Using LiDAR Data and ArcGIS to Evaluate Subtle Glacial Landforms Associated with the Early Chippewa and Emerald Phase Ice-Margin Positions, Barron County, Wisconsin

Floyd[1], Corrie T., Syverson[1], Kent M., and Hupy[2], Christina M.

[1]Department of Geology, [2]Department of Geography, University of Wisconsin-Eau Claire, Eau Claire, WI 54702-4004, floydct@uwec.edu

Abstract

Glacial landforms in Barron County, Wisconsin, are the result of at least four glacial advances during the Pleistocene Epoch (2.58 to 0.012 Ma). During the early Chippewa and Emerald Phases (Late Wisconsin Glaciation, 31-17 ka), till of the Pokegama Creek and Poskin Members of the Copper Falls Fm. were deposited over till of the River Falls Fm. (Illinoian Glaciation, >130 ka). These tills are all reddish-brown, sandy, and lithologically very similar. Johnson (1986) was unable to map the location of the Emerald Phase ice margin using glacial geomorphology because these till surfaces do not display obvious glacial landforms in the field. Johnson used Late Wisconsin lake sediment in the northwest-flowing Fourmile Creek valley as evidence for the Emerald Phase ice-margin position. In addition, Fourmile Creek makes a 90° bend, and Johnson (1986) attributed this to flow along the Emerald Phase ice margin. LiDAR data obtained from the Barron County Land Information Office was used to evaluate the early Chippewa and Emerald Phase ice-margin positions proposed by Johnson (1986).

High-resolution terrain models have been generated using the LiDAR data. The point spacing of the data is about 3 ft, and compared to ground truth points, the root mean square error (RMSE) of the survey is 0.33 ft. Even with LiDAR's high resolution, primary glacial landforms are lacking on till surfaces in the 90 km² study area.

However, ArcMap's 3D analyst tools and ArcScene's 3D visualization capabilities reveal three distinct fluvial channels incised in the Poskin and Pokegama Creek till surfaces. Longitudinal and cross-sectional profiles were generated to study channel morphology. These meltwater channels are sinuous, 900 to 1000 ft long, and reach maximum depths of 20 ft. They are different from modern channels because they cut across drainage divides, are sub-parallel to the land contour in some places, and typically appear abruptly on the landscape with little area for water catchment. Channel MC-1 is an example of a lateral meltwater channel formed during deglaciation from the early Chippewa Phase ice maximum. Overall, these channels are evidence for a younger, less-modified landscape impacted by the Late Wisconsin Glaciation as compared to the River Falls Fm. till surface from the Illinoian Glaciation which lacks fresh glaciofluvial and glacial landforms. LiDAR data did not reveal a sharp landform-assemblage difference between the Late Wisconsin and Illinoian till surfaces.

Introduction

The glacial landforms in Barron County, western Wisconsin, are the result of at least four glacial advances during the Pleistocene Epoch (2.58 to 0.012 Ma) (Johnson, 1986; Syverson and Colgan, in press; Fig. 1). Sediment in Barron County consists mainly of glacial tills of the River Falls Formation (Illinoian Glaciation, >130 ka) and the Copper Falls Formation deposited during the Late Wisconsin Glaciation (31-17 ka, Syverson et al., 2011). During the early Chippewa and Emerald Phases, till of the Pokegama Creek and Poskin Members of the Copper Falls Fm. were deposited over till of the River Falls Fm. (Figs. 2, 3). These tills are all reddish brown, sandy, and very similar lithologically.

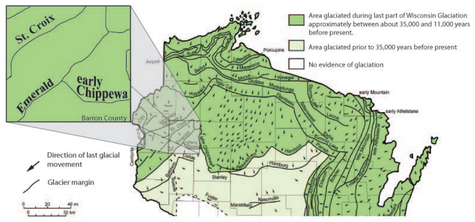

Figure 1. Phases of glaciation in northern Wisconsin and Barron County (enlarged). Ice-margin positions in Barron County are from Johnson (1986, 2000). The early Chippewa and Emerald Phase margins are the major focus of this study. Modified from Syverson and Colgan (in press).

