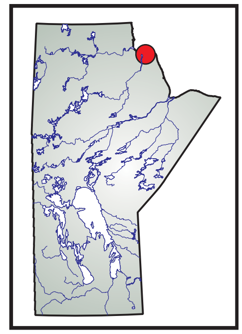
GS-3 Far North Geomapping Initiative: palimpsest bedrock macroforms and other complex ice-flow indicators near Churchill, northern Manitoba (part of NTS 54L16)

by M.S. Trommelen and M. Ross[1]



Trommelen, M.S. and Ross, M. 2011: Far North Geomapping Initiative: palimpsest bedrock macroforms and other complex ice-flow indicators near Churchill, northern Manitoba (part of NTS 54L16); *in* Report of Activities 2011, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 29–35.

Summary

A 30 km stretch of well-exposed bedrock on the southwestern coast of Hudson Bay, near Churchill, Manitoba, was thoroughly examined for erosional ice-flow indicators. Low-lying Churchill quartzite outcrops inland and higher rocky bluffs near the shoreline preserve a complex palimpsest record of whaleback drumlins and roches moutonnées commonly grooved in numerous orientations. Crosscutting relationships and position on bedrock outcrops suggest ice flowed over time to the north-northwest to northwest→south→west→east-southeast→southeast→south→southwest→west-southwest with late deglacial flow between east and east-southeast and west and northwest. These ice-flow indicators likely record more than just the late Wisconsinan glaciation and were formed by a mix of Keewatin and Quebec-Labrador ice sources.

Introduction

Bedrock outcrops accessible from Churchill, Manitoba, were visited during summer 2011 to look for bedrock-inscribed ice-flow evidence. This project was initiated because recent mapping in the nearby Great Island–Kellas Lake area (Trommelen et al., 2010) has shown that the ice-flow record was significantly more complex than previously mapped. Questions arose regarding the behaviour of the Laurentide Ice Sheet (LIS), especially in the Churchill area (Figure GS-3-1), where it has been suspected that paleoice flowed from both the Keewatin Sector to the northwest and the Quebec-Labrador region to the east (Shilts, 1980; Boulton and Clark, 1990; Dredge and Nixon, 1992). The presence of complex ice-flow indicators at Churchill were hinted at in Dredge (1992) but never mapped in detail (Dredge and Nixon, 1981a, b).

