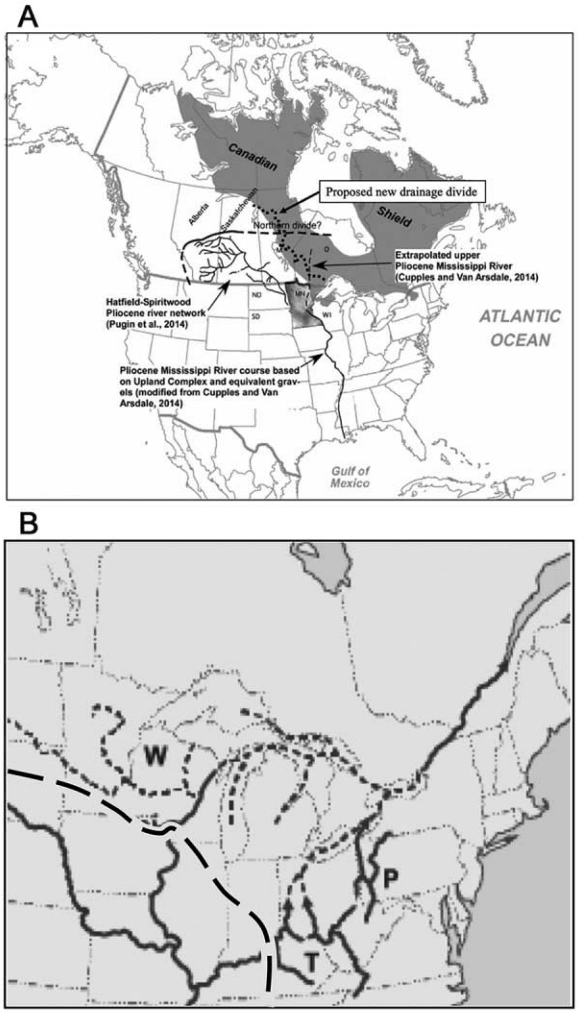

Figure 1. *A*, Preglacial Pliocene Mississippi River basin (modified from Cox et al. 2014). Our interpretation places the Pliocene Mississippi River drainage divide along the northwest-trending dotted line (flexure) in Manitoba and Ontario. Greater depth to bedrock in Minnesota is indicated in dark shading. *B*, Proposed configuration of the ancestral Wyalusing (W), Teays (T), and Pittsburgh (P) rivers as they evolved before Quaternary glaciations. The long-dashed line represents the approximate location of the continental divide (from Carson et al. 2018). A color version of this figure is available online.

of the Pliocene Mississippi River basin locally extended across Manitoba and northwestern Ontario (in Canada this portion of Ontario is called northwestern Ontario and that terminology is used herein; fig. 1). If this more northern drainage divide interpretation is true, then the Pliocene landscape of southern Manitoba and northwestern Ontario would have sloped south to the Pliocene Hatfield-Spiritwood River, a south-flowing ancestral Red River, and ultimately the Mississippi River. This study was undertaken to determine whether the northern drainage divide of the Pliocene Mississippi River extended across Manitoba and northwestern Ontario.

Geology of Manitoba and Northwestern Ontario. The geology of Manitoba and northwestern Ontario consists of Phanerozoic sedimentary and Precambrian igneous and metamorphic rocks (fig. 2) overlain by Quaternary glacial, fluvial, and marine sediments (Prest et al. 1968; Shilts et al. 1987; Johnson et al. 1992). The Hudson Bay Lowland of northern Manitoba and Ontario is within the Hudson Bay basin (HBB). The middle of the HBB contains 2500 m of essentially flat-lying upper Ordovician through upper Devonian shallow marine strata overlain by thin Middle Jurassic, lower Cretaceous, and Miocene terrestrial and shallow marine strata (Pinet et al. 2013; Lavoie et al. 2015). The HBB is locally covered by Pleistocene glacial and fluvial sediments and Holocene marine clay (Skinner 1973; Shilts

