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TABLE OF CONTENTS

Appendices

The Readme file provides the complete list of files and sub-directories containing the datasets:

LIST OF TABLES

LIST OF FIGURES

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TILL COMPOSITION AND ICE-FLOW INDICATORS WEST OF REPULSE BAY: 2010 AND 2011 RESULTS FROM THE GEM WAGER BAY SURFICIAL GEOLOGY ACTIVITY

INTRODUCTION

As part of the Geo-mapping for Energy and Minerals (GEM) Program, the Geological Survey of Canada has initiated a surficial geological mapping activity in the Wager Bay region of mainland Nunavut west of Repulse Bay (Fig. 1). The project area lies within the western Churchill Geological Province where active precious and base metal exploration is ongoing. The Ukkusiksalik National Park encompasses the central part of the area. This region includes a variety of Quaternary glacial and post-glacial landforms and sediments yet, only limited Quaternary mapping and field-based observations are available. This project will fill in major knowledge gaps and better constrain the Quaternary geology of the region which will contribute to effective management of the terrain and interpretation of mineral and park resources. The project focuses on surficial geological mapping (1:100 000 scale) and regional-scale till sampling (10-km spacing) that will provide new data in support of mineral exploration, sustainable resource development and land-use management (e.g., Campbell and McMartin, 2010, 2011; Campbell et al., 2011; McMartin et al., 2012; Wityk et al., 2011, 2012, 2013; Huntley et al., in prep.). The purpose of this Open File publication is to release the field database and analytical results from the 2010 and 2011 field seasons over portions of NTS sheets 46E, 46K, 46L, 46M, 56I and 56P (Fig. 1).

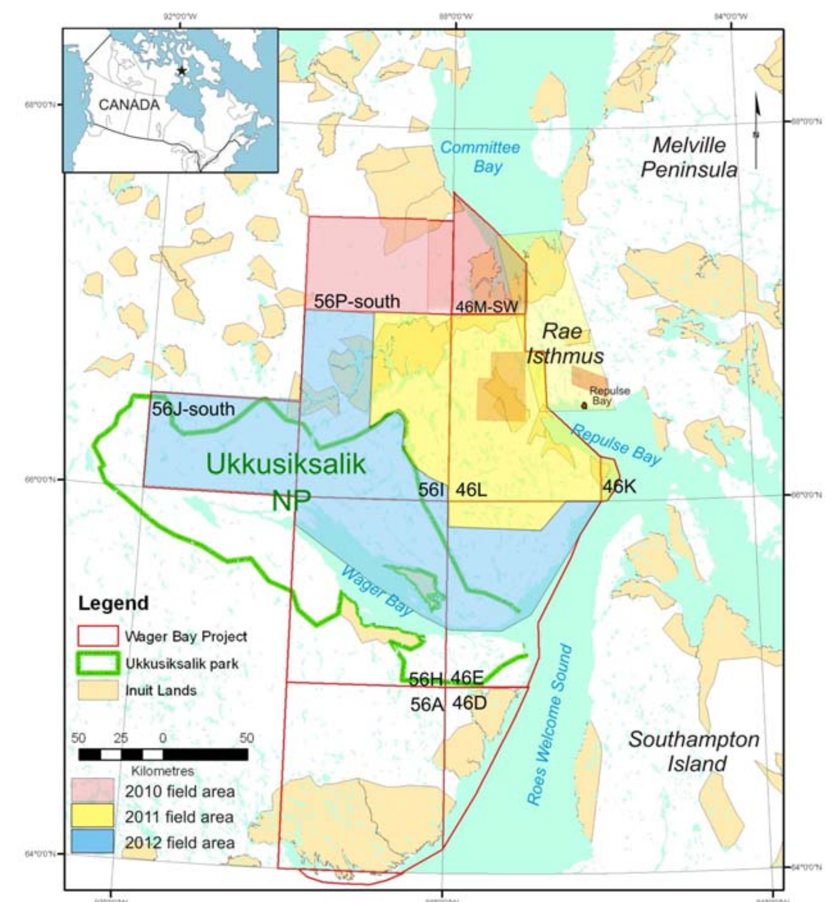

Figure 1. Location map of project area showing NTS map sheets (outlined in red) and each field season areal coverage.

REGIONAL SETTING

Location and physiography

The project area lies on either side of Wager Bay in central Nunavut between latitudes 64° and 68° and longitudes 86° and 92°, immediately west of the community of Repulse Bay (Fig. 1). It covers 3 complete map sheets at 1:250 000 scale (NTS 56A, 56H, 56I) and parts of 6 others (NTS 46D-mainland, 46E-mainland, 46K-southwest mainland, 46L-west, 46M-southwest, 56J-south). The southern portion of NTS 56P, previously field mapped and sampled during the Committee Bay TGI Project in 2002 (i.e. McMartin et al., 2003a, 2003b; Little, 2004), is also included. Although a first draft of the surficial geology map was available prior to the start of the Wager Bay Project for NTS 56P-south, it had never been completed and published. Field activities in 2010 and 2011 were concentrated in an area west of Repulse Bay outside the National Park's boundaries and covered approximately 14,000 km^2 (Fig. 2).

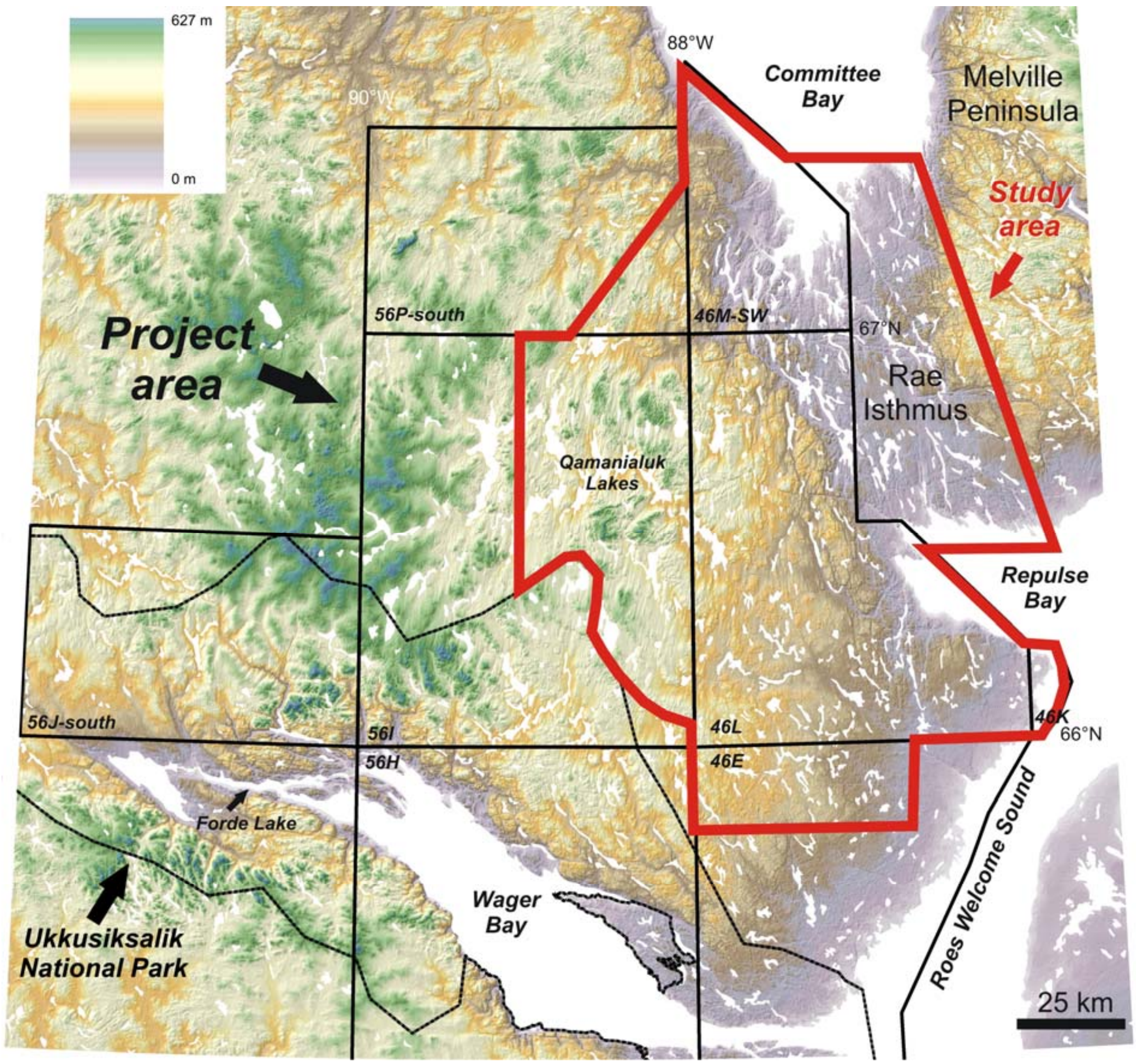

Figure 2. DEM generated from CDED 1:50K topography. Project area is outlined in black and area with 2010 and 2011 data reported in this Open File is highlighted in red ("study area").