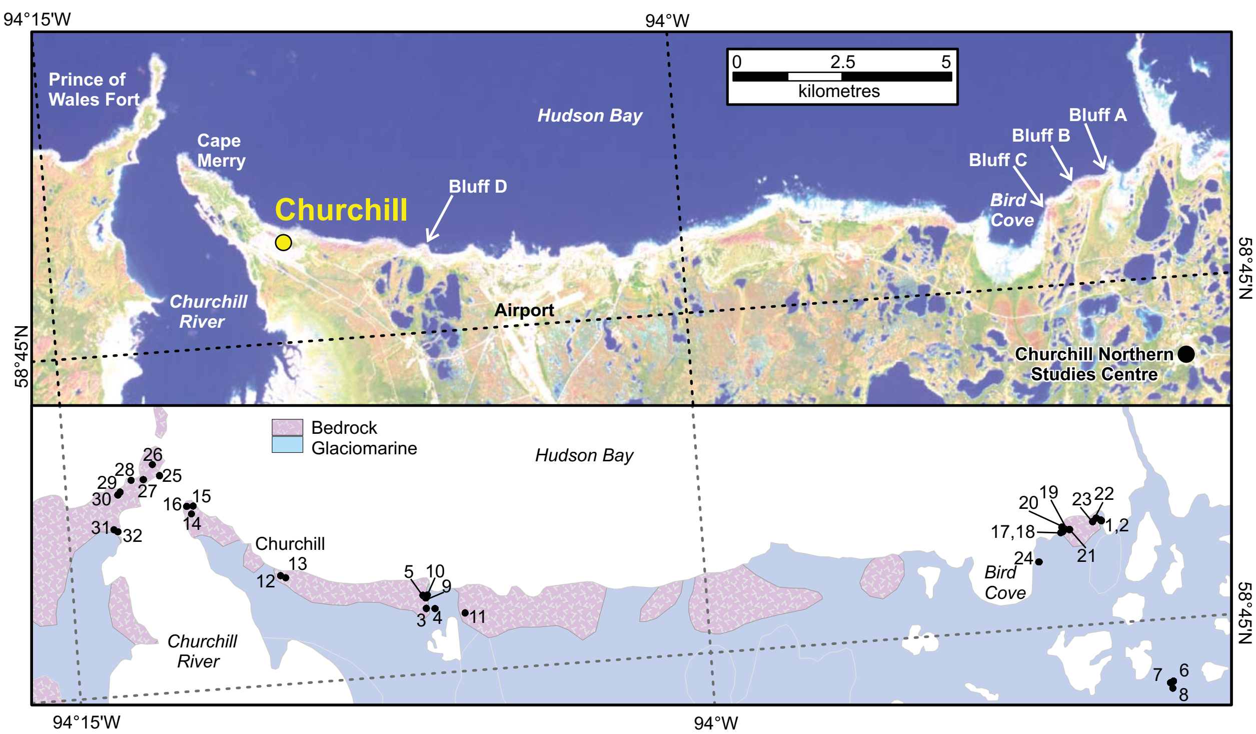


Figure GS-3-1: *Field area in northeastern Manitoba, with Spot 4 imagery as background in top map and simplified surficial geology in bottom map (Dredge et al., 2007). Field sites are numbered.*

[1] Department of Earth and Environmental Sciences, University of Waterloo, 200 University Ave. West, Waterloo, Ontario N2L 3G1

Churchill quartzite outcrops along the Hudson Bay coast in the Churchill area (Manitoba Department of Energy and Mines, 1980). These outcrops form resistant ridges inland, and large rock bluffs along the shore (Bluffs A to D, Figure GS-3-1). Most outcrop surfaces are variably striking swales, plucked faces and stoss slopes, which proved to be ideal for protection and preservation of older ice-flow indicators.

Ice-flow reconstructions in northern Manitoba suggest that the region was covered at least twice by ice from the Keewatin sector, and at least three times by ice from the Labradorean sector (Dredge et al., 1986; Dredge and Thorleifson, 1987; Boulton and Clark, 1990; Dredge et al., 1990; Dredge and Nixon, 1992). Stratigraphic sections in northeastern Manitoba broadly suggest the presence of a pre-Illinoian Harts/Sundance till (Keewatin) capped by an interglacial paleosol, overlain by the Illinoian Amery till (Labradorean), overlain by interglacial Sangamonian Nelson River sediment, overlain by Wisconsinan Seal till (Keewatin), and Long Spruce and Sky Pilot tills (Labradorean). For more details on stratigraphic work in the field area, the reader is referred to the following papers: Klassen (1986), Nielson et al. (1986), Berger and Nielson (1990), Dredge et al. (1990), Dredge and Nixon (1992), Nielson (2001, 2002), Nielson and Fedikow (2002) and Kaszycki et al. (2008). Near the end of the late Wisconsinan deglaciation (between 8000 and 7700 C^{14} BP), the Churchill region was inundated by the Tyrrell Sea (Dredge and Nixon, 1992). Beaches at 165 m elevation, northwest of Churchill, record the maximum marine limit for the area (Dredge, 1992).

Methods

One week was spent in the Churchill area, in the summer of 2011, to thoroughly map all field-based ice-flow indicators. Erosional ice-flow indicators documented in the field area include nondirectional indicators, such as striae and grooves, and directional indicators, such as rat tails, chattermarks, gouges, crescentic fractures and stoss-lee relationships. Macroform features encountered in the study area include roches moutonnées and whalebacks (rock drumlins). Visited outcrops were surveyed in detail to record rare and protected ice-flow indicators and their position on bedrock outcrops, in addition to the dominant indicators. Whenever possible, rare and/or protected ice-flow indicators were confirmed to be present on multiple outcrops at a site, before being documented. Striae clearly indicative of ice deflection around bedrock outcrops were not collected. Where crosscutting patterns were found, the relative ages of flows were determined where possible. Ice-flow indicators preserved on the top and side of an outcrop were assumed to be youngest. Rare ice-flow indicators present on some part of the outcrop other than the top were assumed to be old. Relative ages, and a summary of trends, was compiled for each site; based on compiled ice-flow indicators from at least four outcrops at each site. After the field season, compiled data from each site was upscaled to devise a regional ice-flow history for nine locations in the area.

Results

Multifaceted, crossgrooved quartzite outcrops, similar to those described by Veillette and Roy (1995) in James Bay, were found to be widespread in the Churchill area. These palimpsest (characteristics predominately related to an earlier glacial movement in a different direction, and only partially modified by glacial movement in a younger new direction) features preserve a wide range of ice-flow indicators formed over time by different ice-flow orientations. The field data collected last summer in the Churchill area can be found in Data Repository Item DRI2011001[2]. Locations of 32 visited field sites are shown on Figure GS-3-1, where a total of 291 ice-flow indicator measurements were taken.

