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History of ice flow in the Schultz Lake and Wager Bay areas, Kivalliq region, Nunavut

I. McMartin and L.A. Dredge

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Abstract: In the Schultz Lake area, faceted and striated bedrock surfaces and palimpsest streamlined landforms record multiple ice flows. An old southeastward flow across the area was followed by a north-northwestward flow and a late westward ice-streaming event. In the Wager Bay area, striations and glacial landforms are less developed. In the northern parts of this area, flow was to the north-northwest, with late flows into Wager Bay. In the south, flows shifted between southward and southeastward. A central 20 km wide belt of weathered upland terrain has few striae or glacial landforms. Although both areas lay beneath the Keewatin Ice Divide during the last glaciation, ice-flow directions, sequences, and glacial landscapes are different. Mobile, wet-based ice and a shifting ice divide characterized the Schultz Lake area. In contrast, the ice divide at Wager Bay seems to have been fairly stable and could have been cold based prior to deglaciation.

Résumé: Dans la région du lac Schultz, des surfaces rocheuses striées et tronquées et des formes fuselées palimpsestes témoignent d'écoulements glaciaires multiples. Un ancien écoulement vers le sud-est dans l'ensemble de la région a été suivi d'un mouvement vers le nord-nord-ouest et d'un événement tardif vers l'ouest associé à un courant de glace. Dans la région de la baie Wager, les stries et les formes glaciaires sont moins bien définies. Dans le nord de cette région, l'écoulement glaciaire a été vers le nord-nord-ouest avec des mouvements tardifs dans la baie Wager. Dans le sud, les directions d'écoulement ont varié entre le sud et le sud-est. Une zone centrale de hautes terres altérées de 20 km de largeur présente peu de stries ou de formes glaciaires. Bien que la ligne de partage glaciaire du Keewatin ait chevauché les deux régions pendant la dernière glaciation, les directions d'écoulement glaciaire, la séquence des écoulements et les modelés glaciaires y sont différents. La région du lac Schultz était caractérisée par la présence d'un glacier mobile à base humide et d'une ligne de partage glaciaire transitoire. Par contre, la ligne de partage glaciaire dans la région de la baie Wager aurait été relativement stable et le glacier aurait eu une base froide avant la déglaciation.

INTRODUCTION

In the summer of 2004, the GSC conducted Quaternary mapping in the Schultz Lake (NTS 66 A) and Wager Bay (NTS 56 G) map areas in central Nunavut (Fig. 1). Both areas were located beneath the Keewatin Ice Divide during the last glaciation (Fig. 2). Field work included surficial mapping, regional-scale till sampling, stratigraphic studies, and ice-flow indicator surveys. An understanding of ice-flow directions and the sequence of flow changes will enhance mineral exploration, particularly drift prospecting for diamonds. This report summarizes findings related to ice-flow directions, patterns, and the sequence of flow events in the two map areas.

REGIONAL SETTING

The Schultz Lake map area includes the community of Baker Lake, located about 300 km inland from the west side of Hudson Bay (Fig. 1). Drainage is toward Hudson Bay through the Thelon River that flows into Baker Lake and Chesterfield Inlet (Fig. 2). Relief is subdued with elevations ranging from 3 m a.s.l. at Baker Lake to 283 m a.s.l. along a bedrock ridge west of Pitz Lake. Drift is relatively thick (>5 m) and continuous south of the Thelon River, forming locally streamlined, rolling till plains (Fig. 3a). In contrast, thin till (<2 m) and exposed bedrock are predominant north of the river (Fig. 3b). Marine and/or glaciolacustrine sediments occur in poorly drained, low-lying terrain, or form flights of raised strandlines on the sides of till and broad bedrock hills. This map area is essentially devoid of glaciofluvial sediments (cf. Fig. 2), although restricted areas north and south of Schultz Lake show evidence for proglacial and subglacial meltwater erosion.

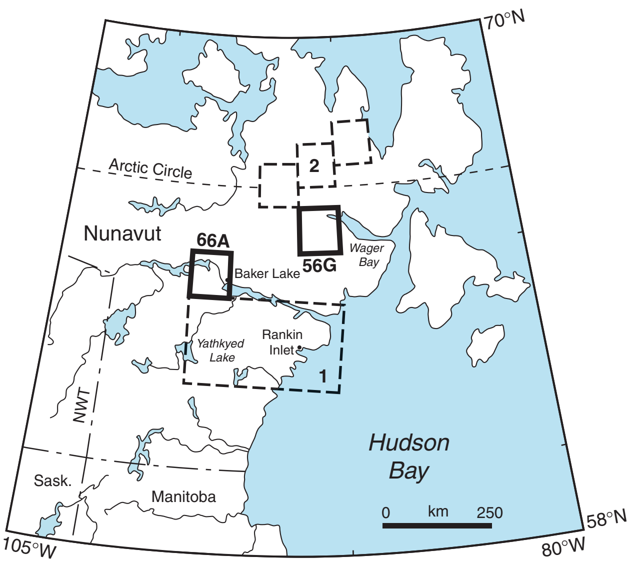

Figure 1. Location map of the two study areas in central mainland Nunavut: Schultz Lake (NTS 66 A) and Wager Bay (NTS 56 G). The Western Churchill NATMAP area and the Committee Bay Targeted Geoscience Initiative area discussed in the text are located within dashed areas 1 and 2 respectively.