This 2010-2011 study area lies in the Kazan Physiographic Region of Canada within the Wager Plateau Division (Bostock, 1967). Drainage is predominantly towards Hudson Bay via rivers that drain into Repulse Bay and Roes Welcome Sound. The northernmost parts of the area drain towards the Arctic Ocean via Committee Bay. Physiography is typical of the Canadian Shield in Keewatin i.e. it consists of generally low relief, with gently rolling hills interspersed by isolated or groups of bedrock hills, lakes, valleys and depressions. The greatest relief is produced by Proterozoic rocks of the Penhryn Group that commonly form prominent ENE-WSW trending bedrock ridges in the central part of the study area, and by mixed Archean granitic and gneissic rocks that outcrop in the northern part of Rae Isthmus. The most striking elements of the relief are the numerous northerly-trending crag-and-tail glacial landforms in the western part of the study area and the extensively gullied marine plain sediments along the western side of Committee Bay. Elevations range from sea level rising westward to 520 m a.s.l. in the Qamanialuk Lakes area (Fig. 2). The area lies within the Wager Plateau Ecoregion of Canada (#30) having a mean annual temperature of approximately -11°C (summer mean of 4.5°C; winter mean of -26.5°C) and a mean annual precipitation of 200-300 mm (http://ecozones.ca/english/region/30.html). It is characterized by continuous permafrost with low ice content and a discontinuous tundra vegetation cover. Turbic and Static Cryosols developed on sandy diamicton and glaciofluvial deposits are the dominant soils, while large areas of Regosolic Static Cryosols are associated with the marine deposits along the coast of Committee Bay.

Bedrock geology

The study area lies within the 2.7-2.6 Ga Rae Domain of the western Churchill Geological Province. It is underlain by a variety of Archean through Paleoproterozoic supracrustal and intrusive rocks, and, except for the Committee Bay greenstone belt area over 56P-south, has seen little geological field mapping since the 1960’s (Heywood, 1967) (Fig. 3). Interest by Parks Canada in the development of a national park in the Wager Bay area prompted a mineral-resource assessment by the Geological Survey of Canada that resulted in detailed bedrock geology maps around Wager Bay (cf. Jefferson et al., 1991, 1993; Chandler et al., 1993).

Bedrock geology in the study area comprises the Committee Bay supracrustal belt in the north, composed of Prince Albert Group (PAG) rocks dominated by semipelite and psammite with lesser iron-formation, quartzite, komatiite, komatiitic basalt and felsic metavolcanic rocks (i.e. Skulski et al., 2003; Sandeman et al., 2004). These are intruded by diverse Archean plutonic bodies including granodiorite and monzogranite. To the south and east of this belt, rocks that comprise part of the southern Walker Lake intrusive complex consist of foliated, ca. 2.61 Ga magnetite-bearing, K-feldspar-megacrystic granodiorite and monzogranite, older granodiorite gneiss, and younger ca. 1.82 Ga biotite-fluorite Hudsonian monzogranite (Peterson et al., 2002). These younger granites are abundant throughout the northeastern Rae domain and extend to the SW towards Ford Lake (e.g., Ford Lake batholith; LeCheminant et al., 1987). Most of NTS 46L is underlain by mixed gneisses (amphibolite gneiss, homblende-biotite gneiss, granitoid gneiss and migmatite; in part derived from sedimentary and volcanic rocks) and generally foliated to gneissic granitoid rocks (undifferentiated) (Heywood, 1967; Jefferson et al., 1991; Skulski et al., in prep). Some of these rocks engulf Archean supracrustal screens of komatiite, quartzite, banded iron formation (BIF), amphibolite, and semipelite. Metamorphosed Paleoproterozoic cover sequence rocks, part of the Penrhyn Group, are confined to a narrow ENE-trending belt north and west of Repulse Bay. These contain unsubdivided pelitic gneiss, marble and metawacke gneiss and schist, with minor metabasalt, gabbro and thin quartzite. Areas offshore in Repulse Bay and Roes Welcome Sound are underlain by undifferentiated Paleozoic Hudson Platform sequences.

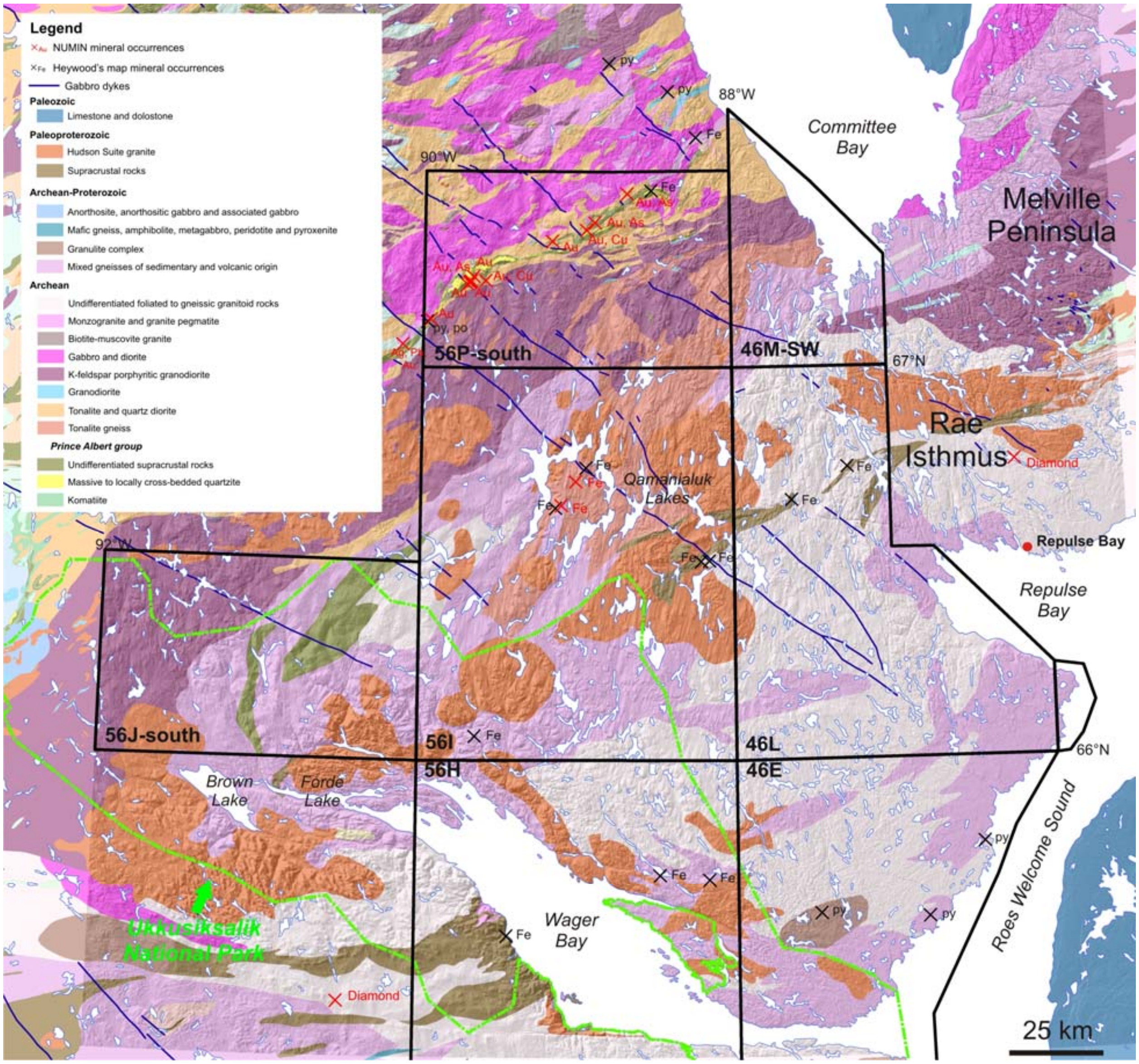

Figure 3. Bedrock geology map (from Skulski et al., in prep.) and mineral occurrences (from Heywood, 1967 and NUMIN) within the project area north of Wager Bay.

