The Edinburg Moraine

Part 2: An Answer to the Problem

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Introduction and review

The Edinburg moraine marks the limit of the last major advance of late Wisconsinan glaciers into the Red River Valley. As described in part 1 (Manz, 2016), the tills (the Falconer and Huot Members of the Forest River Formation) deposited during this event are highly calcareous, an indication of ice entering the Valley from the north subsequent to overriding Paleozoic limestones and dolostones around Lake Winnipeg. Yet the composition of tills sampled on and adjacent to a roughly 30-mile-long upland section of the western arm of the Edinburg moraine bears a closer resemblance to older glacial sediments, specifically the Heiberg Member of the Goose River Formation, derived from more northwesterly sources. Informally referred to as the Inkster member, this till was nevertheless designated a subunit of the Forest River Formation.

It is possible to formulate an explanation for the anomaly that is the Inkster member by reconsidering the origin of the Edinburg moraine. This interpretation of the facts is an extrapolation of recent findings in Minnesota that add to a growing volume of evidence (Margold and others, 2015) that deglaciation of the Laurentide Ice Sheet along its western and southern margins was controlled by processes previously only recognized in a marine environment.

Fast-moving ice

A look at the southern margin of the Laurentide Ice Sheet during late Wisconsinan time (about 18,000 ^{14}C yr BP) reveals several elongate protrusions, or lobes, of ice that extend across the Great Lakes region and well into the eastern Dakotas, western Minnesota and northern Iowa (fig. 1). With no known modern analogs, the nature and origin of these curious structures remained a bit of a mystery until the discovery of ice streams in the Antarctic Ice Sheet in the 1970s (e.g. Robin and others, 1970; Hughes, 1977).

Figure 1. Approximate location and configuration of the central southern margin of the Laurentide Ice Sheet at about 18,000 ^{14}C yr BP according to Dyke and others (2003). The map identifies some of the numerous ice lobes in the region that extended along an irregular front well to the south of the main glacial boundary (see inset). Arrows indicate the direction of ice flow.

Ice streams are fast-flowing currents of ice within an ice sheet (fig. 2). They are large, highly dynamic features with dimensions measured in tens to hundreds of kilometers that extend deep into the interior of an ice sheet via a single, large channel or a network of trunk streams and tributaries. Like their fluvial counterparts, ice streams are drainageways, and whereas they only represent a fraction of the ice margin, they account for as much as 90% of the mass (ice, meltwater, and sediment) discharged by the ice sheet (Bamber and others, 2000).

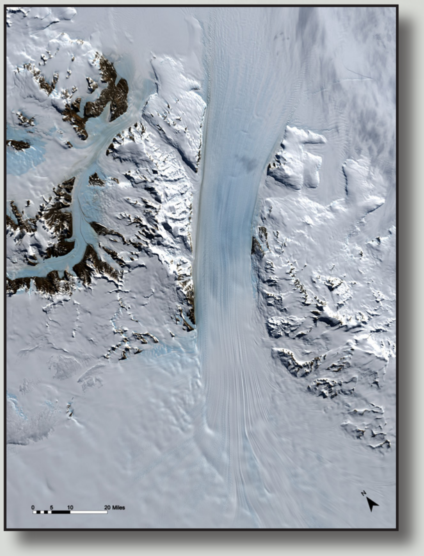


Figure 2. The Byrd glacier is an ice stream in the Antarctic Ice Sheet. More than 100 miles in length, this large, fast-flowing ice stream passes through a deep valley in the Transantarctic Mountains and drains into the Southern Ocean via the Ross Ice Shelf at a rate of about half a mile (0.8 km) per year. The strongly lineated flow pattern and abrupt boundary with the surrounding, slower-moving ice are typical of contemporary ice streams. Flow is towards the top of the image. Image source: NASA Earth Observatory (http://earthobservatory.nasa.gov).

Streaming is the result of a reduction in friction at the base of a glacier by elevated subglacial water pressure. Sustained flow rates are typically on the order of hundreds of meters a year – at least an order magnitude greater than the surrounding, slower flowing ice. The primary control that determines how and where ice streams form is topography but there are others, including geology and the availability of subglacial water that also come into play. Ultimately, it is the complex interactions between all these influences that govern ice stream behavior, much of which remains largely unknown.