The Wager Bay map area spans parts of the new Ukkusiksalik National Park around Wager Bay (Fig. 2). Relief is much more pronounced, with rugged terrain and uplands dissected into fiords and cliffed river valleys. Bedrock highlands south of Wager Bay separate drainage flowing into Wager Bay from drainage flowing south into Chesterfield Inlet or directly into Hudson Bay. The terrain rises abruptly from sea level at Wager Bay to a maximum of 578 m a.s.l. in the uplands within the park, then slopes gently southward down to 250 m a.s.l. The landscape is largely controlled by bedrock structure and till deposits are regionally thin (<2 m). Glaciated uplands with glacial troughs and veneers of till dominate the areas north of Wager Bay (Fig. 3c). Some drumlinized till plains with bouldery surfaces occur in the northwest area. Uplands south of Wager Bay have little till, but extensive areas of weathered rock (Fig. 3d). South of the uplands are meltwater-dominated landscapes, where till has been washed and/or dissected by meltwater during ice recession. Limited marine and glaciolacustrine deposits are found mainly around Wager Bay (Dredge and McMartin, work in progress, 2005; Dredge and McMartin, 2005).

Both map areas lie within the Archean Rae domain of the Western Churchill Province (Paul et al., 2002). The Schultz Lake area is covered by thick sequences of distinctive red volcanic and sedimentary rocks of the Proterozoic Dubawnt Supergroup (Hadlari et al., 2004). The remaining areas are underlain by Archean granitoid or gneissic rocks and metamorphosed Archean and Proterozoic sedimentary and volcanic rocks. The Wager Bay area is covered for the most part by a mix of Archean granitoids, gneiss, and paragneiss, with a thin belt of Archean sedimentary and volcanic rocks in the south (Panagapko et al., 2003). A belt of Proterozoic gneiss, paragneiss, and some quartzite occurs in the central area.

PREVIOUS WORK

Tyrrell was the first to measure striations in the Schultz Lake area as he travelled down the Thelon River in 1893. A page figure in his report shows several striations indicating opposite flows between Schultz Lake and Baker Lake (Tyrrell, 1897). These findings led him to suggest a 'Keewatin Glacier' that served as one of a number of dispersal centres around Hudson Bay. Bird in 1948 measured glacial striae and drumlins in the middle and lower Thelon Basin and found evidence in the Schultz Lake area for west-northwestward and north-northwestward flows (Bird, 1951). Fyles conducted work on ice-flow directions in central Keewatin in 1954 as part of 'Operation Baker'. His findings were summarized in a report by Wright (1967), and a map of surficial features shows several striations indicating ice flow toward the northwest and the southeast in the Schultz Lake area. A westerly ice flow is also indicated by streamlined landforms. On the basis of this work by Fyles and of fieldwork by Lee (1959) in southern Keewatin and by Craig (*in* Wright,