From a metallogenic perspective, supracrustal rocks of the PAG contain a number of proven (Au in iron formation) and possible commodities (Ni, Cu, PGE's in mafic and ultramafic volcanic and intrusive rocks) (Deyell and Sherlock, 2003; Sherlock and Deyell, 2003; Skulski et al., 2003). Recently, an emerald occurrence was found in drill core in the Anuri gold prospect area in the southeast part of the Committee Bay greenstone belt (http://northcountrygold.com/). Slivers and screens of equivalents of PAG rocks outcrop to the south of the Committee Bay greenstone belt and have similar mineral potential. Paleoproterozoic sediments of the Penhryn Group have potential for base metals (Pb-Zn ± Co, Cu, Ni, U, Mo), Au and Ag (Heywood, 1967; Jefferson et al., 1991; Tremblay et al., 2010). Intrusive rocks, including the 1.84-1.80 Ga Hudson granite suite, have potential for Mo, Sn, W, U-REE, Pb-Zn and Cu (LeCheminant et al., 1987; Jefferson et al., 1991). Numerous kimberlites are known to outcrop and subcrop in the region (i.e. Nanuk, Qilalugaq, Amaruk) which suggests there is potential for diamonds in the study area.

Quaternary Geology

Previous work

During the last Wisconsinan glaciation, the Wager Bay region was affected mainly by Keewatin Sector Ice of the Laurentide Ice Sheet and its interplay with Melville Ice of the Foxe Sector on Melville Peninsula (e.g. Dyke and Prest, 1987; Dredge, 2002). The area lay under the eastern part of a major ice divide in Keewatin (Lee et al., 1957; Aylsworth and Shilts, 1989; McMartin and Henderson, 2004). Only reconnaissance-scale Quaternary mapping with limited field work is available for the project area. The Glacial Map of Canada depicts a handful of superimposed streamlined forms north of Wager Bay, ice-flow indicators which converge into Rae Isthmus and others that diverge on either side of the Chantrey Moraine System (Prest et al., 1968). Decreasing marine limit elevations from 240 m asl to 110 m asl southward are shown within the project area. The 1:1 million scale map compilation of Aylsworth and Shilts (1989) shows the study area with few surficial features except for eskers and small areas of streamlined landforms forming a distribution pattern that is roughly opposite on either side of Wager Bay (Fig. 4). Northward meltwater corridors are shown to begin abruptly in NTS maps 56I-north and 56J-south, while a few eastward trending eskers are depicted within NTS 46L and 46E.

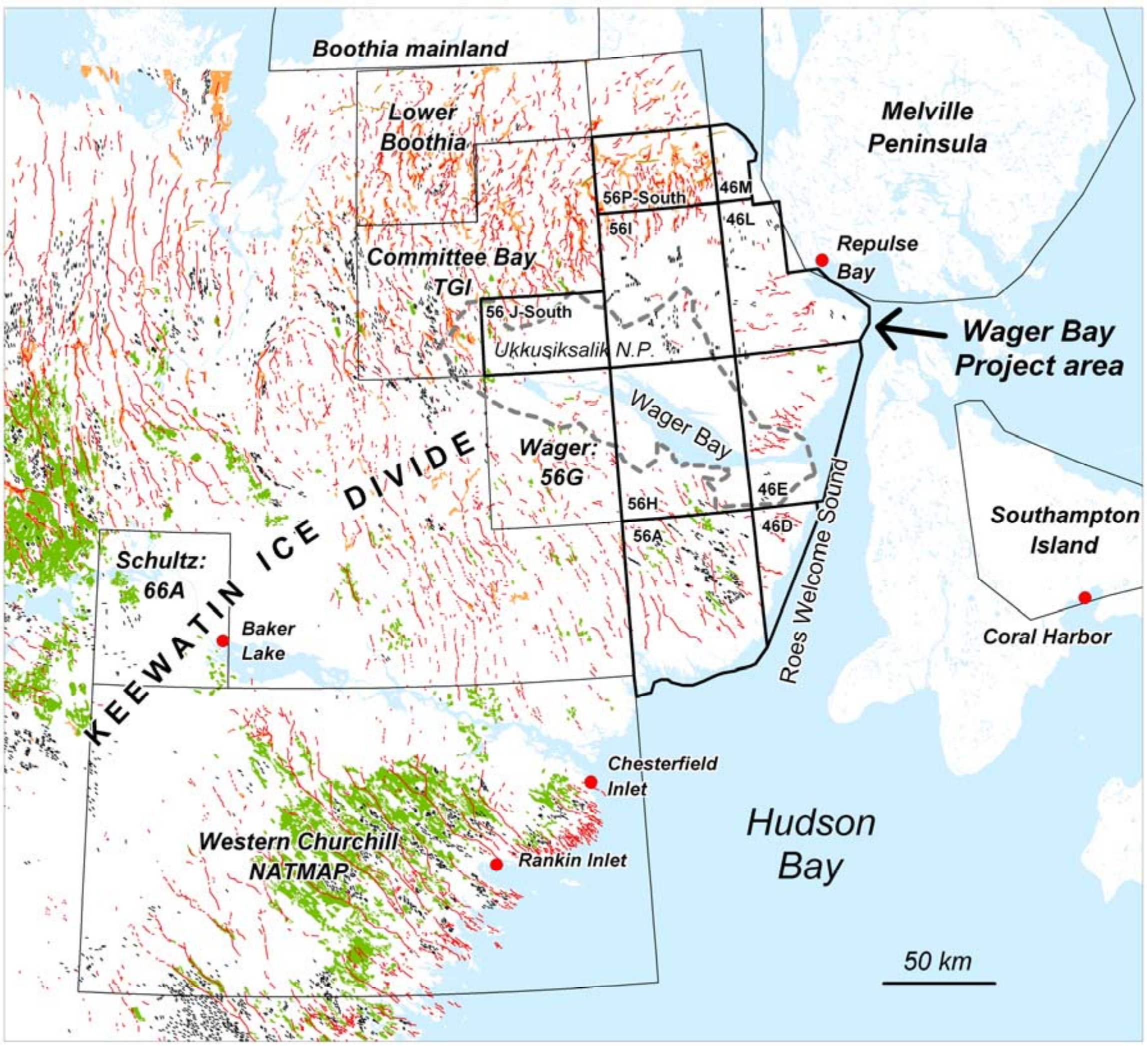

Figure 4. Regional Quaternary map (derived from Aylsworth and Shilts, 1989) showing location of eskers (red), streamlined forms (black lines), ribbed moraine (green) and glaciofluvial deposits (orange). Recent government surficial mapping (field-based) project areas and Wager Bay Project area are outlined.

Smith's (1990) work in the Ukkusiksalik National Park area brought to light a complex late glacial history for the Wager Bay area. Much of her work was based on glacial geomorphology, in particular till landforms and meltwater channels. In adjacent areas to the east over Melville Peninsula (i.e. Dredge, 1990, 1995, 2000, 2001, 2002, 2009; Tremblay and Paulen, 2012), to the north in the Committee Bay supracrustal belt (e.g. Ozyer and Hicock, 2002; Little et al., 2003; Giangioppi et al., 2003; McMartin et al., 2003a, 2003b; Little, 2004; Utting et al., 2009), and to the west in NTS map sheet 56G (Dredge et al., 2005; McMartin and Dredge, 2005; Dredge and McMartin, 2007), surficial geological mapping and till sampling have provided valuable field-based information for studies of ice-flow chronology, deglacial history and till provenance.

Based on remotely sensed data, drift lineations and other glacial landforms were compiled at different scales in the study area and adjacent regions (Boulton and Clark, 1990; Clark, 1997; De Angelis, 2007; De Angelis and Kleman, 2005, 2007, 2008; Kleman et al., 2002, 2010; Shaw et al. 2010a, 2010b). These studies revealed some cross-cutting drift lineations, areas of cold-based ice, end moraines and ice-streaming events, although the lack of or limited ground truthing of these maps has frequently resulted in either misinterpretation of the landforms (i.e. nature, sense of ice flow, relative chronology), or over-simplification (i.e. continuity, generalization in areas of complex ice flow).

Glacial landscapes and surficial sediments

Field observations and imagery interpretation in the region to date (Campbell and McMartin, 2010, 2011; Campbell et al., 2011; McMartin et al., 2012; Wityk et al., 2011, 2012, 2013; Huntley et al., in prep.) have revealed diverse glacial landscapes and Quaternary sediments with distinct landform assemblages, and a complex ice-flow history. Of particular interest in the area covered by this report are the striking northward-trending crag-and-tail landforms in NTS 56I-east, north-flowing (56I-north) and east-flowing (46E and L) meltwater corridors with complex sediment-landform assemblages, exotic carbonate-rich till south of Repulse Bay (46L-southeast), and extensive areas of exposed and gullied marine silts along the Committee Bay coast (46M-southwest).

Till landforms

Till blankets and till veneers are scattered throughout the area but are dominant above the marine limit (see section below). Conspicuous northward-trending crag-and-tail landforms, and other streamlined landforms (drumlins, flutings, pre-crags), are found mostly in NTS 56I-east and 46L-west-northwest (Fig. 5a). These landforms, centered around the Qamanialuk Lakes area, can be clearly detected on the digital elevation model (Fig. 2). Hand dug pits in the streamlined landforms indicate that the surface material is composed of a poorly sorted, massive, silty sand diamicton (till), with a variable clast content. The provenance of the material is predominantly local and appears to be related to a general northward direction of glacial transport (Campbell et al., 2011; McMartin et al., 2012). Thin clayey diamictic layers were found at 3 sites in the west-central part of the study area, intercalated or underlying the regional till sheet. Permafrost features include frost boils, sorted nets, and some ice-wedge polygons. Boulder cover is variable but in many areas, the boulder cover is very dense especially where the till is thin or has been affected by meltwater/surface erosion (Fig. 5b).