Johnson (1986) was unable to map the location of the Emerald Phase ice margin using glacial geomorphology because the till surfaces do not display obvious glacial landforms in the field. Johnson used Late Wisconsin lake sediment in the northwest-flowing Fourmile Creek valley as evidence for the Emerald Phase ice-margin position (Fig. 2). In addition, Fourmile Creek makes a 90° bend, and Johnson (1986) attributed this to flow along the Emerald Phase ice margin.

Recent advances in LiDAR technology have made the analysis of low-relief landscapes possible (e.g. Smith et al., 2006; Curry et al., 2010). LiDAR data has been used to seek subtle glacial landforms to better delineate the early Chippewa and Emerald Phase ice-margin positions proposed by Johnson (1986) (Fig. 2).

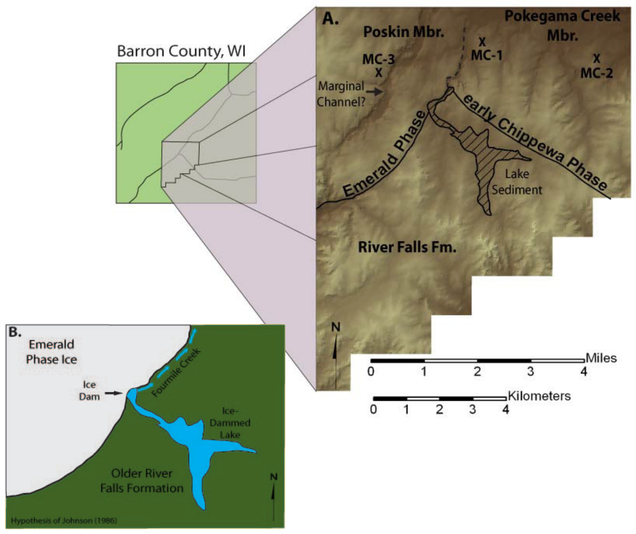

Figure 2. Location of the study area relative to the proposed ice-margin positions of Johnson (1986). (A) Ice-margin positions in Barron County and a LiDAR-derived elevation model of the 90 km² study area (enlarged). The dendritic drainage pattern is more pronounced on the River Falls Fm. and Pokegama Creek till surfaces. Each "x" marks meltwater features discovered by LiDAR terrain analysis. (B) Johnson (1986) used Late Wisconsin lake sediment and the 90° bend in Fourmile Creek as evidence for the Emerald Phase ice margin.

Methods

- Processed LiDAR multipoint data using ArcGIS 10 to generate a terrain model of the 90 km² region (Fig. 2). The raw data has a point spacing of 3 ft and a root mean square error (RMSE) of 0.33 ft (Barron County LiDAR Project Report; Fig. 4).
- Visually analyzed the terrain using 3D analyst tools in ArcMap10. Created 3D models of select features in ArcScene10 to evaluate landform signatures on the River Falls, Pokegama Creek, and Poskin till surfaces.
- Compared the regional topography with LiDAR terrain data, orthophoto imagery, and contour maps to search for primary glacial landforms and to compare the geomorphic expression of the River Falls, Pokegama Creek, and Poskin till surfaces.
- Used ArcMap's 3D analyst tool to generate longitudinal and cross-sectional profiles of select fluvial features to evaluate modern drainage (Fig. 6).
- Field-checked the glaciofluvial landforms discovered using LiDAR data in April 2011. The distribution of glacial landforms was compared to the proposed ice-margin positions of Johnson (1986).

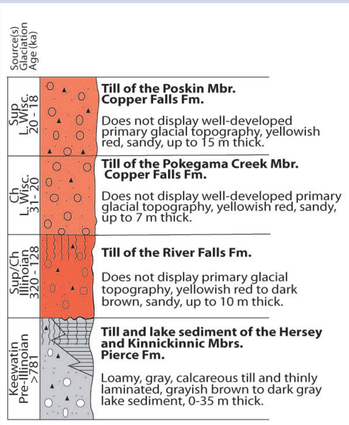

Figure 3. Glacial lithostratigraphic units deposited in western Wisconsin by the Superior (Sup), Chippewa (Ch), and Keewatin (northwesterly provenance) lobes. Vertical scale is approximate. The River Falls, Pokegama Creek, and Poskin till units are very similar lithologically. Modified from Syverson and Colgan (in press).

