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Glacial landforms and preliminary chronology of ice-movement in the Arrowsmith River map area, Nunavut[1]

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Abstract: Preliminary investigation of ice-flow directions in the Arrowsmith River map area in the Committee Bay area of Nunavut, indicates that ice moved in four directions: initially toward north-northwest, then to the north, then towards the northeast, and then north-northeast. It is uncertain whether these shifts in direction indicate discrete ice advances and retreats or directional shifts of the same advance. Moraine segments, striae, roches moutonnées, and crescentic gouges provide evidence of paleo-ice-flow direction. Prominent features such as eskers and Nye channels with cataracts and plunge pools indicate meltwater drainage to the north. Other features such as proglacial lakes, raised shorelines, and large imbricated channel boulders suggest that the area experienced high water levels and associated high meltwater discharges during ice disintegration. Till and esker samples are being analyzed for grain size, stone provenance, and heavy minerals to determine potential ore dispersal (if any) since ice flow was across Archean greenstone belts.

Résumé : Un examen préliminaire des directions d'écoulement glaciaire sur le feuillet cartographique d'Arrowsmith River, dans la région de la baie Committee (Nunavut), indique que les glaces se sont déplacées dans quatre directions différentes : tout d'abord vers le nord–nord-ouest, puis vers le nord et enfin vers le nord-est et le nord–nord-est. On ne peut confirmer si ces changements de direction témoignent d'intervalles distincts d'avancée et de retrait des glaces ou s'ils sont le reflet de changements de direction pendant une même avancée. Des segments de moraines, des stries, des roches moutonnées et des marques d'arrachement falciformes témoignent des anciennes directions de l'écoulement glaciaire. Des entités dominantes, notamment les eskers et les chenaux de Nye avec des cataractes et des marmites de géants, indiquent un drainage des eaux de fonte vers le nord. D'autres entités, dont des lacs proglaciaires, des lignes de rivage soulevées et des blocs de chenaux imbriqués, indiquent que la région a connu des niveaux d'eau élevés accompagnés de forts débits d'eau de fonte pendant la désagrégration glaciaire. Des échantillons de tills et d'eskers font l'objet de diverses analyses pour établir la granulométrie, la provenance des cailloux ainsi que le contenu en minéraux lourds afin de déterminer la dispersion possible de minerai, le cas échéant, puisque les glaces en mouvement ont recoupé des ceintures de roches vertes de l'Archéen.

[1] Contribution to Targeted Geoscience Initiative

INTRODUCTION

Central mainland Nunavut provides a natural laboratory for the study of ice-sheet dynamics in the northern part of the Laurentide Ice Sheet. Northeast of the study area (Fig. 1), on Melville Peninsula, Dredge (2000) found carbonate till dispersal plumes attributed to ice streams, as did Dyke et al. (1982) on the Boothia Peninsula. These ice streams emptied into the Arctic Ocean and might have fed the iceberg armadas that were responsible for Heinrich events and Dansgaard-Oeschger cycles in the north Atlantic Ocean (e.g. Hiscott et al., 2001). To the southwest, Little (2001) and McMartin and Henderson (1999) confined the location of a shifting ice-divide within the Keewatin Sector of the Laurentide Ice Sheet. Thus, glacial events in the study area may help to refine our knowledge of ice-sheet dynamics and their responses to climate changes in the Canadian Arctic. Of practical importance, the Arrowsmith map area is located down-ice from prominent greenstone belts and therefore has a potential to the reveal new mineral deposits in those belts through drift-prospecting techniques. Ice-movement indicators were carefully documented and preliminary results are presented in this paper.

REGIONAL SETTING

An overview of the glacial history and latest ice-movement patterns in central-mainland Nunavut are given in Little et al. (2002). Similarly, methods and sampling strategy are discussed in that paper. This paper focuses on detailed ice-movement directions, and two glacial phenomena that are prominent in the Arrowsmith River map area: end moraines and evidence of high meltwater discharge.

The Arrowsmith River map area (Fig. 1) contains four distinct geomorphic areas. The southeast is dominated by kame-and-kettle topography and other significant features that include proglacial lake shorelines, eskers, and moraines. The northeast is dominated by bedrock outcrops, till veneers, and glaciofluvial channels. The southwest is dominated by a significant number of large paleochannels and a series of moraines; till veneer and till blankets are also common in this area. The northwest is dominated by kilometre-wide sand-filled valleys, thermokarst lakes, and eskers. The northward-flowing Arrowsmith River is the main drainage system in the central and western parts of map area NTS 56-O, whereas the northward-flowing Kellet River is the dominant drainage system in the eastern portion of the map area.

