Glacial landforms of northwest Saskatchewan

Sophie L. Norris\textsuperscript{a}, Martin Margold\textsuperscript{a,b} and Duane G. Froese\textsuperscript{a}

\textsuperscript{a}Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Canada; \textsuperscript{b}Department of Physical Geography, Stockholm University, Stockholm, Sweden

**ABSTRACT**

A comprehensive map of glacial landforms is presented for the area of northwest Saskatchewan, Canada. Remote sensing of 1-arc (∼30 m resolution) Shuttle Radar Topography Mission digital elevation models over an area of approximately 15,000 km\(^2\) were used as the primary data source for landform identification. A total of 16,856 landforms were identified pertaining to Quaternary glacial and postglacial activity. Ten landform types were mapped: ice flow parallel lineations (flutings, drumlins, mega-scale glacial lineations, and crag-and-tail ridges), moraines (major and minor), ice-thrust ridges, crevasse-fill ridges, meltwater landforms (major and minor meltwater channels and eskers), palaeo-shorelines and dunes. Collectively, these landforms constitute a glacial and postglacial landform record, which exhibits a more complex pattern than previously recognised, with evidence of multiple cross cutting ice flow directions. This geomorphological mapping of the regional landform record provides the prerequisite for future reconstructions of the glacial dynamics and chronology of northwest Saskatchewan.

**1. Introduction**

The Canadian Prairies contain a glacial landform record that documents the dynamic behaviour of the Laurentide Ice Sheet during the last glacial cycle. Of particular interest are the northern portions of Alberta and Saskatchewan, where the spatial and temporal patterns of deglaciation are linked to the timing of meltwater fluxes from glacial Lake Agassiz (Figure 1; Dyke, Moore, & Robertson, 2003; Fisher, Waterson, Lowell, & Hajdas, 2009). The location of glacial Lake Agassiz in this central region of North America gives it the potential to deliver large amounts of freshwater; north to the Arctic ocean, east to Hudson Bay, east to the North Atlantic via the St. Lawrence Seaway, and south to the Gulf of Mexico. Therefore, switching of glacial Lake Agassiz outlets has been suggested to have triggered climate change during the last deglaciation (Broecker et al., 1989; Clark et al., 2001), and a number of studies have attempted to reconstruct the evolution of its drainage (e.g. Breckenridge, 2015; Christiansen, 1979; Fisher & Smith, 1994; Teller & Clayton, 1983; Teller & Leverington, 2004). However, the palaeoglaciological dynamics, on which these studies base their inferences, are still poorly understood and the chronological controls on the position of the ice sheet margin remain sparse. Previous geomorphological investigations (first summarised in Prest, Grant, & Rampton, 1968) within the Canadian Prairies have demonstrated the rich nature of the landform-sediment record in this region. Glacially streamlined landforms have been used to identify ice flow patterns and ice stream corridors (Evans, Clark, & Rea, 2008; Evans, Young, & Ó Cofaigh, 2014; Margold, Stokes, & Clark, 2015a, b; Moran, Clayton, Hooke, Fenton, & Andriashek, 1980; Ó Cofaigh, Evans, & Smith, 2010; Ross, Campbell, Parent, & Adams, 2009; Stokes, Margold, Clark, & Tarasov, 2016). Equally, collections of terminal and recessional moraine ridges have been used to reconstruct the stabilisation or slow retreat of the ice sheet margin (Christiansen, 1979; Evans et al., 2014; Kleman et al., 2010). In order to aid in further studies, the landform record for the entirety of Alberta has recently been synthesised into a province-wide glacial geomorphological map (Atkinson, Utting, & Pawley, 2014a, b). In contrast, there is an absence of comprehensive mapping to underpin Late Wisconsinan glacial and deglacial dynamics for northwest Saskatchewan. Glacial geomorphological maps of a single landform type, such as glacial lineations, have been presented at a provincial or continental scale only (Shaw, Sharpe, & Harris, 2010; Simmon, 2011). At a local scale, parts of and single National Topographic System (NTS) tiles have also been mapped and their Quaternary geology recorded (Campbell, 1988, 2006, 2007; Campbell, Ashton, & Knox, 2006; Hanson, 2014, 2015a, b, c; Schreiner, 1984a, b, c, d, e, f, g, h, i, j, Scott, 1965; Shaw et al., 2010; Simpson, 1988, 1997; Simmon, 2011). However, detailed glacial geomorphological

**CONTACT** Sophie L. Norris slnorris@ualberta.ca

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mapping similar to that available for Alberta is absent. In an effort to aid understanding of the palaeoglaciology of northwest Saskatchewan, this study presents a detailed 15,000 km² glacial landform map covering the entirety of northwest Saskatchewan (Main Map). The study area within which this map ranges is between 106°00′–110°00′W and 55°00′–60°00′N, encompassing ten 1:250,000 NTS tiles (73M-O, 74B-G, J-O; Figure 1).

