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Glacial geology, ice-movement chronology, and drift prospecting in the vicinity of Icebound Lakes, northern Baffin Island, Nunavut

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Abstract: The Canada–Nunavut Geoscience Office, in collaboration with the GSC and the Polar Continental Shelf Project, has begun a new geoscience initiative to evaluate the economic potential of northern Baffin Island, with the overall intent to reduce exploration risk in this remote region of Nunavut. The 2003 field season focused on the NTS 37 G map area, centred 170 km northwest of the Barnes Ice Cap. Specific objectives include the production of two 1:100 000-scale surficial geology maps (37 G east and 37 G west), evaluation of ice-movement chronology and glacial history of the region, and a reconnaissance-scale till geochemical survey. At this preliminary stage of the research, four regional ice-movement events and numerous local, late-deglacial flow events have been interpreted from data collected during the 2003 field season. The glacial history is complicated by overprinting from both warm- and cold-based basal thermal regimes at various stages of the deglaciation.

Résumé : Le Bureau géoscientifique Canada-Nunavut, en collaboration avec la CGC et l'Étude du Plateau continental polaire, a lancé une nouvelle initiative géoscientifique pour évaluer le potentiel de la région septentrionale de l'île de Baffin, dans l'intention générale de réduire les risques d'exploration dans cette région éloignée du Nunavut. La saison de terrain 2003 a porté sur la région couverte par la carte 37 G du SNRC, centrée à 170 km au nord-ouest de la calotte glaciaire de Barnes. Les objectifs particuliers comprennent la production de deux cartes des formations en surface à l'échelle de 1/100 000 (37 G partie est et partie ouest), l'évaluation de la chronologie de l'écoulement des glaces et de l'histoire glaciaire de la région, et l'exécution d'un levé géochimique de reconnaissance du till. À cette étape préliminaire, quatre épisodes régionaux et de nombreux épisodes tardiglaciaires d'écoulement des glaces ont été interprétés d'après les données recueillies pendant la campagne de travaux sur le terrain de 2003. L'histoire glaciaire est complexifiée par la surimpression de régimes thermiques à base tempérée et à base froide à divers stades de la déglaciation.

INTRODUCTION

Regional surficial mapping and complementary detailed bedrock mapping of key localities (*see* Young et al., 2004) on northern Baffin Island were undertaken within the NTS 37 G map area during the summer of 2003 (Fig. 1). The objectives include the production of two 1:100 000-scale surficial geology maps (37 G east and 37 G west), the evaluation of ice-movement chronology and glacial history of the region, and the execution of a reconnaissance-scale till geochemistry survey.

Accomplishments and data collected include 763 Quaternary-related description stops, 206 paleo-ice flow measurements, 156 till geochemistry samples, 4 carbon-14 samples, and 23 cosmogenic exposure age samples. Preliminary findings suggest that the glacial history of the area is complex, with evidence for overriding by both warm- and cold-based ice during the last glaciation. The provenance and sequence of overriding ice masses along with their basal thermal states will be determined only after a more detailed synthesis of field data and airphoto analysis.

In the absence of well developed exposures in the map area that would provide sedimentological, stratigraphic, and structural data, glacial history is determined from mapping and geomorphological analysis, along with the use of terrestrial cosmogenic nuclide exposure (TCN) dating

This paper discusses those aspects of glacial geology that bear on the interpretation of the geochemical data that will be released in GSC open files. The discussion includes ice-movement indicators, basal thermal regimes, and glacial history of the region. Finally, the paper briefly introduces the 2003 sampling program and work intended for the 2004 field season.

REGIONAL SETTING

The NTS 37 G study area is located on northern Baffin Island, 75 km south of Pond Inlet at its closest (Fig. 1). It encompasses three main physiographic regions and encroaches upon a fourth, fifth, and sixth (Fig. 2); these include the Baffin Upland, the Davis Highlands, the Arctic Lowlands, the Lancaster Plateau, the Foxe Plain, and the Coastal Foreland (Bostock, 1970a, b, as referenced *in* Jackson, 2000).

Baffin Upland

The Baffin Upland region dominates the study area. Its boundary with the Davis Highlands corresponds closely with both the fiord heads and the main distribution of the Cockburn Moraines system (i.e. Hodgson and Haselton, 1974). This area is characterized by extensive till and boulder fields exposed on a flat to gently rolling surface; the modal elevation of about 510 m decreases gently to the southwest.

Davis Highlands and western Coastal Foreland

The Davis Highlands are characterized by high plateaus with a modal elevation of about 720 m. This high plateau has been deeply incised by northeast-trending fiords and anastomosing valleys. In some cases (e.g. North Arm Fiord in the northeast corner of 37 G), nearly vertical valley walls extend >1000 m from sea level to the plateau surface. The numerous valley glaciers (hanging and piedmont) occurring along fiord walls contribute to the uniqueness of this physiographic region.

Elevation drops rapidly from the plateau of the Davis Highlands to the plain of the western Coastal Foreland. This narrow region is characterized by a flat to hilly, discontinuous stretch of land with a modal elevation of about 326 m. Although the study area *sensu stricto* does not contain the Coastal Foreland region, the study area's northern reaches do lie in close proximity.

Arctic Lowlands and Lancaster Plateau

The Arctic Lowlands, located in the northwestern portion of the Icebound Lakes map area, have a modal elevation of about 328 m, but are characterized by wide, deep fiords and valleys, often exhibiting end-moraine segments (Hodgson and Haselton, 1974); till veneers dominate the surface. Many geomorphic characteristics in this region (e.g. wide deep valleys) were produced by erosive processes acting on the underlying bedrock and, therefore, the region generally conforms to the distribution of sedimentary successions of the weakly to unmetamorphosed Bylot Supergroup (cf. Jackson and Iannelli, 1981).

Although some researchers extend the Lancaster Plateau to include the Arctic Lowlands (e.g. Jackson, 2000), the Lancaster Plateau exhibits a much different physiographic character. The region consists of a graben situated between the Nina Bang (southwest-bounding) and Central Borden (northeast-bounding) faults; it is underlain by Cambrian to Silurian sedimentary rocks, has a modal elevation of about 265 m, and is characterized by numerous lakes, bogs, flat to rolling till plains, and subdued bedrock ridges. Numerous lateral meltwater channels and recessive end-moraine sequences are present within the study area.

Foxe Plain

The Foxe Plain is characterized by low hills with a modal elevation of about 130 m; it generally slopes gently toward Steensby Inlet. Its main expanse is located west of longitude 80°W and south of latitude 71°N; however, small patches are present in the western portion of the study area. The eastern portions of the study area are north of the Foxe Plain limits.

Superimposed on these physiographic regions are the following four main drainage basins: flow west-northwestward into Milne Inlet, flow northward toward Eclipse Sound, flow northeastward toward Baffin Bay, and flow southward toward Steensby Inlet and the Foxe Basin (Fig. 3).

BEDROCK GEOLOGY

The bedrock within the NTS 37 G map area consists of metamorphosed Archean supracrustal rocks of the Mary River Group and Archean–Paleoproterozoic intrusive rocks, weakly to unmetamorphosed siliciclastic and carbonate rocks