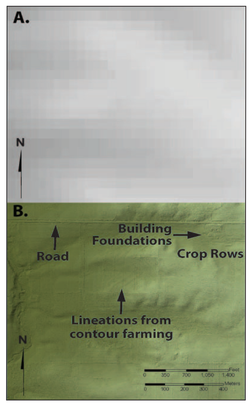

Figure 4. Digital elevation models (DEMs) for the same area generated using different data sources. (A) Topography shown using a 30 m USGS DEM. (B) A LiDAR-derived DEM. LiDAR's sub-meter resolution reveals roads and ditches, building foundations, and crop rows too small to see in a typical 30-meter DEM. For this reason, LiDAR is ideal to locate subtle glacial landforms that cannot be resolved in the field or on maps and aerial photographs.

Results

1. Visual analysis reveals that the dendritic drainage pattern on the till surfaces of the River Falls Fm. and the Pokegama Creek Mbr. is better developed than on the Poskin Mbr. till surface (Fig. 2). The younger Poskin Mbr. surface has been less modified by erosion.

2. Constructional glacial landforms are not observed on the River Falls Fm., Pokegama Creek Mbr., and Poskin Mbr. till surfaces even using the high-resolution LiDAR data.

3. Sharp relict drainage features have been discovered on the Pokegama Creek and Poskin till surfaces, but not on the older River Falls Fm. till surface. Three meltwater channels (MC, Fig. 2) are different from modern channels because they cut across drainage divides, are sub-parallel to land contours in places, and typically appear abruptly on the landscape with little area for water catchment. Two of the channels appear to be lateral meltwater channels (e.g. Benn and Evans, 1998:336; Syverson and Mickelson, 2009) and will be addressed separately below.

MC-1

Channel MC-1, 0.6 mi south and 400 ft east of the intersection of 11 ½ Ave. and 16th St., 2 mi SE of the City of Barron. The channel is 2,000 ft long, up to 20 ft deep, and is incised in Pokegama Creek Mbr. till (Figs. 5, 6, 7).

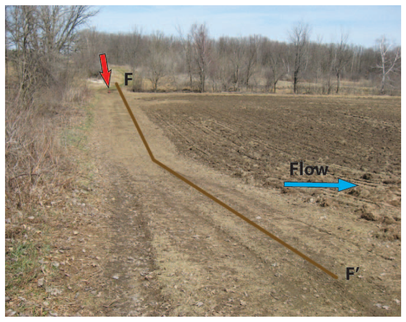

Figure 5. View looking north along MC-1 cross-section F-F' (Fig. 6). The land slopes consistently away from the channel bank in the foreground, so glacial ice must have blocked drainage to the north and deflected water flow to the east (blue arrow). This is conclusive evidence for a lateral meltwater channel. Hiking day pack for scale (red arrow). Photo taken 5 April 2011.

MC-1 (continued)

Figure 6. (B, C, D) LiDAR-derived cross-sectional profiles and Figure 5 show that the midsection of the channel is one sided, so ice formed one wall of the lateral meltwater channel and diverted water flow toward the east (C, yellow dot) rather than down the modern northerly slope direction. Cross sections to the west and east (B, D) reveal a two-sided channel, so meltwater was not necessarily flowing adjacent to the ice margin in those locations.

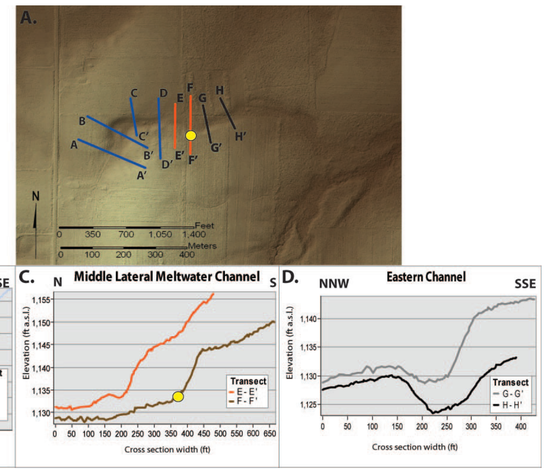

Figure 6. (A) Channel MC-1's meandering shape, abrupt incision, lack of modern water catchment, and sharp definition are evidence for Late Wisconsin glacial meltwater drainage.