Palimpsest macroforms

Upon close inspection of most bedrock outcrops, stoss/lee macroforms are present but the dominant orientation varies (Figure GS-3-2) from site to site and also at a single site (Figure GS-3-3a–d). Furthermore, some macroforms are clearly palimpsest, whereby they have been moulded by ice in one direction, and then partially re-moulded by ice in a different direction. Regionally, macroforms record ice-flow to the southwest (two phases), northwest, southeast, south-southeast and south. The surfaces of roche moutonnées are often multifaceted. This can be seen in Figure GS-3-3d to g, where younger grooves and striae on macroform tops truncate older ice-flow indicators on the protected sides/ faces of the macroform. These palimpsest landforms are textbook examples of the 'vanished protector' (Veillette and Roy, 1995), whereby till cover likely prevented the destruction of a striated surface, while ice moulded the outcrop in a different orientation. This protective till was later removed (vanished) by wave-washing from the Tyrell Sea (Dredge and Nixon, 1992), exposing the multifaceted outcrops.

Complex crossgrooved record

A summary of field-based ice-flow indicators, for nine different areas, is depicted in Figure GS-3-4. Regionally, ice-flow indicators trend to the southwest

[2] MGS Data Repository Item DRI2011001, containing the data or other information sources used to compile this report, is available online to download free of charge at http://www2.gov.mb.ca/itm-cat/web/freedownloads.html, or on request from minesinfo@gov.mb.ca or Mineral Resources Library, Manitoba Innovation, Energy and Mines, 360–1395 Ellice Avenue, Winnipeg, Manitoba R3G 3P2, Canada.

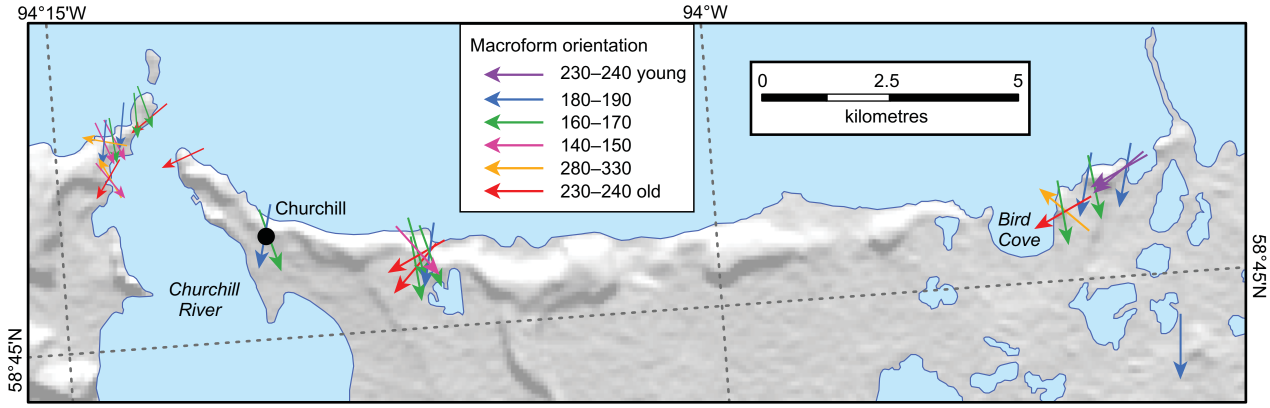


***Figure GS-3-2:** Macroform locations and orientation in the field area, with the Shuttle Radar Topography Mission (SRTM) 90 m resolution hillshade (United States Geological Survey, 2004) as background. Most orientations can be found regionally, with the exception of the young 230–240°, which was only found at bluff A.*

(two phases), west, northwest (two phases), east-southeast (two phases) and southeast to south-southwest (two phases). Bedrock surfaces were moderately weathered, and most ice-flow indicators mapped are grooves; shallower finer striae were rarely seen. Likely owing to the vanished protector (Veillette and Roy, 1995), ice-flow indicators are present on all faces, including gentle stoss tops and sides, steep lee slopes and steeper stoss slopes (Figure GS-3-5). Directional indicators (Figure GS-3-6) include chattermarks and gouges, crescentic fractures and nailhead striae. To determine the relative ages of ice-flow indicators, the location of ice-flow indicators on the outcrop matters just as much as obvious crosscutting relationships. By piecing together what flows may have been protected by till or local bedrock topography from other flows of a different orientation, along with the dominance/strength of erosion, a relative age summary has been reconstructed for each site (Data Repository Item DRI2011001). Then, data from each site within a similar area were compiled into a more regional summary of relative-aged ice-flow features. Old northwest- to north-northwest-, west- and southwest-trending, and younger southwest- and southeast- to south-southwest-trending ice-flow indicators were found throughout the field area. Older south-southeast- to south-southwest-trending and east- to east-southeast-trending indicators are rarer. The youngest regional ice-flow indicators trend east-southeast, and occur everywhere in the field area except at Cape Merry. Young northwest-trending ice-flow indicators were only found in the most easterly area (Bluff A).