Ice streams in the Laurentide Ice Sheet

Because ice streams are critical to the mass balance of modern ice sheets, it is reasonable to suppose that the Pleistocene ice sheets were regulated in much the same way. All contemporary ice streams are marine-based, that is, they terminate at the ocean either directly or via an ice shelf. As a result, when geologists began looking for evidence of streaming in the Laurentide Ice Sheet the focus was on the Canadian Arctic Archipelago and the Atlantic seaboard (e.g., Sharpe, 1988; Hodgson, 1994). However, the intensely streamlined surface imprint characteristic of former ice streams was soon being noticed in areas adjacent to terrestrial ice margins as well (fig. 3). These ice streams had clearly never reached the ocean but instead had terminated on land as lobes that extended well beyond the edge of the ice sheet (Patterson, 1997, 1998; Jennings, 2006).

Figure 3. Streamlined surfaces are indicative of fast flowing ice and are key criteria for the identification of former ice streams. Since they were first recognized in the Canadian Arctic in the 1980s, evidence of approximately 120 paleo-ice streams, distributed throughout the expanse of the Laurentide Ice Sheet, has been located and mapped (Margold and others, 2015). This Google Earth image shows part of the track of a former ice stream near Lac la Biche in east-central Alberta. Flow was towards the southeast (top left to bottom right) and is traceable for about 200 miles to where it enters the Buffalo corridor (see figure 4).

Low relief and predominantly fine-grained shaly bedrock predispose the North American interior plains to ice streaming (Marshall and others, 1996). The ice lobes that spread into North Dakota were fed by several streams flowing from the northwest off the plains of Saskatchewan and Manitoba through a broad, topographic lowland called the Buffalo corridor (fig. 4) (Ross and others, 2009; O'Cofaigh and others, 2010). Streaming was confined to shallow topographic troughs where ice tends to be thicker than on the surrounding uplands. The thicker ice favored pressure melting and the accumulation of subglacial water that remained trapped beneath the glacier by unconsolidated clay-rich sediments derived from the underlying shale. If the resultant increase in subglacial pore pressure was sufficient to overcome the gravitational force (normal stress) exerted by the ice mass, rapid flow was possible by bed deformation, that is, forward movement of the water-saturated substrate upon which the ice essentially "floats." Subglacial water also functioned as a lubricant, which enhanced flow by facilitating basal sliding and promoted further melting by the generation of frictional heat.

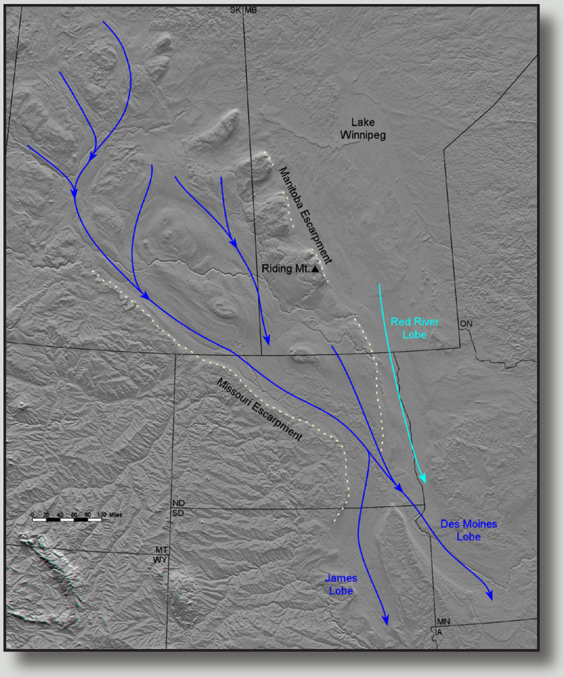


Figure 4. Shuttle Radar Topography Mission (SRTM) image of the Buffalo corridor. The corridor is a broad, shallow trough bounded by the Missouri, Manitoba and Pembina (not labeled) Escarpments. Blue arrows indicate the direction of ice flow and associated lobes are color-coded accordingly. The light blue arrow to the east of the Pembina Escarpment is outside the corridor and denotes the ice stream originating from a catchment area near Lake Winnipeg that fed the Red River lobe. The ice stream that created the landscape shown in figure 3 entered the corridor from the northwest (top left of the picture). (Modified from Ross and others, 2009; and Lusardi and others, 2011.) Image source: NASA/JPL.