Glaciofluvial corridors

In the northern part of 56I-east, prominent north-flowing meltwater corridors with thick packages of sediments occur as subglacial ice-contact landforms (eskers/kames), supraglacial terraces, and proglacial aprons/deltas and outwash trains and fans (Fig. 6a). These deposits, typically filling wide topographic lows, occur in association with small hummocks (c.f.. Utting et al., 2009), meltwater channels, crevasse-filled ridges, kettles and knobs, small end moraines, and trimlines, and reflect southward ice retreat and a succession of depositional environments related to meltwater erosion and deposition. Surface materials in these corridors vary considerably and include sand and gravel, boulders, eroded tills, glacial diamictons, and glacial lake sediments.

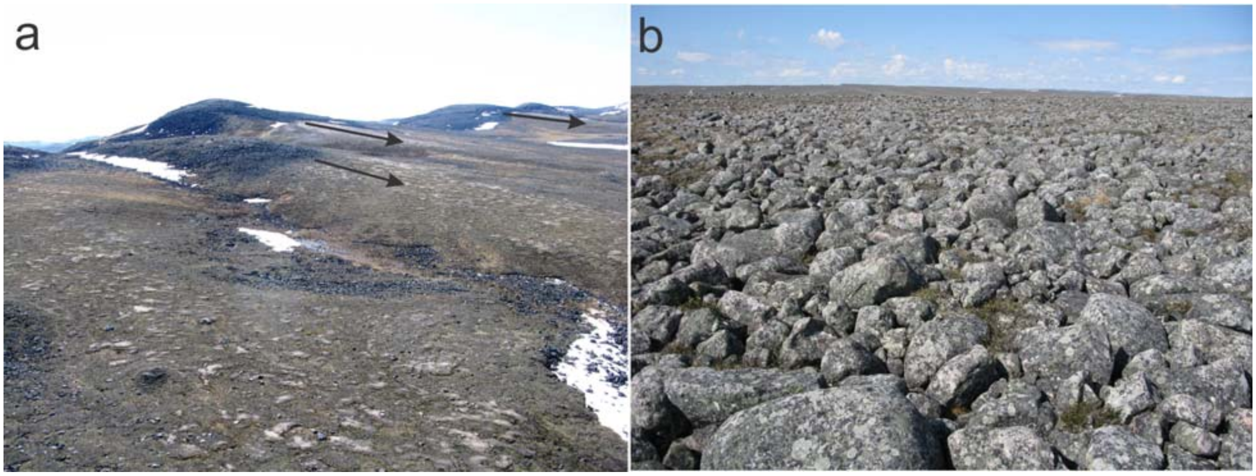

Figure 5. Photographs of till landscapes: a) crag-and-tail landforms in NTS 56I-east showing bedrock crags in Penrhyn Group outcrops, well-developed tails of till with frost boils and variable boulder cover between the landforms (view is to the southwest); b) boulder cover is abundant on the till plains in NTS 46L-SW.

East-flowing meltwater corridors form shallow, 5-10 km wide channels characterized by complex sediment-landform assemblages including boulder fields and eroded tills, small hummocks, transverse ridges and small subglacial ice-contact (eskers) landforms (Fig. 6b). These corridors indicate a westward retreating ice margin in NTS 46E-north and 46L-south and reflect primarily erosional processes. They crosscut northward-trending streamlined landforms near the map border with NTS 56I. Surface materials include eroded till, glacial diamictons, boulders and sand and gravel. Both the northward and eastward meltwater corridors originate in the uplands close to modern topographic drainage divides (Committee Bay and Repulse Bay).

<u>Carbonate drift</u>

A previously unknown, exotic carbonate-rich sandy silty till underlain by glacially-scoured Archean mixed gneisses forms a low-relief plain on an upland south of Repulse Bay (NTS 46L-SE) (Fig. 6c). The presence of carbonate till in NNW-trending streamlined landforms in this area extends the southern limit of the Rae Isthmus Ice Stream (e.g., Dredge, 2002) south of Repulse Bay, indicating that the source area was near the west side of Southampton Island-Roes Welcome Sound, not Foxe Basin as previously suggested (Dredge, 2002). This discovery changes the interpretation of source location for the carbonate till, and the ice-flow dynamics in the Repulse Bay – Southampton Island – southern Melville Peninsula area (e.g. Prest, 1984; Dyke and Dredge, 1989; Ross et al., 2011). In addition, the carbonate till contains small, thick pieces of marine shells, presumably redeposited from the floor of Roes Welcome Sound. Detailed work on these shells, including radiocarbon age determinations, is ongoing.

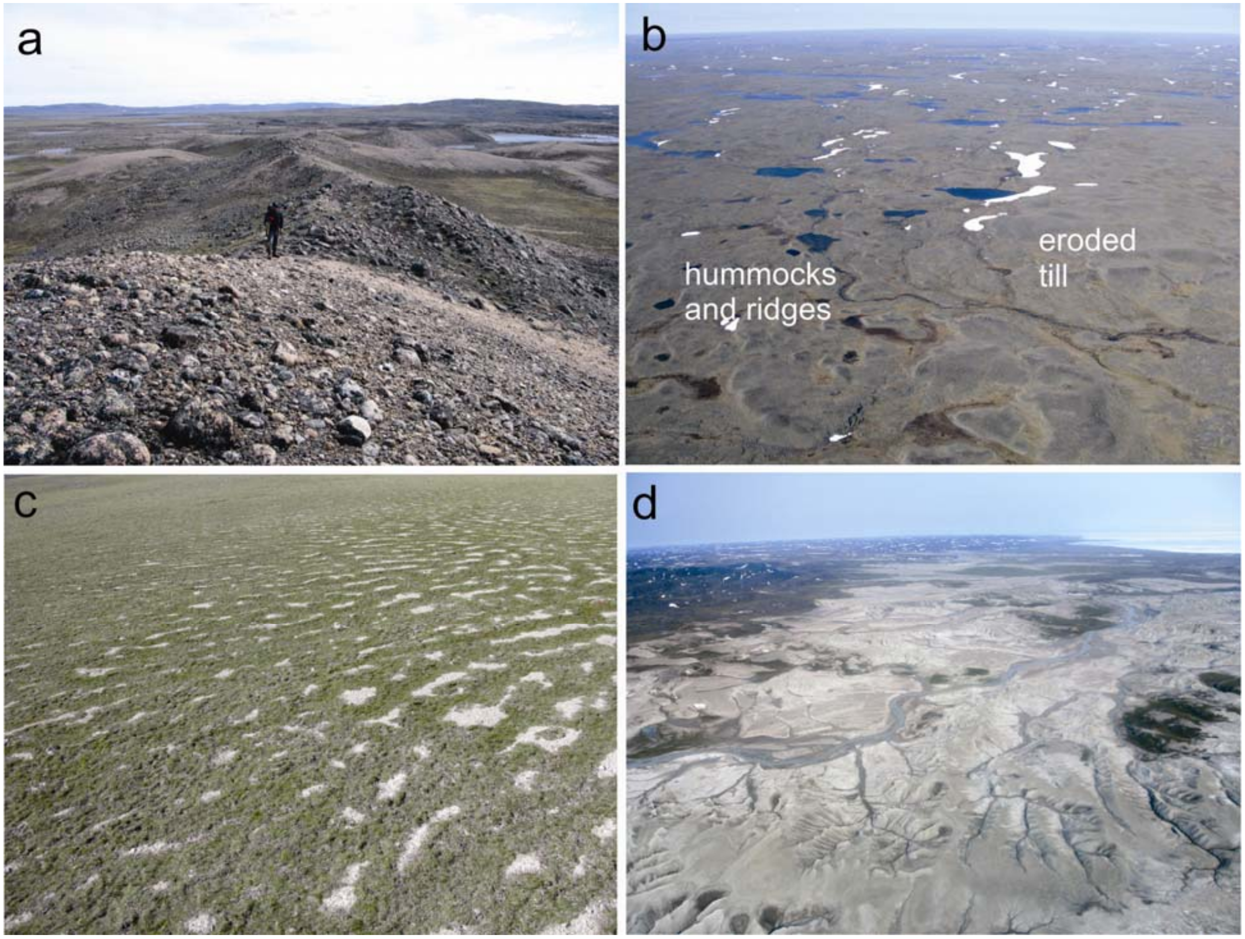

Figure 6. Photographs of various glacial sediment types in the study area: a) large esker in north-flowing meltwater corridor (NTS 56I-NE); b) east-flowing meltwater corridors with areas of small hummocks and ridges, bordered by eroded till (NTS 46L-SW); c) silty calcareous till with elongated bare frost boils (NTS 46L-SE); and d) extensive gullying in thick marine offshore sediments along Committee Bay (NTS 46M-SW).