Regional glacial history

The ice-flow record revealed by ice-flow indicators measured at 32 sites in the study area is complex across the entire region. Nine ice-flow phases have inscribed the quartzite exposures in the Churchill area.

Rare and/or protected ice-flow indicators and old macroforms suggest four phases of ice flow occurred, probably during the pre-late Wisconsinan. North-northwest- to northwest-trending (350–280°) ice-flow indicators represent the oldest preserved ice-flow phase in the Churchill region; likely formed by Labradorean-sourced ice. The first set of southwest-trending (230–250°) and south-southeast- to south-southwest-trending (140–190°) ice-flow indicators were likely formed by Keewatin-sourced ice. Westerly trending ice-flow indicators (270–280°) were likely sourced again from the Labradorean sector of the LIS. Southeast- and southwest-trending ice-flow phases are regionally extensive, and here it is suggested that they are likely correlative to ice-flow indicators in the Great Island region (Trommelen et al., 2010). Northwest-trending ice-flow was not documented in the field-based ice-flow indicator record for the Great Island area, but is required to explain the presence of carbonate-bearing clasts in the area.

More common ice-flow indicators were formed later, probably during the early to late Wisconsinan glaciation. Ice from the Keewatin Sector of the LIS initially flowed east-southeast (90–150°). With migration of the Keewatin Ice Divide eastward (McMartin and Henderson, 2004), ice-flow over the Churchill area was transitionally deflected through south to the south-southwest over time. West- to northwest-trending ice-flow indicators were also documented at Bluff A, where they are crosscut by southwest- and east-southeast-trending ice-flow indicators. These west- to northwest-trending ice-flow indicators were likely formed by a westward-shift of ice from the Labradorean Sector, and provide the only indication of possible interaction between the two ice sectors in the Churchill area.

Deglacial ice-flow indicators, typically finer and only situated near the top of outcrops, suggest late-stage ice flowed east to southeast throughout the study area. This same ice-flow phase is recorded in the Kellas Lake area approximately 150 km northwest of Churchill (Trommelen et al., 2010), and likely records ice-flow into