Bedrock in the Arrowsmith River map area comprises northeast-trending greenstone belts of the Archean Prince Albert group that are flanked by paragneiss and granitoid bodies (Sandeman et al. 2001). The main rock types in the area consist of metasedimentary, metavolcanic, and granitic rocks (*see* Little et al. (2002) and references therein for a detailed summary).

OBJECTIVES

Quaternary research conducted within the Arrowsmith River map area (NTS 56-O/1–8) during the 2001 field season represents one component of the Committee Bay Project, a

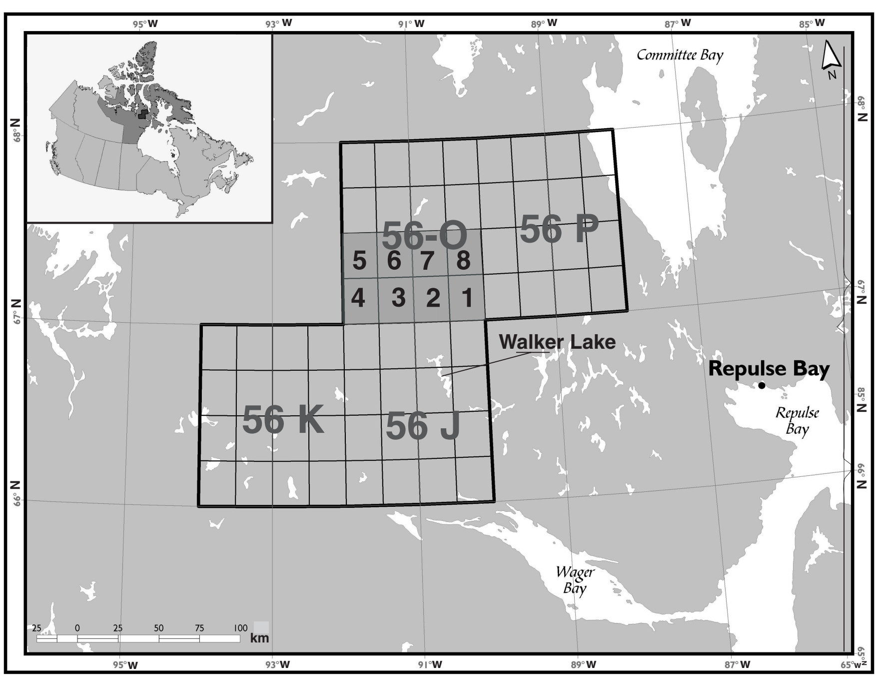

Figure 1. *Location of Arrowsmith River map sheet (NTS 56-O/1–8).*

multidisciplinary, integrated geoscience project. The main objective of the Quaternary component is to complement research conducted by geophysical and bedrock mapping teams in order to reduce exploration risk within this region of Nunavut. In order to facilitate this objective, research in NTS 56-O/1–8 will: 1) produce eight detailed 1:50 000-scale surficial geology maps; 2) conduct reconnaissance-scale till-geochemistry and kimberlite heavy-mineral indicator surveys; and 3) investigate the glacial history and ice-movement chronology within this region. The data produced will then be correlated and linked with similar data collected from NTS 56 J/9–16 (cf. Utting et al., 2002) and NTS 56-K (cf. Little, 2001).

METHODS

Prior to fieldwork, airphotos of the study area were interpreted. Features formed by glacial processes were identified on airphotos, and include glaciofluvial hummocky terrain, till blankets, and till veneers. Problematic areas were then ground-truthed in the field to assure that accurate interpretations are used in compiling the surficial geology maps. Methods used to obtain till samples for the till-geochemistry survey and esker samples for the kimberlite heavy-mineral survey are discussed in Little et al. (2002). A brief summary is presented below.

Till sampling

Ninety-seven till samples were collected in map areas 56-O/1–8. Where sufficient geological data exists, sample density was increased to target areas thought to have a higher potential for mineralization. Also, given the interpreted generally northward ice-movement direction (*see below*), sample-site concentration was increased north of these target areas. At each site, a 3 kg sample was taken, whereas both 10 kg and 3 kg samples were obtained only from selected sites (*see* Little *et al.* 2002).

