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Abstract: In the northern half of the Walker Lake map area, three glaciofluvial landforms — eskers, transverse ridges, and irregular mounds, were identified, interpreted, and related to the deglacial history. Two types of eskers are present. Type-A eskers cut across topography and formed early during deglaciation, representing englacial channels. The larger type-B eskers follow major valleys and formed throughout deglaciation, representing subglacial and/or supraglacial channels. Irregular mounds and transverse ridges formed in the later stages of deglaciation and represent accumulations of material along topographic lows on the surface of the ice sheet that correspond to the major valleys in the area. This integrated hypothesis explains the distribution of the eskers and the fact that the irregular mounds and transverse ridges occur in linear zones that are commonly associated with eskers.

Résumé : Dans la moitié nord de la région cartographique de Walker Lake, trois formes de terrain fluvioglaciaires (des eskers, des crêtes transversales et des monticules irréguliers) ont été relevées, interprétées et associées à l'évolution de la déglaciation. Deux types d'eskers sont distingués. Les eskers de type A sont discordants par rapport au relief; leur formation remonte au début de la déglaciation et ils constituent la trace de chenaux intraglaciaires. Les eskers de type B suivent les vallées principales; ils sont apparus tout au long de la période de déglaciation et ils représentent des chenaux sous-glaciaires ou supraglaciaires. Des crêtes transversales et des monticules irréguliers se sont formés vers la fin de la déglaciation par accumulation de matériaux dans des dépressions à la surface de la nappe glaciaire qui coincident avec les principales vallées de la région. Cette hypothèse intégrée explique la répartition des eskers et le fait que les crêtes transversales et les monticules irréguliers se présentent dans des zones linéaires qui sont associées généralement aux eskers.

INTRODUCTION

Surficial geology field mapping of the northern half of the Walker Lake map area (NTS 56 J/9–16; Fig. 1) was performed as part of the multidisciplinary Committee Bay Project that is exploring the economic mineral potential of the Prince Albert Group and associated felsic intrusive rocks, central mainland, Nunavut. This collaborative effort between the Canada–Nunavut Geoscience Office and the Geological Survey of Canada (GSC) is presently in its second year of the three-year program intent on mapping geophysical, bedrock, and surficial components within NTS 1:250 000 map areas 56 K, 56 J (north half), 56-O (south half), and 56 P. During the 2001 field season, surficial and bedrock geology mapping were initiated in the northern sector of the Walker Lake (56 J) map area, with surficial geology mapping extending into the northern sector of Laughland Lake (56 K) and the southern sector of Arrowsmith River (56-O) map areas.

Detailed field research included the following: ground-truthing of units mapped through airphoto interpretation, measurement of ice-movement indicators, and sampling of tills and eskers as part of a drift-prospecting survey (details regarding field methods of these components are presented *in* Little et al. (2002)). Special attention was given to glacial landforms including their morphology, spatial distribution, and spatial relationship with other surficial units, topography, and surrounding geomorphology.

Observations and interpretations during mapping allowed for the identification of three landforms requiring further investigation: eskers, transverse ridges, and irregular mounds. Each of these features is described and interpreted. A hypothesis is then developed that links their origin with the deglacial history.

REGIONAL SETTING

Walker Lake is situated above the Arctic Circle, approximately 210 km west of Repulse Bay, Nunavut (Fig. 1). The area lies in the continuous permafrost zone which is significant for this study, because it limits how field investigations can be conducted. Primary structures within the active layer are highly deformed or destroyed, making interpretations difficult. Excavation into permafrost is exceedingly laborious and time-consuming, rendering examination of the frozen ground problematic. Cryoturbation of the active layer produces frost boils (cf. mud boils) from which till samples were obtained (cf. Little et al., 2002). Potential sections are also disturbed by pervasive solifluction of unconsolidated materials, making vertical exposure within the region rare.