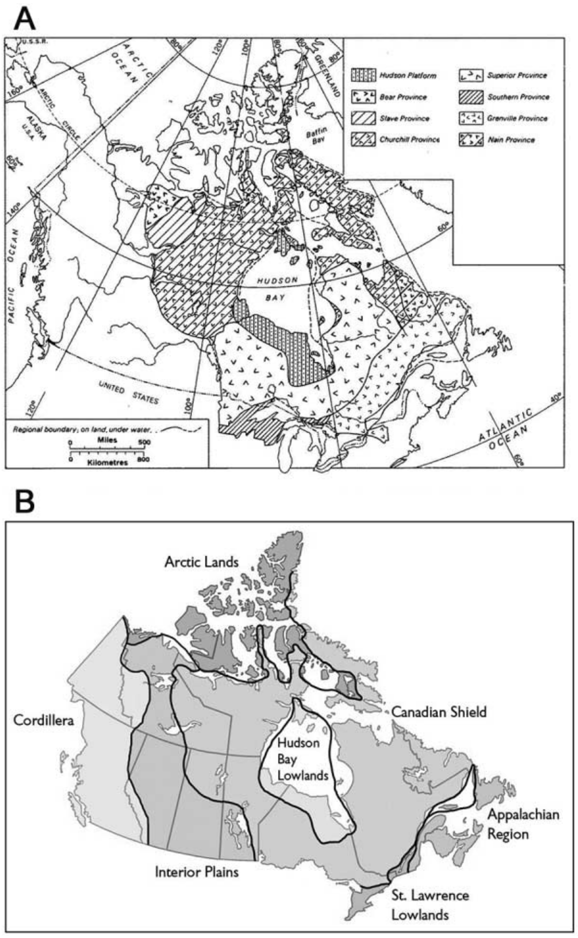

Figure 2. *A*, Bedrock geology of Canada (from Shilts et al. 1987). *B*, Physiography of Canada (from Acton et al. 2015). A color version of this figure is available online.

et al. 1987). Along the southern perimeter of the HBB is the Canadian Shield, consisting of Precambrian igneous and metamorphic rock (fig. 2*A*) overlain (in general) by ≤5 m of Quaternary sediments (Shilts et al. 1987; Thurston et al. 1992). South and west of the Canadian Shield, the sedimentary rock Interior Platform sequence (fig. 2*B*) includes 2270 m of Cambrian, Silurian, Devonian, Jurassic, and Cretaceous strata in the Southwest Upland of Manitoba (Hinton et al. 2007), 1087 m of Ordovician to Devonian strata in Georgian Bay of southeastern Ontario (Liberty and Bolton 1971), 1609 m of Paleozoic, Mesozoic, and Paleogene strata in Minnesota (Mossler 2008), and 6737 m of sedimentary rocks of the entire Phanerozoic era in North Dakota (Murphy et al. 2009). These sedimentary rocks are overlain by Pleistocene glacial and Holocene marine sediments in the HBB that are up to 200 m thick and Pleistocene glacial and Lake Agassiz sediments that are up to 150 m thick in southeastern Manitoba, northeastern North Dakota, northern Minnesota, and northwestern Wisconsin (Fisher 2020).

The Ordovician to Devonian and Cretaceous sedimentary units along the southern margin of the HBB are separated from sedimentary units of the same ages in southwestern Manitoba, North Dakota, Minnesota, and Wisconsin by a 700-km-wide belt of exposed Archean bedrock (fig. 2). The similarity of these Paleozoic and Cretaceous lithologies strongly suggests that the systems were coextensive (Meneley 1964; Norris and Sanford 1968; Sanford et al. 1968; Liberty and Bolton 1971). Pinet et al. (2013) and Lavoie et al. (2015) propose that the Hudson Bay Platform—of which the HBB is a part—is the erosional remnant of strata of an epeiric sea that probably had episodic connections with depocenters of the St. Lawrence Platform, Michigan basin, and Williston basin during the Paleozoic and Mesozoic. Lavoie et al. (2015) correlate the upper Ordovician and lower Silurian strata in the HBB with the Tippecanoe supersequence (sequence of Sloss 1988) of the United States. Episodic connections with marine domains also occurred during the Carboniferous (Tillement et al. 1976) and Mesozoic (White et al. 2000), which is supported by outliers of Cretaceous sedimentary strata on the Canadian Shield in Ontario and Manitoba (Zippi and Bajc 1990; White et al. 2000). The Miocene Bell River is interpreted to have flowed across Canada from the western Canadian Cordillera to the Labrador Sea (Duk-Rodkin and Hughes 1994; Corradino et al. 2022).