Considerable variation was noted among samples within the eight map sheets including: pebble size and count, grain-size and sorting, and colour. Many till samples contained less than 10% pebbles, whereas others contained up to 50% pebbles. Till colour varies from light grey (most samples), to olive-green, to brown.

Esker sampling

Thirty-one 20 kg esker samples were collected for kimberlite heavy-mineral indicators. Sample locations were chosen based on the location of eskers and on spatial distribution optimization. In some cases, sample density was increased based on aeromagnetic modelling of kimberlite potential. Samples were excavated from the crests of eskers in locations where there is relatively little debris such as boulders and organic matter. There is wide variation in grain size throughout the study area. Most eskers have relatively high matrix-to-clast content ratios, suggesting abundant supplies of fine-grained materials in the area.

ICE-MOVEMENT INDICATORS

Striae, roches moutonnées, lunate fractures, crescentic gouges, and grooves were used to determine paleo-ice-movement direction. Striae are well preserved, particularly on finely crystalline ultramafic rocks and pegmatite containing K-feldspar megacrysts (Fig. 2). Preliminary analysis of combined ice-movement indicators from the eight map areas in NTS 56-O suggests general ice-movement to the north-northeast (Fig. 3A, B). It must be noted, however, that much more data were collected at sites where striae are well preserved. Therefore, the direction of ice-movement in the NTS 56-O map area, considering all bidirectional data together, may be biased toward those sites with well preserved striae and should be interpreted with caution.

Crosscutting relationships in striae, combined with unidirectional indicators, were used to determine the relative age of each ice-movement direction. Ice-movement proxy data were plotted as rose diagrams for each site. These rose diagrams were then compared, revealing four distinct directions of ice-movement in the Arrowsmith River area (Fig. 4). These are not interpreted as discrete events, but as a continuum of ice-movement directions (e.g. 3–4 transition) resulting from shifts within the ice sheet and/or movement of an ice divide. McMartin and Henderson (1999) and Little (2001) both referred to an ice-divide north of Baker Lake, Nunavut, and Little et al. (2002) suggested that this divide was nonlinear (cf. Aylsworth and Shilts, 1989a, b). Data presented here support the notion that ice-divide dynamics were responsible for changes in ice-movement direction within the Committee Bay Project study area (cf. Fig. 2B *in* Little (2001)).

Preliminary analysis of unidirectional ice-movement indicators in the study area (Fig. 3B) such as nailhead striae, chatter marks, lunate and/or crescentic fractures, crescentic gouges (Fig. 5), and roches moutonnées show strong northerly ice movement.

Figure 2. *Well preserved striae on polished pegmatite. Pencil aligned with dominant stria trend and ice-movement direction. Photograph by S. Hicock.*

GLACIAL LANDFORMS

The Arrowsmith River map area contains many landforms produced during deglaciation. Kames, kettles, eskers, and meltwater channels are generally well preserved. Kames up to 30 m in height are common in the area (Fig. 6).