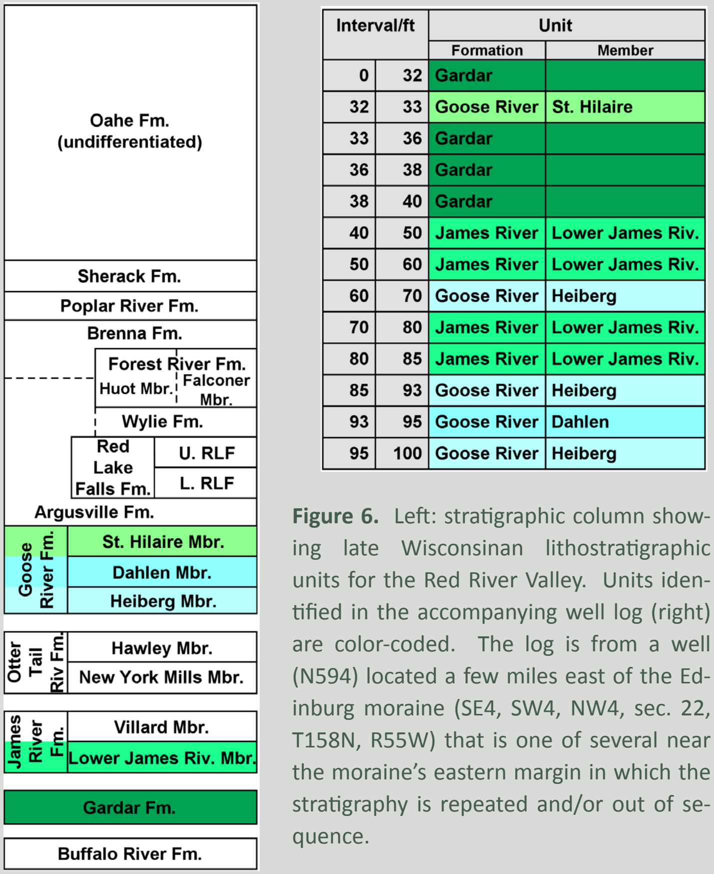
Streaming continued beyond the ice margin for as long and as far as conditions allowed. Radiocarbon dates indicate that the lobes associated with the Buffalo corridor ice streams were active during deglaciation (Clayton and Moran, 1982), over a period of roughly 4,000 years beginning about 14,000 ^{14}C yr BP (Ross and others, 2009). Studies of Des Moines lobe sediments and landforms revealed multiple episodes of stagnation and readvance during this time, when flow was temporarily interrupted by a loss of subglacial water, possibly by drainage or freezing in response to basal cooling, or a reduction in supply from the feeder stream (Lusardi and others, 2011). Subtle variations in the composition of Des Moines lobe till units suggest contributions from different provenances, interpreted as reflecting temporal and spatial shifts in the ice stream trajectory and/or catchment area within the Buffalo corridor; or simultaneous deposition by independent ice streams (sublobes) flowing side by side.

The Villard and Heiberg Members* of the New Ulm Formation (Des Moines lobe till) are lateral equivalents that were deposited by adjacent, coeval ice streams. The contact between the members coincides with a low, broad morainal ridge that marks the shear zone separating the margins of the former ice streams and consists largely of alternating layers of the two tills (Lusardi and others, 2011; Jennings and others, 2012). This interbedding of tills is testament to a recurrent lateral migration of the ice margin, possibly the upshot of a competition for space between two alternately dominant and independently driven ice streams. (It was eventually won by the more southerly of the two streams, which was carrying the Heiberg Member – the uppermost unit in the till sequence.)