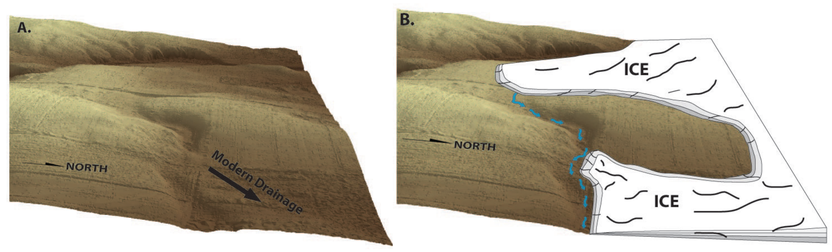

Figure 7. (A) A 3D view of MC-1 looking west up the slope of the meltwater channel (VE 4x). Arrow indicates the modern land-surface slope to the northeast. (B) Schematic diagram illustrating the formation of MC-1. Meltwater was forced to flow east (blue arrows) because glacial ice along the north bank prevented flow down the land-surface slope.

MC-2

Channel MC-2, 0.2 mi north and 0.4 mi west of the intersection of 11th St. and State Hwy. 25, 2 mi SW of the City of Barron. The channel (in two segments) is 1,000 ft long, up to 15 ft deep, and is incised in Pokegama Creek till.

The origin of this channel MC-2 is more complex than that of MC-1. However, MC-2 displays abrupt incision at the channel head with minimal water-catchment area (Figs. 8, 9). The two segments of this channel must have formed quickly as land-surface hills emerged during deglaciation (Fig. 8).

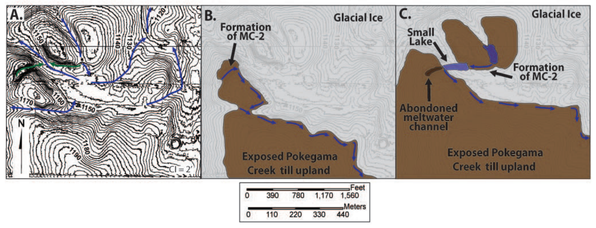

Figure 8. (A) LiDAR-derived contour map showing channel MC-2 (green arrows) and the modern drainage (blue arrows). (B) As land-surface hills emerge from the melting ice, meltwater flowing northeastward incises a 15-ft-deep channel in Pokegama Creek Mbr. till. Water also flows over a drainage divide to the south and then eastward along the ice margin. The western part of channel MC-2 is rapidly abandoned as ice wastes down the land-surface slope and exposes lower pathways for water flow. (C) Ice remains in pre-existing valleys as the ice wastes down the slope. Pooled meltwater to the northeast crosses drainage divide and flows west along the ice margin into a small lake. Water continues to flow southeastward along the ice margin (blue arrows). Both channels probably formed in a matter of weeks, as observed by Syverson and Mickelson (2009) in Alaska.

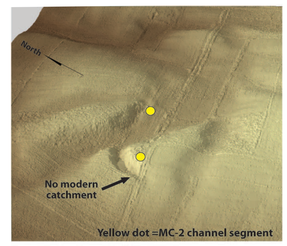

Figure 9. A 3D view of MC-2 looking northeast (VE 4x, yellow dots mark the two channel segments). The valley bisecting the different segments of channel MC-2 was filled with ice when the channel segments were forming (see Fig. 8B, C).

Conclusions

- LiDAR data do not reveal a sharp glacial landform-assemblage difference between the Illinoian and Late Wisconsin Glaciation till surfaces. However, the older River Falls Fm. (Illinoian) and Pokegama Creek Mbr. (Late Wisconsin) till surfaces display a more pronounced dendritic drainage pattern than the younger Poskin (Late Wisconsin) till surface.
- ArcMap's 3D analyst tools and ArcScene's 3D visualization capabilities reveal three distinct fluvioglacial channels incised in the Pokegama Creek and Poskin till surfaces. These channels are evidence for a younger, less-modified landscape impacted by the Late Wisconsin Glaciation. The older River Falls Fm. till surface from the Illinoian Glaciation lacks fresh glaciofluvial and glacial landforms.
- The meltwater channels formed quickly (in several weeks?) as the Late Wisconsin glacial ice wasted.

Acknowledgments

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