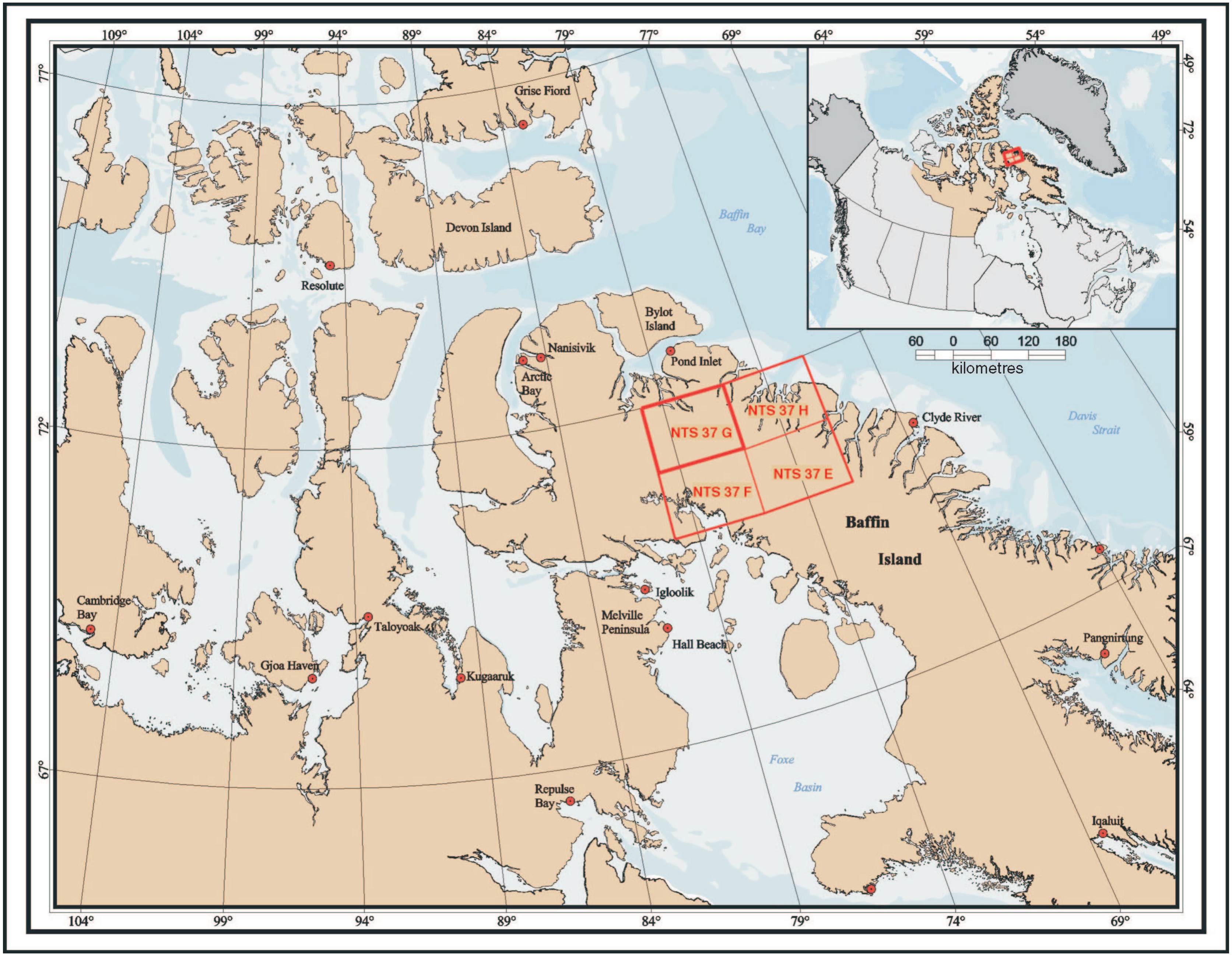

Figure 1. *General location map of study area. Field work conducted in 2003 by Canada–Nunavut Geoscience Office personnel in the NTS 37 G map area (Icebound Lakes sheet).*

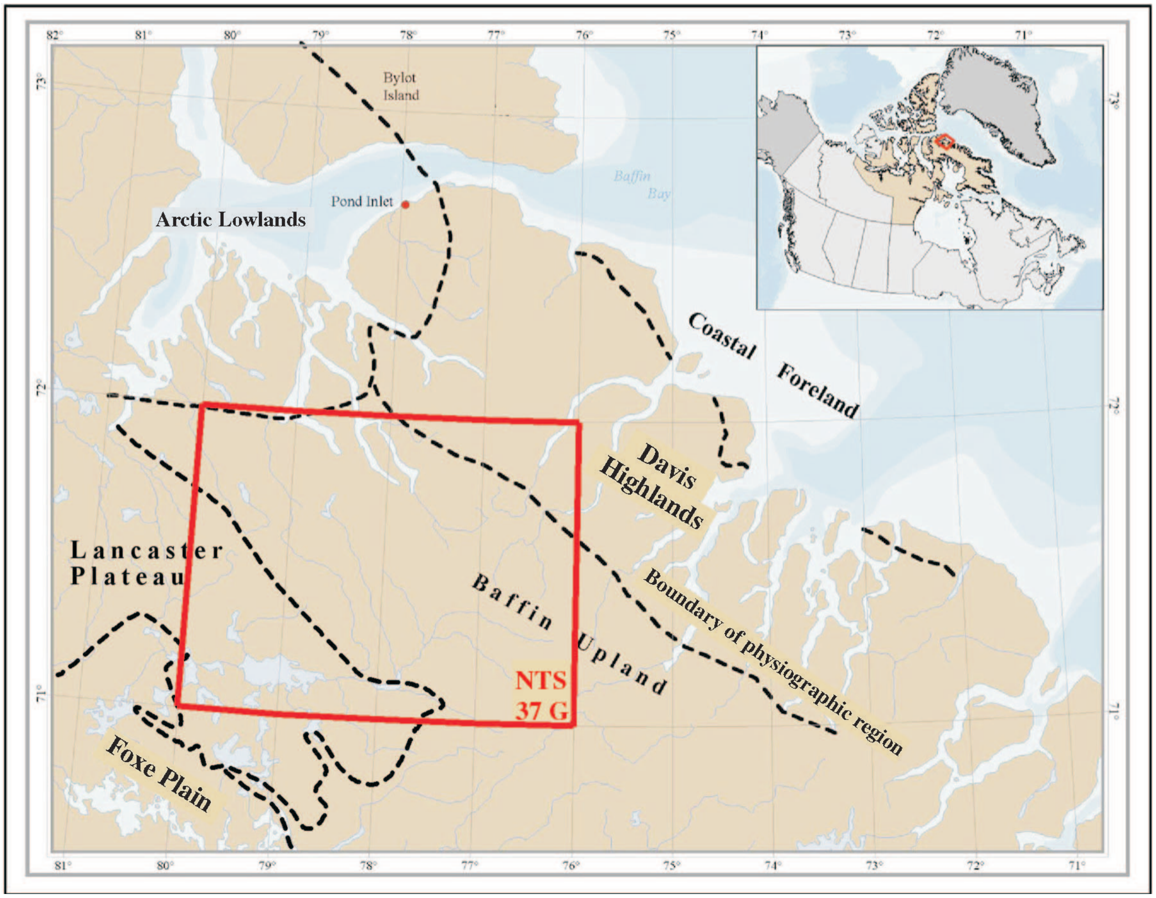

Figure 2. *Main physiographic regions associated with the study area (*modified from *Hodgson and Haselton, 1974, and Jackson, 2000).*

of the Mesoproterozoic Bylot Supergroup, and Paleozoic unmetamorphosed siliciclastic and carbonate rocks (Young et al., 2004).

Most of the map area is underlain by Archean and Paleoproterozoic rocks that are well exposed in the west-central, northern, and eastern parts of the map area. The central part of the map area consists of a thick till blanket; bedrock is exposed rarely, as tors. The Mary River Group consists of a belt trending east-northeast in the west-central map area and north-south through the north-central map area. Enclaves of supracrustal rocks occur to the south and east and are enveloped by granodiorite to monzogranite. The supracrustal rocks consist of psammite, amphibolite, Algoma-type iron-formation, quartzite, komatiite, and intermediate volcanic rocks. Interbedded psammite, amphibolite, and komatiite are the main rock types in the southern part of the map area, whereas amphibolite, iron-formation, quartzite, and intermediate volcanic rocks predominate in the north. Ultramafic sills intrude the lower part of the sequence and are locally abundant in the southern and west-central parts of the map area. Supracrustal rocks of the Mary River Group are prospective for a number of commodities including iron, gold, copper, platinum-group elements, and carving stone; regionally, the area has a potential for diamonds.

The Bylot Supergroup is preserved in a northwest-trending graben structure in the northwestern part of the map area. It consists predominantly of siliciclastic rocks of the Adams Sound and Arctic Bay formations. Rock types belonging to these formations include basal quartz-pebble conglomerate grading upward into turbidite sequences consisting of quartz arenite and minor shale and siltstone. Postdepositional reduction and oxidation of these rocks are pervasive and impart a mottled green and red appearance to the rocks. Minor stromatolitic dolostone of the Society Cliffs Formation overlies these rocks in the northernmost part of the map area.

In the southwestern part of the map area, Cambrian to Silurian strata unconformably overlie the Archean–Paleoproterozoic basement. The trace of the unconformity follows the topographic and structural Central Borden Fault break, with the Paleozoic rocks exposed to the south. Small outliers of these rocks may occur to the north on the uplands. These rocks consist of a basal polymictic conglomerate comprising angular fragments of Mary River Group and intrusive rock types. This unit is overlain by coarse- to medium-grained quartz arenite and consists typically of redbeds. These redbeds are distinguished from the oxidized arenite of the Bylot Supergroup by alternating red and paler colours defining bedding (a primary depositional texture), as opposed