Pleistocene erosion of at least 30 m of Paleozoic strata from the Canadian Shield in northwestern Ontario has been proposed based on studies in the Mississippi River valley (Cupples and Van Arsdale 2014). The Upland Complex in the Mississippi River valley is floodplain alluvium of the ~3.6 Ma Pliocene (Odom et al. 2020) Mississippi/Ohio river system whose headwaters are proposed to have been in Paleozoic strata of southern Canada (Cox et al. 2014; Cupples and Van Arsdale 2014; Lumsden et al. 2016). Barnett (1992) argues that the present bedrock surface of the Canadian Shield has not changed substantially from that which existed when Pleistocene glaciation began. Shilts et al. (1987) and Dredge and Cowan (1989) believe that only a few meters to a few tens of meters of Paleozoic strata have been removed from the Precambrian bedrock surface by Pleistocene glacial erosion. Till provenance in the United States also indicates that Paleozoic strata overlaid the shield of Manitoba and Ontario during early Pleistocene. The oldest Pleistocene tills in the United States (1780 ka with Matuyama reversed magnetic polarity) have a significantly lower percentage of crystalline rock clasts derived from the Canadian Shield than younger tills and are dominated by sedimentary rock clasts (Horberg 1954; Boellstorff 1978; Schreiner 1990; Roy et al. 2004; Rovey and Spoering 2020), suggesting that early Pleistocene glaciations stripped Paleozoic sedimentary strata from the shield, exposing Archean rocks as a major source of clasts in middle and late Pleistocene glacial tills (Meneley 1964).

Topography of Manitoba and Northwestern Ontario. Manitoba and northwestern Ontario consist of three regions from north to south: the Hudson Bay Lowland, the Canadian Shield, and the Interior Platform region of southwestern Manitoba where greater relief exists (fig. 2*B*). Except for southwestern Manitoba, the relief of Manitoba and northwestern Ontario is low (<90 m), with most rivers flowing north into Hudson Bay. The largest river system is the Red River (Brooks 2017) that flows north into Lake Winnipeg and the Nelson River that flows from Lake Winnipeg north to Hudson Bay (fig. 3).

The topography of much of Manitoba and Ontario is rising because of glacial isostatic adjustment (GIA; van der Wal et al. 2009). Tilted Lake Agassiz paleo-shorelines in Saskatchewan, Manitoba, northwestern Ontario, Minnesota, and North Dakota indicate Holocene isostatic uplift that continues to occur 33 degrees northeast toward Hudson Bay (Teller and Thorleifson 1983). The north-flowing Red River has decreased in slope by 60% in the last 8000 years (Brooks et al. 2005). This uplift has contributed to the southward expansion of Lake Winnipeg (Lewis et al. 2000). The northern portions of

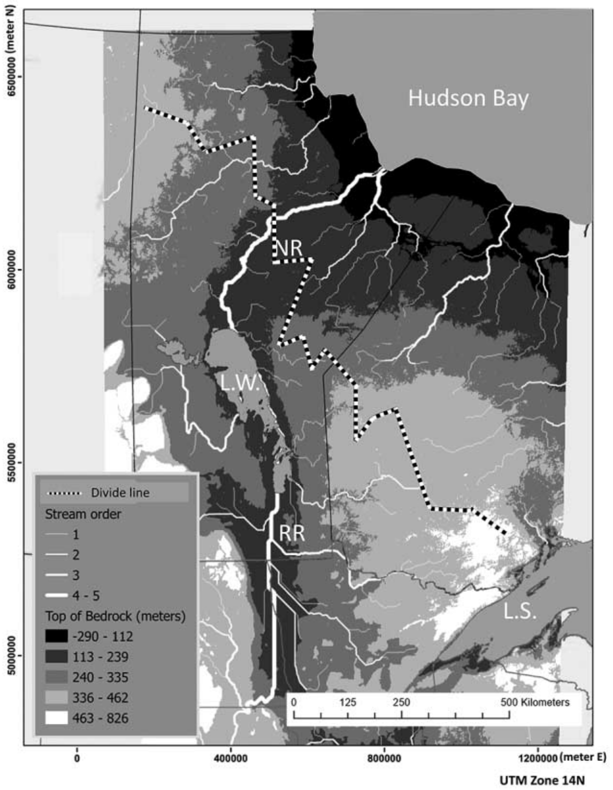

Figure 3. Top-of-bedrock map of Manitoba, northwestern Ontario, northeastern North Dakota, northeastern South Dakota, northern Minnesota, and northwestern Wisconsin. L.S. = Lake Superior; L.W. = Lake Winnipeg; NR = Nelson River; RR = Red River. The dashed line shows the Pliocene Mississippi River drainage divide as determined in figures 5–7. A color version of this figure is available online.

Manitoba and Ontario along Hudson Bay are rising at ~10 mm/y while the United States immediately south of the international border is subsiding ~2 mm/y (fig. 4; Henton et al. 2006; Sella et al. 2007). Remaining GIA is estimated to be 100–120 m along the southwestern margin of Hudson Bay in northeastern Manitoba and northwestern Ontario and diminishes to the southwest and south (Andrews 1968).