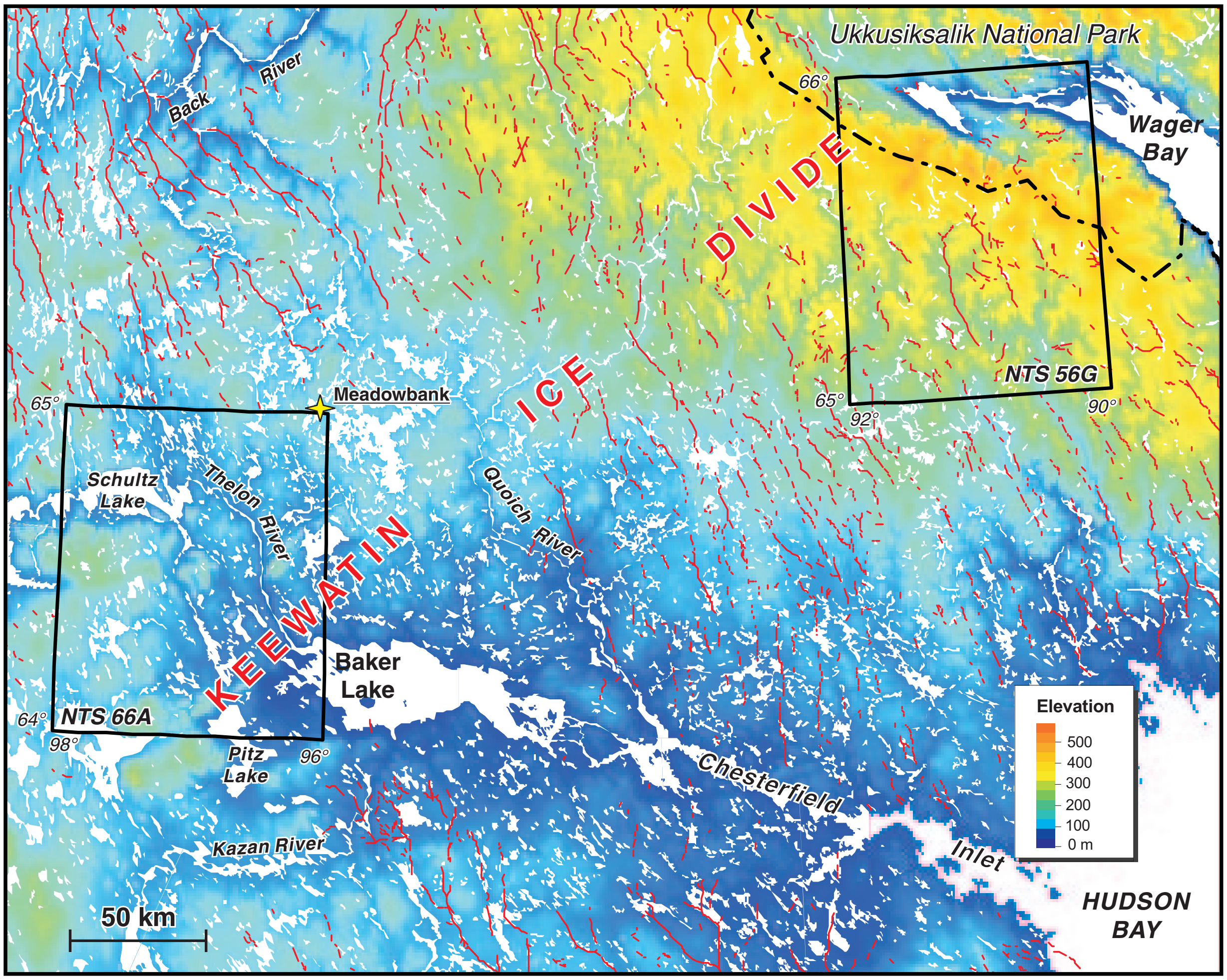

Figure 2. *Topography in the two map areas and adjacent region (derived from Canada 3D DEM). Trends of major eskers (red) are shown on either side of the Keewatin Ice Divide (*modified from *Aylsworth and Shilts, 1989).*

1957) in eastern District of Mackenzie (now eastern Northwest Territories), Lee et al. (1957, p. 1760) defined the Keewatin Ice Divide as the zone occupied by the last glacial remnants of the Laurentide Ice Sheet west of Hudson Bay.

Ice-movement indicators demonstrating pervasive ice flow toward Hudson Bay and a dispersal train of red Dubawnt Supergroup rock types extending to the southeast led Shilts and others to redefine the Keewatin Ice Divide as a relatively static, long-lived feature of the Laurentide Ice Sheet (e.g. Shilts et al., 1979; Shilts, 1980). Although the predominant regional ice-flow trend was recognized as being to the southeast, evidence for an old southward flow was indicated by striations and southward transport of erratics (i.e. Lee, 1959; Shilts, 1973; Cunningham and Shilts, 1977). Cunningham and Shilts (1977) found evidence for southward, northwestward, and westward directions of ice flows in the Baker Lake area and suggested a southeastward migration of the ice divide, an idea originally proposed by the pioneering work of Tyrrell (1897). Aylsworth et al. (1990) compiled a map of landforms and materials for the Schultz Lake map area based mainly on airphoto interpretation, and this together with adjacent maps were used to provide a b road regional interpretation of constructional glacial landforms around the Keewatin Ice Divide (Aylsworth and Shilts, 1989). These authors characterized the divide as a broad area with no dendritic esker systems, few constructional glacial landforms, and abundant hummocky moraine. They placed it in a curvilinear zone extending northward between south-central Kivalliq and Wager Bay, which corresponds closely to the 8.4 ^{14}C ka Keewatin Ice Divide of Dyke and Prest (1987). Aylsworth and Shilts (1989, p. 3) reported that "...although the dispersal center had migrated eastward and southward...it probably migrated no more than 100 km." On their maps, the Schultz Lake and Wager Bay map areas lie within the Keewatin Ice Divide and hummocky moraine Zone 1.

On the basis of till composition mainly south of Baker Lake, Klassen (1995) showed strong evidence for southeastward till dispersal over the Keewatin Ice Divide area, hence supporting the southeastward migration of the divide. McMartin and Henderson (1999, 2004) made systematic measurements of striations in the Western Churchill NATMAP area (*see* Fig. 1 for location) and provided new evidence for the mobility of ice divide(s) and resulting major shifts in ice-movement directions. Utting and McMartin