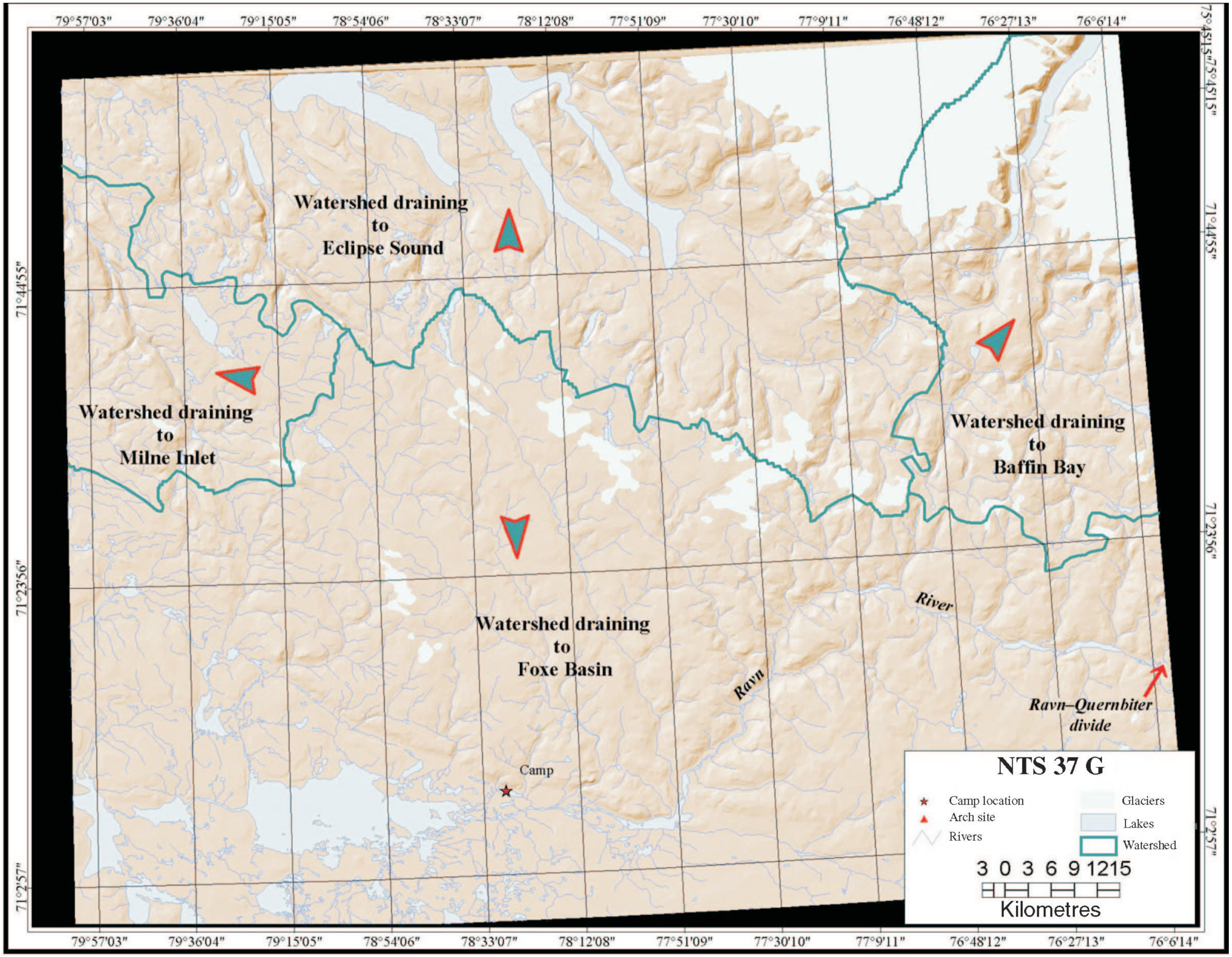

Figure 3. *Main drainage basins in the study area.*

to the blotchy and irregular appearance of the arenite. They are overlain by buff, commonly fossiliferous, silty limestone, the predominant rock type of the Paleozoic strata.

PREVIOUS WORK

The Quaternary glacial history of the Eastern Canadian Arctic has been a significant component of the broader effort to decipher the glacial history of the Laurentide Ice Sheet. During the last 50 years, the general consensus of contributors has moved through two major paradigms spurred by evidence from field-based research and fundamental advances in the understanding of glacier dynamics and glacial geology. Aided greatly by the recent availability of TCN dating, a new paradigm is gaining acceptance; it accounts for recent findings from marine seismic stratigraphy and ^{14}C ages from lake sediment cores.

The regional correlation of deposits and landforms identified during early reconnaissance mapping and field investigations led, in 1943, to the first widely accepted model of the northeastern margin of the Laurentide Ice Sheet during the last glacial maximum, known as the ‘Flint Paradigm’. This model viewed the Laurentide Ice Sheet as a single-domed body, which, at its maximum, extended in the northeast to the very edge of the coastal shelf of the Eastern Canadian Arctic (Flint, 1943, as referenced *in* Miller et al., 2002).

Two decades later, the paradigm was challenged when an undisturbed, ice-proximal raised marine delta was discovered at Cape Aston and dated at >50 000 BP using ^{14}C from in situ marine bivalves (Løken, 1966, as referenced *in* Miller et al., 2002). From this, it was interpreted that the site had not been overrun by ice from the last glacial maximum and that the local limit of the Laurentide Ice Sheet lay inland. Shortly thereafter, several studies began to produce evidence for ice-free conditions at other coastal sites (e.g. Ives and Buckley, 1969; Andrews et al., 1972). Although an improved understanding of glacial dynamics brought some evidence into doubt, the body of data was enough to convince the majority of researchers. From this, a new, restricted ice-coverage hypothesis — the Minimalist Paradigm — became widely accepted. According to this model, the Laurentide Ice Sheet was less extensive during the last glacial maximum, not reaching the coastline of the eastern Canadian Arctic and leaving many interfiord uplands ice-free.

In 1986, however, seismic stratigraphy on the Baffin Shelf (MacLean et al., 1986; Praeg et al., 1986) and sediment cores from Cumberland Sound (Jennings, 1993; Jennings et al., 1996) indicated that grounded ice had been present in those regions during the last glacial maximum. Because the Minimalist Paradigm predicted that these areas should have been ice-free during the last glacial maximum, it was rejected. However, a new hypothesis was not formulated immediately as the inability to directly date moraines and other terrestrial surfaces remained a critical hindrance to the development of a new model.

The development of TCN dating allowed the calculation of critical age data on glacial landforms. Using ^{14}C ages from lacustrine deposits (Wolfe et al., 2000) and extensive TCN dating of moraines (e.g. Bierman et al., 1999; Marsella et al., 2000), researchers reassessed the glacial history and developed a new concept, the Goldilocks paradigm (Miller et al., 2002). In this model, the Laurentide Ice Sheet was seen to have been warm based in fiords where it reached the coast and calved into the sea, and cold based on adjacent uplands where it halted short of the coast. This accounted for the glacial modification of the fiords during the last glacial maximum and the preservation of highly weathered surfaces on uplands, upon which were found glacial erratics dating to the last glacial maximum.

Terrestrial cosmogenic nuclide exposure dating by Briner et al. (2003), using nuclides of ^{10}Be and ^{26}Al in weathered upland surfaces and associated (locally) erratic cobbles and boulders in Clyde Inlet, provides support for the Goldilocks hypothesis. Briner et al. (2003) established cosmogenic exposure ages of 10.5 ± 1.1 ka, 11.3 ± 1.0 ka, and 16.7 ± 1.7 ka for (local) erratics sitting on two weathered upland surfaces, and >60.3 ± 4.1 ka and >66.9 ± 7.0 ka, respectively, for the weathered upland surfaces. From this they concluded that cold-based glacial ice overrode upland block fields and tors at elevations between 460 and 505 m during the last glacial maximum.

GLACIAL GEOLOGY

At this preliminary stage it is already apparent that the region has a complex Quaternary glacial history. Overriding ice has produced myriad deposits, landforms, and ice-flow indicators across much of the area, but left some parts completely unmodified except for a clast lag of erratics and local rock types.

Key issues to be resolved in the study include ice-mass provenance, differentiation of overriding events, relative and absolute timing of these events, and ice-mass thermal regimes and dynamics during both glacial and deglacial conditions.

A glacier’s basal thermal regime is the main parameter affecting its ability to modify the landscape. At the base of a warm- or wet-based glacier, meltwater acts as a lubricant, allowing the glacier to slide over the substrate and abrade it. On the other hand, the base of a cold- or dry-based glacier is frozen to the substrate, so the ice can flow only by internal deformation; in this case, erosion of the substrate is minimal and is due mainly to plucking.

The terrain inventory of map area NTS 37 G documented many deposits and landforms consistent with a glacially modified terrain. The following types of evidence for glacial overriding were found; they are differentiated here by association with basal thermal regime.

Evidence of glaciation (cold-based versus warm-based ice)

Evidence for warm-based ice activity:

- subglacial till deposits (Fig. 4A), outwash deposits
- end and lateral moraines (Fig. 4B)
- glacially sculpted terrain
  - U-shaped valleys
  - roches moutonées (Fig. 4C)

  - stoss-and-lee features on bedrock forms
  - fluting
- glacially abraded bedrock surfaces (Fig. 4D) and clasts
- ubiquitous erratic clasts
- kame terraces
- widespread occurrence of large meltwater channels
- large (a few hundred metres to a few kilometres wide) meltwater channels

Evidence for cold-based ice activity:

- Angular erratics strewn across a landscape devoid of other glacial deposits, sculpting, and abrasion.
- Extensive network of relatively small lateral meltwater channels (Fig. 4E) nested along valley walls, which have been documented elsewhere (cf. Dyke, 1993) as relating to retreat of cold-based ice.

