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Glacial history and drift prospecting, Conn Lake and Buchan Gulf, northern Baffin Island, Nunavut

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Abstract: Northeast Baffin Island, in the region of Conn Lake and Buchan Gulf, is an area having high exploration potential for precious metals, base metals, and diamonds; however, much of the region is extensively covered by thick glacial deposits that hinder traditional, bedrock-focused exploration techniques. A better understanding of glacial deposits, transport, and history is essential to reduce exploration risk in the region. This study presents the results of fieldwork in 2005 focused on glacial deposits and complex ice-movement history (four phases are proposed) of northeast Baffin Island. This paper provides a review of previous work; it also includes a summary of field operations and presents a glacial chronology based on geomorphology and ice-movement indicators.

Résumé : La région du lac Conn et du golfe de Buchan, dans le nord-est de l'île de Baffin, présente un potentiel élevé pour l'exploration à la recherche de métaux précieux, de métaux communs et de diamants. Cependant, une bonne partie de cette région est recouverte d'épais dépôts glaciaires qui nuisent à l'application des méthodes classiques d'exploration axées sur le substratum rocheux. Une meilleure compréhension de ces dépôts glaciaires, de leur transport et de leur histoire est essentielle pour réduire les risques rattachés à l'exploration dans la région. Cet article présente les résultats de travaux sur le terrain menés en 2005, centrés sur les dépôts glaciaires ainsi que sur la complexe histoire des déplacements de la glace (quatre phases sont ici proposées) dans le nord-est de l'île de Baffin. En plus d'un sommaire des travaux antérieurs, il contient un résumé des activités de la campagne de terrain, ainsi qu'une chronologie glaciaire fondée sur la géomorphologie et les indices d'écoulement glaciaire.

INTRODUCTION

In 2005, the Canada–Nunavut Geoscience Office, in collaboration with the Geological Survey of Canada, University of Alberta, Dalhousie University, and Polar Continental Shelf Project, expanded the North Baffin Project (Little et al., 2004) from Icebound Lakes (NTS 37 G) southeastward to Conn Lake (NTS 37 E) and eastward to Buchan Gulf (NTS 37 H) on northeastern Baffin Island (Fig. 1). The primary goal of this study is to reduce mineral exploration risk in this remote area by improving the existing geoscience knowledge base. The project involves mapping the surficial geology at 1:100 000 scale; collection of drift, stream, and bedrock prospecting samples; and detailed bedrock mapping of key localities. The results of the bedrock mapping will be reported in a separate paper (S.M. Johns and M.D. Young, work in progress, 2006). A total of 321 till samples and 31 stream-sediment samples have been collected for geochemistry and kimberlite indicator mineral analyses; 123 bedrock samples have been collected for assay and 90 for lithogeochemical analyses. In addition, the project has yielded 1387 map ground-truthing sites, 336 paleo-ice-movement measurements, 27 terrestrial cosmogenic nuclide dating samples, and 49 shell samples for radiocarbon geochronology; together, these data will allow for advanced research into glacial dynamics influencing the surficial geology of north Baffin Island.

This paper provides a summary of the 2005 field season and a glacial chronology based on geomorphology, ice-movement indicators, and previous work. Four phases of ice flow were identified and modified from Little et al. (2004). The earliest, phase 1, the authors relate to the Last Glacial Maximum. The second phase the authors associate with the formation of the Coburn Moraine system in the midfiord region. The next two phases of ice flow are thought to be related to the proto-Barnes Ice Cap, when all glacial ice was grounded on Baffin Island. Several other investigations were initiated in the 2005 field season, but they rely on data that has not yet been analyzed, and are therefore not discussed in this report. A summary of these investigations is included in the 'Related studies' section.

PHYSIOGRAPHIC AND GEOLOGICAL SETTING

Study area

The north Baffin Island project's 2005 field program covered NTS 37 E and 37 H (south), following the 2003 field season focused on NTS 37 G (Fig. 1). Together, these areas span five of Bostock's (1970) physiographic regions: Baffin Coastal Lowlands, Davis Highlands, Baffin Uplands, Lancaster Plateau, and Foxe Plain (Fig. 2). Four collections of drainage basins are superimposed on these physiographic regions: Ravn River–Steensby Inlet, Isortoq River–Steensby Inlet, Buchan Gulf–Scott Inlet, and Milne Inlet (Fig. 1). The western reaches of the Barnes Ice Cap are located in the southeast portions of NTS 37 E, and Oliver Glacier occupies a northern portion of NTS 37 G. Numerous smaller, unnamed ice caps are present on the interfiord highlands.