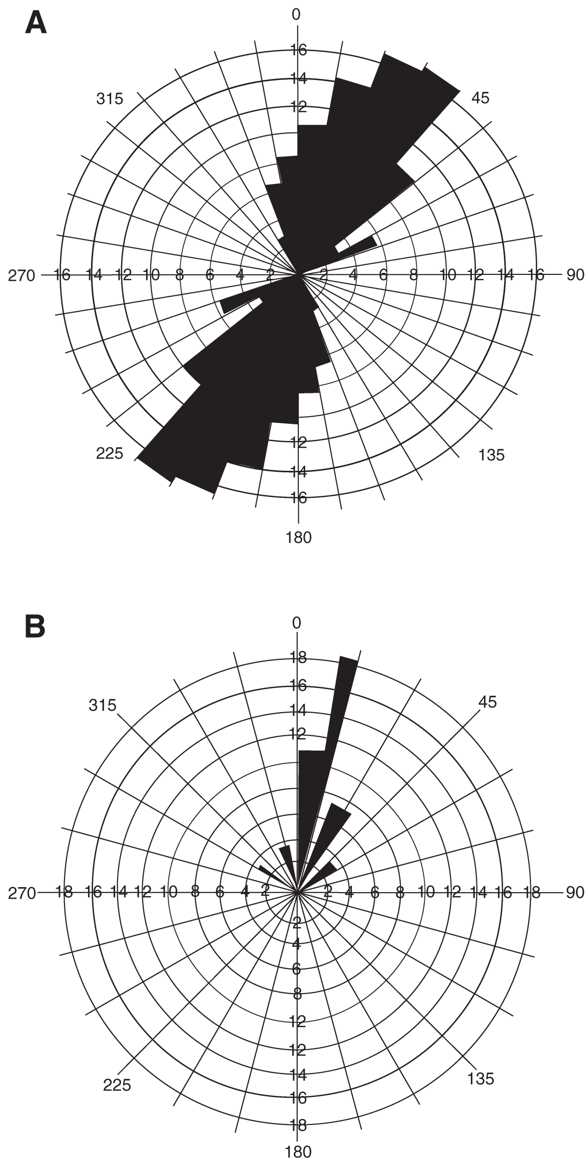

Figure 3. *A) Rose plot of all bi-directional data from NTS 56-O. N=282.* ***B)*** *Rose plot of unidirectional ice-movement data (nailhead striae, chattermarks, roches moutonnées, crescentic gouges) from NTS 56-O. N=27.*

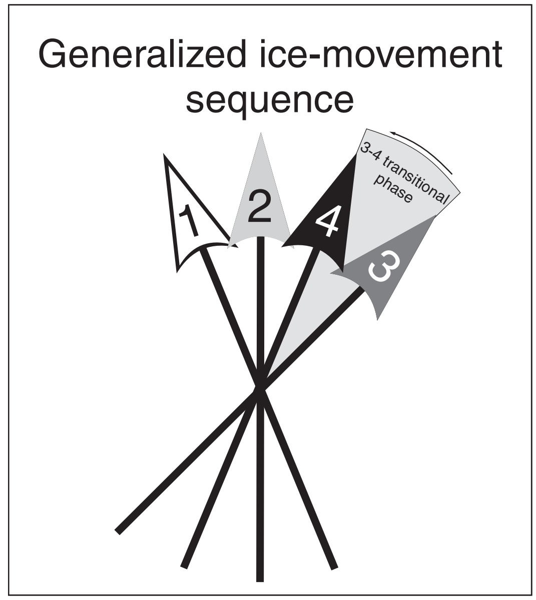

Figure 4. *Generalized ice-movement sequence.*

Figure 5. *Crescentic gouges to the right of the knife. Arrow points in direction of ice movement. Photograph by C. Ozyer.*

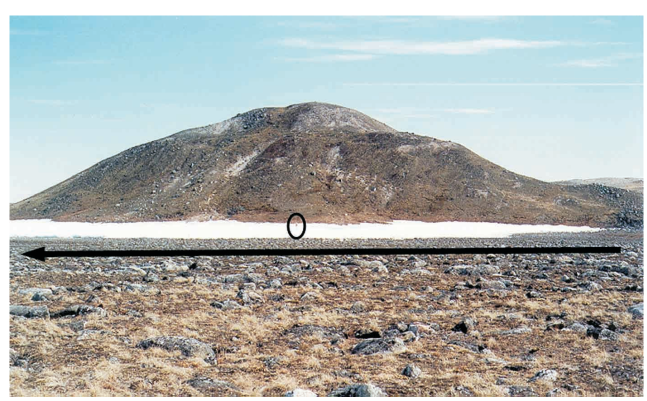

Figure 6. *Looking eastward at an example of a 30 m high kame. Arrow indicates paleo-meltwater channel and inferred paleoflow. Assistant circled in centre of snow patch for scale. Photograph by C. Ozyer.*

Kettles

Kettles and kettle lakes are abundant and vary in size from tens of metres to kilometres. In many cases kettle lakes are bordered by eskers. Syngenetic kettle-esker complexes likely formed when isolated ice blocks lodged in meltwater channels deflected flow and caused sediments to be deposited around them. Depths of kettle lakes range from a few metres to greater than 20 m.

Eskers

Eskers are common in the area, but not as common as in the Walker Lake area to the south (cf. Utting et al., 2002). Eskers trend north-northwest to north, indicating general meltwater paleoflow to the north (Utting et al., 2002). Their composition and size, however, are highly variable: many are sandy with few cobbles and/or boulders on the surface (Fig. 7), whereas others are covered with boulders (Fig. 8) and filled with pebbles and/or cobbles. Eskers vary in length from a few metres to several kilometres.