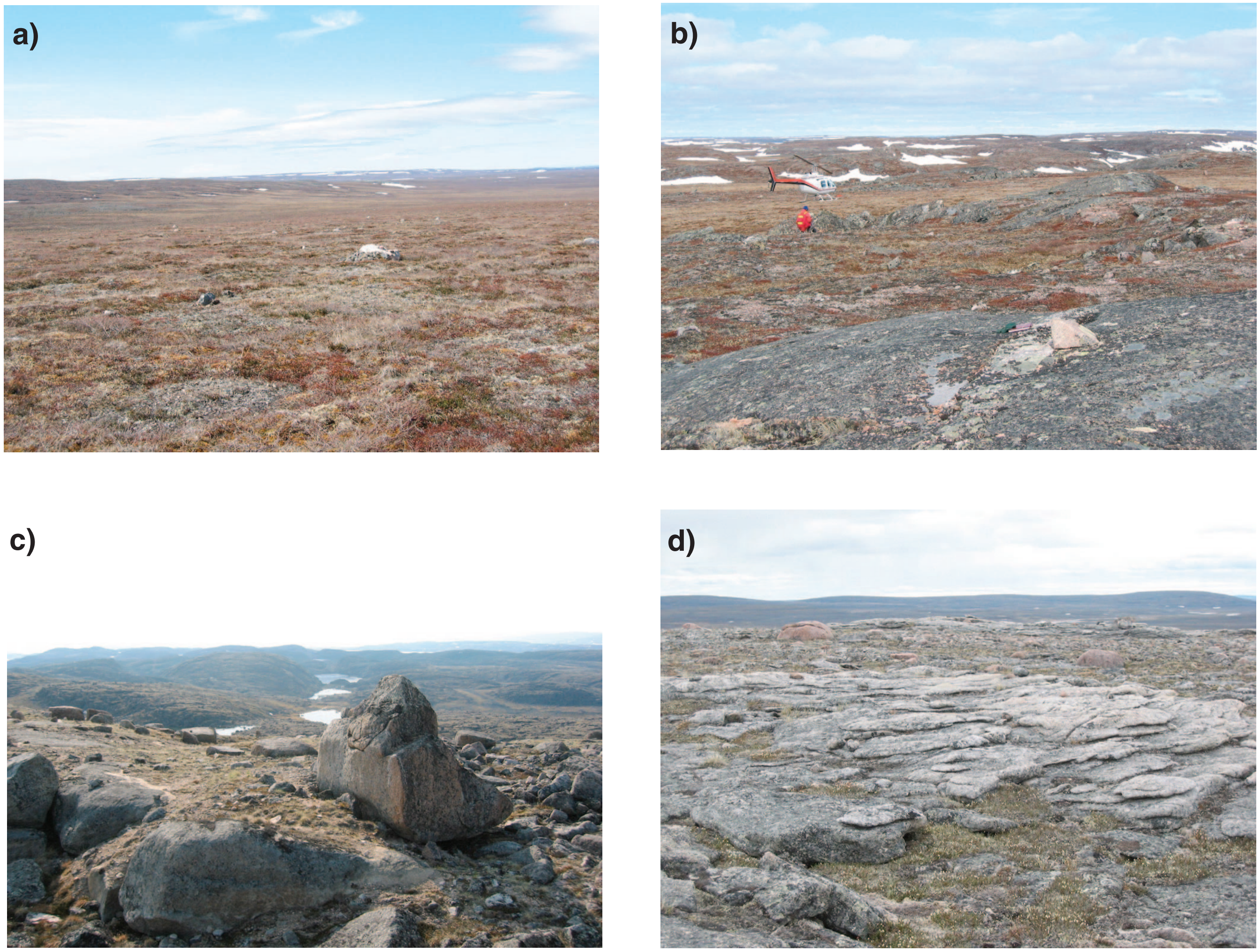

Figure 3. ***a)*** *In the Schultz Lake map area, the landscape south of the Thelon River is characterized by locally streamlined, rolling till plains over and down-ice from Proterozoic Dubawnt rocks. GSC 2005-017.* ***b)*** *On granitic terrain mainly north of the Thelon River, the landscape is largely controlled by bedrock structure and till deposits are thin and discontinuous. GSC 2005-018.* ***c)*** *Hilly terrain north of Ford Lake in the Wager Bay map area has a veneer of till. Note accordant plateau elevations and glacial trough in the background. GSC 2005-019.* ***d)*** *Spalled granite bedrock surface lacking striae in the uplands of the Wager Bay area. GSC 2005-020. All photographs by L. Dredge.*

(2004) mapped ice-movement indicators in the vicinity of the Meadowbank gold deposits (*see* Fig. 2 for location) and identified three main phases of ice flow between northward and northwestward.

Less information is available for the Wager Bay map area. Two page figures by Lee (1959) show one northward striation in the Wager Bay area and suggest that this area lies along an extension of the same ice divide as that found in the vicinity of Schultz Lake. The area is also within the Aylsworth and Shilts landform compilation, which shows it to be an area with few ice-flow indicators. Smith (1990) provided information on the glacial history of the Wager Bay area, which included the northern part of the Wager Bay map sheet. Much of her work related to ice flow was based on till landforms, and her conclusions about ice flow differ significantly from results from striation measurements shown in this report.

METHODS

Systematic coverage of the two areas was conducted with helicopter support. Ice-flow indicator measurements were made at about 90 sites in the Schultz Lake area and 80 sites at Wager Bay. Field site locations and descriptions of ice-flow indicators have been published in McMartin et al. (2005). Although the project included observations of streamlined till forms and various constructional landforms, the main field determinations of ice movement were based on measurements of striations and related small-scale ice abrasion marks, rat tails, and roches moutonnées. Relative ages of striations were interpreted by examining crosscutting relationships and by comparing azimuths on lee-side (down-ice) positions relative to stoss-side (up-ice) striated facets. In the Schultz Lake area, many rock surfaces, particularly low outcrops surrounding lakes, had heavily striated or grooved, highly polished surfaces, so measurements were made on surfaces across whole outcrops (Fig. 4a). In contrast, in the Wager Bay area, rock surfaces tended to be rough and weathered. Although some areas had polished outcrops, many measurements were made on microstriae on crystal faces of coarse-grained granitoid rocks (Fig. 4b). In some cases, striations could only be found by removing the feather-edge of till adjacent to outcrops and holding a flashlight at a low, raking angle.

Figure 4. a) *The glacial erosional record is very well preserved in the Schultz Lake area, both on the Proterozoic uplands and along lake shorelines on Archean granitic (this photograph) and volcanic rocks. Photograph by J.-F. Gagnon. GSC 2005-021.*

Figure 4. b) *In the Wager Bay area, feldspar grains or quartz veins are commonly the only surfaces with striations. The photo shows weathered, folded gneiss with striations preserved on protruding, less weathered quartz veins. Photograph by L. Dredge. GSC 2005-022.*

STRIATION RECORD IN THE SCHULTZ LAKE MAP AREA

In the Schultz Lake area, bedrock outcrops commonly display two or more sets of striations having distinct trends, indicating major changes in ice-flow directions (Fig. 5). The following section presents a preliminary interpretation of the ice flow record, from the oldest recognized ice-flow events to the most recent flow(s).

