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Evidence for early Pleistocene glaciation in central Alberta, Canada

[1]Laurence D. Andriashek and [2]René W. Barendregt
[1]Alberta Geological Survey, Alberta Energy Regulator
[2]Geography Department, University of Lethbridge

Summary

A magnetostratigraphic record from central Alberta has been established for sediments previously assumed to represent multiple continental (Laurentide) glaciations, but for which no pre-late Wisconsin geochronology was available. Polarity measurements of subsamples collected from bore-cores provide the first evidence of early Pleistocene glaciation in the central Alberta Plains. The data reported from these new study sites places the westward extent of Laurentide ice to at least the 760 m contour. Comprising primarily tills and lesser thicknesses of inter-bedded glacio-lacustrine and outwash sediments, the record is extensive, reaching to thicknesses of 300 m within buried valleys. Most of the sampled units are not accessible from outcrop and their sedimentology and stratigraphy is derived from core data only. The lowermost till (Bronson Lake Fm) is reversely magnetized in many of the bore-cores sampled to date. This till is underlain by Empress Fm sediments and/or Colorado Gp shale, and overlain by normally magnetized glacial and interglacial sediments. The Bronson Lake Fm till reveals a weathering horizon at its surface, suggesting that interglacial or non-glacial conditions persisted for some time after its deposition. This new record of early Pleistocene glaciation in central Alberta places the westernmost extent of earliest Laurentide ice ~300 km beyond its previously established limit in the Saskatoon-Regina-Swift Current region of the western Canadian prairies. This new limit is still well short of the maximum limit (1500 m elevation) reached during the Late Wisconsin (late Pleistocene) Laurentide glaciation in the foothills of the Alberta and Montana Rocky Mountains. Ice-extent maps for known glaciations in the Canadian Prairies are presented by combining these new results with previously reported evidence of pre-late Wisconsin glaciations in southeastern Alberta and southern Saskatchewan from fossils and tephras between tills and in pre-glacial sediments.

Introduction

While Late Neogene paleoclimate records depicting isotopic evidence of Pleistocene glaciations are well known from ocean cores (Lisiecki and Raymo, 2005), the timing and extent of early Pleistocene glaciations in the western Canadian Prairies are poorly constrained, apart from sites in southwestern Alberta and northern Montana, where well developed paleosols separate Cordilleran tills of both reversed and normal polarities (Cioppa et al., 1995, and Karlstrom and Barendregt, 2001), and sites in Saskatchewan where dated tephras (fission track ages) constrain the earliest glaciation in Saskatchewan to the early Pleistocene (Barendregt et al., 1998; 2012).

This study forms part of a broader examination of glacial deposits in northwestern North America (Figs. 1 & 2) to better define the ages and extent of Laurentide glaciations during the Pleistocene (Barendregt and Duk-Rodkin, 2011; Barendregt, 2011). With improved age control, glacial deposits can be assigned to the appropriate cold peaks of the global marine oxygen isotope record (Fig. 3). The combination of till magnetostratigraphy with other geochronological controls such as tephrochronology, exposure dating, and/or paleontology, enables glacial events to be placed in a time-stratigraphic framework (Barendregt and Irving, 1998; Jackson et al. 2011). Although the ages and extent of late Pleistocene continental glaciations in the western Canadian prairies are relatively well constrained, they are less well defined for the middle and early Pleistocene. Paleomagnetic measurements of samples collected from five unoriented borecores located in buried valleys and adjacent uplands in north-central Alberta (Andriashek, 2003; Fenton et al., 2006) provide an opportunity for correlation of sediments with the global polarity time scale. These new paleomagnetic data were obtained from an extensive Pleistocene stratigraphy, for which the lower units were assumed to be pre-Illinoian (pre-Saalian) but for which no geochronology was available (Barendregt et al. 2014).