Bedrock geology

The area is primarily underlain by Archean supracrustal rocks of the Mary River Group, variably metamorphosed and deformed Archean granitoid rocks and related gneiss and lesser amounts of Paleoproterozoic intrusive rocks (de Kemp and Scott, 1998; Jackson, 2000; Young et al., 2004; S.M. Johns and M.D. Young, work in progress, 2006). In the northwest part of NTS 37 G is a northwest-trending rift basin of weakly to unmetamorphosed siliciclastic and carbonate rocks of the Mesoproterozoic Bylot Supergroup (Young et al., 2004). West and south of the study area are unmetamorphosed Paleozoic siliciclastic and carbonate rocks (de Kemp and Scott, 1998; Young et al., 2004).

The area also includes some rare occurrences of a conglomerate and laminated siltstone which, on the basis of contact relationships, are inferred to be the youngest bedrock unit. These were first recognized by Andrews et al. (1972), who interpreted a Paleogene age based on the palynology of the strata. In 2005 these rocks were rediscovered in situ within fractures and on granodioritic and syenitic gneiss in an area south of Rimrock Lake (Fig. 1). These rocks are useful because they provide a minimum age for the exhumation of the Baffin Surface (discussed below) following rifting from Greenland, as well as the associated uplift and denudation.

Preglacial landscape elements

Baffin Island has two prominent upland surfaces, or peneplains, having concordant elevations: the Penny Surface at 1500 m to 1800 m and the Baffin Surface from 600 m to 730 m (Bird, 1967). On southern Baffin Island, high topographic relief Precambrian rock with a Baffin Surface elevation is exposed in fault contact with flat-lying Ordovician strata, indicating the Precambrian rock has been uplifted since the Ordovician (Sanford and Grant, 2000). It is probable that this peneplain surface existed prior to Ordovician sedimentation (Bird, 1967). The Ordovician rocks also outcrop south of the field area in Foxe Basin (Sanford and Grant, 2000).

Glacial erosional landscape elements

Dyke et al. (1982) examined major topographic elements that indicated the extent of glacial erosion on the Cumberland Peninsula of easternmost Baffin Island. Major elements are: 'plateau', gently rolling with no distinct summits; 'dissected plateau', similar to plateau, but dissected by troughs and/or fiords; 'scalloped-dissected plateau'; and 'fretted mountains'.

Figure 1. Study area location, drainage basins, and features discussed in text.