The Edinburg moraine

Could competing ice streams account for the tills in the Edinburg moraine? It is certainly feasible given the available evidence. The Heiberg till was deposited sometime before about 12,300 ^{14}C yr BP during a southeastward readvance of the Des Moines lobe that extended across eastern North Dakota and well into Minnesota (Johnson and others, 2016). It is partly overlain by the St. Hilaire and Dahlen Members of the Goose River Formation, which are the youngest of the Des Moines lobe tills, although other units of similar age have also been recognized (Hobbs, 1975; Hobbs and Bluemle, 1987). The Forest River Formation, on the other hand, was deposited by ice that came from a more northerly direction via the Red River lobe, which was fed by a different ice stream originating outside the Buffalo corridor in the vicinity of Lake Winnipeg.

Following deposition of the Goose River Formation, the Des Moines lobe began to decline, receding out of Minnesota and eastern North Dakota at least as far as the western edge of the Red River Valley, and quite possibly beyond. Then, perhaps in response to the same forcing that triggered the reactivation of the Red River lobe, it underwent a minor readvance, depositing the Inkster till on top of Goose River sediments on the uplands above the Pembina Escarpment and for a short distance onto the valley floor, where the two lobes met (fig. 5). It is not clear what happened after that because erosion and reworking of the glacial deposits by the waters of Lake Agassiz have obliterated much of the evidence. The result, albeit more well-defined, was a landform similar in appearance to the shear margin described by Lusardi and others (2011): a broad ridge that diminishes in elevation towards its southern extent. The Edinburg moraine's higher relief may be a manifestation of its apparent disinclination



Interval/ft		Unit	
		Formation	Member
0	32	Gardar	
32	33	Goose River	St. Hilaire
33	36	Gardar	
36	38	Gardar	
38	40	Gardar	
40	50	James River	Lower James Riv.
50	60	James River	Lower James Riv.
60	70	Goose River	Heiberg
70	80	James River	Lower James Riv.
80	85	James River	Lower James Riv.
85	93	Goose River	Heiberg
93	95	Goose River	Dahlen
95	100	Goose River	Heiberg

Figure 6. Left: stratigraphic column showing late Wisconsinan lithostratigraphic units for the Red River Valley. Units identified in the accompanying well log (right) are color-coded. The log is from a well (N594) located a few miles east of the Edinburg moraine (SE4, SW4, NW4, sec. 22, T158N, R55W) that is one of several near the moraine's eastern margin in which the stratigraphy is repeated and/or out of sequence.