The map area occupies three drainage basins (*see* Fig. 2 *in* Little et al. (2002)). Tributaries of the Hayes River drain Walker Lake and flows into Chantrey Inlet (Gulf of Boothia west watershed). Pearce Lake, on the east side of the divide, flows into Wager Bay, and Hudson Bay (northwest Hudson Bay watershed). Present-day fluvial erosion and related

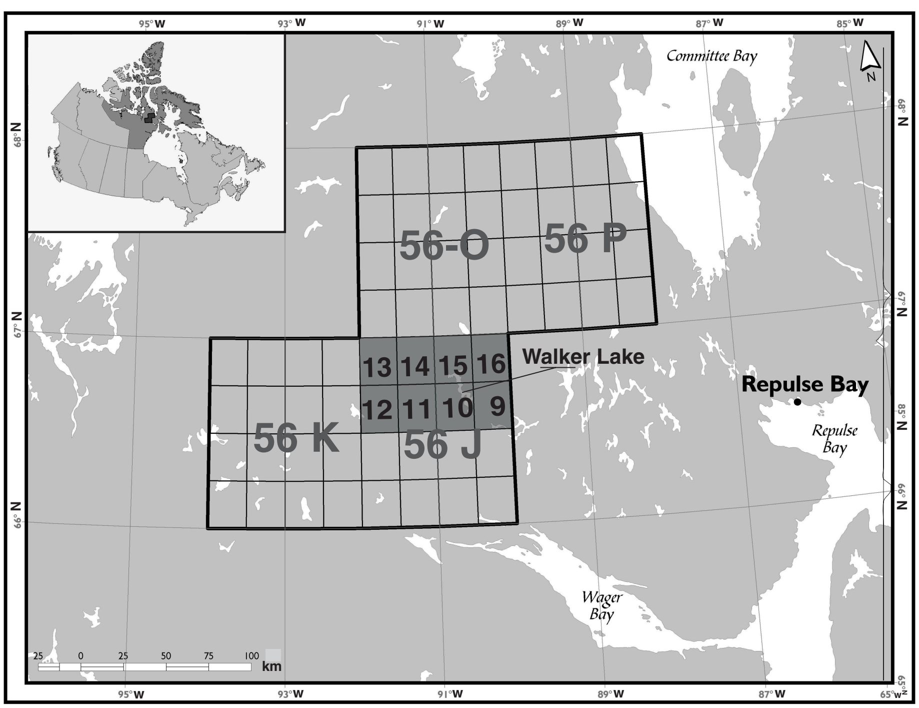

Figure 1. Location of Walker Lake map area. Numbers 9 to 16 correspond to the eight 1:50 000 map sheets discussed in this paper.

exposures are limited. No vertical exposures relating to the material and landforms discussed here were identified during mapping. The trunk valleys are interpreted to have existed prior to the last glaciation, based on their depth and the fact that till drapes the bedrock surface.

Walker Lake map area is underlain by the Archean Prince Albert Group, which contains both metasedimentary and metavolcanic rocks (Jefferson and Schau, 1992). In some cases, the metavolcanic rocks contain komatiitic rocks that tend to form ridges (Chandler et al., 1993). On-going bedrock mapping refines the distribution and resolution of units present in the Committee Bay area (Sandeman et al., 2001a, b; Skulski et al., 2002).

Dyke and Prest (1987) mapped the stages of deglaciation for the Laurentide Ice Sheet, and show that the map area became ice-free at about 8000 BP. Aylsworth and Shilts (1989) show bands of glaciofluvial material, ribbed (Rogen) moraines, and predominantly undifferentiated surficial material in the map area which reflects the 1:100 000-scale mapping. A review of the Quaternary history of the Committee Bay field project area is provided by Little et al. (2002) and references therein.

DESCRIPTION OF UNITS

Mapping was performed primarily by airphoto interpretation. Ground-truthing was done by helicopter and foot traverses, especially in areas difficult to interpret by airphoto analysis alone. Eskers, transverse ridges, and irregular mounds were identified for more intensive analysis. Heights, relative spacing, widths, and slope angles were measured on traverse. Sediments were described and sampled in excavated pits. Textural descriptions refer to field observations.

Eskers

The size and extensive distribution of eskers makes them prominent features on the landscape of the map area (Fig. 2, 3). Excavations indicate that the predominant material is a boulder gravel composed of fine- to coarse-sand matrix and subrounded to rounded boulders clasts (average B-axis 30 cm). Typically, the esker surfaces exhibit higher concentrations of boulders, possibly caused by draping of a coarser unit, winnowing of fines and/or permafrost action. Eskers in the Walker Lake map area generally trend north, and can be subdivided into two broad categories: those that crosscut topography; and those that are predominantly found in valleys and low-lying areas.