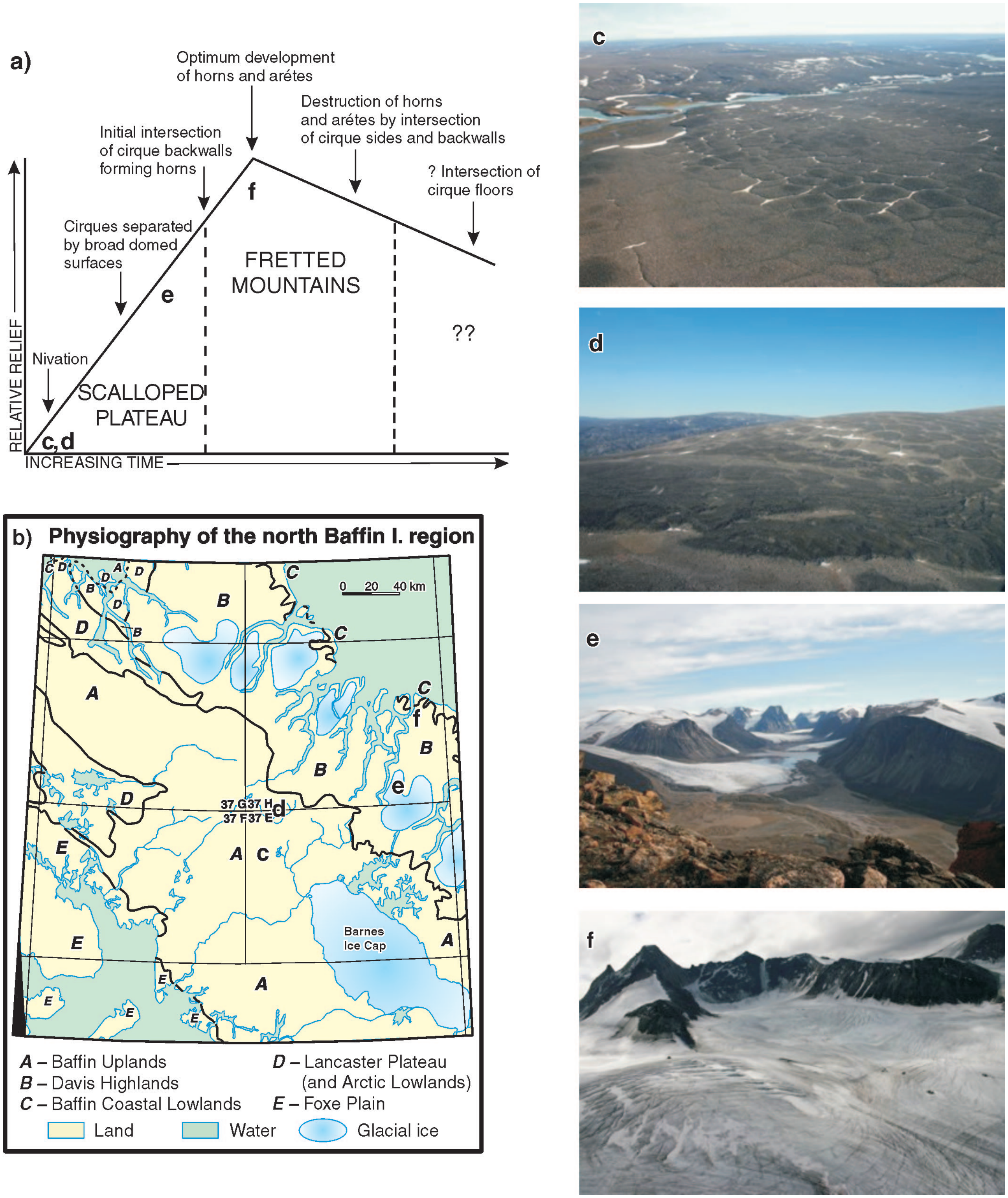

Figure 2. Glacial erosional landscape elements in the North Baffin Project study area. **a)** relationship of the extent of alpine glaciation to the type of landscape, from plateau to fretted mountains (*modified from* Dyke et al. (1982), and concepts of Hobbs (1911) and Davis (1899)). **b)** Location of photographs (c, d, e, and f above) indicated by letter on the physiographic map of region (*modified from* Little et al. (2005) and Jackson (2000)). Oblique aerial photographs looking **c)** southwestward towards a plateau; polygons on surface approximately 25 m in diameter; **d)** northward towards a dissected plateau with broad rounded summits separated by troughs; polygons on surface approximately 25 m in diameter; **e)** southward towards a scalloped-dissected plateau with cirques separated by broad summits and troughs; valley floor to top of upper surface approximately 1000 m; and **f)** eastward towards fretted mountains where cirques have obliterated the remnants of the plateau surface; approximately 1 km from left to right edge of cirque.

The terms 'scalloped' and 'fretted' were derived from the concept of a geomorphic cycle relating the extent of alpine glacial erosion from Hobbs (1911) and Davis (1899; Fig. 2) and refer to the extent of cirque arête and horn development, and whether or not cirques are separated by broad smooth surfaces. Topography on Cumberland Peninsula indicates different styles of glacial erosion: troughs and fiords result from outlet valley glaciers or ice streams, cirques from alpine style glaciation, and areal scour occurred beneath ice caps and ice sheets (Dyke et al., 1982).

Sugden (1978) suggested that the extent of areal scour reflects the thermal regime of an ice sheet. Areas with intense areal scour were thought to have been more intensely eroded and thus covered by actively eroding, warm-based ice (Sugden, 1978). Broad areas of intense areal scour inferred from areas of high lake density were identified on LANDSAT imagery in the southwest of the Conn Lake map area (Andrews et al., 1985, 2002). Conversely, to the northeast between Conn and Bieler lakes and east of Conn Lake, fewer small lakes were noted, suggesting less areal scouring (Andrews et al., 1985, 2002) and coverage by cold-based ice.

The current study area can be divided into the four categories identified by Dyke et al. (1982) (Fig. 2), these were broadly first observed on oblique aerial photographs by Dunbar and Greenaway (1956, Fig. 114, 115). Four implications of the glacial erosional elements are evident:

1) The aerial scour on the plateau indicates glaciation by an ice sheet and/or ice cap. Possibly the southwest sector was covered by erosive (i.e. wet-based) ice for longer periods than the northeast.
2) Dissected plateaus may have been inundated by an ice sheet, but more erosive ice (possibly as ice streams or outlet glaciers) flowed in the troughs for extended periods.
3) Scalloped-dissected plateaus were peripheral to the ice-sheet margin. Inundation by a warm-based ice sheet would likely have eroded the cirque forms, but the troughs were probably still fed by ice from the ice sheet.
4) Fretted mountains were likely glaciated by local glaciers beyond or above the maximum ice sheet extent or were never glaciated by a warm-based ice sheet.