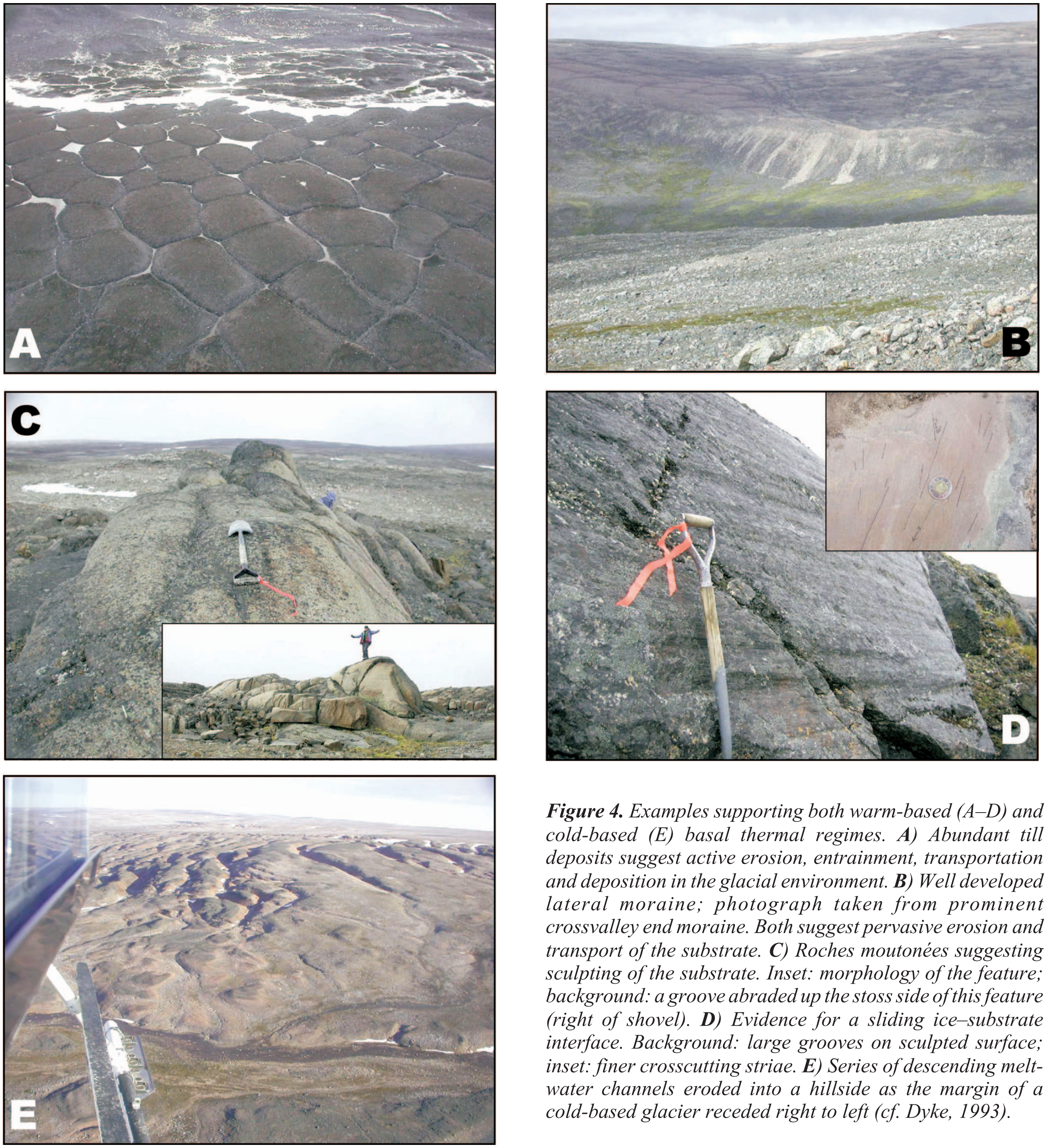

Figure 4. *Examples supporting both warm-based (A–D) and cold-based (E) basal thermal regimes.* ***A)*** *Abundant till deposits suggest active erosion, entrainment, transportation and deposition in the glacial environment.* ***B)*** *Well developed lateral moraine; photograph taken from prominent crossvalley end moraine. Both suggest pervasive erosion and transport of the substrate.* ***C)*** *Roches moutonées suggesting sculpting of the substrate. Inset: morphology of the feature; background: a groove abraded up the stoss side of this feature (right of shovel).* ***D)*** *Evidence for a sliding ice–substrate interface. Background: large grooves on sculpted surface; inset: finer crosscutting striae.* ***E)*** *Series of descending meltwater channels eroded into a hillside as the margin of a cold-based glacier receded right to left (cf. Dyke, 1993).*

ICE-MOVEMENT INDICATORS

Ice-movement directions were determined by measuring the orientation of glacially sculpted features (e.g. roches moutonées), glacial abrasions, and stoss-and-lee features (Fig. 5) on bedrock surfaces. A-axis orientations of clasts in tills (i.e. till fabrics) were not examined as clasts have been reoriented by extensive, postdepositional cryoturbation in the active layer. A significant complication is the likelihood of alteration or masking of ice-movement data by flow-regime overprinting during subsequent overriding events.

In all, 206 measurements of ice-movement indicators were made within the study area (167 bidirectional and 39 unidirectional; Fig. 6A, B; Table 1). Attempts were made at each site to identify any crosscutting relationships. Once all the ice-movement indicator data were collected, comparisons between crosscutting relationships at individual sites were evaluated so as to allow first-order interpretations of the regional ice-movement sequence. Four main regional events were identified within the study area and are presented in Figure 6C.

Event 1

The oldest event identified in the region is characterized by north-northwestward movement (Fig. 7A), with a minor (single) instance of topographic deflection (*see* below). The majority of ice-movement indicators associated with this event were observed in the northwest quadrant of the map area, supporting the notion of an older, more extensive ice cover.

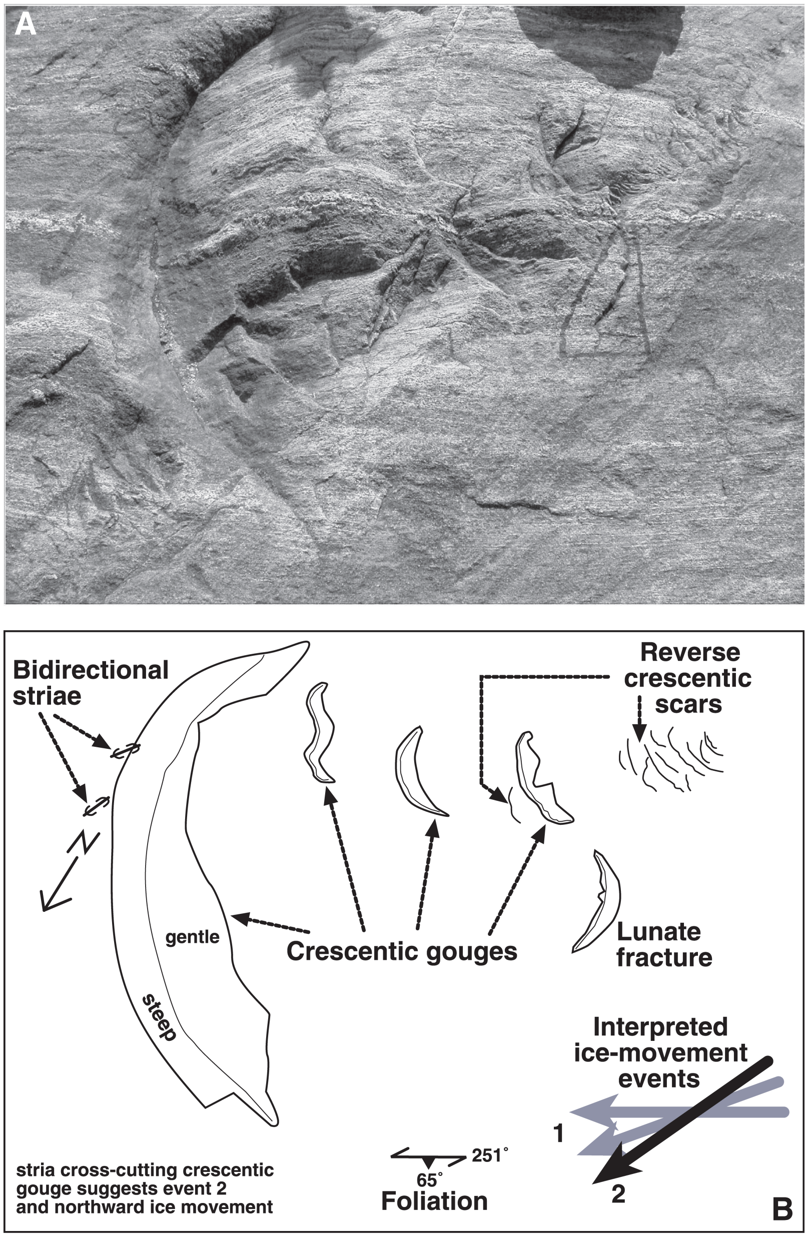

Figure 5.