Some eskers that crosscut topography are draped over isolated bedrock features, other eskers, or other surficial units. These eskers are referred to as 'type-A' eskers. The trend of these eskers does not appear to be influenced by the underlying topography, regardless of scale. Preserved type-A esker segments are typically less than a few hundred metres long, but individual esker systems may extend for up to several kilometres. Type-A eskers are generally sharp crested with heights and widths usually less than 10 m.

The largest eskers are typically found in valleys and other low areas and are referred to as 'type-B' eskers. Type-B eskers are on average 30 m high (maximum >100 m) and have widths up to several hundred metres. They extend for several kilometres, and in some cases more than 30 km. These eskers are more morphologically variable than type-A eskers. Kettles within type-B esker systems are common, as are flat-topped segments interspersed between the more typical sharp-crested segments. A flat-topped morphology has been identified in other areas by Taylor (1956) and Aylsworth and Shilts (1989).

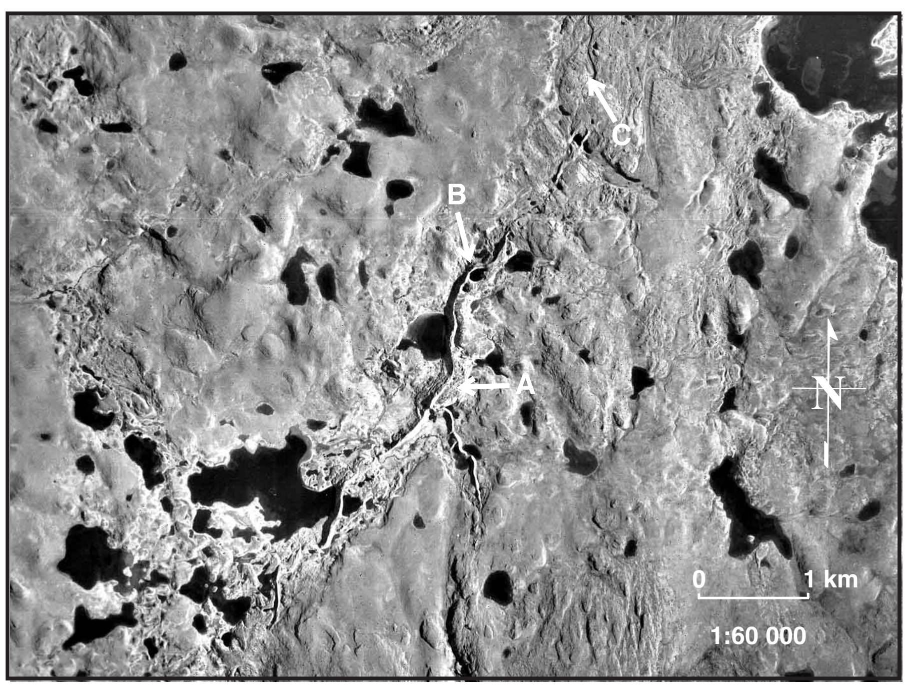

Figure 2.

Esker in Walker Lake map area (scale 1:60 000); A, flat-topped portion of esker; B, kettle; C, Nye channel. NAPL A15744-4

Transverse ridges

Deposits previously identified by Aylsworth and Shilts (1989) as ribbed (Rogen) moraines were examined in the field (Fig. 4). They form parallel ridges transverse to last ice-movement direction (cf. Little et al., 2002).

Field investigations focused on the eastern margin of the structures identified as ribbed (Rogen) moraine by Aylsworth and Shilts (1989; their map 24-1987, UTM 504000 7385000). These deposits are composed of coarse-sand, matrix-supported, subangular to subrounded boulder gravel (average B-axis 60 cm). The ridges are asymmetrical, with down-ice slopes up to 14° and up-ice slopes up to 9°. They tend to be 10–15 m high with rounded crests and an average wavelength of approximately 30 m. Troughs contain a greater percentage of boulders than ridges, and in many cases contain ponded or flowing water. A silty, fine-sand diamicton blanket (most likely till) is commonly present at the margins of transverse ridges.