PREVIOUS LAST-GLACIATION STUDIES

The first geological observations in the area were by J.M. Wordie who voyaged into Cambridge Fiord (Fig. 3) in 1937, noting a similarity to Glen Roy Fiord in Scotland, with similar high "terraces" (Dunbar, 1958). In the 1950s, the Arctic Institute of North America (AINA) instituted a field

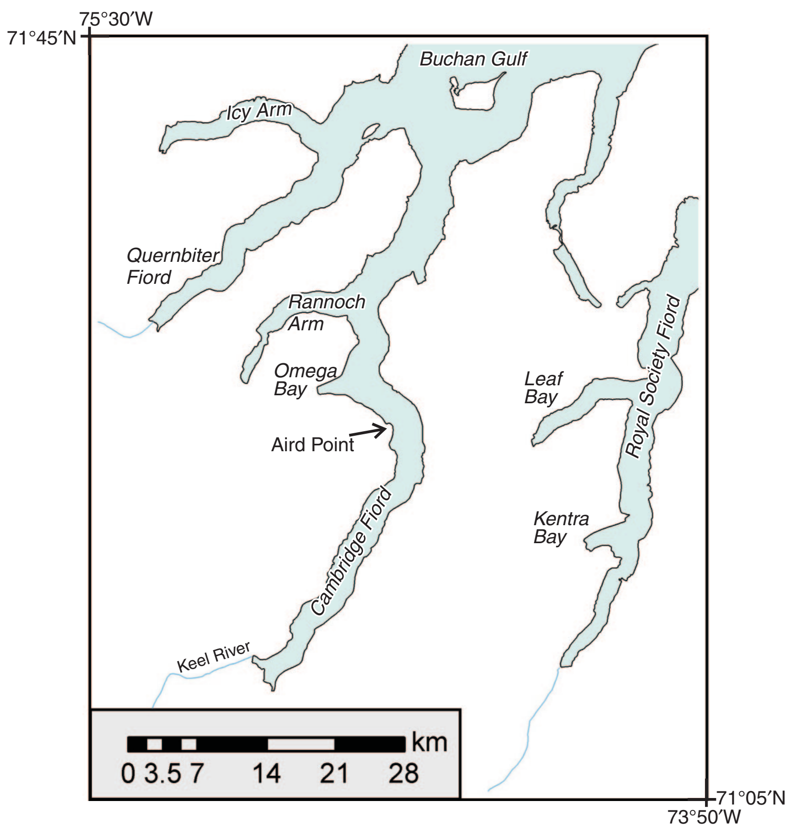

Figure 3. Cambridge Fiord area with features discussed in text, location of area on Figure 1.

program, based from Clyde River and on the Barnes Ice Cap, investigating the geomorphology, glaciology, and meteorology of east-central Baffin Island and the Barnes Ice Cap (Baird, 1952).

From 1961–1964 the federal Geographical Branch conducted studies in the area (Andrews, 1963; Ives and Andrews, 1963c). Preliminary work produced a 1:500 000 scale glacial features map (Cockburn Land) that includes the North Baffin Project study area (Ives and Andrews, 1963a), and a 1:250 000 scale glacial features map of Conn Lake (NTS 37 E), then called Isortoq River (Ives and Andrews, 1963b). Terminology introduced in their study included the Cockburn I moraine sets, relating to the most extensive ice position (at the fiord heads), and Cockburn II, relating to a margin when ice in the Foxe Basin had retreated onto Baffin Island (Ives and Andrews, 1963c). Cockburn II moraines (Ives and Andrews, 1963b, Fig. 21) roughly correspond to the "Isortoq Phase moraines" mapped near Isortoq Lake and that are estimated to be between 7000 BP and 5500 BP, based on ages from associated marine sediments (Andrews, 1966). Falconer et al. (1965) correlated the Cockburn moraines with to a broad readvance recorded on Melville, Hall, and Cumberland peninsulas as well as mainland Nunavut, which they named the Cockburn Moraine System of the Cockburn Glacial Phase.

Subsequently, Andrews and Ives (1978) defined the "Cockburn Substage" as sediments of 8000 BP to 9000 BP (i.e. "Cockburn age") and "Baffinland Drift" as fresh, unsoliflucted glacial materials located at the head of fiords on the northeast coast of Baffin Island. Miller and Dyke (1974) concluded the Cockburn moraines corresponded with the Late Wisconsinan ice limit, based on surface weathering and the development of patterned ground distal to the moraines, despite the occurrence of ice-wedge polygons proximal to the moraines (Andrews and Ives, 1978). The Miller and Dyke (1974) minimalist ice margin was to set the standard in Quaternary reconstructions of Baffin Island until the late 1990s.