A) Bedrock surface with numerous decimetre-scale ice-movement indicators. ***B)*** *Interpretation of indicators observed in (A).*

Event 1 is tentatively associated with a middle to early post-last glacial maximum (ca. 10–20 ka in this region) for the following reasons: 1) the general ice-movement indicator orientation is compatible with an ice source over the Foxe Basin (cf. Dyke et al., 2003); 2) these indicators are extremely consistent, being deflected only by the most prominent topographic features (e.g. in the northeastern quadrant of the study area, ice from the last glacial maximum is interpreted to have been deflected into North Arm Fiord); and 3) these indicators are commonly robust features such as roches moutonées and deep grooves crosscut by younger abrasive events.

Table 1. Information relating to rose diagrams (A) and (B) in Figure 6.

	Rose A	Rose B
Calculation method	Frequency	Frequency
Class interval	5 degrees	5 degrees
Petal length	Percentage	Percentage
Data type	Bidirectional	Unidirectional
Population	167	39
Maximum percentage	10.80%	7.70%

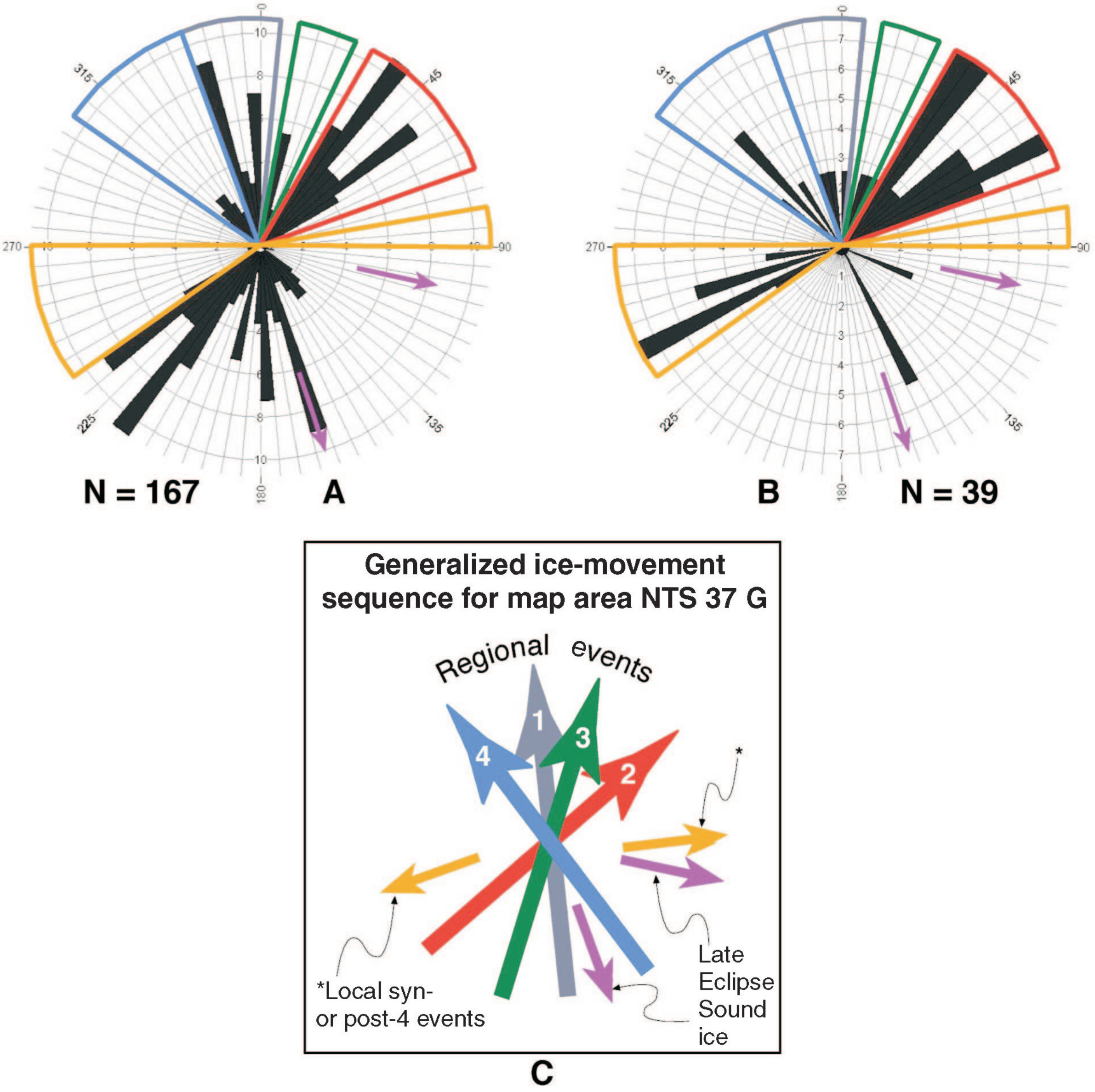

Figure 6. *Rose diagrams of **A**) raw bidirectional and **B**) raw unidirectional ice-movement indicator data. Coloured 'pie' slices highlight data that are associated with particular events. **C**) Generalized sequence of ice-movement events ('1' is the oldest event). The 'late Eclipse Sound ice' refers only to the region from which the ice was originating (i.e. northwest of the study area) and is not to be confused with the 'Eclipse Glaciation'* (see *Klassen, 1993*)

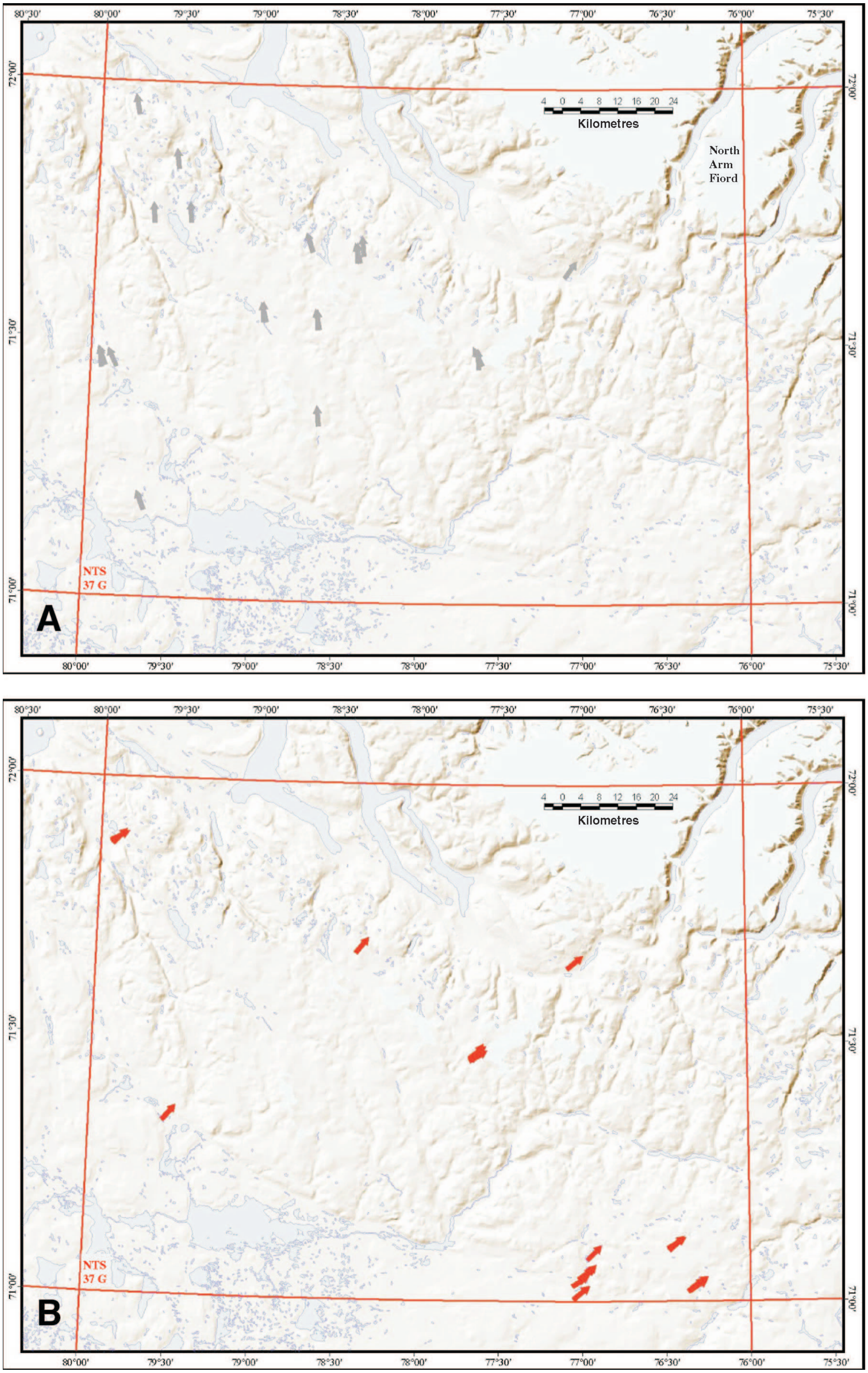

***Figure 7.** Regional interpretations of ice-movement data at sites associated respectively with the **A**) first and **B**) second ice-movement events.*

Event 2

Event 2 is characterized by a clockwise shift of approximately 45° to 50° in the ice-movement indicators (Fig. 7B). This regional shift to a northeast ice movement is attributed to significant changes in ice dynamics associated with the collapse of the Foxe Ice Dome and the development of the Baffin Ice Cap (ca. 9 ka, Dyke et al., 2003), which became separated from the mainland Laurentide Ice Sheet. The collapse of the Foxe Ice Dome would have resulted in the development of new ice divides or domes on Baffin Island, at least one of which would have developed southwest of the study area, causing ice to overrun the region from that direction (cf. Fig. 3.77 *in* Andrews, 1989).