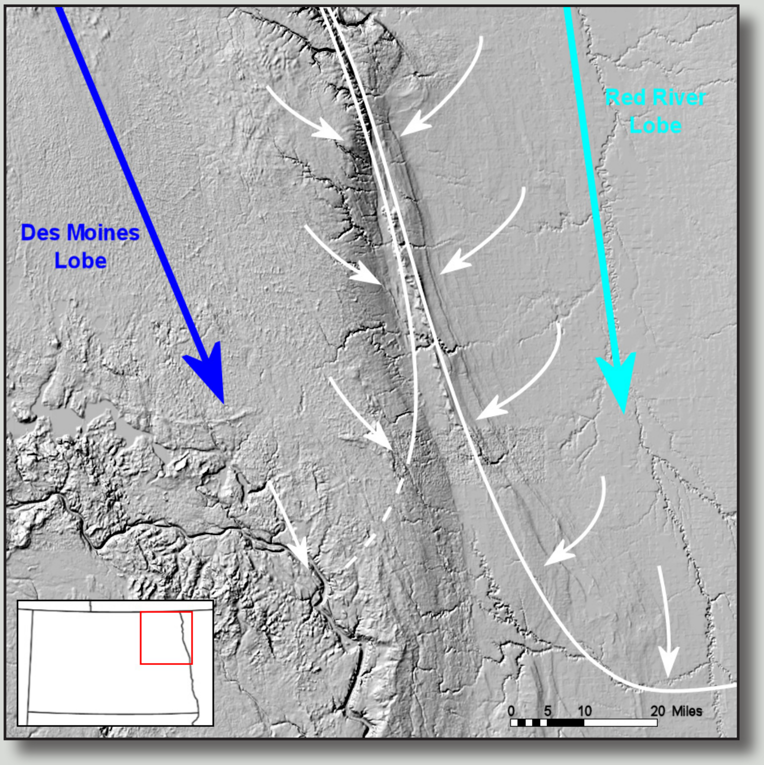


Figure 5. Shaded relief map of the northern Red River Valley from the Canadian border to the Traill-Cass County line showing the possible role of ice streams in the formation of the Edinburg moraine. Colored arrows indicate the general direction of ice flow; white arrows depict the direction of flow at the lobe margins (white lines). The moraine was constructed in the zone between the two lobes as the fluctuating energy of their feeder ice streams forced them into a competition for space. Image source: The National Map (www.nationalmap.gov).

** The Heiberg Member is part of the Goose River Formation in North Dakota but is a subunit of the New Ulm Formation in Minnesota. The Villard Member in North Dakota is part of the James River Formation (See figure 2 in part 1).*

to lateral movement – indicated in borehole data by a general absence of interbedding between the Inkster and Forest River tills (L.A. Manz and K.L. Harris, unpub. data, 2014). If true, this implies that the ice streams fueling the Des Moines and Red River lobes were fairly evenly matched, at least for a time. Notwithstanding, a number of well logs do show repeated and/or reversed sequences of Goose River and, in places, older stratigraphic units, suggestive of glacial thrusting (fig. 6). These observations are supported by cross-sections through the moraine that furthermore indicate the thrusting was towards the west, and therefore the work of the Red River lobe. The overall effect is not unlike the merging of lateral moraines at the confluence of two valley glaciers (fig. 7) although the latter is commonly only a surface feature that does not extend all the way to the base of the ice.

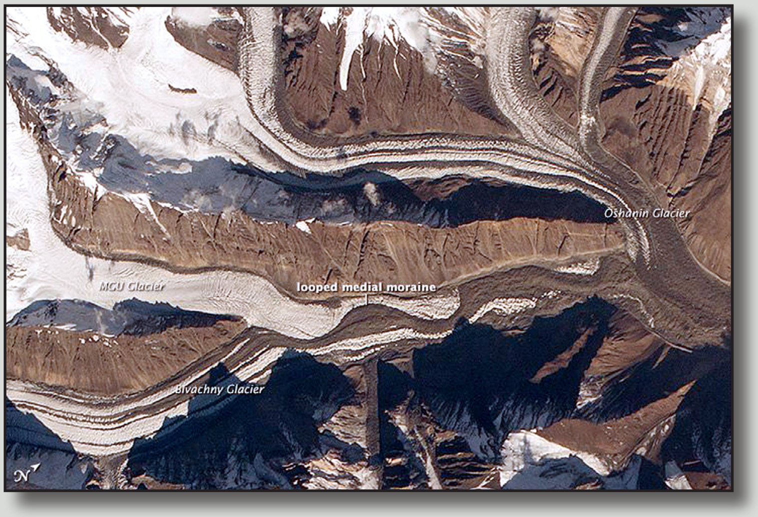


Figure 7. Two glaciers compete for space in the Pamirs Mountains of Tajikistan. The medial moraine below the confluence of the MGU and debris-streaked Bivachny glaciers (upper and lower left respectively) is contorted into loops and folds as it is pushed back and forth by their alternately superior flow regimes. The Edinburg moraine may have formed when a similar scenario was played out between the Red River and Souris lobes during the final major advance of the Laurentide Ice Sheet into northeastern North Dakota. Image source: NASA Earth Observatory (http://earthobservatory.nasa.gov).

Summary

The Edinburg moraine was, indeed, built by the same ice that deposited the Forest River Formation. It is not, however an end moraine as previously thought, but more likely an interlobate or medial moraine, constructed between two independent ice fronts, one advancing from the northwest (Des Moines lobe) and the other from the north (Red River lobe) and fed by ice streams originating deep within the waning Laurentide Ice Sheet. Tills of the Goose River Formation, to which the Inkster member has been reassigned, were deposited by the Des Moines lobe and thrust up and back into a high ridge by the ultimately dominant Red River lobe when the two came together near the western edge of the Agassiz basin.

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