Reconnaissance mapping by Hodgson and Haselton (1974) in the northern portion of the study area (Buchan Gulf, NTS 37 H) produced a 1:500 000 scale surficial materials map, and a 1:500 000 scale glacial features map. In Buchan Gulf, ice was thought to have inundated the fiord region overrunning the foreland and inner continental shelf. Buchan Gulf is a deep trough across the shelf, whereas North Arm and Coutts Inlet are deep (400 m below sea level), but gradually shallow towards their mouth to 150 m below sea level near Nova Zembla Island. Multiple ridges about 20 km offshore (Loeken and Hodgson, 1971) were thought to represent the terminal position of the North Arm–Coutts Inlet lobe, suggesting that less ice flowed through these fiords than through Buchan Gulf. Shells in marine sediment dissected by marginal meltwater channels at the furthest terrestrial extent of North Arm–Coutts Inlet moraines were dated at more than 28 000 BP (GSC-1090). A readvance phase within the fiord heads at about 8 000 BP was based on shells of 'Cockburn age' collected in outwash at Kentra Bay (8090 ± 140 BP; GSC-1060) and Rannoch Arm (7890 ± 160 BP; GSC-1064). Proximal to the moraines in Cambridge Fiord shell dates from outwash provide a minimum age of 6330 ± 140 BP (GSC-1094) for final fiord deglaciation.

Stravers and Syvitski (1991) correlated onshore stratigraphy with marine seismic stratigraphy to identify three sedimentary basins in Cambridge Fiord divided by sills interpreted to be moraines. They concluded that Laurentide Ice scoured the fiord of any pre-existing sediment, formed the sills during retreat, and subsequently refilled the resulting basins. Ice retreated from Omega Bay at ca. 8800 BP and then formed the Aird Point moraine (Fig. 3); based on shells from deformed and eroded silts in Omega Bay dated at 8770 ± 60 BP (GSC-4514). The Cambridge Fiord glacier subsequently readvanced over these marine sediments, forming the marine limit delta at Omega Bay, 7810 ± 150 BP (Beta-20726) and retreated from Omega Bay to the Aird Point moraine. Finally, the 300 m thick Keel Basin moraine formed between 7700 BP and 7200 BP. Stravers and Syvitski (1991) correlated the Keel Basin moraine with prominent onshore moraines, likely the Cockburn moraines. These moraines are farther inland, and younger, than sediments at Kentra Bay assigned a 'Cockburn age' (Hodgson and Haselton, 1974).

Miller et al. (2002) and Little et al. (2004) summarized the arguments for extensive ice (out to the continental shelf break) and against restricted ice (to the Cockburn moraines); the current paradigm has ice flowing out of the fiords and troughs as low-gradient outlet glaciers or ice streams onto the continental shelf. Briner et al. (2005) used cosmogenic boulder ages to show that cold-based piedmont lobes of Laurentide Ice covered part or all of the coastal forelands. Upland interfiord areas were either glaciated by local, cold-based ice caps, or were ice-free (Miller et al., 2002). Ice retreated from the Last Glacial Maximum position, leaving the coastal forelands ice-free after 14 ka (calendar age; Miller et al. (2005)).

Dyke and Hooper (2001) mapped deglaciation of northwest Baffin Island, including Borden and Brodeur peninsulas, up to the western margin of NTS 37 G (the 2003 field area of Little et al. (2004)) using ice-marginal features such as moraines and lateral meltwater channels. This reconstruction shows a readvance of the Navy Board Inlet ice stream at ca. 10 000 BP, and slow retreat (relative to the Lancaster Sound–Prince Regent Inlet ice stream) to the head of Milne Inlet at Cape Hatt by 9530 ± 180 BP (GSC-3318 (Klassen, 1993)). The slow rate of retreat is thought to result from positive glacier mass balance counteracting eustatic sea-level rise that might be expected otherwise to drive retreat of marine-based ice (Dyke and Hooper, 2001).

Klassen (1993) mapped the area north of NTS 37 G, Pond Inlet (NTS 38 B), and Bylot Island, and published a 1:250 000 scale surficial geology map for the area. He mapped the Late Wisconsinan ice-sheet margins as less extensive than the more recent interpretations (Dyke and Hooper, 2001; Dyke et al., 2002), based on amino-acid ratios of shells with infinite radiocarbon ages.