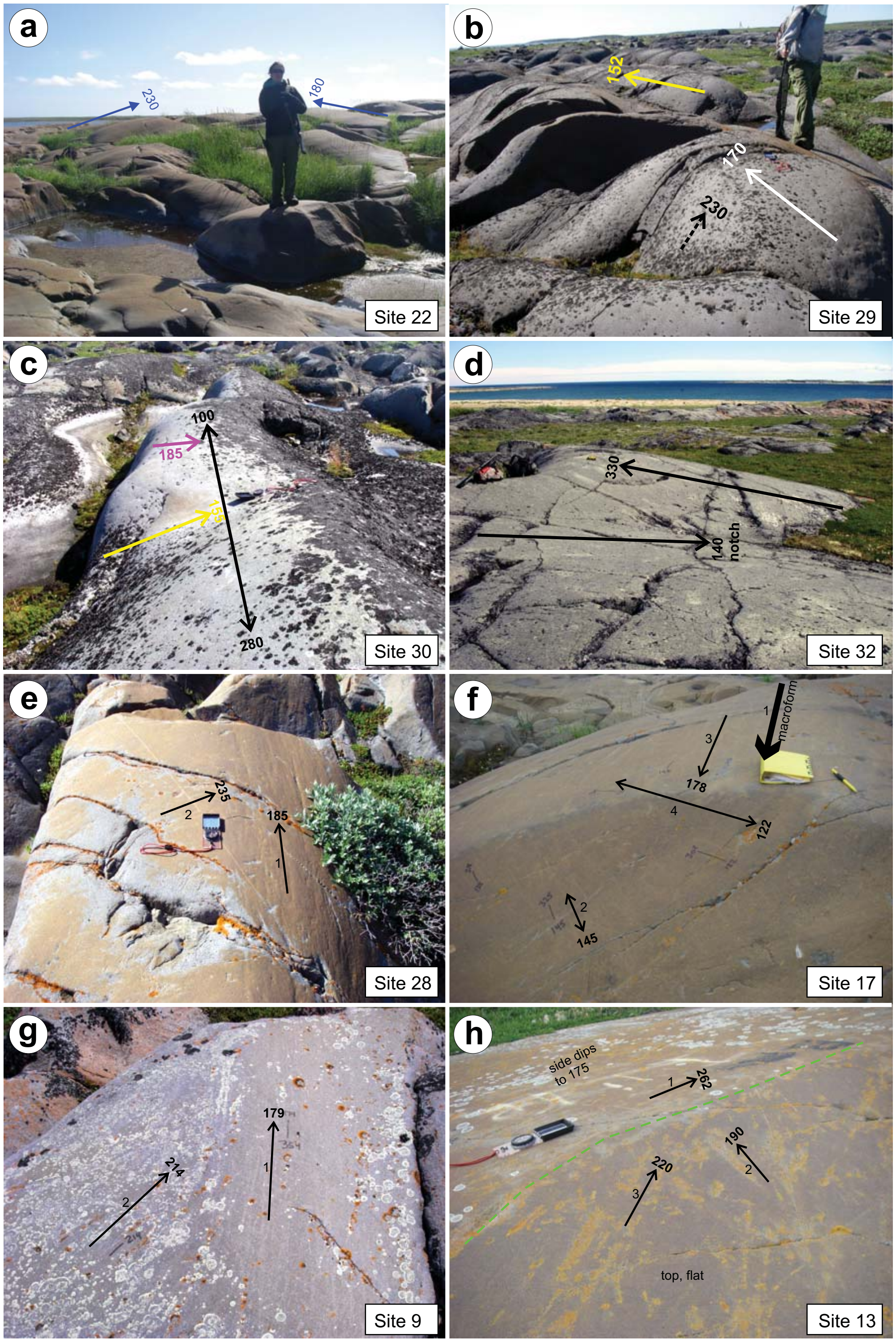


Figure GS-3-3: *Palimpsest macroforms in the field area;* ***a)*** *and* ***b)*** *sites with two differently trending roches moutonnées;* ***c)*** *small roches moutonnées trending to 185°, superimposed on a whaleback drumlin trending to 280°, both notched by a younger deep groove trending 155°;* ***d)*** *two roches moutonnées trending to 330° notched in the middle by a deep groove trending to 140°;* ***e)*** *the west-dipping side of this roche moutonnée preserves grooves that trend to 185°, whereas the flat top surface is grooved to 235°;* ***f)*** *the top surface of this roche moutonnée is grooved to 178°, parallel to the macroform. The protected lee slope, however, is grooved to 145 to 325° and 122 to 302°;* ***g)*** *grooves trending 179° on the top of a roche moutonnée are protected in a shallow groove from later grooves trending 214°;* ***h)*** *grooves trending 262° were preserved on a south-dipping face, and protected from later ice-flow phases trending to 190 and 220° inscribed on the top surface.*