Early flows

Evidence of an early west-southwestward flow is subtle in the map area, with poorly preserved striations trending 227° to 260° (Fig. 5a). Old southwesterly striations were also observed within the adjacent map area to the east (Cunningham and Shilts, 1977; Schau, 1981), to the south (McMartin and Henderson, 2004), and in the Wager Bay map area as part of the current study. In addition, early south-southwesterly (188°–201°) striations were measured at a few sites, mainly around Whitehills Lake (Fig. 5a). This south-southwest flow clearly predated the later northwesterly flows (*see* below), but the age relationship with the other flows remains uncertain.

Southerly flows

Striations indicating a south-southeastward (159°–178°) flow are well preserved throughout the central part of the map area. They are found on both high and low ground and may occur on bedrock surfaces striated by later northwesterly flows. They were observed as far north as 5 to 10 km north of Schultz Lake (Fig. 5b). The northern limit of this striation set would indicate an early position of an ice divide within or close to the map area. At two sites in the south-central part of the map area, well defined easterly striations (104°) were found on glacially shaped outcrops. At one of these sites, the easterly striations appear to postdate south-southeasterly striated surfaces.

The south-southeast flow appears to have shifted southeasterly as indicated by striations trending 122° to 152° (Fig. 5c). These southeast striations are restricted to an area south of Schultz Lake, suggesting that the ice divide migrated southerly across the map area during this phase. The preservation of southeasterly trending crag-and-tail landforms east and southeast of Schultz Lake together with the lack of landforms associated with the south-southeast flow suggest that the southeast flow postdated the south-southeast flow.

Northwesterly flows

A major flow reversal occurred in the entire Schultz Lake map area as indicated by north-northwest (336°–348°) striations occurring on both high and low terrain (Fig. 5d). Associated landforms are predominant in the southwest part of the area, but are best preserved on low ground suggesting a thinning ice sheet during their formation. North-northwest ice-flow indicators were reported as far as Kaminuriak Lake 100 km southeast of the map area (McMartin and Henderson, 2004).

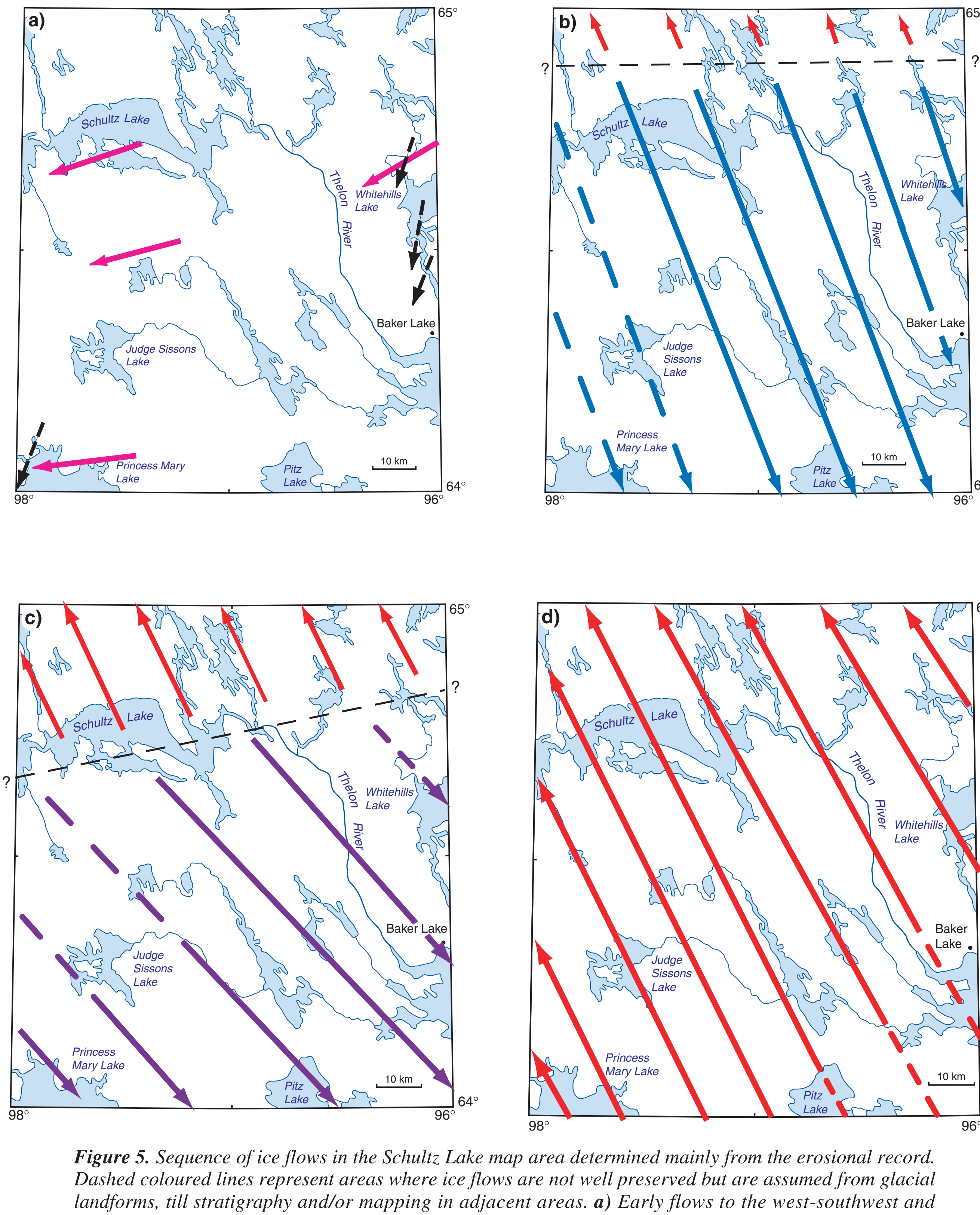

Figure 5. *Sequence of ice flows in the Schultz Lake map area determined mainly from the erosional record. Dashed coloured lines represent areas where ice flows are not well preserved but are assumed from glacial landforms, till stratigraphy and/or mapping in adjacent areas.* ***a)*** *Early flows to the west-southwest and south-southwest;* ***b)*** *south-southeast flow;* ***c)*** *southeast flow;* ***d)*** *north-northwest flow;* ***e)*** *northwest flow followed by west-northwest flow; and* ***f)*** *westerly flow in the southern half of the map area and last position of the Keewatin Ice Divide (KID).*