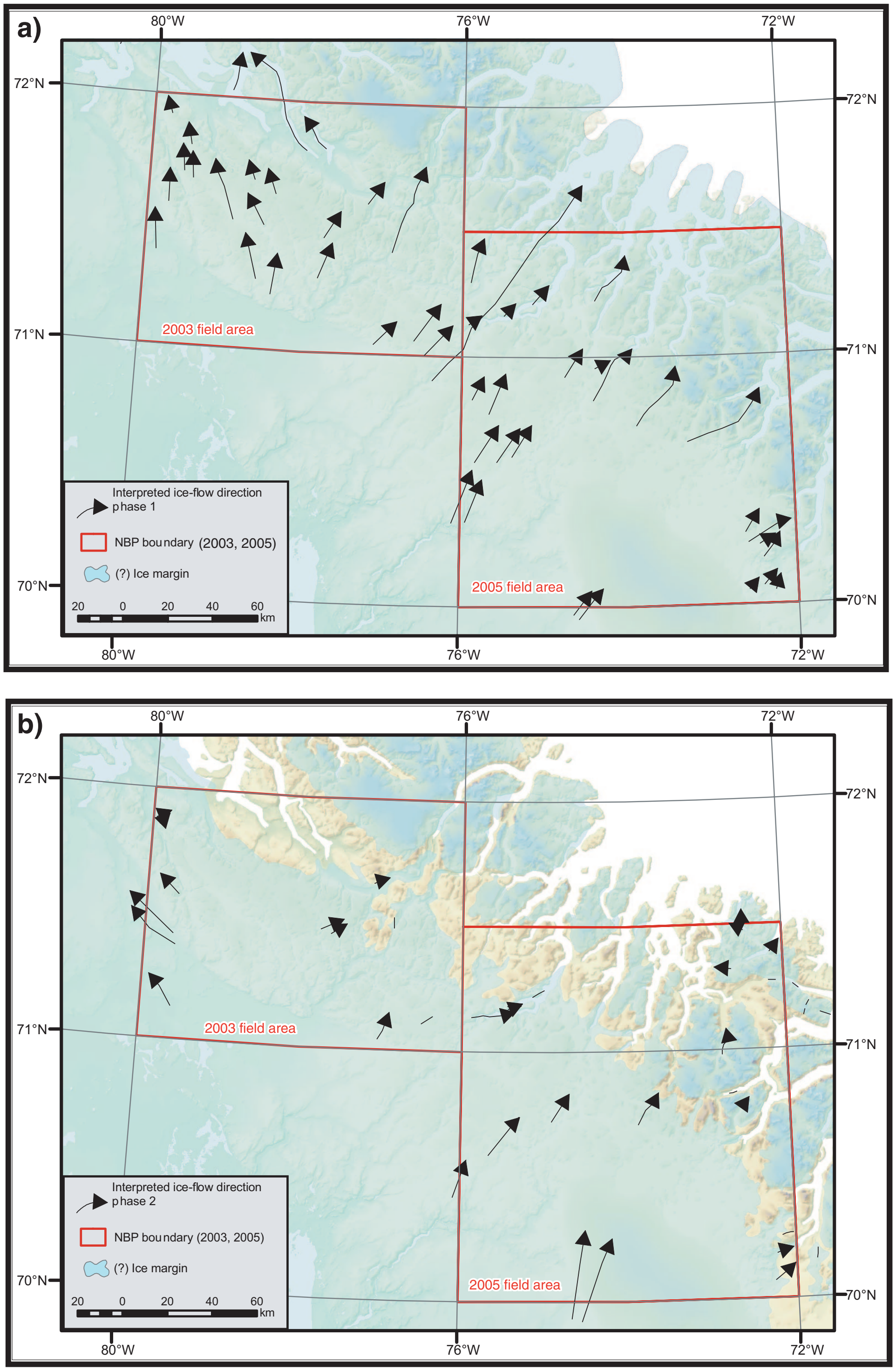

Figure 4. Ice-flow maps phase 1 and 2, discussed in text. **a)** Ice margin for phase 1 is from Dyke (2004). **b)** Phase 2 margin is modified from the relatively small-scale Dyke (2004) ice maps to match the location of Cockburn moraines, where present. NBP = North Baffin Project.

Dredge (2004) mapped Lake Gillian (NTS 37 D), south of NTS 37 E. Dyke (2005) mapped Steensby Inlet (NTS 37 F), south of NTS 37 G and west of NTS 37 E. Little et al. (2004) summarized field activities in the NTS 37 G map area, and presented a new preliminary ice-flow chronology. Their phase 1 is Last Glacial Maximum ice flow, phase 2 is a greater Baffin Island Ice Cap, and phase 3 and 4 are the proto-Barnes Ice Cap.

ICE-FLOW INDICATORS FROM THIS STUDY

A total of 136 ice-flow indicators were measured in 2005, providing a total of 336 in the area including NTS 37 G, 37 E, and 37 H. Relatively few indicators were measured in the area to the northeast of the Barnes Ice Cap. Paleozoic sedimentary erratics were commonly found in the northwest of NTS 37 E, and the west of NTS 37 H(south), Rannoch Arm area, although the complete pebble lithology data is not yet available. More of these erratics were found in NTS 37 G in 2003. Crosscutting relationships, and a regional picture of deglaciation based on larger geomorphic features such as troughs and moraines, were used to produce four glacial ice-flow phases, discussed in the context of the glacial history below.