Events 3 and 4

Events 3 and 4 represent end-members of a continuum of changing ice-movement directions resulting from the eastward migration of the Baffin ice spreading centre; as the Baffin ice sheet was shrinking and the incipient paleo-Barnes Ice Cap was forming, the associated changes in ice dynamics are interpreted to have forced the original Baffin Ice Cap divides to alter as well (e.g. Dyke and Prest, 1987, schematic diagrams of Baffin-related ice coverage at 9 ka, 8 ka, and 7 ka). Ice-movement event 3 represents an eastward shift in the ice divide(s) to positions south-southwest of the study area. This ice-divide configuration would allow for the regional northeastward ice movement presented in Figure 8A. As the ice sheet associated with event 3 was thinner than that associated with events 1 and 2, increased deflection by topographic features is more readily identified for event 3. Continued retreat of the paleo-Barnes margin following event 3 gave rise to event 4, which is uniquely characterized by northwesterly ice movement (Fig. 8B). This is interpreted to represent a much later phase in the development of the Barnes (or paleo-Barnes) ice-divide configuration. During this event, the spreading source had migrated farther eastward and the margin of the ice sheet was immediately north of the study area. Thus, the northwesterly ice movement represents the ice-sheet flow lines oriented toward the northwestern portion of the (paleo-)Barnes ice-sheet margin.

Localized ice-movement indicators during and after events 3 and 4

Evidence of localized ice movements was recognized throughout the study area and includes the following orientations (Fig. 8B): 1) southeastward movement in the extreme northwestern corner of the study area; 2) east-northeastward movement in the northwestern quadrant; and 3) southwestward ice movements in the west-central, central, and southern portions of the study area.

Southeastward ice movement

Some evidence suggests southeastward ice movement in the extreme northwestern portion of the map area. First, there is a well developed moraine concave to the northwest with associated lateral moraines, each of which descends upvalley; a large kettle lake occupies a moraine-proximal, up-ice–down-valley position. Second, three different locations are recognized where southeastward-trending unidirectional ice-movement indicators are observed.

Two possibilities are presented for the timing of this localized southeastward ice-movement event: a maximum ice scenario and an association synchronous with or postdating events 3 and 4. The former was rejected on the basis of research on Bylot and northern Baffin islands by Klassen (1993). He interpreted ice advancing from the southeast (i.e. map areas NTS 37 G and 47 H) into Milne Inlet, Eclipse Sound, and Pond Inlet during maximum ice conditions (Fig. 34, 39 *in* Klassen, 1993). Therefore, the southwest-oriented event that produced the observed ice-movement indicators in this region is interpreted to be a much younger ice advance following retreat of the main Laurentide and Baffin ice out of valleys along the east coast of Eclipse Sound. With the retreat of the extensive ice cover in the northern reaches of the map area, ice had advanced either from the highlands of the Borden Peninsula or from the Milne Inlet ice stream (A.S. Dyke, pers. comm., 2003). In either case, the ice would have filled Milne Inlet and Eclipse Sound and pushed up these tributary valleys.

East-northeastward ice movement

In the vicinity of Icebound Lakes (west-central NTS 37 G; Fig. 8B), indicators of an early northward-oriented ice-movement event are crosscut by northeast-trending striae. The trend of the striae is parallel to a small tertiary valley system (Fig. 8B); thus, a northward ice-movement direction is associated with this event. Local ice flowing from these highlands moved down through the valley system toward the western branch of Tay Sound.

Southwestward ice movement

Evidence of southwestward ice movement was observed in the central, west-central, and extreme southeastern portions of the study area. In the central portion, it is simply attributed to neoglacial ice movement from the local ice cap immediately northeast of the site (Fig. 8B). In the west-central and extreme southeastern portions, it is attributed to ice streams that drained the paleo-Barnes ice sheet, i.e. the Steensby Inlet (A.S. Dyke, pers. comm., 2003) and Milne Inlet ice streams, respectively.

In the southeastern region, regional flow prior to the Steensby ice stream was northeastward, away from the paleo-Barnes ice divide. As the Steensby ice stream developed, its head encroached northeastward across the ice sheet. Eventually, it would have overlain the sites in the southeastern portion of the study area and, at that time, flow would have drastically changed toward the southwest. Ice-movement indicators from the areas under the influence of this ice stream within the Steensby map area corroborate ice movement toward 210°.

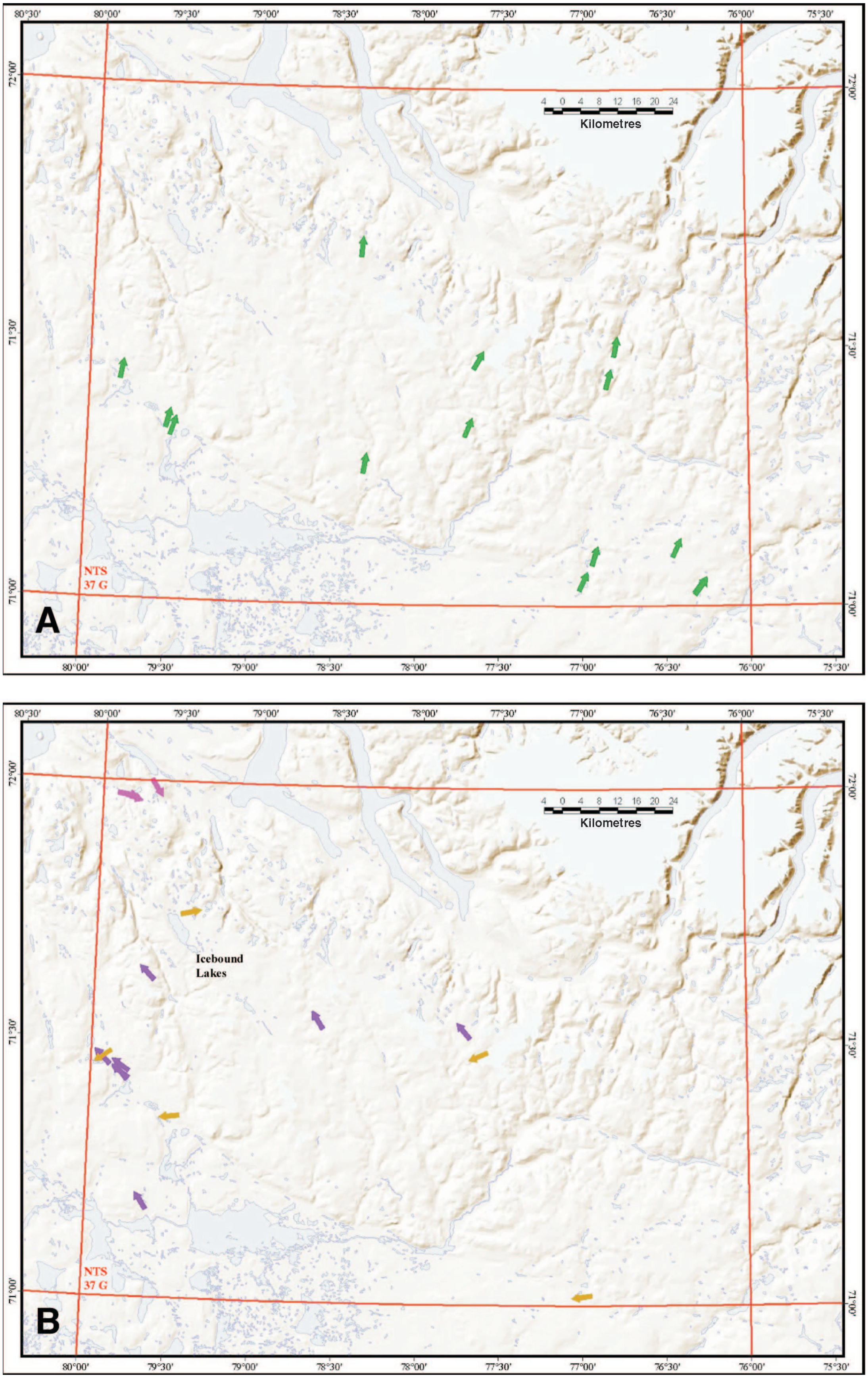

Figure 8. *A), B) Regional interpretations of ice-movement data at sites associated respectively with the* ***A)*** *third and* ***B)*** *fourth ice-movement events. Also presented in (B) are local ice movements synchronous with or postdating events 3 and 4* (see *text for details).*

A similar scenario occurred in the west-central region; however, the ice stream interpreted to be responsible for the observed change in ice movement was the Milne Inlet ice stream (A.S. Dyke, pers. comm., 2003). Prior to this, the ice movement was that of the regional event 4 (northwestward). Following the advance of the northern limb of the ice-stream head over the west-central portion of the map area (Fig. 8B), the ice movement changed from the regional signal (event 4) to southwestward, draining the local ice volume into the main Milne Inlet ice stream.