Marine limit and cover sequence

A series of high-level marine trimlines at an elevation of 240 m asl west of Committee Bay, dropping to about 140-150 m west of Repulse Bay, records the southward declining marine limit in the study area. These contrasting marine limit elevations suggest the ice remained much longer over the Rae Isthmus and to the south, relative to areas west of Committee Bay. This confirms that paleo-Committee Bay must have been open and stable over a significant time period, likely related to the position of the Chantrey-Melville moraine system (Dredge, 1990). Eight radiocarbon dates on marine shells collected in 2010 and 2011 are reported here (Table 1) and indicate a minimum deglaciation age of approximately 5.4 to 6.6 ka ^{14}C BP for the study area (corrected for isotopic fractionation, and marine reservoir – see McNeely et al., 2006). The location, detailed description and nature of inclosing sediments for these shell samples are provided in Appendix III.

The marine sequence includes, from the limit of marine incursion to the present-day coastline, thick sequences of deltaic sands and gravels, marine offshore and offlap silts and sands, and sand and gravel littoral sediments. Thick accumulations of marine silts and fine sands, often exposed by extensive gullying and rilling, dominate the west coastal plain of Committee Bay in NTS 46M-southwest (Fig. 6d). These marine sediments extend up valleys into NTS 56P-south, reaching elevations up to 170 m above sea level (Giangioppi et al., 2003; Campbell et al., 2013). Evidence for marine reworking, to varying degrees, such as sand veneers and patches of wave-washed tills, is present at all elevations below marine limit. Throughout the map area, younger alluvial sediments and slope wash deposits occur in low-lying areas, and may be overlain by thin, fibrous peat.

Table 1. Radiocarbon ages on marine mollusks (AMS dating at BETA Laboratory). Locations are shown on Figure 11.

Site	Elevation (m)	GSC sample ID	BETA ID	$^{13}C/^{12}C$ 0/00	Conventional ^{14}C age (BP)	Corrected ^{14}C age (BP) for marine reservoir	Species
A	50	10MOB-I063A01	293257	+1.5	6750 +/- 40	6010 +/- 40	*Hiatella arctica*
B	108	10MOB-I051A01	293256	+1.3	6930 +/- 40	6300 +/- 40	Unidentified
C	44	10MOB-I038A02	293255	+0.4	6150 +/- 40	5410 +/- 40	*Hiatella arctica*
D	121	11MOB-M045A02	315077	+1.7	6720 +/- 30	6090 +/- 30	Unidentified
E	30	11MOB-C087A02	315075	+2.2	7260 +/- 40	6630 +/- 40	*Hiatella arctica*
F	60	11MOB-C033B01	315074	-0.6	7250 +/- 40	6620 +/- 40	*Hiatella arctica*
G	87	11MOB-C029B01	315073	+0.4	6940 +/- 40	6310 +/- 40	*Mya truncata*
H	111	11MOB-M023A01	315072	-1.1	6890 +/- 40	6150 +/- 40	*Macoma calcarea*

Relative ice-flow chronology

The recent mapping of striations, roches moutonnées, and streamlined landforms indicate the area was influenced primarily by ice flowing north, from an ice mass centered within and/or immediately south of Wager Bay (Fig. 7). The predominant northward direction of streamlined landforms is parallel to the latest erosional ice-flow indicators in some areas but not at all sites, suggesting a complex relationship between landform formation, small-scale erosional forms and glacial transport processes and timing. As far inland as 80 km from the coast of Repulse Bay, southward, southeastward and eastward ice-flow indicators overprint the dominant northward flow and reflect a late ice-flow convergence into Repulse Bay, oblique and even reverse to the dominant northward ice flow such as over the southern part of the Rae Isthmus (Figs. 7 and 8). This late convergent ice flow is associated with opening of Repulse Bay during deglaciation, changes in the ice margin configuration, and radial flow from a remnant ice mass in the highlands north of Wager Bay (Campbell et al., 2011; McMartin et al., 2012). It may have significant implications for mineral exploration, specifically for following up indicator mineral dispersal trains. Divergent ice-flow directions are also found on either side of the Chantrey Moraine System in NTS 46M and 56P as a result of ice front reorientation during ice retreat (McMartin et al., 2003a, 2003b; Campbell et al., 2013).

METHODS

Field procedures

Field data collection

Field work was completed from July 16th to 28th in 2010 and July 3rd to 25th in 2011 by Janet Campbell and Isabelle McMartin (GSC) with assistance from students and local hires. Access was primarily by helicopter from the town of Repulse Bay. Field work involved surficial geological mapping from helicopter and ground traverses, ground site observations, ice-flow indicator mapping, till sampling, ground truthing of preliminary remote predictive maps, and taking photographs from the ground and from the air. A total of 282 sites were visited and are described in Appendix I.

Ice-flow indicator mapping

The orientation and sense of 436 small-scale erosional ice-flow indicators were measured from 187 sites in 2010 and 2011 (Fig. 8). Indicators include striations (deep and fine), microstriae, grooves, nail-head striae, rat tails, chattermarks, crescentic fractures and gouges, stoss and lee forms, fluted bedrock, and roches moutonnées (Fig. 9). The sense of ice-flow movement was derived from nail-head striae, rat tails, crescentic fractures, and roches moutonnées, or from stoss and lee topography (general shape of outcrop). Relative ages of striated facets were established at 138 sites (i.e. Figs. 8 and 9). Detailed ice-flow indicator measurements and descriptions are provided in Appendix II. Data is presented in a format easily importable in a geographic information system (GIS).

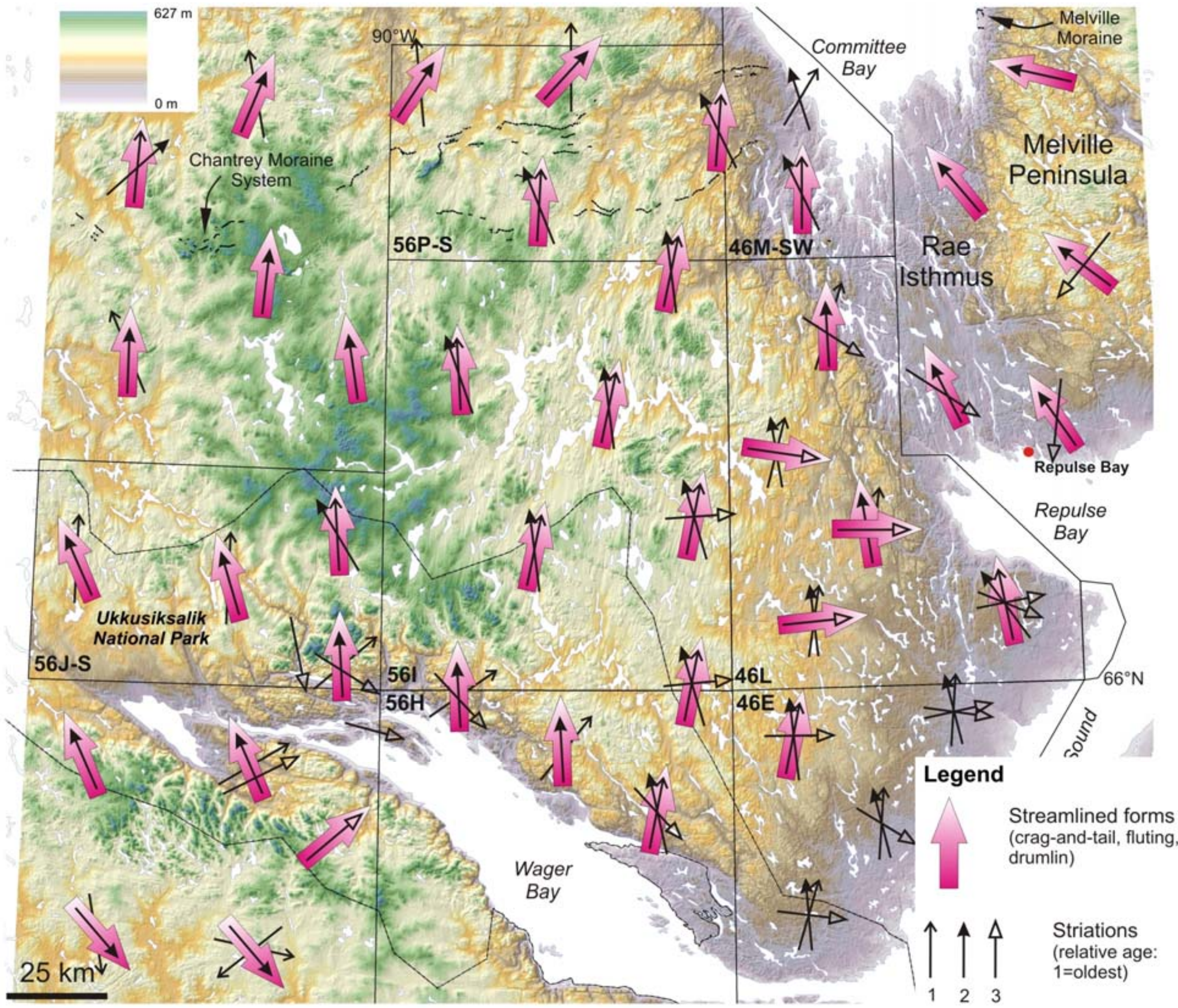

Figure 7. Generalized ice-flow sequence map for areas north of Wager Bay. General trends of streamlined forms are derived from published and preliminary surficial geology maps and from the Wager Bay Project DEM. Striation trends and relative ages are taken from recent field work in the Wager Bay Project area and from existing maps in adjacent areas (Dredge, 2002; McMartin et al., 2003a; Dredge and McMartin, 2007; Tremblay et al., 2010).