GLACIAL HISTORY

Based on previous work, preliminary results of ice-movement indicators, erratic dispersal patterns, and geomorphological observations, a tentative glacial history is proposed for the study area. During full glacial conditions, including (phase 1, Fig. 4):

1) Ice reached the outer coast by flowing through the deep trough of Buchan Gulf and continued out toward the shelf margin. A lesser ice flow through North Arm and Coutts Inlet did not reach the shelf edge (Hodgson and Haselton, 1974). In the west (NTS 37 G), ice flow was directed to the north out of Tay Sound and Paquet Bay towards the Navy Board Inlet ice stream (Dyke and Hooper, 2001), and east out of Pond Inlet (cf. Klassen, 1993; Dyke, 2004). These divergent flows suggest there was an ice divide in the Steensby Inlet area, and a saddle between Baffin and Bylot islands.
2) Observations of the major topographic elements suggest the uplands on parts of the outer coast were beyond the extent of the ice sheet, or that ice only coalesced for a short period. Actively eroding, local, alpine-style glaciers covered these areas.
3) Farther inland, the uplands were glaciated by less erosive ice caps that may or may not have coalesced with the ice sheet.
4) The area northeast of the Barnes Ice Cap was covered with less erosive cold-based ice, based on the relative scarcity of small lakes and relatively few ice-movement indicators.
5) The area to the southwest of the Barnes Ice Cap was covered with more actively eroding, warm-based ice. This may have been the origin of an ice stream across Baffin Island into the Rannoch Arm area that deposited the sedimentary erratics.

The retreat phase can be characterized by ice retreating up the fiords becoming disconnected with the local upland ice (Dyke, 2004). Ice had retreated to a midfiord position in both Cambridge Fiord and Royal Society Fiord by the end of the Cockburn Substage (phase 2)(Stravers and Syvitski, 1991). Based on Dyke's (2004) regional reconstructions of glaciation, ice was still grounded in Foxe Basin at 8000 BP (i.e. during the Cockburn Substage), and was not related to ice flow during the early stages of the Barnes Ice Cap as reported in Little et al. (2004, their phase 2) . Later readvance (phase 3, not shown) formed the "Isortoq Phase moraines" of Andrews (1966). Continued deglaciation (phase 4) resulted in the damming of several lakes in the study area and formation of cross-valley (De Geer) moraines (Andrews, 1963).

DRIFT, STREAM, AND BEDROCK PROSPECTING

To date, 321 till samples and 31 stream-sediment samples were collected for till or stream sediment geochemistry and kimberlite indicator mineral analyses (Fig. 5, 6), 123 bedrock samples were collected for assay, and 90 for lithogeochemical analyses. Analysis are ongoing and data will be released in a separate report. Little et al. (2005) presented the till and rock geochemistry data from the 2003 field season.

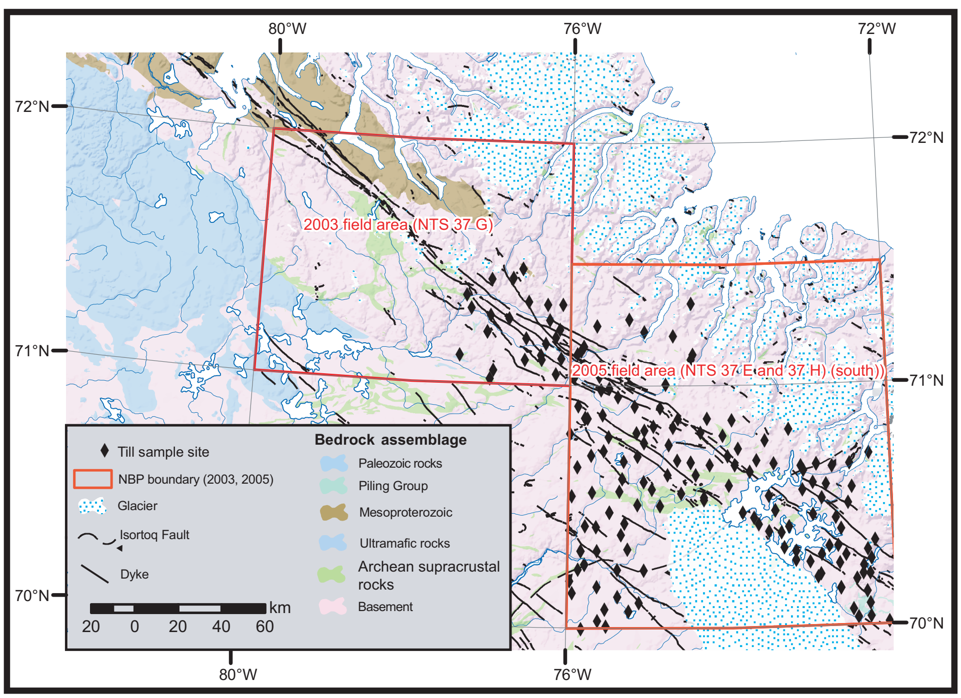

Figure 5. Location of till samples collected in 2005, shown on a simplified bedrock geology map (de Kemp and Scott, 1998). NBP = North Baffin Project.