Other late local ice-movement events produced crossvalley moraines and down-valley descending lateral moraines. However, because mapping was still preliminary at the time of writing, they are not discussed herein.

PRELIMINARY GLACIAL HISTORY

During the last glacial maximum, ice flowed northward from the Foxe Ice Dome of the Laurentide Ice Sheet and occupied most or all of the NTS 37 G map area. During this advance, the Laurentide Ice Sheet was largely warm based and actively eroding its substrate. This appears to have been the most extensive late Quaternary Laurentide advance as it eroded or overprinted evidence of any previous regional advances. The ice sheet eroded much of the landscape, leaving extensive but discontinuous till sheets across the area. This advance produced most of the glacial features and material reported in the terrain inventory.

The Cockburn Moraines system (Falconer et al., 1965) has been regarded as marking the northernmost (i.e. maximum) extent of the Laurentide Ice Sheet (e.g. Dyke and Prest, 1987). It extends across the fiord heads of northeast Baffin Island and is clearly observed along the northern edge of the Baffin Upland region within the study area. However, ice-movement indicators suggesting northeastward movement into the North Arm Fiord were identified north of the Cockburn Moraines and therefore suggest that these moraines postdate the maximum extent of the Laurentide Ice Sheet in the valley systems (e.g. Hodgson and Haselton, 1974). It is speculated, therefore, that the Cockburn Moraines present within the NTS 37 G map area may be related to an early phase in the formation of the paleo-Barnes Ice Cap, perhaps ice-movement event 2 (outlined above and in Fig. 7B), when a major dome and/or divide was located southwest of the study area and ice movement was northeastward. In this paper, regional deglaciation is considered to have occurred following the formation of these moraines.

DEGLACIATION

To simplify the following discussion on deglaciation, the late post-last glacial maximum sequence of events is described in relation to the main physiographic regions presented in Figure 2. Regional deglacial phases included the retreat of the Laurentide Ice Sheet margin southeastward from the Cockburn Moraines system, leaving a local remnant — the Baffin ice sheet — in place over the area (approximately ice-movement event 2). Continued deglaciation within the study area resulted in the reduction of ice-sheet volume, modification of the ice-divide configuration, and the inception of the paleo-Barnes Ice Cap (i.e. an ice sheet more closely associated with the present-day Barnes Ice Cap than with the large ice sheets of the early post-last glacial maximum). This transition is tentatively associated with the southeastward shift in the paleo-Barnes ice divide (event 3). During these phases, the ice caps in this region were likely warm based, given the amount of sediment, the numerous ice-movement indicators, and the relative inferred thickness of the ice at these times.

By the time the divide had migrated farther eastward, resulting in northwest flow within the study area, ice had in all likelihood thinned considerably. At this time (event 4), local ice caps would have become isolated in the Davis Highlands and the Baffin Upland north of the paleo-Barnes Ice Cap. Because of the lack of indicators, these local ice caps are inferred to have been predominantly cold based. Also, the scarcity of ice-movement indicators related to event 4 throughout the study area suggests that some portions of the paleo-Barnes Ice Cap may have been cold based. In other regions, major ice streaming (e.g. Milne Inlet and Steensby Inlet ice streams, A.S. Dyke, pers. comm., 2003) of the paleo-Barnes Ice Cap occurred. Clearly, this phase of deglaciation was complex and further research is needed to confirm or refute the ideas presented above.

Continued retreat of the paleo-Barnes Ice Cap south of the Lancaster Plain–Baffin Upland boundary (i.e. Central Borden Fault) would have left only the coalesced mass of local ice caps on the Baffin Upland and Davis Highlands of map area NTS 37 G. However, along the border between the Lancaster Plateau and the Baffin Upland in the southwestern third of the map area, interaction may have occurred between the paleo-Barnes Ice Cap and coalesced masses of local ice caps. Here, the paleo-Barnes Ice Cap would have inhibited the drainage of those local ice caps flowing down major valleys within the Baffin Upland southward onto the Lancaster Plain.

Ice-damned lakes were pervasive during this phase of deglaciation (i.e. during and after ice- movement event 4). Deltas scattered at different elevations across the upland plateau and in valleys indicate that meltwater was ponding in small proglacial lakes across the map area during ice retreat. This alone is not indicative of warm- or cold-based ice conditions, as it simply reveals the production of much meltwater and the presence of ice-damned valleys. However, evidence for both warm- and cold-based glaciers during the final phases of deglaciation in the region is found on the Baffin Upland and on the Lancaster Plateau.

As is the case for the scenario presented for ice-movement event 4 (above), the occurrence of numerous, relatively small lateral drainage channels and the well preserved evidence of earlier glacial phases suggest that during the latest deglaciation of local ice caps, basal thermal regimes were predominantly cold based (cf. Dyke, 1993). In contrast, on the Lancaster Plateau, the deglacial scenario is much more complex; evidence for warm- and cold-based episodes during the final stages of the paleo-Barnes Ice Cap retreat out of the

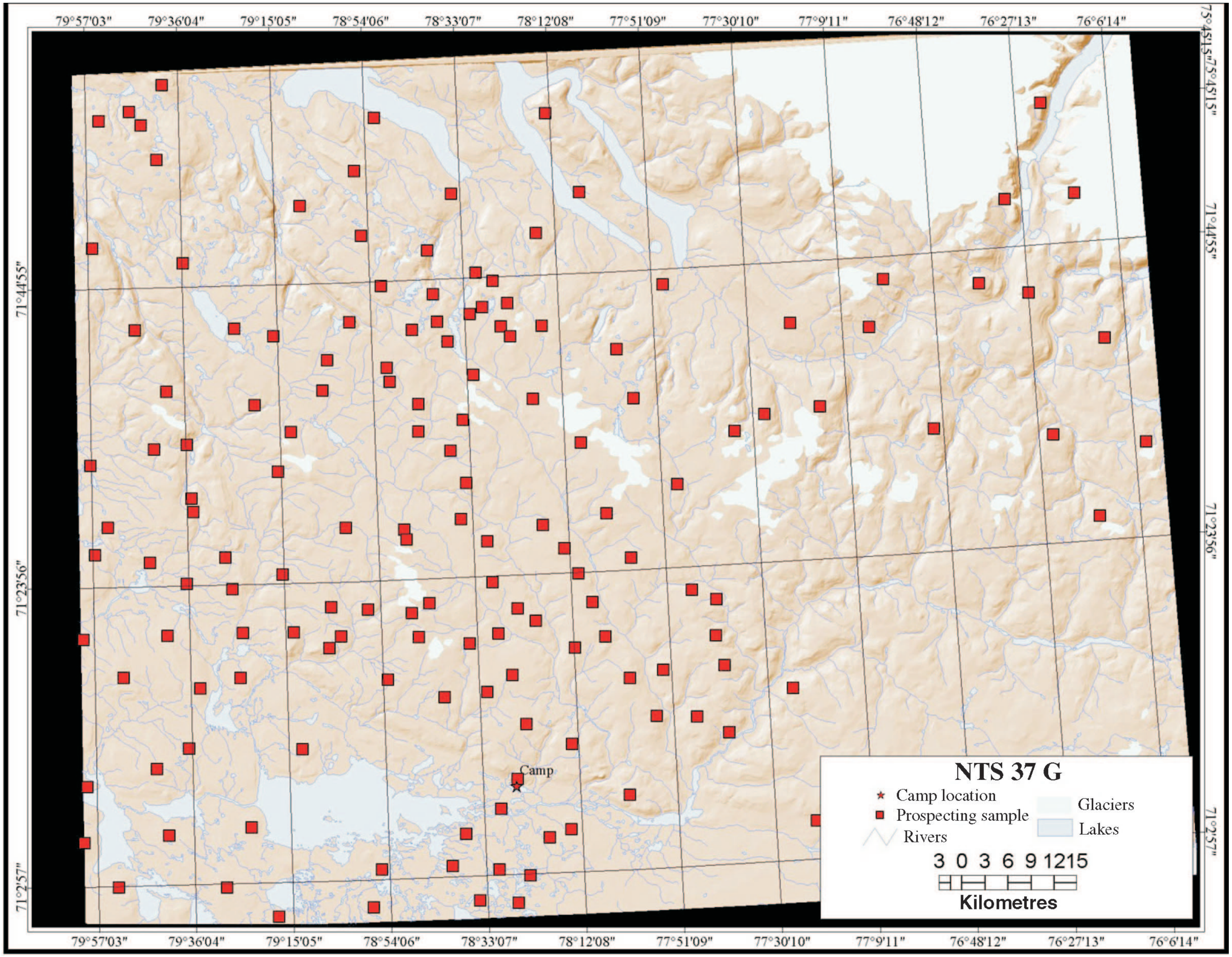

Figure 9. *Distribution of till geochemistry sample sites.*

study area are observed together. Here, end moraines, rolling till plains, and eskers typically associated with a warm-based thermal regime are present along with successive sequences of meltwater channels superimposed on hills and ridges; these meltwater channels are indicative of the former positions of the cold-based marginal paleo-Barnes Ice Cap. Although the relative timing of the events that produced both the cold- and warm-based features can be deduced, absolute ages for these events are currently unavailable.