Figure 3. *Oblique view of esker in Walker Lake map area.*

Irregularly shaped mounds

Features lacking the well defined linear organization of transverse ridges are termed irregularly shaped mounds (Fig. 5, 6). These features range in plan shape from circular to elliptical forms, with some being elongate parallel to ice movement. Average relief of these features is 10 m. These deposits are composed of coarse sand, matrix-supported, subangular to subrounded boulder gravel (average B-axis 30 cm). The percentage of matrix in the mounds is highly variable, but the matrix texture (coarse sand) is relatively consistent. The mounds are found in linear zones, both with and without eskers. No crosscutting relationships between eskers and mounds were observed. The lateral margins of these zones are sharp, and commonly in contact with silty, fine-sand diamictons. The mounds are also associated with transverse ridges.

DISCUSSION

Based on the texture of the material, irregular mounds and transverse ridges were either produced by glaciofluvial processes or by reworking of earlier glaciofluvial deposits. We present three hypotheses to explain the genesis of these forms and discuss the development of eskers.

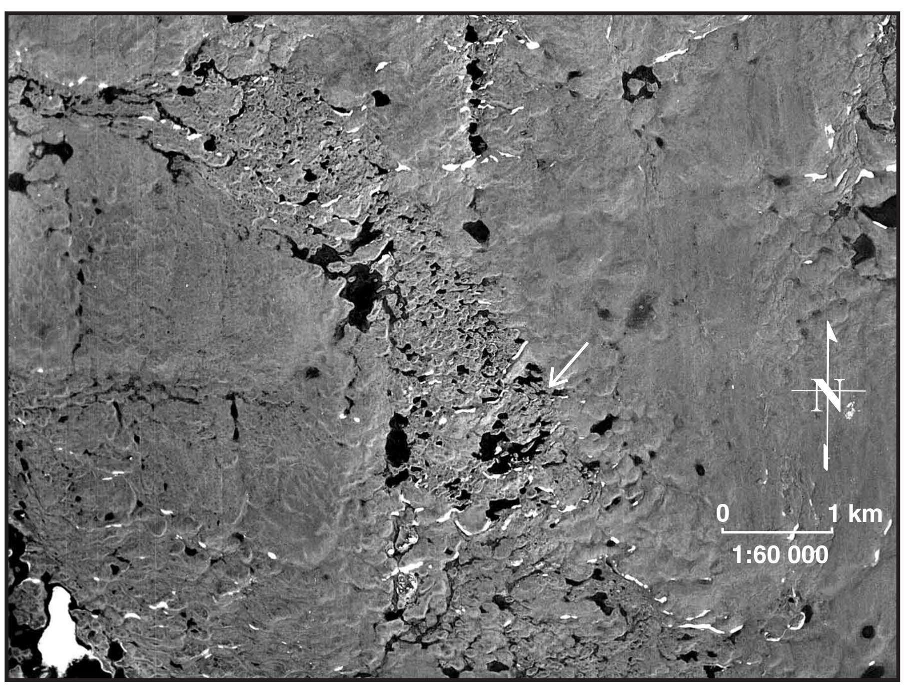

Figure 4.

Transverse ridges originally interpreted as ribbed (Rogen) moraines by Aylsworth and Shilts (1989) in Walker Lake map area (scale 1:60 000). Location of field observations indicated by arrow. NAPL A15321-27

Ribbed (Rogen) moraine hypothesis

Rogen moraines (from the type area at Lake Rogen, Sweden) have been discussed in detail by Lundqvist (1989). The term is strictly descriptive, applying to a landscape of ridges aligned transverse to ice flow. The ridges composing Rogen moraines are commonly 10–20 m high, 100–300 m apart, and 50–100 m wide. They are convex on the up-ice side, and concave on the down-ice side. By definition, drumlinoid features should be found in association with these ridges to warrant classification as Rogen moraine. In North America, Rogen moraines are usually referred to as ribbed moraines. These terms are herein considered synonymous.