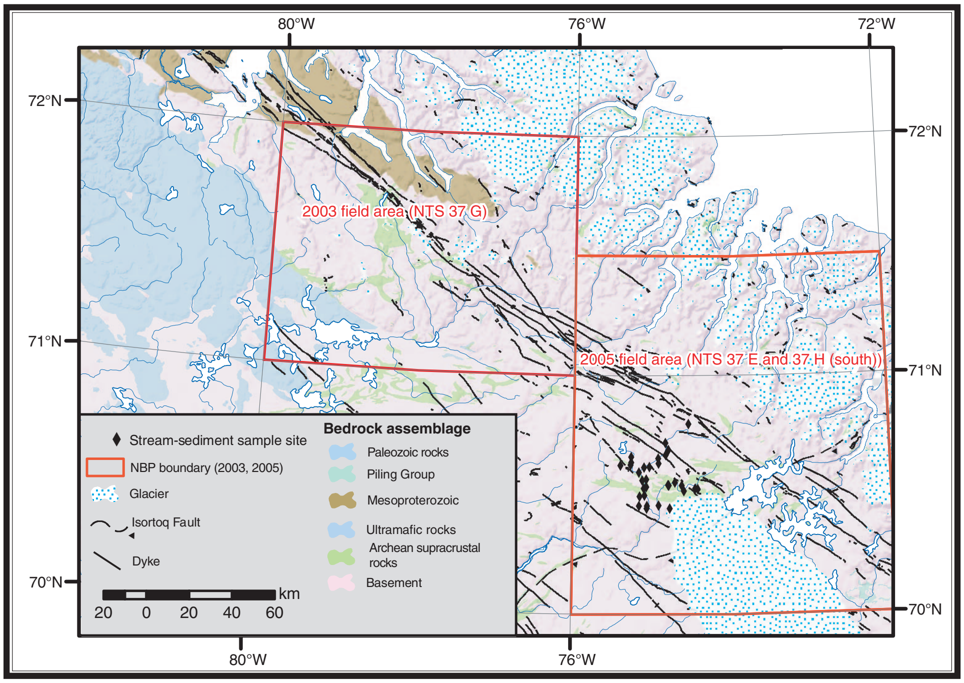

Figure 6. Location of stream sediment samples collected in 2005, shown on a simplified bedrock geology map (de Kemp and Scott, 1998). NBP = North Baffin Project.

The complicated glacial history of the area will affect interpretation of the drift samples. In areas where cold-based ice predominated (likely in the area northeast of the Barnes Ice Cap) relatively short transport distances are expected. Comparatively, in the area southwest of the Barnes Ice Cap greater distances are expected. Although no specific interpretations are presented here, the transport distances could be as great as the width of Baffin Island, based on the presence of Paleozoic erratics found in Rannoch Arm.

RELATED STUDIES

A study to refine deglacial chronology by mapping and dating raised marine shorelines was undertaken. Surficial geology maps generated from LANDSAT and RADARSAT imagery were ground-truthed in the field. Geomorphological studies of crossvalley (De Geer) moraines and glacial lake levels in the Isortoq River area will refine the late stages of deglaciation. Isotopic studies of a small glacier north of Keel River will attempt to determine if such features are remnants from the continental ice sheet (i.e. Pleistocene aged), or if they are entirely Holocene glacial ice. Boulders were sampled for terrestrial cosmogenic nuclide analysis on a northwest-trending transect from the current Barnes Ice Cap margin, on a transect of Cockburn moraines north of Keel River and across Isortoq moraines near Isortoq Lake, to improve the deglacial chronology. A low-temperature thermochronology sampling program was initiated to determine the age of uplift of the eastern arctic rim and of incision of the fiords. Detailed bedrock mapping was done at key localities to refine the understanding of the structure and stratigraphy because a 1:250 000 scale bedrock geology map is already published for the field area (Jackson, 2000).

SUMMARY

New field studies on northern Baffin Island are being conducted to improve the geoscience knowledge base for an area of Nunavut where bedrock is extensively masked by glacial drift. To date, an improved understanding of glacial history and mineral prospectivity have resulted from the North Baffin Project. Refined ice-movement trends and chronology, in addition to reconnaissance-scale drift-prospecting surveys and geochronology will significantly add to the regional understanding of glaciation since the Last Glacial Maximum. Together, the complementary surficial and bedrock components of this multidisciplinary project greatly reduce exploration risk within the study area.

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