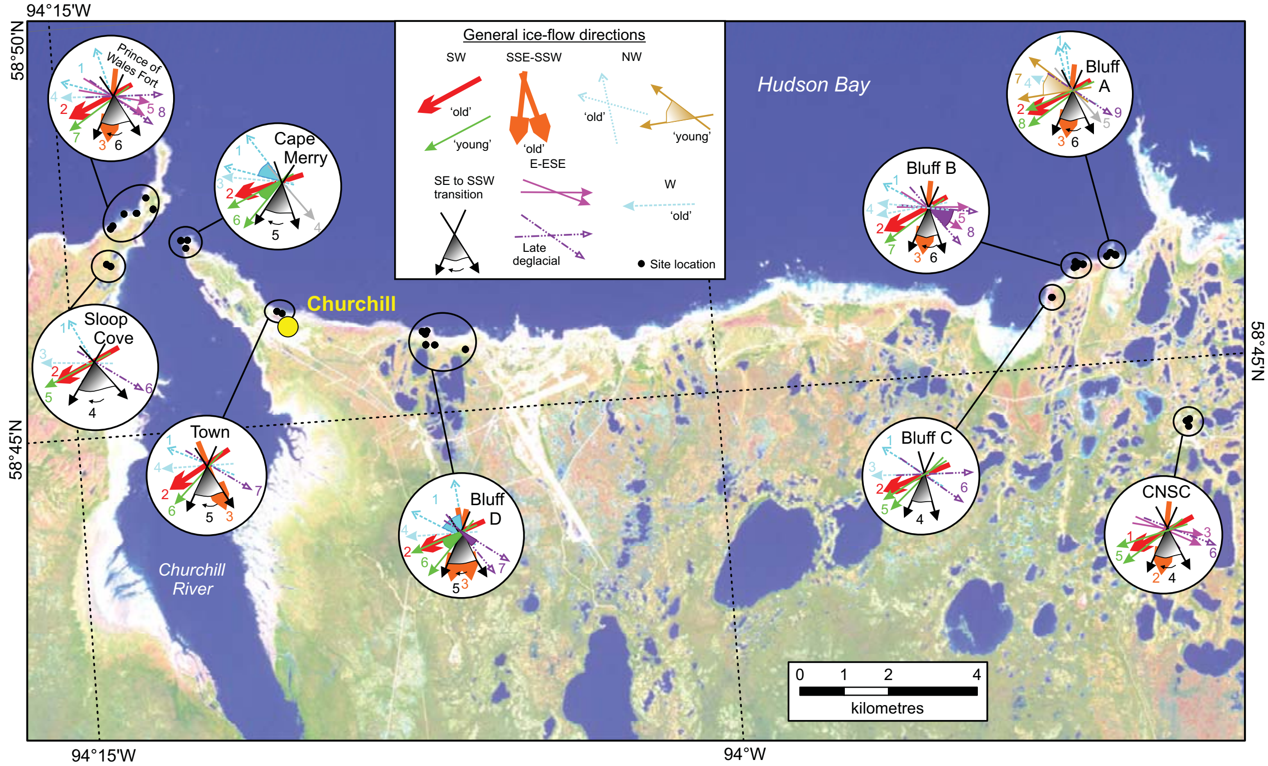


Figure GS-3-4: *Summary of ice-flow indicator trends for nine areas in the Churchill region. Ice-flow indicators were stratified by relative age according to position on outcrops, erosional strength and regional correlation. Location of the outcrop/site relative to the surrounding topography (i.e., on northeast or northwest side of bluff) seemed to affect which ice-flow phases were stronger, or even preserved, at any one site. Abbreviation: CNSC, Churchill Northern Studies Centre.*

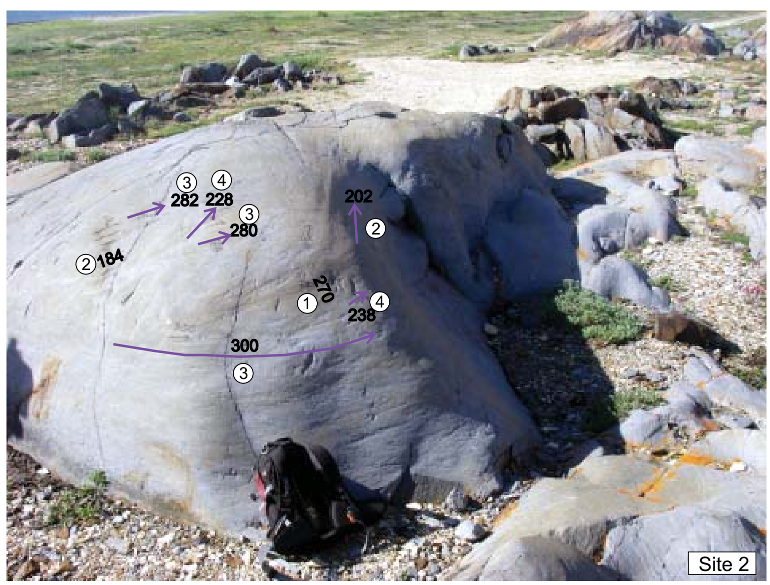


Figure GS-3-5: *Position of ice-flow indicators and their relative age, on one outcrop at site 2. By using crosscutting relationships, and position on outcrop, the ice-flow history for this outcrop is as follows: 1) smoothed and crosscut chattermark protected from S flow; 2) smoothed chattermark, common grooves on protected steep west-facing slope; 3) common grooves on northeast- and north-facing steep stoss slope, as well as fewer on top that crosscut other grooves; 4) rarer grooves all over that crosscut other grooves.*

the Tyrrell Sea, after drainage of glacial Lake Agassiz (Klassen, 1983).

Economic considerations

As bedrock outcrops are rare, a thorough understanding of ice-flow history is essential for drift prospecting in Manitoba's northern region. The Churchill area has a complex ice-flow history, as it was influenced by multiple phases of ice-flow from both the Keewatin and Labradorean sectors of the LIS. This report elucidates which ice-flow phases, in which order, left an erosional record in the Churchill area. In combination with clast-dispersal and stratigraphic data, this information will help