2. Methods

2.1. Primary data

The glacial geomorphology of northwest Saskatchewan was primarily mapped from hillshade imagery derived from 1-arc Shuttle Radar Topography Mission (SRTM) digital elevation models. These data were selected as they provide the best to-date available spatial coverage and resolution (~30 m pixel size) for the study area. Data were downloaded in GeoTIFF format from GeoGratis (http://geogratis.cgdi.gc.ca) and then projected in Universal Transverse Mercator (UTM) zone 12N referenced to the North American Datum 1983.

As proposed by Smith and Clark (2005), to minimise azimuth bias, multiple illumination angles were used to aid mapping. Illumination angles orthogonal to each other were used to account for the varying orientation and scale of landforms occurring in the study area (Smith & Clark, 2005).
2.2. Secondary data

Multiple additional data sources assisted the identification of landforms in the study area; surficial geology maps and structural geology data (Slimmon, 2011) helped to ensure glacial landforms were not interpreted where there was an alternative origin, either geological, structural or due to modern-day landscape alteration. Published literature was also used to support landform identification and provide a useful component for mapping (Campbell, 1988, 2006; Hanson, 2014, 2015; Schreiner, 1984a, b, c, d, e, f, g, h, i, j; Scott, 1965; Shaw et al., 2010; Simpson, 1988, 1997; Slimmon, 2011). However, as previously published maps portray varying landform types and occur at varying map scales depending on the region and purpose of the mapping, all previously mapped areas were remapped.

2.3. Landform mapping

A repeat-pass method (i.e. landform by landform and area by area type) was employed to ensure consistency in the final map. Each landform type was mapped for the entire study area ensuring multiple passes of all areas, thus allowing for details to be added or refinements made to the initial mapping with each pass. Mapping was conducted at 1:30,000 – 1:70,000. A variable scale was used depending on the landform type under investigation. Individual landforms were identified on the imagery based on their morphology, spatial arrangement and association with other features (see Table 1 for diagnostic characteristics). To enable detailed inspection of landforms and their associated patterns and systems, this map is designed to be printed and viewed at AO size (841×1189 mm). Each individual landform was identified and digitised as a single line or a closed polygon depending on its shape and size in relation to SRTM data resolution. Ten landform types were mapped: ice flow parallel lineations, moraines (major and minor), ice-thrust ridges, crevasse-fill ridges, meltwater landforms (major and minor meltwater channels and eskers), palaeo-shorelines, and dunes (Figure 2). These landform types are now discussed below.

3. Results: descriptions of glacial geomorphology

3.1. Ice flow parallel lineations

Ice flow parallel lineations include flutings, drumlins, mega-scale glacial lineations, and crag-and-tail ridges (Figure 2(a)). Lineations mapped here confirm and extend the previously mapped inventory; this is especially evident north of the Cree Lake Moraine where the number of lineations is considerably denser than portrayed by previous mapping. Lineations show a complex pattern across the study area and occur extensively except in areas where bedrock is exposed (e.g. in NTS 74O and 74N, north of Lake Athabasca). A clear division in the morphology of lineations is recorded within the mapped area (Figure 3). In the northern part of the study area, which overlies the Canadian Shield, lineations are of high density and comprise varied northeast–southwest orientations. These lineations are typically 100–250 m wide and 800–1500 m long, with elongation ratios between 5:1 and 8:1 (Figure 3(a,c)). In contrast, south of the Canadian Shield boundary, glacial lineations display higher attenuation, with elongation ratios ranging between 15:1 and 86:1 (Figure 3(b,d)). Their orientations are more complex, documenting substantial changes in ice flow directions.

3.2. Moraines (major and minor)

Moraines occur as arcuate ridges that collectively display lobate planforms. These landforms are split into two categories based on size. Minor moraines are typically 1–10 m high, 50–100 m wide, and up to 5 km long, and are mapped as single lines drawn along the crest of the ridge. Major moraine ridges range between

| Table 1. Diagnostic criteria that underpin the identification of geomorphological features from SRTM imagery. |
|---------------------------------------------------------------|---------------------------------------------------------------|
| Landform group | Diagnostics used for landform identification | Mapping symbol |
|-----------------|---------------------------------------------|----------------|
| Ice flow parallel lineations | Elongate landforms which typically occur in groups with contrasting tone on either side of a linear crestline. Regular morphology, spacing and orientation often found between neighbouring landforms. | Landform crest drawn as single line |
| Moraine ridges | Broadly linear ridges which exhibit variation in tone across their crestline. Ridges may be dissected by meltwater channels. | Landform outline drawn as polygon (major moraine ridge) or crestline (minor moraine ridge) |
| Ice-thrust ridges | Arcuate ridges with strong variation in tone along their crestline. They are often associated with a depression/basin where sediment rafts were dislocated. | Landform crest drawn as single line |
| Crevasse-fill ridges | Linear, curvilinear, or v-shaped ridges. They may intersect forming cross cutting patterns. | Landform crest drawn as single line |
| Meltwater channels | Branching networks of incised topography. The edges of these channels are defined by changes to a contrasting dark tone on either side. | Centre of incised topography drawn as single line |
| Eskers | Sinuous ridges. Often form complex networks with tributary eskers. | Landform crest drawn as single line |
| Palaeo-shorelines | Sinuous, often arcuate steps or ridges in the landscape, which mark the shorelines of former lakes. They are often found to have contrasting terrain on either side. | Landform crest drawn as single line |
| Dunes | Parabolic or longitudinal in shape, ridges typically occur in groups. Sharply crested and commonly asymmetric in cross profile. | Landform crest drawn as single line |
1 and 3 km wide, up to 60 km long and 50 m high, and exhibit obvious outlines; these were mapped as polygons (Figure 2(c)).