Meltwater channels

A significant number of major paleo-meltwater channels range from a few metres to greater than a kilometre wide. Bedload material in these channels ranges from pebbles to boulders, in some instances exhibiting imbrication, giving paleoflow direction. An imbricated boulder channel (Fig. 9) was studied by measuring the strikes and dips of the A-B planes of the clasts. Results from these data (Fig. 10) suggest northward paleoflow.

Moraine systems

Numerous end moraine segments are present throughout NTS 56-O. Most trend northeasterly suggesting ice retreat to the southeast. These moraines are likely part of the Chantrey moraine system (e.g. Dyke and Prest, 1987). Several of these moraine segments are discussed below.

Figure 7. *Example of a sandy esker excavated for kimberlite indicator-mineral samples. Photograph by C. Ozyer.*

A detailed study of one moraine segment in 56-O/1 showed unusual structural deviations, likely the result of a rapidly melting glacier. This moraine (‘A’ on Fig. 11) is about 5 km long, trends northeast, averages more than 30 m in height, and varies in width from 60 m to more than 200 m. It appears to have dammed a large subglacial lake to the south and a large proglacial lake to the north, which is bordered by bedrock on its eastern and western margins. On the southeast side of the moraine a meltwater chute (‘B’ on Fig. 11) was incised where water flowed upslope under pressure from the ice load. On the northwest side of the chute there is a large delta (‘C’ on Fig. 11) that is level with the top of the moraine. This chute rises 30 m and is lined with metre-sized boulders at the base that grade upwards into cobbles, pebbles, and then sand. The top of the delta is composed of sand, but, it is suspected that its lower part contains much coarser sediment. This would be expected with initially high-velocity flow that transported comparatively large particles, followed by lower velocity (waning) flow that transported finer material. This chute was likely the result of a stagnant glacier resting on top

Figure 8. *Example of a boulder-covered esker. Note esker bordering kettle lake at right. Photograph by S. Hicock.*

Figure 9. *Imbricated boulders in paleo-meltwater channel. North is to the left. Photograph by S. Hicock.*

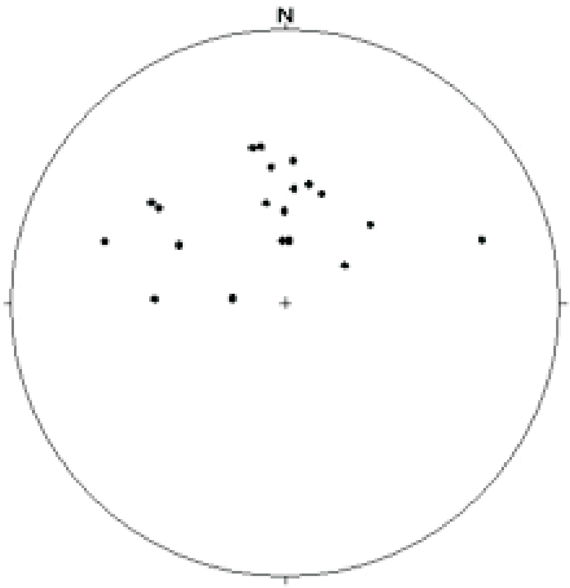

Figure 10. Lower hemisphere, equal-area plot of poles to A-B planes of imbricated boulders in the paleochannel, indicating northward meltwater flow; N=20

of the moraine while a water-filled subglacial cavity formed below the ice. The pressure that the weight of the glacier exerted on the subglacial water may have forced water upwards to the front of the moraine where the glacier rested at its top (Fig. 11, inset). This situation could have produced a rapid-release point from which the top of the moraine was eroded while forcing out relatively coarse-grained sediments. A subsequent breach ('D' on Fig. 11) 1 km southwest of the chute created a 30 m wide channel. This breach likely led to rapid drainage of the subglacial lake, thereby causing water flow through the chute to wane and deposit the fines that cap the delta. The southeast side of the moraine contains unusual hummocky and drumlinoid sand deposits, whereas its northwest side is flat and covered with sand, likely due to rapid flooding caused by the breaching of the moraine. At each end of the moraine, distal bedrock exposures have been washed clean of debris ('E' on Fig. 11). This washing probably occurred when water spilled over the edge of the moraine onto bedrock surfaces.