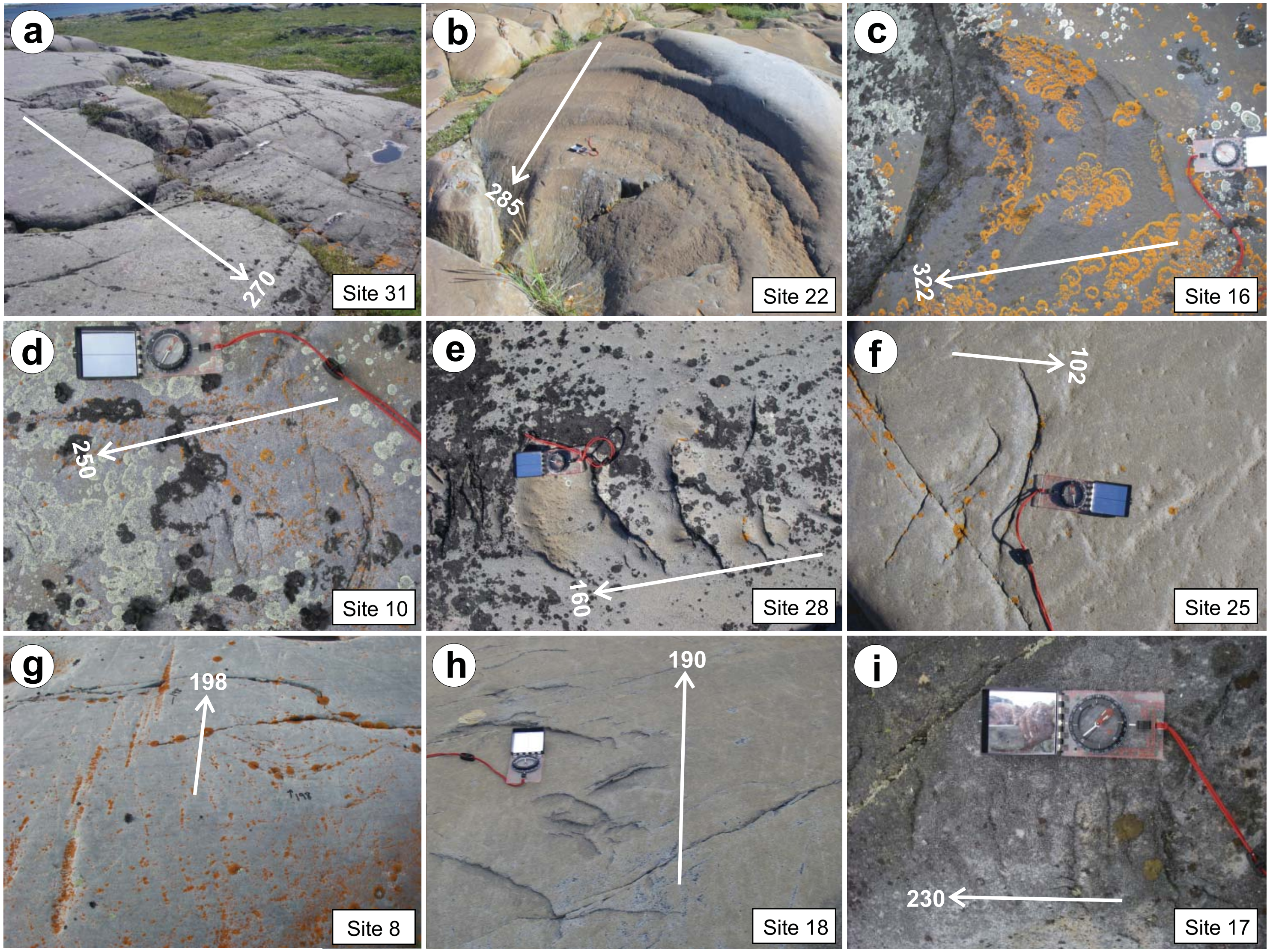


***Figure GS-3-6:** Directional indicators in the field area: **a)** large (5 m long) staircase-like chattermarks trending toward 270°; **b)** large (3 m long) chattermark set trending toward 285°; **c)** large (2.5 m long) crescentic scour set trending toward 322°; **d)** crescentic fracture trending toward 250° (25 cm long); **e)** large (2 m long) chattermark set trending toward 160°; **f)** four crescentic gouges trending toward 102° (30 cm wide); **g)** crescentic fracture and deep grooves trending toward 198°; **h)** large (3 m long) crescentic gouges set trending toward 190°; **i)** small (20 cm long) chattermark set trending toward 230°.*

determine up-ice source areas and possible palimpsest dispersal vectors for drift prospecting in the north.

Acknowledgments

This project was made possible thanks to a Northern Scientific Training Program grant from Indian and Northern Affairs Canada, with additional support from the Geological Survey of Canada (Geo-mapping for Energy and Minerals project). The Churchill Northern Studies Centre is thanked for providing lodgings, meals and bear monitoring. Parks Canada is thanked for access to Cape Merry and the Prince of Wales Fort Historic Site. R. Paulen is thanked for introducing the first author to the concept of a vanished protector.