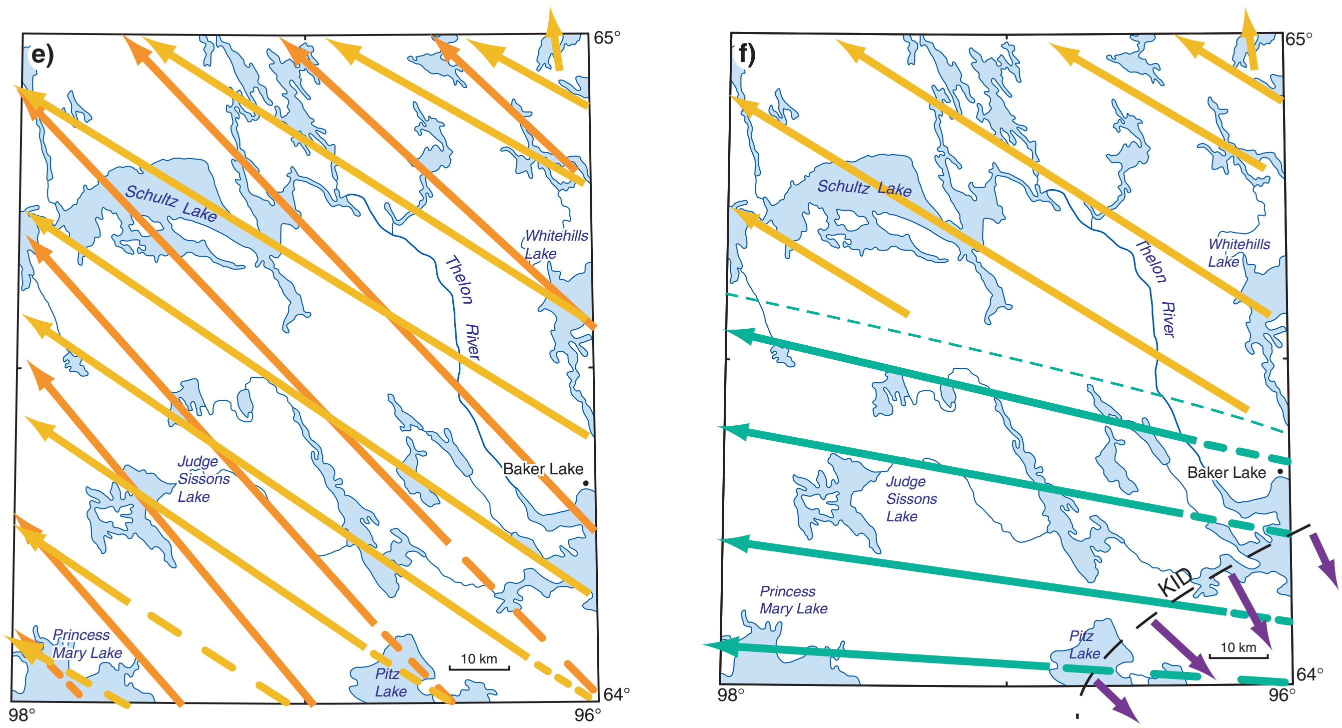

Figure 5. (Cont.)

Evidence for northward glacial transport there is the presence of distinctive Proterozoic dolomite boulders over the Yathkyed greenstone belt derived from Hurwitz Group outcrops to the south (McMartin and Henderson, 1999). This flow is significant in that it implies that the ice divide continued to migrate toward the southeast, prior to the latest southeastward flows across the region.

The north-northwest flow progressively shifted to the northwest (318°–334°), then to the west-northwest (284°–315°), as indicated by crosscutting striations (Fig. 5e). Palimpsest landforms associated with these flows are found around the east end of Schultz Lake where long northwest-trending till forms are superimposed by short west-northwest-trending drumlins. The counter-clockwise rotation in ice-flow trends probably occurred as the divide migrated back toward the northwest, to a position located directly south of the map area (McMartin and Henderson, 2004). In the northeast extremity of the map area, the latest flow is more northerly (Utting and McMartin, 2004) and may represent the head of an ice stream flowing north toward the Back River basin.

Late westerly flow

The last flow was westerly and was restricted to the southern half of the map area as indicated by late striations trending 268° to 283° and westerly trending short drumlinoid features (Fig. 5f). The northern limit of the westerly indicators forms the abrupt northern margin of a drumlin field marking a major late-glacial ice stream ('Dubawnt Lake ice stream', Stokes and Clark, 2003). This ice stream extended westerly into the higher portions of the Thelon River basin as far as longitude 106°W (Stokes and Clark, 2003), and southerly across Yathkyed Lake (McMartin and Henderson, 2004). The westerly landforms associated with this late flow are commonly superimposed on large north-northwest- and northwest-trending drumlins and crag-and-tail landforms.