Another moraine segment about 3 km long trends east-northeast and straddles the 56-O/2–3 boundary. It is about 180 m wide and 20 m high. The moraine is asymmetrical: steep on the north side with its apex located about 50 m

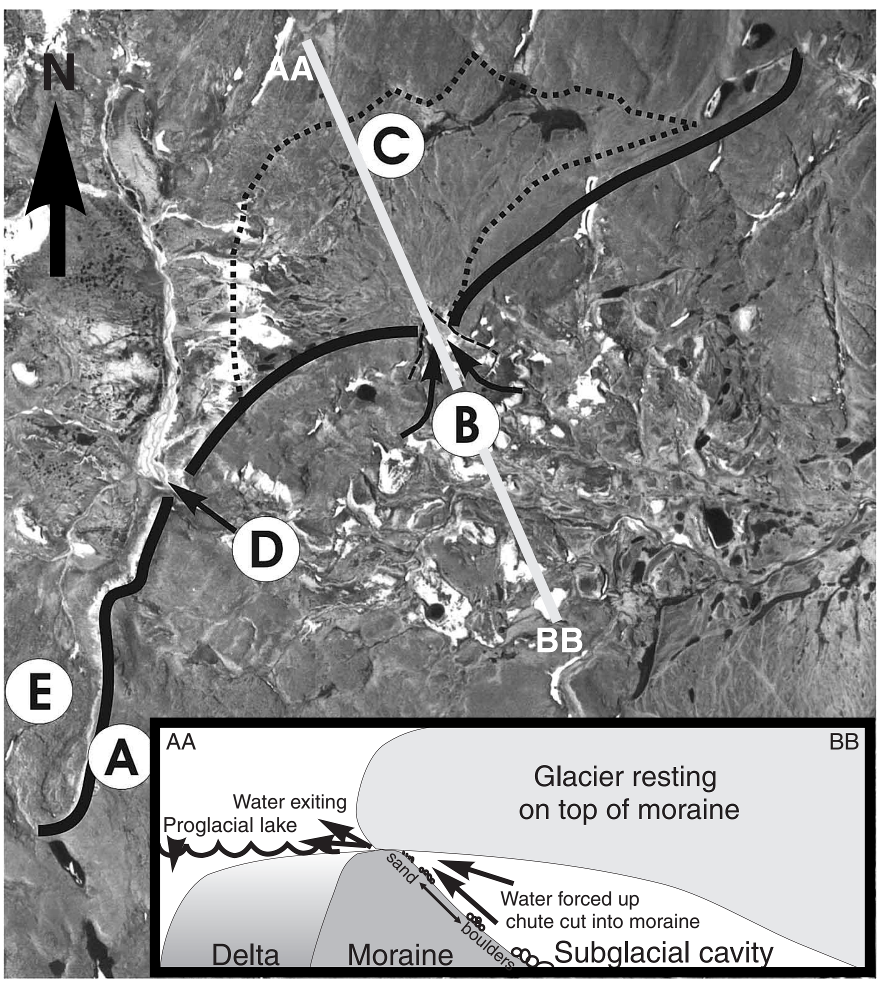

Figure 11.

Airphoto of moraine, A; chute, B; raised delta, C; breach, D; rock outcrop washed clean, E. Cross-section AA-BB (inset) reconstructs the breaching of the moraine and formation of the delta. NAPL A15792-179 from the distal northern slope. The surface of the moraine consists of metre-sized, well rounded boulders of which approximately 1% are iron rich.

A third moraine segment about 2 km long trends east-northeast in NTS 56-O/3. This moraine is about 200 m wide and 15–20 m high. The southeast (proximal) side of the moraine is quite steep with a slope of about 20° that decreases to 5° near the top. The moraine has a branch on the south side that trends north-northeast. The main section of the moraine contains numerous channels about 2 m wide, about 0.5 m deep, and about 6 m apart that cross the moraine crest obliquely. The crest of the moraine contains sediment with 40% pebbles and 60% sand (by area). A-axis lengths of clasts vary from 0.2 cm to 150 cm, and average 20 cm. Clasts are angular to subrounded, and average subrounded. The area on the north side of the moraine contains finer sediment than those in the area south of it. Till samples were collected on both the north and south sides of the moraine for textural and geochemical comparison.