Evidence of neoglacial activity in the region includes the presence of cirques on many of the north-facing slopes of high-elevation areas, as well as extant ice caps. Because of the relief in the Davis Highlands, local alpine-like glaciers continue to exist within many of the northeastern fiords. During the late phases of deglaciation, however, alpine-like glaciation, analogous to that currently affecting the Davis Highlands, would have occurred in the major valleys farther south and west (e.g. Ravn and Turner river valleys).

DRIFT PROSPECTING

In order to advance our understanding of the glacial geology of the study area, the North Baffin Project also initiated a drift-prospecting program. The 2003 field survey collected 156 till samples (Fig. 9) for gold-grain counts, pebble provenance studies, and till-matrix geochemical analyses. Heavy-mineral concentrates obtained during gold-recovery analyses will be archived for possible future kimberlite indicator mineral studies initiated through collaboration between the GSC and industry. As of the writing of this paper, samples are being processed; results will be released in a GSC Open File at a future date.

CONCLUSIONS

The North Baffin Project was initiated in order increase our understanding of the glacial history and mineral potential of the area defined by NTS 37 E, F, G, and H. In 2003, the project focused the field work within the Icebound Lakes map area (NTS 37 G). Numerous ice-movement indicators and till samples were collected for geochemical and heavy-mineral analyses. In addition, a complex glacial history was recognized for the region: four main regional ice-movement events were identified and correlated with different phases of deglaciation from the early post-last glacial maximum to the final phases of the paleo-Barnes ice sheet. Superimposed on these regional events were several local events, from ice caps located on the Baffin Upland to ice stream(s) that developed within the paleo-Barnes Ice Cap (Milne Inlet and Steensby Inlet ice streams). Geochronological research was undertaken to better understand the timing and dynamics of deglaciation, but more work is required for this extremely complex glacial–deglacial environment.

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REFERENCES

Andrews, J.T.
1989: Quaternary geology of the northeastern Canadian Shield; *in* Chapter 3 of Quaternary Geology of Canada and Greenland, (ed.) R.J. Fulton; Geological Survey of Canada, Geology of Canada, no. 1, p. 276–317 (*also* Geological Society of America, The Geology of North America, v. K-1, p. 276–317).

Andrews, J.T., Mears, A., Miller, G.H., and Pheasant, D.R.
1972: Holocene late-glacial maximum and marine transgression (<8000 BP) in the Eastern Canadian Arctic; Nature 239, p. 147–149.

Bierman, P.R., Marsella, K.A., Patterson, C., Davis, P.T., and Caffee, M.
1999: Mid-Pleistocene cosmogenic minimum-age limits for pre-Wisconsinan glacial surfaces in southwestern Minnesota and southern Baffin Island; a multiple nuclide approach; Geomorphology, v. 27, p. 25–39.

Bostock, H.S.
1970a: Physiographic regions of Canada; Geological Survey of Canada, Map 1254, scale 1:5 000 000.
1970b: Physiographic subdivisions of Canada;, *in* Geology and Economic Minerals of Canada, (ed.) R.J.W. Douglas; Geological Survey of Canada, Economic Geology Report 1, p. 10–30.

Briner, J.P., Miller, G.H., Davis, P.T., Bierman, P.R., and Caffee, M.
2003: Last Glacial Maximum ice sheet dynamics in Arctic Canada inferred from young erratics perched on ancient tors; Quaternary Science Reviews, v. 22, p. 437–444.

Dyke, A.S.
1993: Landscapes of cold-centred Late Wisconsinan ice caps, Arctic Canada; Progress in Physical Geography, v. 17, no. 2, p. 223–247.

Dyke A.S. and Prest, V.K.
1987: Late Wisconsinan and Holocene Retreat of the Laurentide Ice Sheet; Geological Survey of Canada, Map 1702A, scale 1:5 000 000.

Dyke, A.S., Moore, A., and Robertson, L.
2003: Deglaciation of North America; Geological Survey of Canada, Open File 1574 (32 maps at 1:7 000 000 scale with accompanying digital chronological database and one poster (in two sheets) with full map series).

Falconer, G., Ives, J.D., Løken, O.H., and Andrews, J.T.
1965: Major end moraines in eastern and central Arctic Canada; Geographical Bulletin, v. 7, p. 137–153.

Flint, R.F.
1943: Growth of the North American ice sheet during the Wisconsin age; Geological Society of America, Bulletin, v. 54, p. 325–362.

Hodgson, D.A. and Haselton, G.M.
1974: Reconnaissance glacial geology, northeastern Baffin Island; Geological Survey of Canada, Paper 74-20, 10 p.

Ives, J.D. and Buckley, J.T.
1969: Glacial geomorphology of Remote Peninsula, Baffin Island, N.W.T.; Arctic and Alpine Research, v. 1, p. 83–96.

Jackson, G.D.
2000: Geology of the Clyde-Cockburn Land map area, north-central Baffin Island, Nunavut; Geological Survey of Canada, Memoir 440, 303 p.

Jackson, G.D. and Iannelli, T.R.
1981: Rift-related cyclic sedimentation in the Neohelikian Borden Basin, Northern Baffin Island; *in* Proterozoic Basins of Canada, (ed.) F.H.A Campbell; Geological Survey of Canada, Paper 81-10, p. 269–302.

Jennings, A.E.
1993: The Quaternary history of Cumberland Sound, southeastern Baffin Island: the marine evidence; Géographie physique et Quaternaire, v. 47, p. 21–42.

Jennings, A.E., Tedesco, K.A., Andrews, J.T., and Kirby, M.E.
1996: Shelf erosion and glacial ice proximity in the Labrador Sea during and after Heinrich events (H-3 or 4 to H-0) as shown by foraminifera; *in* Late Quaternary Paleoceanography of the North Atlantic Margins, (ed.) J.T. Andrews, W.E.N. Austin, H. Bergsten, and A.E. Jennings; Geological Society of London, Special Publication 111 p. 29–49.

Klassen, R.A.
1993: Quaternary geology and glacial history of Bylot Island, Northwest Territories; Geological Survey of Canada, Memoir 429, 93 p.

Løken, O.H.
1966: Baffin Island refugia older than 54,000 yrs; Science, v. 153, p. 1373–1376.

MacLean, B., Williams, G.L., Jennings, and A.E., Blakeny, C.
1986: Bedrock and surficial geology of Cumberland Sound, N.W.T.; *in* Current Research, Part B; Geological Survey of Canada, Paper 86-1B, p. 605–615.

Marsella, K.A., Bierman, P.R., Thompson Davis, P., and Caffee, M.W.
2000: Cosmogenic ^{10}Be and ^{26}Al ages for the Last Glacial Maximum, eastern Baffin Island, Arctic Canada; Geological Society of America, Bulletin, v. 112, no. 7, p. 1296–1312.

Miller, G.H., Wolfe, A.P., Steig, E.J., Sauer, P.E., Kaplan, M.R., and Briner, J.P.
2002: The Goldilocks Dilemma: big ice, little ice, or "just-right" ice in the Eastern Canadian Arctic; Quaternary Science Reviews, v. 21, p. 33–48.

Praeg, D.B., MacLean, B., Hardy, I.A., and Mudie, P.J.
1986: Quaternary geology of the southeast Baffin Island continental shelf, N.W.T.; Geological Society of Canada, Special Paper 85-1, 38 p.

Wolfe, A.P., Frechette, B., Richard, P.J.H., Miller, G.H., and Forman, S.L.
2000: Paleoecological assessment of a >90,000-year record from Fog Lake, Baffin Island, Arctic Canada; Quaternary Science Reviews, v. 19, p. 1677–1699.

Young, M.D., Sandeman, H.A., Berniolles, F., and Gertzbein, P.M.
in press: Preliminary stratigraphic and structural geology framework for the Archean Mary River Group, northern Baffin Island, Nunavut; Geological Survey of Canada, Current Research 2004.

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