Till sampling

Regional-scale till samples were collected for geochemical and indicator minerals analyses, and gold grain counts. Survey design was devised to obtain evenly spaced samples from across the entire study area (average of 10-km spacing). Samples were collected in Cy-horizon material from hand dug pits in frost boils, at an average depth of 30 cm, to obtain relatively unaltered material (Fig. 10). In total, 140 regional till samples were collected in the study area in 2010 and 2011 (Fig. 11). At each site, one small sample (~3 kg) and one large sample (mean=13 kg; range=6.4-19.0 kg) were collected, mainly from active frost boils. At three sites in the east-central part of the study area, a clayey diamict layer found intercalated with the regional till was collected for geochemistry. At one site along the coast in 46L-south, beach sand and gravels were collected for heavy minerals due to the lack of till in the area. At all sites, special care was taken to exclude layers of organic material or heavily oxidized clasts. One sample per block of about 20 samples was collected as a field duplicate to test site variability (less than 10 m apart). The routine and corresponding field duplicate were labelled with the same sample code except for one digit (e.g. 10MOB-I071A01 for the routine sample and 10MOB-I071A02 for the field duplicate). Field duplicate sites were randomly chosen within each block of 20 samples. The location and description of all samples are presented in Appendix III.

Analytical procedures

Sample preparation

A 2-kg split of all ~3-kg samples was air-dried and dry-sieved in GSC's Sedimentology Laboratory, Ottawa using a stainless steel 230 mesh screen to obtain the <0.063 mm size fraction (Girard et al, 2004). The remainder (<800 g) of each 3-kg till sample was archived at the GSC, Ottawa. The ~13-kg till samples were shipped to Overburden Drilling Management Ltd (ODM) for processing and the production of heavy mineral concentrates. Samples were processed in the order they are listed in the ODM raw data file in Appendix XI: the first batch collected in 2010, and the second batch collected in 2011. Sample were disaggregated in water and screened at 2 mm to produce a non-ferromagnetic heavy mineral concentrate for picking indicator minerals involving a two step process with a shaking table and heavy liquids. The oversize was wet-sieved to collect the 4-8 mm and >8 mm fractions for lithological analysis. Sample preparation and analytical procedures for all till samples are summarized in Figure 12. The analytical and QA/QC procedures follow the protocols for till samples collected as part of GEM projects (Spirito et al., 2011).

Matrix geochemistry

Approximately 30 g of the silt+clay-sized fraction (<0.063 mm) of till were analyzed at Acme Analytical Laboratories Ltd., Vancouver for a suite of trace, major and rare earth elements using ultratrace ICP-MS, following a hot (95°C) aqua regia digestion (HCl-HNO_3, 3:1) (Group 1F06-1F09: 65 elements). In addition, a separate 0.25 g split of the same fraction was analyzed at Acme using ultratrace ICP-MS, 4-acid digestion (HNO_3-$HClO_4$-HF dissolved in HCl: Group 1T-MS: 43 + REE elements). Another separate 0.2 g split was analyzed for whole rock plus Cu, Mo, Ni, Pb, Sc and Zn analysis by ICP-ES, and for total trace elements by ICP-MS following a lithium metaborate/tetraborate fusion and dilute nitric digestion (Extended Group 4A-4B: 52 elements). Carbon and sulphur were analyzed by Leco as part of the same package. Detection limits and geochemical results are presented by the respective analytical methods in Appendices IV, V and VI. Sample location data (easting and northing) are provided with the geochemical results so that data can easily be imported in a GIS software.

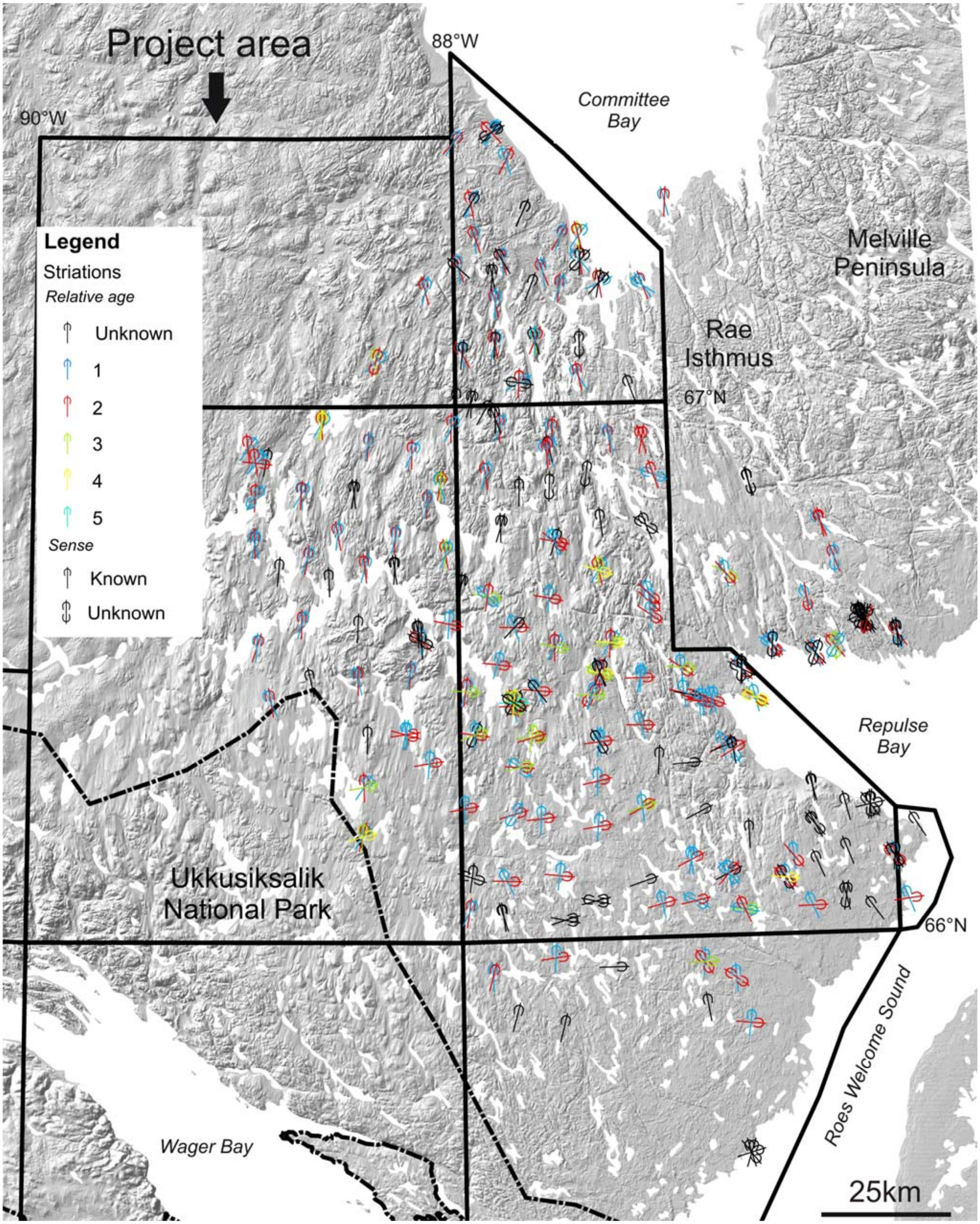

Figure 8. Erosional ice-flow indicator map showing trends and relative ages at each site (1=oldest). Detailed field description and location of the ice-flow indicators are given in Appendix II.