References

Berger, G.W. and Nielson, E. 1990: Evidence from thermoluminescence dating for middle Wisconsinan deglaciation in the Hudson Bay Lowland of Manitoba; Canadian Journal of Earth Sciences, v. 28, p. 240–249.

Boulton, G.S. and Clark, C.D. 1990: A highly mobile Laurentide ice sheet revealed by satellite images of glacial lineations; Nature, v. 346, p. 813–817.

Dredge, L.A. 1992: Field guide to the Churchill Region Manitoba; Geological Survey of Canada, Miscellaneous Report 53, 52 p.

Dredge, L.A. and Nixon, F.M. 1981a: Surficial geology, Cape Churchill, Manitoba; Geological Survey of Canada, Preliminary Map 3-1980, scale 1:250 000.

Dredge, L.A. and Nixon, F.M. 1981b: Surficial geology, Churchill, Manitoba; Geological Survey of Canada, Preliminary Map 4-1980, scale 1:250 000.

Dredge, L.A. and Nixon, F.M. 1992: Glacial and environmental geology of northeastern Manitoba; Geological Survey of Canada, Memoir 432, 80 p.

Dredge, L.A. and Thorleifson, L.H. 1987: The Middle Wisconsinan history of the Laurentide Ice Sheet; Geographie Physique et Quaternaire, v. 41, p. 215–235.

Dredge, L.A., Morgan, A.V. and Nielson, E. 1990: Sangamon and pre-Sangamon interglaciations in the Hudson Bay Lowlands of Manitoba; Geographie Physique et Quaternaire, v. 44, p. 319–336.

Dredge, L.A., Nixon, F.M. and Richardson, R.J.H. 1986: Quaternary geology and geomorphology of northwestern Manitoba; Geological Survey of Canada, Memoir 418, 38 p.

Dredge, L.A., McMartin, I. and Pyne, M. 2007: Surface materials and landforms, northernmost Manitoba; Geological Survey of Canada, Open File 5435, 24 p, 1 sheet, scale 1:500 000.

Kaszycki, C.A., Dredge, L.A. and Groom, H. 2008: Surficial geology and glacial history, Lynn Lake–Leaf Rapids area, Manitoba; Geological Survey of Canada, Open File 5873, 105 p.

Klassen, R.W. 1983: Lake Agassiz and the late glacial history of northern Manitoba; *in* Glacial Lake Agassiz, J.T. Teller and L. Clayton (ed.), Geological Association of Canada, Special Paper 26, p. 97–115.

Klassen, R.W. 1986: Surficial geology of north-central Manitoba; Geological Survey of Canada, Memoir 419, 57 p.

Manitoba Department of Energy and Mines 1980: Churchill, NTS 54L; Manitoba Department of Energy and Mines, Mineral Resources Division, Bedrock Geology Compilation Map, Geological Report 80-9-4, scale 1:250 000.

McMartin, I. and Henderson, P. 2004: Evidence from Keewatin (Central Nunavut) for paleo-ice divide migration; Geographie Physique et Quaternaire, v. 58, p. 163–186.

Nielson, E. 2001: Quaternary stratigraphy, till provenance and kimberlite indicator mineral surveys along the lower Hayes River; *in* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 121–125.

Nielson, E. 2002: Quaternary stratigraphy and ice-flow history along the lower Nelson, Hayes, Gods and Pennycutaway rivers and implications for diamond exploration in northeastern Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 209–215.

Nielson, E. and Fedikow, M.A.F. 2002: Kimberlite indicator-mineral surveys, lower Hayes River; Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Geoscientific Paper GP2002-1, 39 p.

Nielson, E., Morgan, A.V., Morgan, A., Mott, R.J., Rutter, N.W. and Causse, C. 1986: Stratigraphy, paleoecology and glacial history of the Gillam area, Manitoba; Canadian Journal of Earth Sciences, v. 23, p. 1641–1661.

Shilts, W.W. 1980: Flow patterns in the central North American ice sheet; Nature, v. 286, p. 213–218.

Trommelen, M.S., Ross, M. and Campbell, J.E. 2010: Far North Geomapping Initiative: Quaternary geology of the Great Island–Kellas Lake area, northern Manitoba (parts of NTS 54L, M, 64I, P); *in* Report of Activities 2010, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 36–49.

United States Geological Survey 2004: Shuttle Radar Topography Mission, digital elevation model, 3 arc second; United States Geological Survey, URL <http://edcsns17.cr.usgs.gov/NewEarthExplorer/>, portions of files SRTM3N57 and SRTM3N58.

Veillette, J.J. and Roy, M. 1995: The spectacular cross-striated outcrops of James Bay, Quebec; *in* Current Research 1995-C, Geological Survey of Canada, p. 243–248.