Methods

To analyze the surface and top-of-bedrock topographies of Manitoba, Ontario, and the adjacent United States, a topographic analysis was undertaken. Surface topography with a horizontal grid spacing of 30 arcsec (~1 km) was acquired for North Dakota, South Dakota, Minnesota, and Wisconsin from the GTOPO30 data set produced by the US Geological Survey (USGS; http://eros.usgs.gov/products/elevation/gtopo30.html) and for Manitoba and northwest Ontario from the Canada3D elevation data set produced by the Centre for Topographic Information (Sherbrooke), Natural Resources Canada. The bedrock surface elevation data with a horizontal grid spacing of 500 m were obtained for southern Manitoba from the province of Ontario's Ministry of Energy, Northern Development, and Mines (https://www.mndm.gov.on.ca), and top-of-bedrock elevation data for South Dakota, North Dakota, Minnesota, and Wisconsin were obtained from the USGS Scientific Investigations Map (https://pubs.er.usgs.gov/publication/sim3392; Soller and Garrity 2018).

A top-of-bedrock topographic map of the study area was constructed (fig. 3). Where no top-of-bedrock elevation data exist on the Canadian Shield in Ontario and northern Manitoba, surface topographic data were used. Using topographic data where the bedrock surface data are not available is reasonable because these areas of Manitoba and

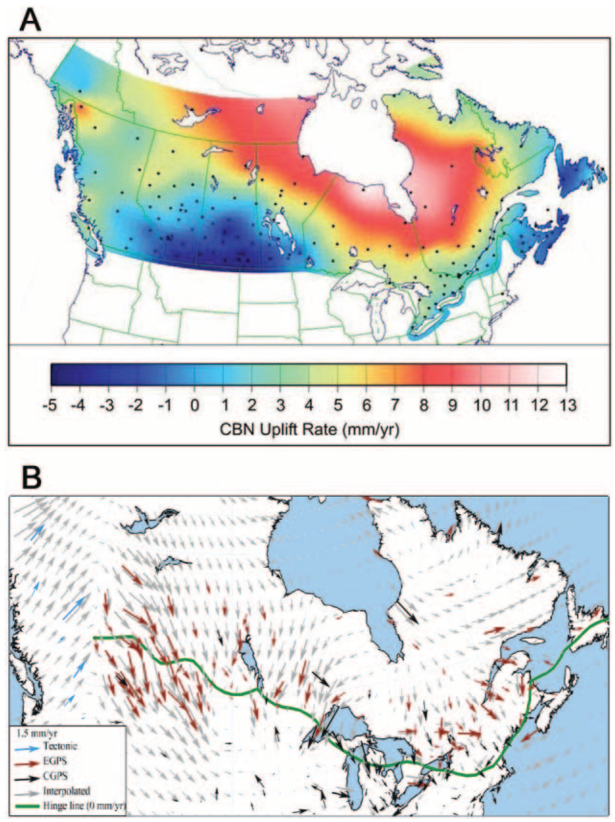

Figure 4. *A*, Current isostatic uplift rates in Canada (from Henton et al. 2006). *B*, GPS horizontal velocities with motion of rigid North America removed, with green line representing the zero line of current glacial isostatic uplift (from Sella et al. 2007). CBN = Canadian Base Network; CGPS = continuously recording GPS; EGPS = episodic GPS.

Ontario have exposed bedrock at the surface with a thin veneer of Quaternary sediments less than 5 m thick (C. Gao, Ontario Geological Survey, pers. comm.). It is acknowledged that, where eskers and moraine ridges occur, the Quaternary deposits can exceed 50 m. However, such deposits are limited in occurrence and areal extent and thus are not considered in this study, which deals with the vast interior of North America. A stream order tool in the hydrology toolbox of ArcGIS Pro was applied to map top-of-bedrock river courses (fig. 3).