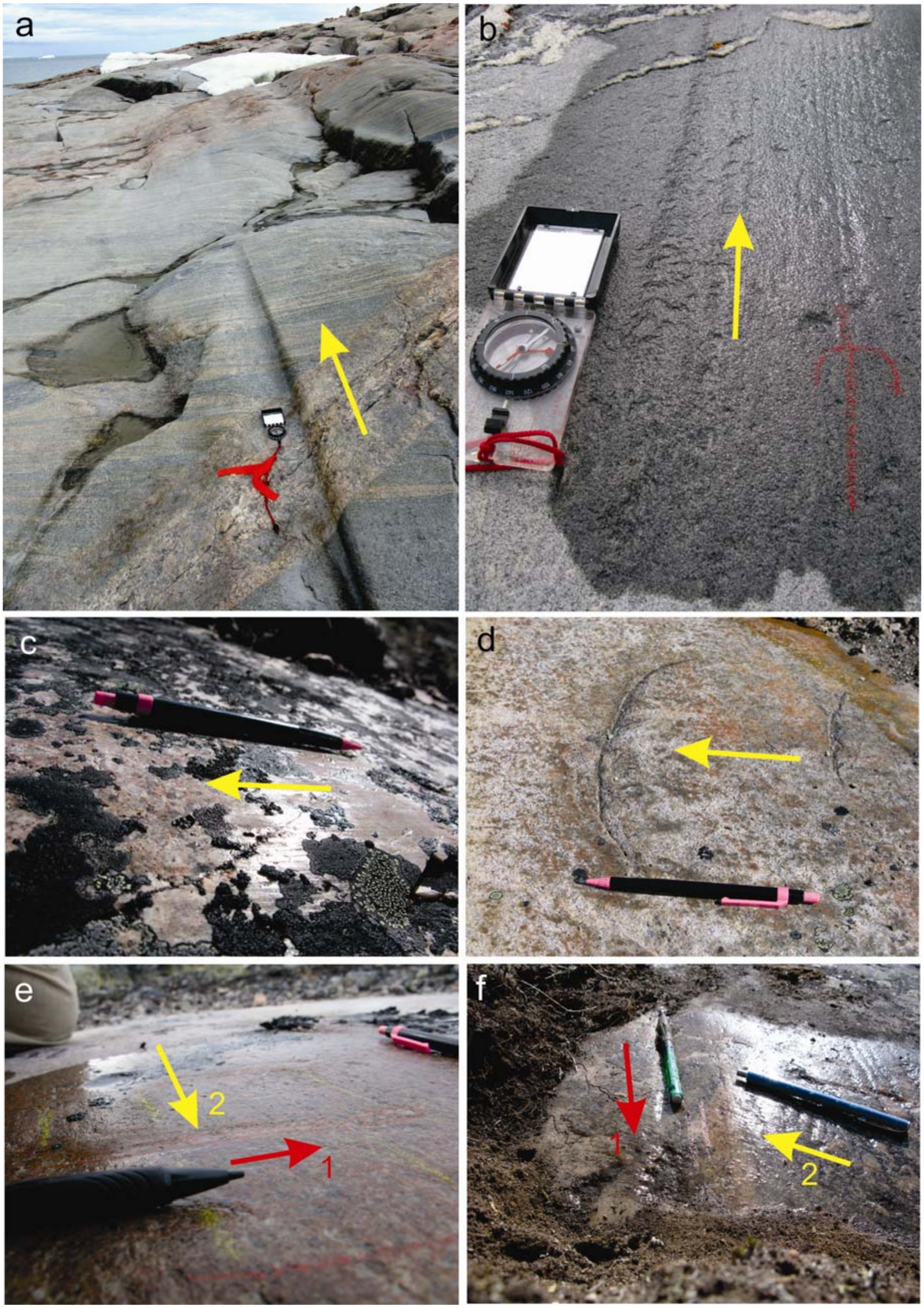

Figure 9. Photographs of various ice-flow indicators: a) straight groove; b) crescentic gouges and deep striae; c) microstriae; d) crescentic gouges; e) and f) northward deep striae cross-cut by fine eastward and southeastward striae. Arrows indicate sense of flow with relative ages where determined.

Figure 10. Photographs of a) typical frost boil from which till samples are collected; b) sample hand-dug pit in a frost boil.

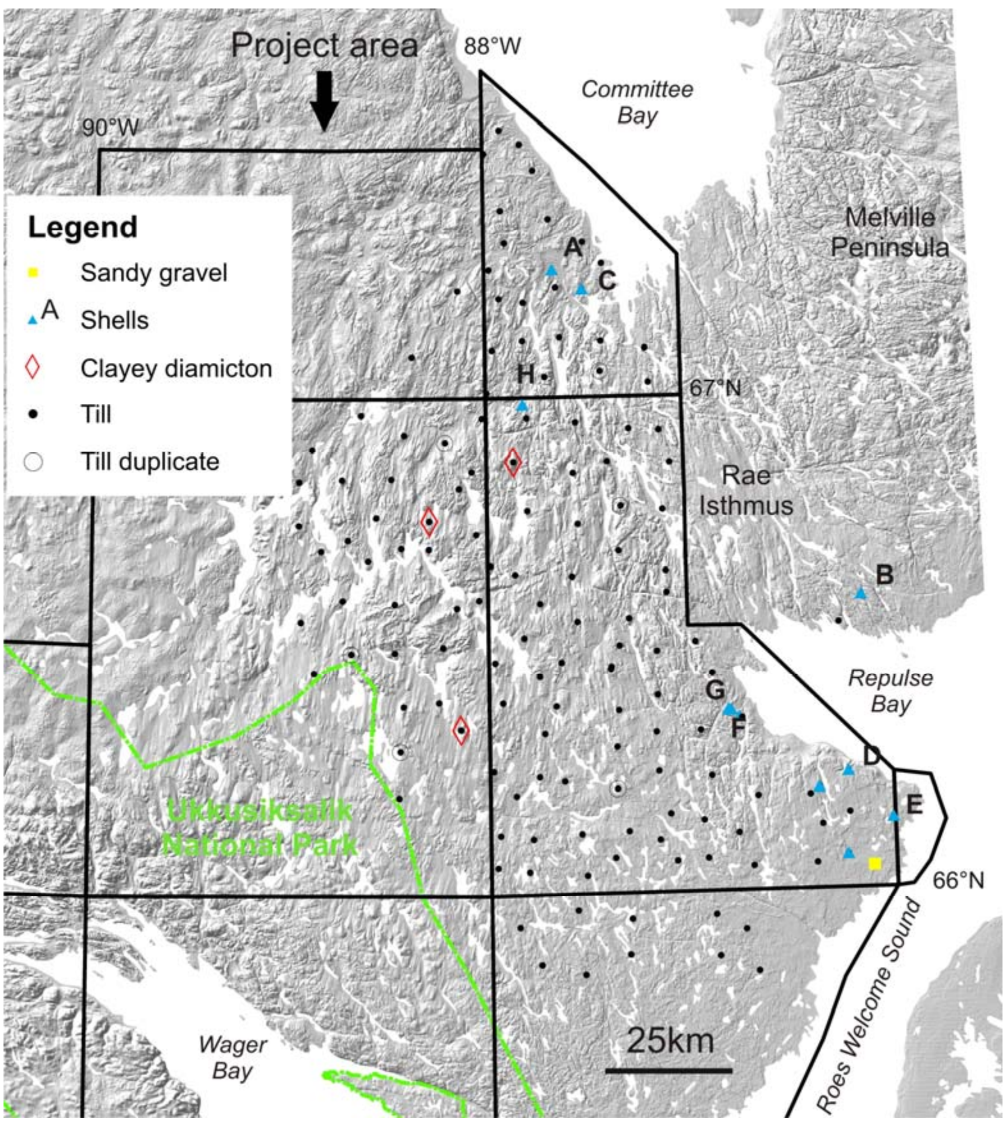

Figure 11. Sample location map. Letters for shell samples refer to ^{14}C age determinations (see Table 1). Detailed description and location of the samples are given in Appendix III.