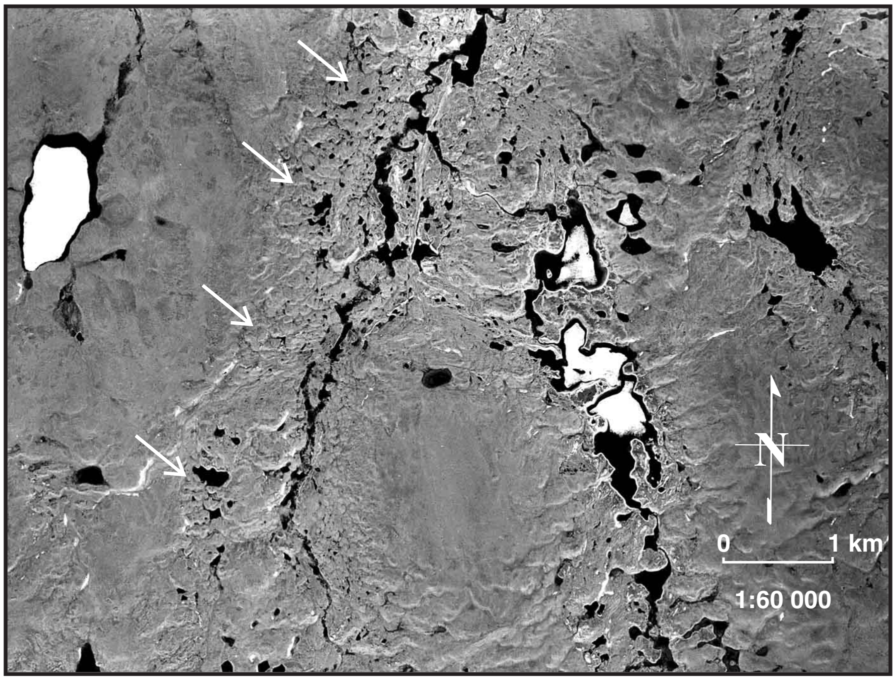

Figure 5.

Irregular mounds in Walker Lake area (scale 1:60 000). Arrows indicate zone of irregular mounds. NAPL A15751-22

Many theories have been developed to explain the origin of ribbed moraines. These include construction by bed deformation (Boulton, 1987), transition from cold- to warm-based thermal conditions (Hattestrand, 1997), thrusting of basal material by shear planes in the ice sheet (Aylsworth and Shilts, 1989), stacking of slices of debris-laden ice, (Bouchard, 1989) or deposition from subglacial meltwater (Fisher and Shaw (1992); discussed in detail below).

In NTS 56 J (north), no drumlinoid features were observed in association with transverse ridges, which brings their previous classification as ribbed moraine by Aylsworth and Shilts (1989) into question. A similar or related origin, however, cannot be ruled out by this alone. At the sites investigated, the moraines are composed of glaciofluvial sediment and are flanked by till. For ribbed moraine development by shear planes, bed deformation, or cold- to warm-based transition, different material types should be deformed. These ribbed moraine processes are all subglacial, therefore till should overlie the landforms in at least some places. The transverse ridges at Walker Lake are smaller than classical Rogen moraines (Table 1). These observations also suggest that the transverse ridges of the study area are not Rogen moraines and that their origin may be different than that of classical Rogen moraines.

Meltwater outburst flow hypothesis

Large bedforms have previously been attributed to subaerial outburst floods in the 'Channeled Scablands' in the Columbia Basin, Washington State, U.S.A. Bedforms that resulted from the release of glacial lake Missoula vary in wavelength from

Figure 6. *Irregular mounds in Walker Lake map area. Arrow indicates person for scale.*

18 m to 130 m, and in height from 0.5 m to 7 m (Baker, 1978). These have a lower amplitude and longer wavelength than those in the Walker Lake area.

A theory proposed by Shaw (1988) suggests that many glacial features (erosive and depositional) result from subglacial meltwater. Fisher and Shaw (1992) compared the morphology of ribbed moraines in the Avalon Penninsula, Newfoundland with river-ice ripples. Based on the similarities between these two features, they proposed a glaciofluvial origin for ribbed moraines. On the Avalon Penninsula, transverse ridges have a wavelength on the order of 500 m and tend to be curved in plan view. In cross-section, the "idealized Rogen ridges" of Fisher and Shaw (1992, Fig. 23) are steeper on the stoss side than lee side. They explain the origin of the features by meltwater sheet-flow along the base of debris-rich ice, which forms erosional mark cavities that then form loci for complex deposition. Accumulations within these cavities form the ribbed ridges.