The resultant down-valley topographic profile of the bedrock surface beneath the Red River/Lake Winnipeg/Nelson River was also made using the stream order tool in the hydrology toolbox of ArcGIS Pro (figs. 3, 5). Figure 5 illustrates an estimated GIA of 100 m (Andrews 1968) uplifted at the northern end of the river profile at Hudson Bay and linearly decreasing to zero uplift at the US-Canada border. We also made surface and top-of-bedrock topographic profiles along north-trending modern drainage divides (figs. 6, 7). The divide profiles are aligned perpendicular to remaining isostatic rebound contour lines (fig. 4; Henton et al. 2006). The profiles in figure 7 also include the estimated remaining GIA (Andrews 1968) added to the profiles. The remaining GIA varies with profile location (fig. 6). Each numbered profile was uplifted linearly from its southwestern end where its current uplift rate is zero to its maximum uplift at its northeastern end (figs. 4, 6; Andrews 1968; Henton et al. 2006). For example, the northern ends of profiles 1 and 2 were rebounded 80 m and the northern ends of profiles 10 and 11 were rebounded 120 m. In effect, the remaining isostatic rebound was added to the Red River/Lake Winnipeg/Nelson River profile (fig. 5) and drainage divide profiles (fig. 7) by tilting the profiles about their zero-rebounded southern ends. The southern end of the Red River profile in figure 5 was located at the US-Canada border. We chose linear uplift because the precise future uplift is not known across Manitoba and northwestern Ontario and linear uplift has been documented along a portion of the Laurentide Ice Sheet in the Lake Champlain basin (Lewis et al. 2021). Linear regression lines were added to the profiles in figure 7 to better illustrate the regional slopes.

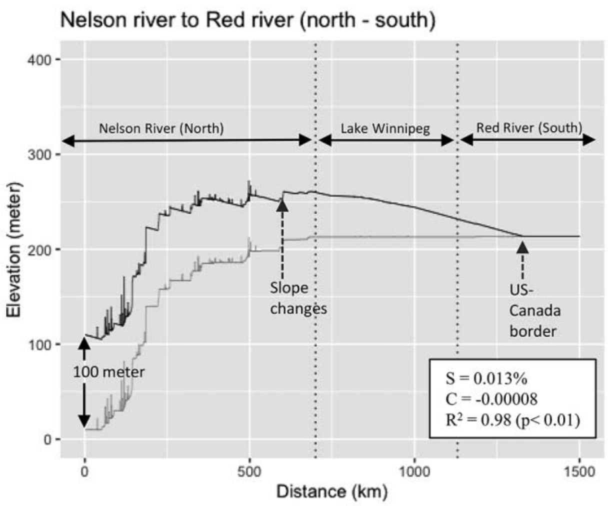

Figure 5. Bedrock topographic profile of the Red River/Lake Winnipeg/Nelson River in lower profile (gray) and with glacial isostatic rebounded in upper profile (black). C = coefficient of slope; S = southerly slope of tilted river profile consisting of Red River, Lake Winnipeg, and southern 200 km of Nelson River. Vertical exaggeration is ×3700.

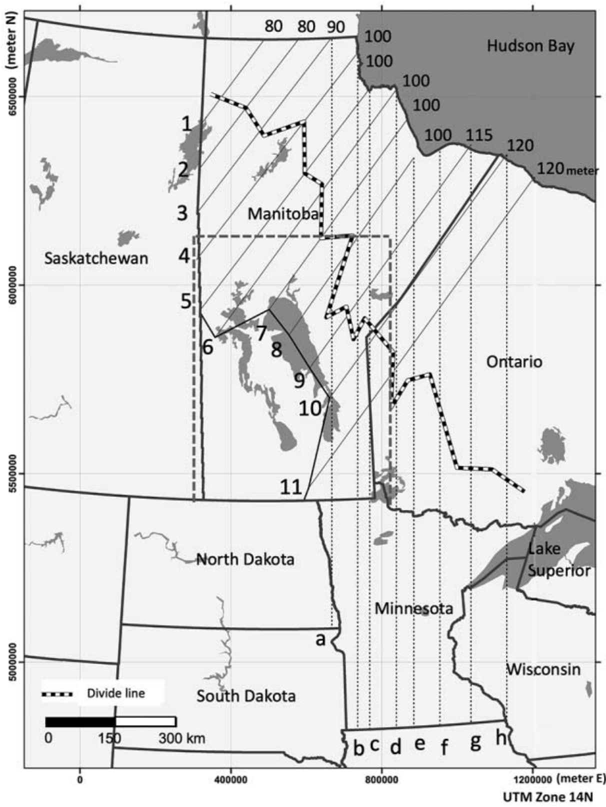

Figure 6. Northeast-trending (solid line) and north-trending (dotted line) topographic and top-of-bedrock profiles in figure 7. Numbers at northern ends of profiles are the estimated remaining glacial isostatic adjustment at that location (from Andrews 1968). The diagonal checkered line is the flexure (drainage divide) across which the topographic and bedrock slopes change from southwest on the southwestern side to northeast on the northeastern side. The dash-outlined box shows the Ontario and Manitoba area where the top of bedrock elevation data exist.