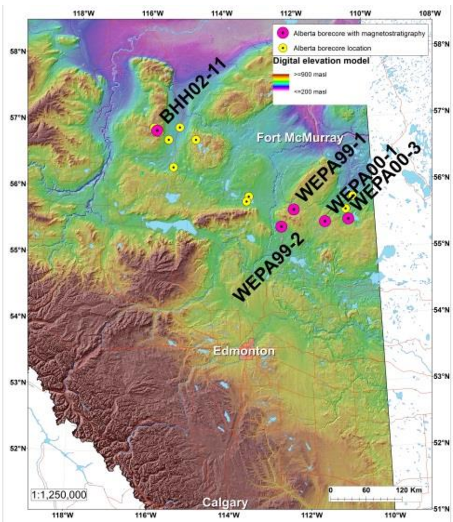

Fig. 1. Bore core locations (pink dots) in north central Alberta

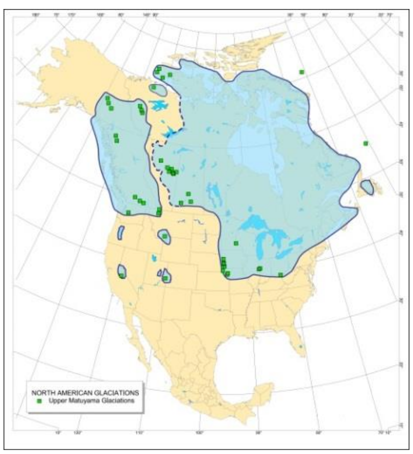

Fig. 2. Proposed Extent of upper Matuyama glaciation in North America

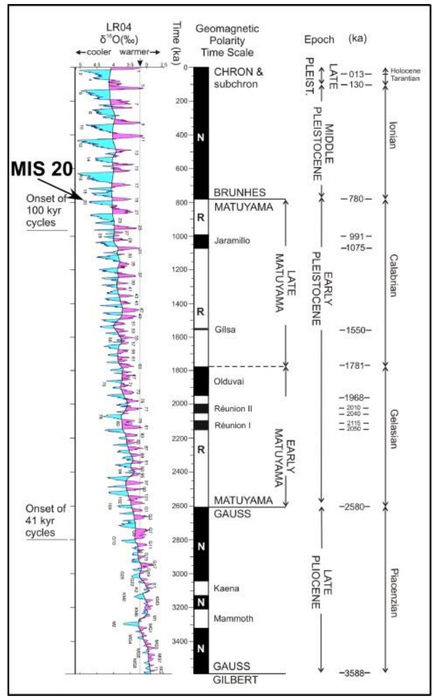

Fig. 3. Geomagnetic polarity time scale and LR04 benthic $\delta^{18}O$ paleotemperature profile. Black/white intervals represent normal/reversed polarity. Marine isotope stages (MIS) on left colored blue for glacials and pink for interglacials

Method and Examples

Major till and inter-till units were described and sampled from archived borecores (unoriented) (Fig. 4). The lowermost (oldest) tills (in contact with preglacial sediments [Empress Fm] or bedrock [Upper and mid-Cretaceous fms]) were sampled in greater detail to determine whether these are reversely magnetized, and thus of early Pleistocene age (Fig. 3). Carbide steel bits (2.54 cm diameter) were used to collect subsamples from cores for which downhole directions are known. Subsamples were placed into polycarbonate cylinders. Four to six samples were collected at depth intervals selected from each of the major till units, with more frequent sampling intervals in the Bonnyville and Bronson Lake fms (lowermost tills) to establish polarity boundaries within the sediment sequence. The polarity data for the 5 borecores were obtained from 166 samples (Fig. 4), of which 141 (85%) gave coherent results (Figs. 5 & 6). Of these, 73 samples were reversely magnetized and 68 samples were normally magnetized. The reversely magnetized samples all came from the Bronson Lake Fm., while all normally magnetized samples were from the Bonnyville, Marie Creek, and Grand Centre fms. The majority of samples (83%) were collected from tills, while a small number (17%) were from inter-till silt and clay beds. Thirty-seven samples, not restricted to any particular unit, gave incoherent results, probably due the coarseness of the sediments. Where the sediment grains are predominantly coarse, the mechanical energies begin to outweigh the aligning influence of the geomagnetic field on ferromagnetic particles (Butler, 1992). The mean inclination values (adjusted through Fisher block rotation analysis for unoriented core segments [Enkin and Watson, 1996]) are −49° for reversed samples, and +48° for normal samples, pointing to inclination flattening for both polarities. The Geocentric Axial Dipole field for the sampling latitude (55.5°N) is 71°, so a mean inclination of 49° suggests an average flattening of approximately 20 degrees. Inclination flattening has been reported in many borecore sediments, especially tills (Verosub, 1977; Verosub et al., 1979; Roy et al**.,** 2004; Barendregt, 2011; Barendregt, 2012).

Fig. 4. Paleomagnetic subsampling of core

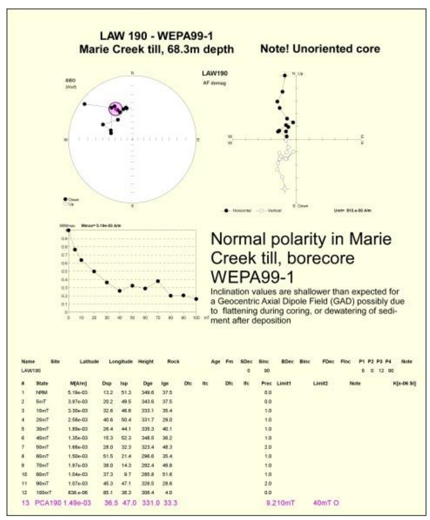

Fig. 5. Orthogonal plot of normally magnetized till of the Marie Creek Fm, borecore WEPA99-1