The features observed at Walker Lake are different in scale from those found in Newfoundland (Table 1), having a much shorter wavelength and opposite slope relationships relative the features presented by Fisher and Shaw (1992). The difference in shape, size, and wavelength suggests that the features found in Walker Lake and Newfoundland result from different processes.

Integrated deglacial meltwater theory

Taylor (1956) proposed that a dendritic pattern of eskers is a consequence of deposition during the late stages of deglaciation, when meltwater flows into low areas that correspond to the pre-existing valley network. His model has been modified and expanded to explain the origin of transverse ridges and irregular mounds. In the new hypothesis, the construction of the three landform types is simplified into a five-phase process (Fig. 7).

Phase 1 is dominated by the development of type-A eskers and Nye channels. In the initial stages of ice-sheet melt, the hydraulic gradient and resultant meltwater flow direction are controlled primarily by the ice-sheet slope, with negligible topographic influence (Shreve, 1972). In the Walker Lake map area, meltwater flowed northwards away from ice divides (e.g. Little et al. 2002). Englacial and supraglacial drainage are primarily in the debris-poor zone of the ice, entraining little sediment. These meltwater flows result in type-A eskers if the meltwater is above the substrate, or Nye channels if the flow becomes subglacial and erosive.

Phase 2 initially results in the development of type-B eskers. At this point, englacial conduits remain in operation. The control of topography on meltwater flow, however, is increased because of the thinning of the ice sheet (Shreve, 1972). This increased topographic control results in meltwater flow being concentrated in major valleys and other low

Table 1. Wavelengths and amplitudes of ridge landforms. Avalon Peninsula and Lake Rogen are ribbed (Rogen) moraines, and Columbia Basin forms are large-scale ripple forms.

Location	Wavelength (m)	Amplitude (m)
Avalon Peninsula, Newfoundland	500	Not reported
Lake Rogen, Sweden	100–300	10–20
Walker Lake, Nunavut	30	10–15
Columbia Basin, Washington State	18–130	0.5–7

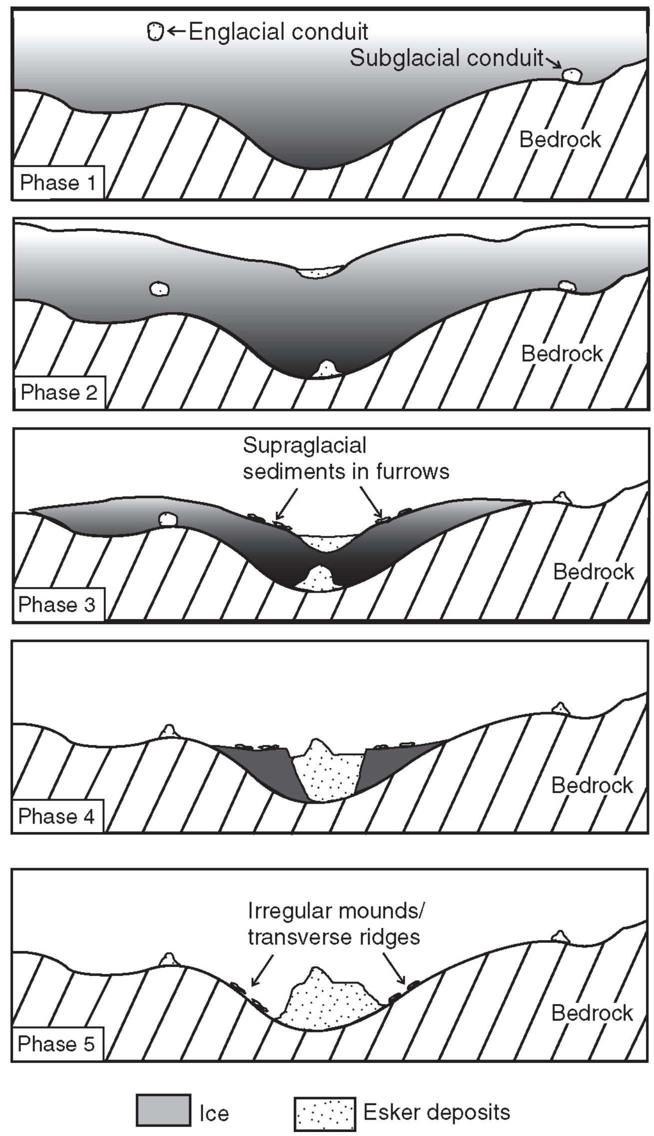

__Figure 7.__ Schematic cross-section diagram of the multiphase deglaciation theory. Phase 1, deposition of type-A eskers; phase 2, deposition of type-B eskers; phase 3, deposition of irregular mounds and transverse ridges; phase 4, esker deposition and erosion; phase 5, ice retreat.