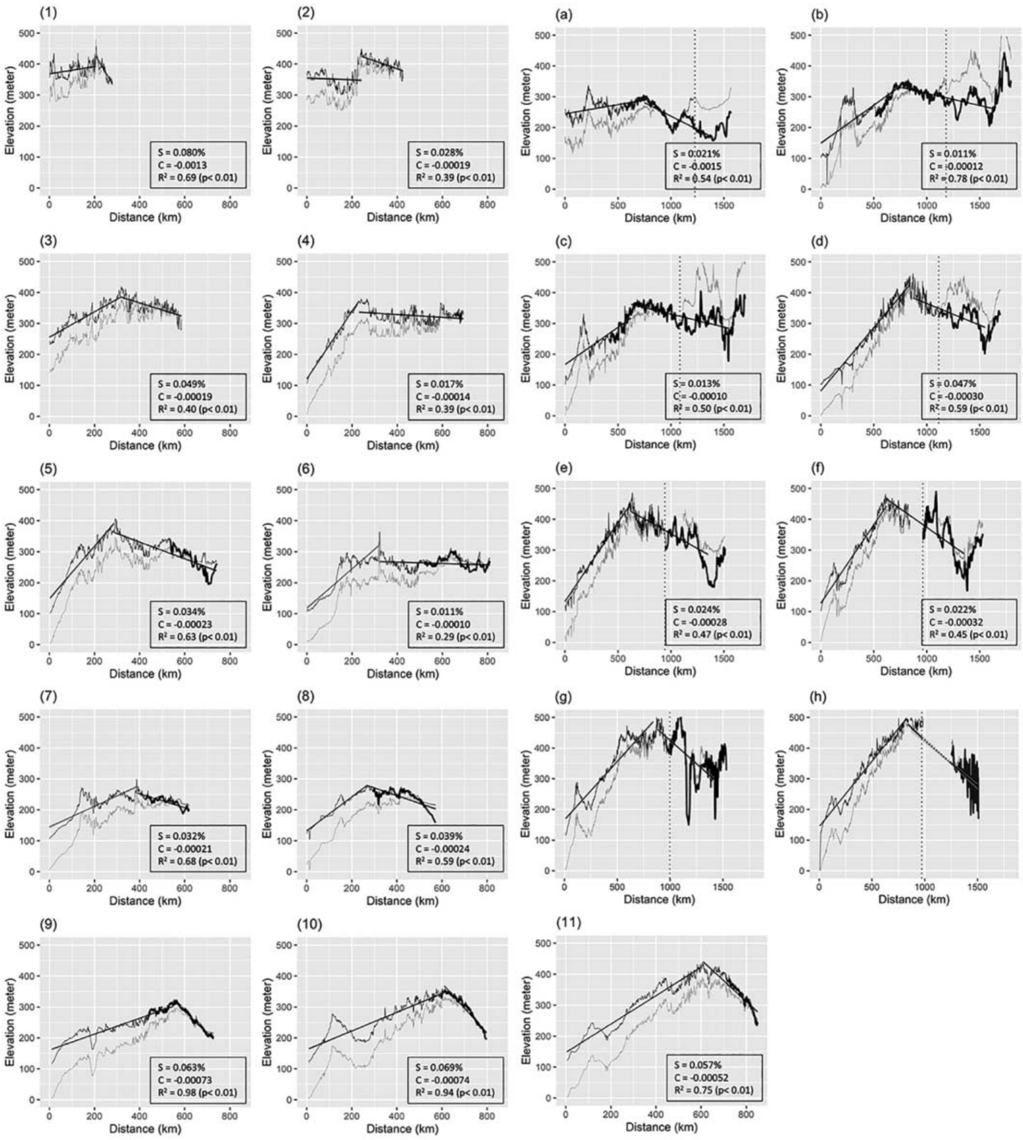

Figure 7. Northeast-trending profiles 1–11 and north-trending profiles a–h located in figure 6. Northeast and north are on the left side of the profiles. Profile lines show topographic (gray), rebounded topographic (thin black), and rebounded bedrock profile (thick black) lines. Linear regression lines ($p < .01$) of rebounded segments meet at (or project to) the flexure line in figure 6. The vertical dotted line (a–h) is the US-Canada border. No elevations are plotted over lakes. In profile h, linear regression is plotted in the southernmost portion of the profile and projected as a dotted line north across Lake Superior to the flexure. Vertical exaggeration is ×1250 in profiles 1–11 and ×2750 in profiles a–h. C = coefficient of southern slope regression line; S = slope of southern regression line. R^2 = goodness-of-fit value of the southern regression line.