The latest ice-flow indicators are southeastward east of Pitz Lake (Fig. 5f). This suggests that late during deglaciation, the ice divide migrated back within the map area, lying across the Pitz Lake basin and the western part of Baker Lake. This is the position that has been shown in maps and reports by Shilts and others as the location of the Keewatin Ice Divide *sensu stricto*.

STRIATION RECORD IN THE WAGER BAY MAP AREA

In the Wager Bay area, a central 20 km wide belt of weathered upland terrain separates northern areas with a well preserved glacial landscape from southern areas characterized by a limited glacial record.

Northern area

Striations are generally well preserved in the northern half of the map area. Polished, striated, and grooved surfaces are common in the northwest, an area of thick till, crag-and-tail forms, and short drumlins. Actively scoured uplands of exposed bedrock and thin till north and south of Ford Lake and areas of outcrop along the head of Wager Bay also contain a well defined glacial record. Limited evidence exists for an early flow to the northwest, recorded only along the northern border of the map area. In the same area, a few drumlinoid forms indicate a northwest flow. These forms show partial remoulding of limbs into north-northwest-trending features. A north-northwest (340°) flow across the area seems to be the dominant glacial flow record and the earliest main regional flow recorded by erosional indicators (Fig. 6). It is succeeded by a north-northeasterly (about 010°) flow across the whole northern part of the area, followed by a northeast (030°–040°) flow limited to areas east of Brown Lake, but found in both highlands and lowlands (Fig. 6). A late sequence of flows, first down the bay and then into the bay from both the north and south shores, is recognized along Wager Bay. Final local flow in the vicinity of Brown Lake may have reverted to the north.

Southern area

Striations are more poorly preserved in the southern part of the map area, which is a landscape of meltwater erosion and deposition. Preserved striations beneath thin till layers suggest

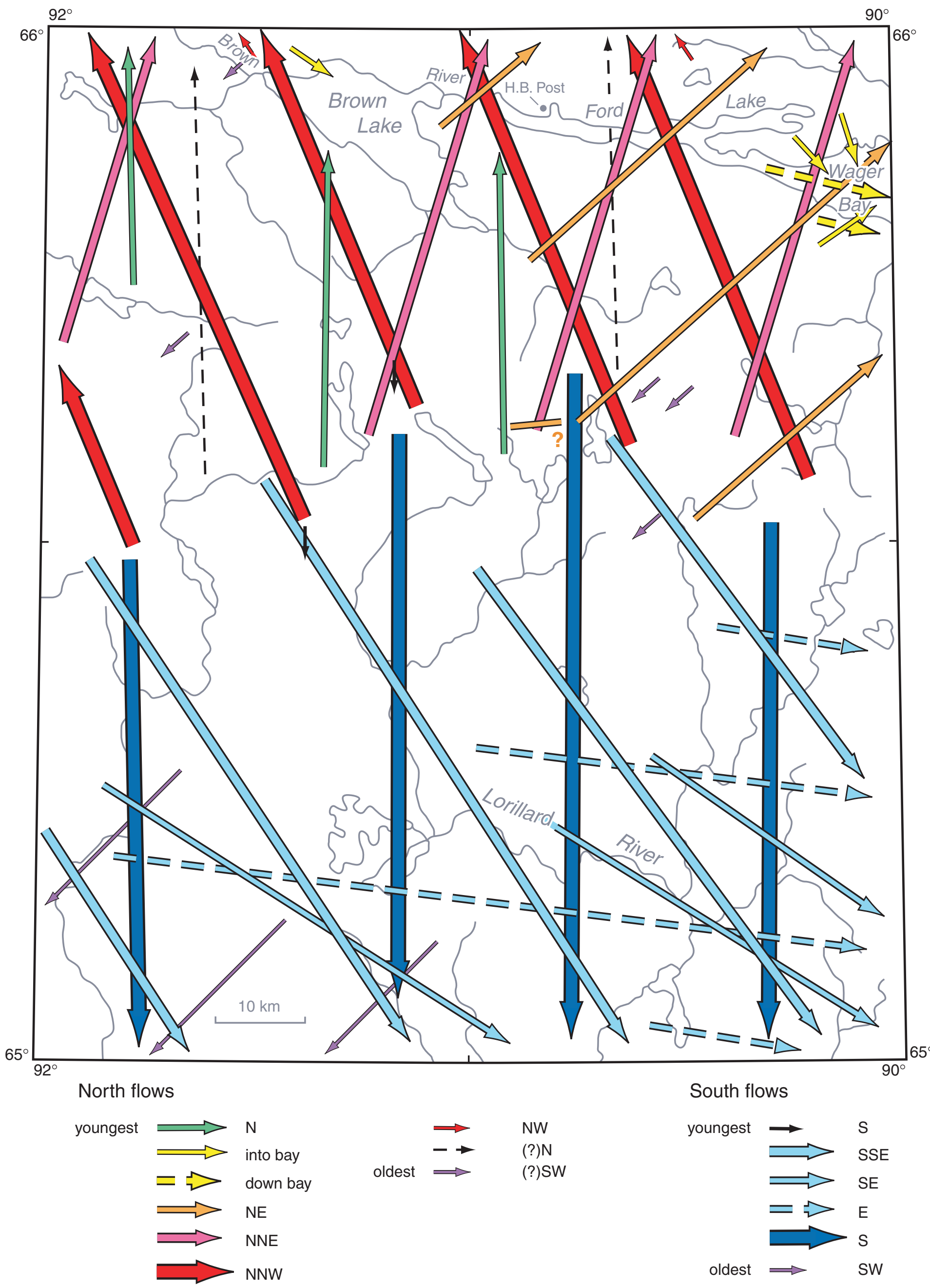

Figure 6. Sequence of ice flows in the Wager Bay map area determined from the erosional record.