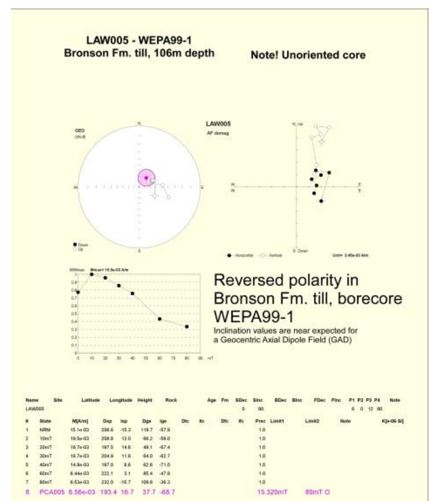

Fig. 6. Orthogonal plot of reversely magnetized till of the Bronson Lake Fm, borecore WEPA99-1

Conclusions

Based on these new data, at least four Laurentide (continental) glaciations are recognized in Alberta, of which the earliest occurred in the late Matuyama Chron (early Pleistocene). A single, reversely magnetized till unit (Bronson Lake Fm) occurs near the base of five sampled borecores and is overlain by three normally magnetized till units (Bonnyville, Marie Creek, and Grand Centre fms, respectively, Figs. 7 & 8). If the Bronson Lake Fm till was deposited by the same ice sheet that deposited the reversely magnetized Mennon till (Sutherland Gp) to the east (near Saskatoon and Regina, Saskatchewan), then it can be assigned to Marine Isotope Stage (MIS) 20, based on bracketing tephra dates and polarity data reported at those sites (Barendregt et al., 2012). MIS 20 spans the interval from approximately 0.83–0.79 Ma (Fig. 3). This places Laurentide ice into northern Alberta prior to the late Pleistocene. It is likely that multiple glaciations occurred in northern Alberta between early and late Pleistocene. It also likely that drainage networks were rearranged during each successive glaciation, accounting for numerous but discrete buried valleys and associated deposits. Stacking of fluvial deposits during these glacial events resulted in a labyrinth of superposed aquifers that are now important to the development of Alberta's hydrocarbon resources. Long periods of erosion may have removed all or part of the sedimentary record of pre-Wisconsinan glaciations in many places, accounting for the difficulty in mapping their extent. Interestingly, the most complete stratigraphic records are not found in buried valleys, but on adjacent uplands. This possibly reflects (1) erosion of pre-existing sediments in buried valleys by evolving fluvial systems, and (2) subglacial dewatering across buried valleys, which facilitates the accretion of greater thickness of glacigenic sediment (diamict) on adjacent uplands.

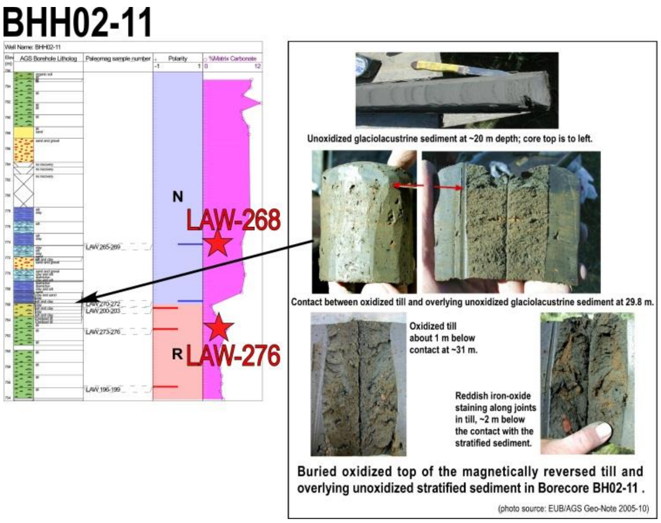

Fig. 7. Oxidized, reversely magnetized, low carbonate till of the Bronson Lake Fm, overlain by normally magnetized high carbonate Marie Creek Fm till and lacustrine clay

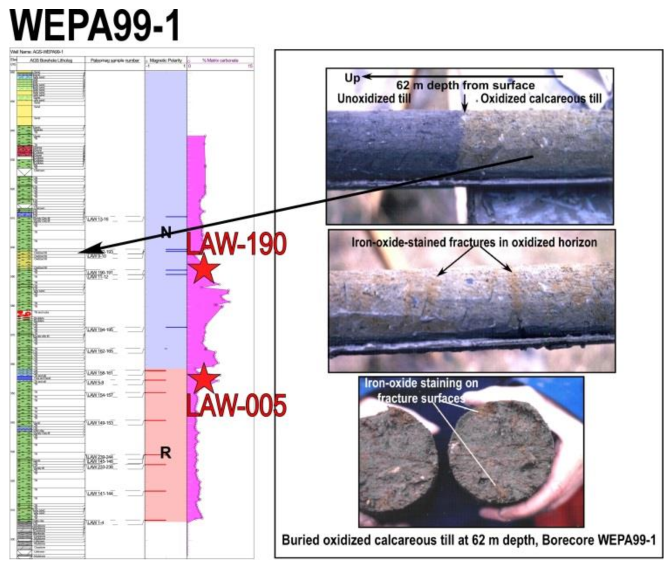

Fig. 8. Reversely magnetized, low carbonate till of the Bronson Lake Fm overlain by oxidized high carbonate Marie Creek Fm till and Grand Centre Fm till, both normally magnetized

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