Eight lettered (a–h) north-south profiles of eastern Manitoba and northwestern Ontario were made that extend south into easternmost North Dakota, Minnesota, and western Wisconsin (figs. 6, 7). In the north-south (a–h) profiles, the zero point of uplift is the US-Canada border (fig. 4). Gaps in the north-south profiles are lake locations. We have not included an estimate of the total remaining forebulge collapse in the United States that would increase the southerly slope in the US portions of the isostatically restored top-of-bedrock profiles (a–h) in figure 7.

We then determined the minimum amount of remaining isostatic rebound at Hudson Bay necessary to cause a southerly slope of 0.01% (0.0001) to the southern 200 km of the Nelson River/Lake

Winnipeg/Red River profile and the southern portions of each top-of-bedrock profile by tilting the profiles. We chose a slope of 0.01% because that is the average slope of the modern Mississippi River.

Results

A top-of-bedrock topographic profile along the course of the Red River/Lake Winnipeg/Nelson River reveals a very gentle (0.00008, 0.008%) northerly slope along the Red River through Lake Winnipeg and the southern 200 km of the Nelson River (fig. 5). The northern portion of the Nelson River flows more steeply north (0.00028, 0.028%) into Hudson Bay. However, after applying the estimated 100 m remaining isostatic rebound at the northern end of the profile (Andrews 1968), the southern half of the profile consisting of the southern 200 km of the Nelson River/Lake Winnipeg/Red River slopes to the south (fig. 5). When applying a range of uplift values at the northern end of the river profile at Hudson Bay, we determined that it was necessary to lift the northern end of the river profile only 80 m to produce a southerly slope of 0.01% for the southern 200 km of the Nelson River/Lake Winnipeg/Red River portion of the profile.

A topographic and top-of-bedrock (subdrift) elevation map was compiled of Manitoba, northwestern Ontario, South Dakota, North Dakota, Minnesota, and Wisconsin (fig. 3). North- and northeast-trending topographic and top-of-bedrock elevation profiles were made to better visualize landscape surface and top-of-bedrock slopes (figs. 6, 7). Profiles 7–11 (fig. 7) were made first to compare the landscape and bedrock profiles where the data are coincident. Profiles 7–11 show parallelism of the two surfaces, a thin veneer of Quaternary sediments over the northern portions of the bedrock profiles, and a change in slope of the bedrock and overlying landscape profiles occurring at the same location, thus supporting the use of surface topography in the portions of the profiles where top-of-bedrock elevation data do not exist over the Canadian Shield (fig. 6).

The surface topography of northern Manitoba and northwestern Ontario slopes north to Hudson Bay (all profiles); in central and southeastern Manitoba and southern Ontario, the surface topography and the bedrock surface slope south (profiles 1, 2, 9–11, d–h), slope north (profiles 4, 6, 8, b, c), and are flat (profiles 3, 5, 7, a). In easternmost North Dakota and western Minnesota, surface slopes are north but the top-of-bedrock slopes are south (profiles a–c); in central and eastern Minnesota and western Wisconsin, surface and bedrock surface slopes are southerly (profiles d–h; fig. 7). When adding the remaining glacial isostatic rebound to the profiles as predicted by Andrews (1968), slopes and slope directions change (fig. 7). The isostatically rebounded top-of-bedrock profiles reveal a northern slope to Hudson Bay in northern Manitoba and northwestern Ontario and a southerly slope in central and southeastern Manitoba, southern Ontario, eastern North Dakota, Minnesota, and western Wisconsin. The transition from north-sloping to south-sloping in the isostatically rebounded topographic and top-of-bedrock profiles is manifest as a clear change in slope direction (hereafter referred to as a flexure) in the profiles (fig. 7). When connecting the bedrock profile flexure points on a map, the flexure axis extends southeasterly across central Manitoba into northwestern Ontario (fig. 6).

In central and southeastern Manitoba and southern Ontario, current top-of-bedrock profiles slope south and north and some are flat. In eastern North Dakota, Minnesota, and western Wisconsin, current top-of-bedrock profiles slope south (fig. 7). To produce a southerly slope for southern portions of the top-of-bedrock profiles 4, 6, 8, b, c (north sloping) and profiles 3, 5, 7, a (flat) requires a minimum glacial isostatic rebound of 60 m at the northern ends (Hudson Bay) of these top-of-bedrock profiles.