Finally, a series of small moraine segments are located approximately 2 km west of the aforementioned moraine. These moraines trend west-northwest, which is transverse to those previously described. These moraines appear to have been connected to the moraines discussed above, but a large paleo-meltwater channel now separates them. The orientations of these segments are consistent with the Chantrey moraine system (Dyke and Prest, 1987).

Nye channels

A considerable number of bedrock-incised subglacial meltwater channels (Nye channels) are present in the Arrowsmith River map area (Fig. 12). These channels range in width from 10 m to more than 100 m, and in depth from 10 m to 30 m. Lengths vary from tens of metres to greater than 1 km (‘A’ on Fig. 12). The channels trend northwest and north which, when combined with approximate locations for proposed ice divides (cf. Little et al., 2002), suggest northward-flowing subglacial drainage. Many of the larger Nye channels have plunge pools located at their northern ends (‘B’ on Fig. 12) and paleo-cataracts descending to the north that also support the interpretation of northerly paleoflow. The plunge pools are commonly more than ten times the channel width and contain well rounded boulders (<1 m to >3 m; ‘C’ on Fig. 12) that accumulated due to decreased water velocity.

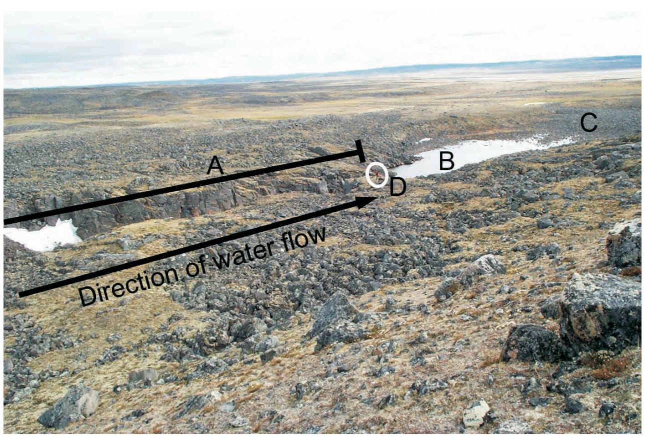

Figure 12. Nye channel, A; plunge pool, B; well rounded boulders, C; person circled for scale, D. Photograph by S. Hicock

In most cases, the preservation of Nye channel walls is poor. Formerly steep walls have been subjected to postglacial frost action, and large angular boulders now cover the channel floor, preventing inspection of sediment within the channels. One Nye channel, more than 100 m wide, contained well rounded, metre-sized boulders in the centre of the channel.

Raised shorelines

The Arrowsmith River map area underwent widespread flooding during deglaciation that left distinct raised shorelines. The southeast region of 56-O/1 contains evidence of at least three different well preserved water levels which might reflect isostatic uplift, changing base level as morainic dams failed, and/or fluctuations in water discharge. The elevation of the highest shoreline is about 460 m a.s.l.; other shorelines are at about 440 m a.s.l. and about 432 m a.s.l.

A large lake adjacent to these shorelines has a present-day surface elevation of about 430 m a.s.l. The shorelines consist mainly of sand. The highest shoreline contains approximately 3 cm of light grey loess at one site, from which samples were collected for textural analysis. Approximately 500 m north of the loess site along the same shoreline, a well preserved, discontinuous layer of peat moss 27 cm thick was observed at a depth of 180 cm. Organic material collected from this section for radiocarbon dating will aid in determining the age of the high-water stand.

CONCLUSIONS

The Arrowsmith River map area has a complex glacial history. The area experienced a series of glacial advances and retreats that left end moraines formed by ice movement toward the north. Crosscutting, bidirectional indicators such as striae and grooves, together with unidirectional indicators, suggest ice movement initially to the north-northwest, then to the north, followed by to the northeast, then a slight transition to the north-northeast.

Unidirectional indicators such as roches moutonnées, chatter marks, and crescentic gouges suggest northerly ice movement. The variation of ice-movement proxies suggests shifts in ice-movement within the Arrowsmith River map area were influenced by a dynamic ice divide reportedly located north of Baker Lake and south of the Committee Bay Project study area.

The Arrowsmith River map area experienced high water-flow regimes during deglaciation that left Nye channels, eskers, and channels with large imbricated boulders and cataracts. All of these features indicate drainage to the north, which is consistent with a glacier retreating southward.

The advanced understanding of ice-movement chronology presented here, in conjunction with esker and till sampling, will provide new data on provenance and dispersal trends for the scientific community as well as for mineral exploration.

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