The Cree Lake Moraine approximately parallels the lithological transition to the Canadian Shield (Figure 1). This moraine system is broadly arcuate and extends from northwest Alberta across the majority of the mapping area. Several prominent moraine ridges also occur northwest of the Cree Lake Moraine and are associated with a narrow topographic low north of Cree Lake.
Additionally, linear moraine ridges, occur at the northwestern edge of the Grizzly Bear Hills, and mark the margin of a smoothed corridor of lineated ground. The morphology and position of these moraines in relation to lineated ground are consistent with lateral shear moraines and are thus interpreted as marking the former margin of a zone of fast ice flow from the surrounding ice sheet (Dyke & Morris, 1988; Hodgson, 1994; Stokes & Clark, 2002).

3.3. Ice-thrust ridges

Ice-thrust ridges are large, parallel, and generally arcuate and sharply crested landforms. Ridges range from 10–60-m high and 150–800-m long and are visible throughout the mapped area, occurring in small concentrations. In many cases these ridges are accompanied by a depression (typically water-filled) directly behind the ridge arc, commonly known as a hill-hole pair (Figure 2(b)). Ice-thrust ridges have previously been mapped sparsely within the study area; therefore, our mapping extends the known distribution and demonstrates that these features are considerably more widespread than previously thought.

3.4. Crevasse-fill ridges

Crevasse-fill ridges occur in small concentrations as linear, curvilinear or v-shaped ridges. These ridges range from 1–5-m high and 200–1200-m long, and are oriented parallel or perpendicular to ice flow. Relatively few crevasse-fill ridges have been previously mapped within the study area and we demonstrate that these features are more prevalent than prior studies suggest. We acknowledge that small crevasse-fill ridges might have been missed in our mapping because their size does not allow for their recognition at the mapping scale.

3.5. Meltwater channels (major and minor)

A complex and extensive system of abandoned channels occur throughout the mapped area and show evidence that drainage has been influenced by regional ice retreat patterns (Figure 2(d)). These channels have been primarily carved by proglacial, supraglacial or subglacial meltwater streams and display incised meanders interspersed with straight reaches. Major channel networks (>30-km long), that are deeply incised and
well-defined have been mapped as solid lines, smaller and more subdued forms are mapped as dashed lines. Due to the small scale of many channels, some of the mapped channel features may be perennial or intermittent subaerial streams, but it is difficult to conclusively differentiate between these using the imagery available.

### 3.6. Eskers

Single ridge eskers and esker networks composed of large sinuous eskers, which join to multiple smaller esker ridges, are prominent throughout the mapped area (Figure 2(e)). These range in height between 5 and 10 m and in length between 2 and 10 km. We acknowledge that small eskers might have been missed in our mapping because their size does not allow for their recognition at the mapping scale.

### 3.7. Palaeo-shorelines

Palaeo-shorelines are erosional or depositional features. These landforms are most prominent in areas to the immediate south of Lake Athabasca (Figure 2(f)). Faint remnants of shorelines are also recorded on the northeastern edge of the Grizzly Bear Hills.

### 3.8. Dunes

Parabolic and longitudinal dunes occur throughout the study area, but most commonly on the low topography surrounding Lake Athabasca (Figure 2(g)). While these landforms are not glacial, they are included in our mapping as they started to form shortly after deglaciation and can be considered in a broader sense as a part of the glacial modification of the landscape. We acknowledge that small or faint dunes have been missed in our mapping because their size does not allow for their recognition at the 30 m SRTM DEM mapping scale.

### 4. Implications and conclusions

The accompanying map provides a comprehensive representation of the glacial landform record in northwest Saskatchewan. This mapped landform assemblage documents a complex glacial history in the region, with traces of multiple ice flow directions overprinted by the landforms of the deglacial envelope. Flow patterns and dynamics revealed by our landform mapping replicate much that has been reported in the existing literature; however in many places it has added significant additional complexities to the landform record. The existence of cross cutting relationships between different landform packages has significant implications for the spatial and temporal configuration and evolution of fast ice flow in the region, and provides the prerequisite for future reconstructions of the deglacial dynamics and chronology of northwest Saskatchewan.

### Software

Hillshade models from SRTM DEM data were produced using Esri ArcMap 10.1. On-screen digitising of landform crestline, break-in-slope and change in direction were conducted in ArcMap 10.1. The map was then exported and finalised using Adobe Illustrator 10.0.

### Data

ESRI shapefiles used in the accompanying map are supplied for all glacial and postglacial landform types discussed.

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No potential conflict of interest was reported by the authors.

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