Discussion

Our research attempts to recreate Pliocene drainage directions along a portion of the Laurentian Ice Sheet perimeter before glaciation. Assumptions and simplifications were made in our research. Currently, there are no updated maps of the remaining GIA along the southwestern margin of Hudson Bay, and therefore the estimate by Andrews (1968) was used in this study. We have assumed that the remaining rebound will increase linearly from the zero point of today's isostatic rebound to the southern margin of Hudson Bay. We have not included an estimate of the total remaining forebulge collapse in the United States that would increase the southerly slope in the US portions of the isostatically restored top-of-bedrock profiles (a–h) in figure 7. Furthermore, we do not know how much Paleozoic and/or Mesozoic strata were eroded from Manitoba and northwestern Ontario during the Pleistocene. We also do not know how much the bedrock isostatic rebound remains from the Pleistocene glacial erosion of the bedrock. If 30 m of Paleozoic bedrock were eroded, as proposed by Cupples and Van Arsdale (2014), then approximately 24 m of isostatic uplift would be expected (Molnar and England 1990). Both bedrock histories, however, would mean increased elevation of the Pliocene landscape of Manitoba and Ontario. We consider the isostatically rebounded Red River/Lake Winnipeg/Nelson River and top-of-bedrock divide profiles of figures 5 and 7 to be reasonable approximations of the Pliocene topography of Manitoba and northwestern Ontario. We also believe that the isostatically rebounded topographic profiles in figures 5 and 7 are the topographic profiles to which Manitoba and northwestern Ontario landscapes will evolve, assuming no future continental glaciation. Thus, the flexure axis that passes through Manitoba into Ontario (figs. 3, 6) is the Pliocene and future drainage divide of the Mississippi River and the Pliocene and future headwaters of the south-flowing Red River and north-flowing Nelson River. It remains undetermined whether this flexure axis is structural, isostatic, or erosional in origin. Whatever its origin is, it appears to have been (and will likely become) a drainage divide. Our use of the remaining GIA around the southern margin of Hudson Bay is based on the work of Andrews (1968) and requires a more quantitative determination of remaining isostatic uplift based on measured uplift rates (e.g., Henton et al. 2006; Sella et al. 2007). With more quantitative rebound and Pleistocene erosion data, which may become available in the future, it may be possible to better determine the Pliocene landscape and its future evolution in Manitoba and northwestern Ontario and perhaps around the entire Laurentide Ice Sheet margin.

We interpret that the flexure (divide) ultimately connects with the divide that bounds the Pliocene drainage identified in Saskatchewan and Alberta (fig. 1) by Pugin et al. (2014). Our data do not directly address whether the Canadian portion of the Pliocene Mississippi River drainage basin, herein presented, drained east through an ancestral St. Lawrence River (Carson et al. 2018) or south to the Gulf of Mexico (Cox et al. 2014; Cupples and Van Arsdale 2014; Lumsden et al. 2016). Our calculated southerly top-of-bedrock slope of southern Manitoba and Ontario suggests that the ancestral Red River was a south-flowing river of this region during the Pliocene. Combining the Alberta and Saskatchewan drainage basins (Pugin et al. 2014) with the southern Manitoba and southern Ontario drainage basins herein identified, into the Pliocene Mississippi drainage basin, would increase the Pliocene Mississippi River drainage basin area by ~30% of today's Mississippi River basin area. However, it is possible that Pliocene south-flowing drainage into the Mississippi River also existed farther north in Saskatchewan (figs. 1*A*, 3).

Conclusions

A detailed geophysical determination of the remaining GIA in Ontario, Manitoba, North Dakota, Minnesota, and Wisconsin will provide additional information as to the future drainage and Pliocene paleo-drainage of this region. Such a study would allow testing of the following geologic- and geomorphic-based conclusions from this study.

1) A bedrock flexure trends southeasterly through Manitoba and northwestern Ontario that we interpret to be a portion of the northern basin margin (divide) of the Pliocene Mississippi River.
2) An 80-m GIA uplift of the northern end of the Nelson River/Lake Winnipeg/Red River profile at Hudson Bay will cause a southerly profile slope of 0.01% south of the bedrock flexure (divide).
3) The Red River, Lake Winnipeg, and the southern 200 km of the Nelson River sloped south during the Pliocene and will flow south again when future GIA is restored.
4) A minimum 60 m of glacial isostatic uplift along the southwestern margin of Hudson Bay and coincident southerly tilt of Manitoba and Ontario will result in a southerly slope of the top-of-bedrock south of the flexure herein identified. We propose that the flexure was the Pliocene—and will be the future—northern drainage divide of the Mississippi River in Manitoba and northwestern Ontario.
5) Our estimate of an increased Pliocene Mississippi River drainage basin area (fig. 1) by approximately 30% supports the interpretation of Cox et al. (2014) that the Pliocene Mississippi River, with a discharge much greater than today's discharge, flowed south past Memphis to the Gulf of Mexico.

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