areas. Type-B eskers may result from either subglacial flow concentrated in either topographically low areas, or from supraglacial flow concentrated in low areas on the ice-sheet surface. Both origins are included in this model. Also, ice ablation resulted in debris-rich ice at the surface producing an abundant sediment input source for the formation of large esker systems. The shape and size of ice-walled channels are controlled by the relationship of two main factors: the rate of melting by friction of running water in the conduit and/or channel, and the rate of closure of the tunnel by pressure and resulting deformation of the surrounding ice (Röthlisberger, 1972). Meltwater flow can decrease faster than the conduit can close and it is during this lag that flat segments of the eskers may be produced from meltwater in partially filled tunnels.

Phase 3 is dominated by the construction of irregular mounds and transverse ridges. These features are formed by supraglacial meltwater flow, when the ice sheet is thin enough to be rich in debris and the surface mimicks topography. The transverse ridges are formed when furrows on the ice-sheet surface channelled meltwater into organized sublinear channels or when supraglacial meltwater was simply directed down-slope towards the centre of the valley system, entraining, concentrating, and depositing debris from the ice. Supraglacial environments with furrows and meltwater channels similar to those observed on Ellesmere Island are envisaged (Fig. 8). In this hypothesis, irregular mounds form where supraglacial debris is not channelled by meltwater in sublinear furrows. Presumably during this stage, a significant amount of meltwater from this supraglacial meltwater would make its way through the ice sheet, by way of moulins or crevasses. This would provide both material and transport mechanisms for subglacial esker systems.

During phase 4 a minor amount of ice is left in the valleys. Here, flat-topped eskers were produced by glaciofluvial erosion or deposition in expansive flat-topped braidplains supported by ice only along their flanks. In the latter case, when the ice wastes away, the sides and marginal portion of the top of the esker collapse, thereby preserving the flat-topped morphology. Melting blocks of ice form the kettles that are commonly associated with these large esker systems. Type-A eskers, previously formed in the englacial and supraglacial environment, are draped over other features in these later stages of deglaciation.

In phase 5, ice has completely retreated. At this point, some debris-covered ice may remain, resulting in the kettles within the type-B eskers. This phase is dominated by paraglacial and postglacial processes. Immediately following deglaciation, surficial processes would be dominated by three factors: availability of material, changing base level resulting from isostatic rebound, and periglacial processes.

This theory attempts to explain the position and relationships of three observed landform types: transverse ridges, eskers, and irregularly shaped mounds. It explains why these landforms are located in modern-day valleys. For instance, irregular mounds are found in modern-day valleys because they represent supraglacial material which was deposited on valley walls after ice-disintegration in the final stages of deglaciation. The theory also explains the genesis of transverse ridges, and why the sediments observed within these features are limited to glaciofluvial material. As well, the observation that no supraglacial debris drapes flat-topped type-B eskers suggests that these eskers are not formed in subglacial environments thereby supporting the scenario put forth in Figure 7, phase 4. The observed asymmetry of the transverse ridges is problematic, however, because this theory only accounts for symmetrical transverse ridges.

Figure 8.

Oblique airphoto (looking east) of possible modern examples of furrows in a superglacial environment, near Yelverton Bay, Ellesmere Island. These would fill with sediment resulting in transverse ridges after ice disintegration, Ellesmere Island; A, sublinear furrows; B, irregular depressions. NAPL T405R-28

CONCLUSIONS

The five-phase deposition of the landform assemblage described above relates transverse ridges and irregular mounds with the morphology and origin of type-A and type-B eskers. This is the first attempt to explain this type of deposition by associating these geomorphic features. Future work will concentrate on the nature of the sediments that make up the transverse ridges and irregular mounds and their morphological variability. The results should aid in understanding the relationships among these features and advance the understanding of the Laurentide Ice Sheet during its deglacial phase.

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