that the rocks have been glacially scoured, but that striations have been worn off most surfaces by meltwater erosion. Measured striations were commonly observed as microstriae on crystal faces (*see* Fig. 4b). Poorly defined striations at a few sites record an early southwest ice flow (Fig. 6). The first regional flow across the south is southward (170°–190°). In eastern areas, this flow is succeeded by a flow eastward (about 110°), which rotated east-southeast (about 135°) in the southeast part of the map area and then southward into a consistent flow at roughly 150° across the entire southern part of the map area. Late local flows out of highland areas were southward.

Central area

An east-west-trending, 10 to 20 km wide belt bisects the map area. It lies mainly, but not entirely, within the uplands and on or directly south of the drainage divide separating streams flowing north into Wager Bay from those draining southward. This area contains outcrops glacially moulded in opposite directions and striations indicating both northward and southward flows (Fig. 6). This zone also contains areas with no striae, in which the rock is spalled, contains weathering pits, and has been weathered to grus; areas with poorly defined striations or striations for which the sense of movement was unresolved; or immature roches moutonnées. Some poorly defined easterly flows may be part of a preserved old flow, or the up-ice end of the northeast flow found in the area south of Wager Bay. Sites where age relationships between the north and south flows can be discerned are rare. One site indicates that the north-northwest flow is older than the southeast flow. Another suggests that the northeast flow may predate the flow toward 150°.

DISCUSSION

In the Schultz Lake map area, recent mapping shows that glacially polished and faceted bedrock surfaces, roches moutonnées, and streamlined landforms are abundant and dominate the geomorphic signature of glaciation in this area. The well developed glacial landscape together with numerous signs of older subglacial erosion on bedrock suggest wet-based conditions during a sequence of multidirectional ice-flow events. The preserved record of opposing ice flows throughout the entire map area as well as paleo-land surfaces containing remnant landforms are indicative of a transitory ice divide with limited duration. Superimposed streamlined forms attest to deformation of landforms by multiple flows, which can only occur at some distance from an ice divide (Clark, 1993). Therefore although the Schultz Lake map area lies within the area affected by ice flow from the Keewatin Ice Divide, much of its glacial landscape relates to older flows, older than the Keewatin Ice Divide itself, and somewhat independent of it. The regional imprint of this complex ice-flow history on the glacial landscape was also observed through multiple-till stratigraphy along the Thelon River, and relict/reworked signatures from older flows in surface till (I. McMartin, L.A. Dredge, and J.-F. Gagnon, work in progress, 2005).

The striation record together with meltwater and till landforms observed in the summer of 2004 suggest that the Wager Bay map area also lies in the area of the Keewatin Ice Divide. Its position coincides with the height of land south of Wager Bay. In contrast to Schultz Lake, the location of the ice divide seems to have been fairly stable in this area, migrating generally over a distance of 10 to 20 km, or up to 40 km in the west where the orientation of the divide may have changed. The limited striation record and the absence of well formed roches moutonnées in the central belt of the Wager Bay map area, combined with grus and weathering pits on rock surfaces in uplands near the ice divide, suggest limited glacial erosion in the central map area, which is compatible with an ice divide, or a secondary limb of a major ice divide, that remained fairly stable. The poor development of polished surfaces and streamlined glacial landforms throughout the central area suggests an ice regime that was different from that in the Schultz Lake area. Striations and large-scale glacial landforms are generally not produced below the central part of an ice dome, where shear stresses are minimal (i.e. Clark, 1993). In addition, ice in the Wager Bay area could have been cold based and protective under the stable ice divide.

The absence of weathered iron or manganese patinas on protected surfaces in both areas suggests that the observed striations could belong to the last glacial cycle. However, the oldest flow recognized in both the Schultz Lake and Wager Bay areas, the southwest flow, occurs consistently over much of the Kivalliq region (McMartin and Henderson, 2004). It could belong to an earlier glaciation, with an ice sheet having an entirely different configuration from the Laurentide Ice Sheet at the last glacial maximum.

The main north-northwest and south flows in the Wager Bay area and the south-southeast flow in the Schultz Lake area may belong to the last glacial maximum, although the north-northwest flow in the Committee Bay Targeted Geoscience Initiative area north of Wager Bay (*see* Fig. 1 for location) is related to late glacial flow to the Chantrey moraine (McMartin et al., 2003). All later flows in both areas could be related to deglaciation, the opening of Hudson Bay, major migrations in the ice divide farther south, the formation of proglacial lakes, and rapid changes in the position and configuration of the ice margin. In the Wager Bay map area, the striation record suggests the presence of an east-west limb of the ice divide slightly south of Wager Bay, then a partial rotation to a northeast-southwest orientation, possibly accompanied by eastward migration of the divide, followed by a slight western migration of the divide and then final glacial recession to the highlands. The east-west ice divide at Schultz Lake also rotated to a northeast-southwest orientation, but migrated southeasterly at least 250 km, before shifting back to a final position just south of Baker Lake. The relationship between these flows and broader regional glacial events and ice sheet configurations has not yet been determined. Mapping of areas adjacent to Wager Bay and north of Chesterfield Inlet is necessary to provide a broader regional context.

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