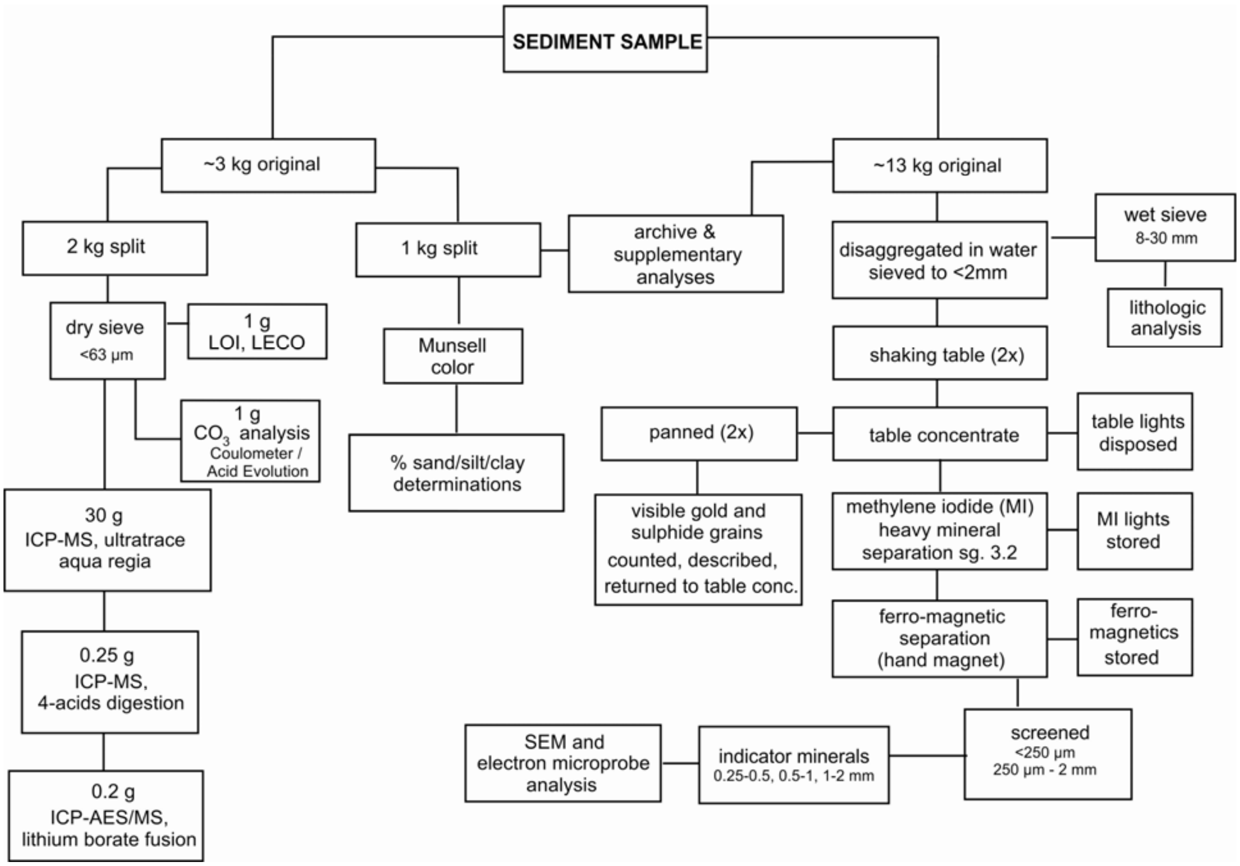

Figure 12. Generalized flow sheet showing steps in till sample processing.

QA/QC analysis of geochemical determinations

Reliability (accuracy or 'trueness', and precision) of analytical data returned from commercial laboratories was determined by including analytical ('blind') duplicates, primary standards and silica blanks within the sample suite submitted to the analytical laboratory. Analytical duplicates were prepared from the field duplicate samples in the laboratory after sieving and were labelled with the same sample code as the sample from which they are derived except for one letter (e.g. 11MOB-C018A02 and 11MOB-C018B02). To monitor potential cross-contamination during the sieving process and to purge the sieves, silicic acid blanks were sieved at the beginning of each block of about 20 samples and sent for analysis. Field duplicates were submitted to provide a measure of the variance due to sediment heterogeneity within a site versus between sites. The QA/QC statistics and plots discussed below are included in the respective appendices for the geochemical results.

<u>Precision</u>

Analysis of analytical duplicate samples is used to monitor analytical precision of the geochemical results. In every analytical batch (2010 and 2011), one analytical duplicate was inserted at the beginning of each block of 20 samples. The results for the laboratory duplicate samples indicate that the analytical precision is good to very good for many elements analyzed by ICP-MS after an aqua regia digestion (Relative standard deviation: RSD≤10%). This method is somewhat less precise for Er, Gd, Hf, K, Lu, Mg, Na, Nb, Ni, Rb, Sc, Sn, and Tm (RSD=10-20%), and even less so (RSD>20%) for Ag, and

Mo in 2011. As, Au, B, Be, Bi, Cd, Ge, Hg, In, Pd, Pt, Re, S, Sb, Se, Ta, Te, W and Yb levels are near or below the lower detection limit in laboratory duplicates, therefore the precision cannot be properly evaluated. For the 4-acid digestion ICP-MS analyses, laboratory duplicates indicate that the analytical precision is very good to excellent for most elements, but less precise in 2010 for Ho and Li (RSD=10-15%) and in 2011 for Cd, Cr, Cs, Cu, Dy, K, Mo and Rb (RSD=10-34%). This method is consistently not precise for Ag and As (RSD=24-60%). Au, Be, Bi, In, Lu, Re, S, Sb, Se, Tm and W levels in laboratory duplicates are near or below the detection limit for this method, therefore the precision cannot be properly evaluated for these elements. For lithium metaborate/tetraborate fusion and dilute nitric digestion ICP-ES/MS analyses, reproducibility is good for most elements (RSD<10%). This method is somewhat less precise for Co, P_2O_5 (2010), Nb (2011), Ta (2010), Yb (2011) and Zn (RSD=10-20%), and not very reliable for Cu, Pb (2010) or V (RSD>20%). Precision improved significantly for Pb in 2011 (RSD=11.5%). Precision for Be, Cs, Cr_2O_3, MnO, Mo, Ni, Sn, W cannot be properly evaluated since the results of the laboratory duplicate analysis are below or close to the lower detection limit. Carbon and sulphur by Leco are reproducible (RSD<10%).

Accuracy

Analysis of primary standards were used to monitor analytical accuracy of the geochemical results. In every analytical batch (2010 and 2011), one standard was inserted randomly within each block of 20 samples (CANMET Standard Till 4). The accuracy in the ICP-MS analysis by aqua regia digestion is good for most elements as results are generally within 10% of the mean of values from the provisional or informational analysis available for Till 4. Values above 10% of the mean are shown in red in the QA/QC report Till 4 sheets. Ag and As, and particularly Hg, are less accurate using this method. The accuracy in the ICP-MS analysis by 4-acid digestion is generally acceptable except for Ag, Ba, Cd, Hf, Rb which are less accurate, mainly in the 2011 batch. Major elements are also irregularly less accurate in the 2011 batch. The accuracy in the analysis by lithium metaborate/tetraborate fusion and dilute nitric digestion is generally good for most elements except for Er (2010), Pb and Sr. Results of silica blanks are low for all elements using all methods.

Analysis of variance

The variability of geochemical data between survey sites must exceed sediment heterogeneity (or heterogeneity at sampling site) and analytical variability in order to generate meaningful maps of element concentrations in sample media (Garrett, 1969, 1983). An estimate of the variance components, i.e. how much of the total variability is 'between' and 'within' the duplicate measurements, is determined using geochemical data from field duplicate pairs and the 'anova' function in the 'rgr' package running under the R system (Garrett, 2013). This random effects ANOVA (analysis of variance) model estimates whether the combined sampling and analytical variability between duplicate pairs is significantly smaller than the variability between the till sites where the duplicates were collected. The variance ratio, F, is calculated in 'anova' to gauge whether the variance 'within' is significantly smaller than the variation 'between'. As a 'rule of thumb' this ratio should exceed 4.0 for sampling and analytical errors to be significantly smaller at the 95% confidence level. The p-value is a measure of the exact level of confidence in the results. Generally an acceptable p-value is less than 0.05 (>95th percentile), i.e. there is a <5% probability the observed F ratio could have occurred due to chance alone. Results of the analysis of variance (ANOVA tab) are presented in each Appendix reporting geochemical results.

The variability ‘between’ sites for a majority of the 65 elements determined in six field duplicate pairs by an aqua regia digestion followed by ICP-MS analysis exceeds variability introduced by sampling and analytical procedures (Appendix IV). All values returned for nine elements (Pd, Ta, Re, Pt, Hg, In, S, Ge, Sb) were below detection limit and their variability could not be estimated. An additional five elements (Te, B, Be, Se, W) returned values at or just above detection levels, and their sampling and analytical variability was not significantly lower than between site variability at the 95% confidence level. Other elements with confidence levels below 95% include Ti, Al, Na, K, Mg, La, Cu, Ag, Ba and Sc. Data for these elements are not suitable for mapping purposes.

The variability between sites for a majority of the 55 elements determined in five field duplicate pairs by a 4-acid digestion followed by ICP-MS analysis (Appendix V) exceeds variability introduced by sampling and analytical variability and can thus be reasonably expected to result in reliable maps. All values for Au, S and Sb were below detection limits and variability could not be estimated. Insufficient data were available for Re, Tl, Se, and Te to estimate variability. Elements with values at or just above detection limits include W, Be and Lu. Other elements not suitable for mapping purposes are Ag, Gd and Eu.

Variability of a majority of the 51 elements and oxides determined in five field duplicate pairs by lithium borate fusion-ICP-MS/ES analysis (Appendix VI) exceeds variability introduced by sampling and analytical variability and thus can be used to produce reliable maps. Values for Ni, Mo, W and total sulphur were below laboratory lower detection limits and variability was not estimated. Values for two elements, Sn and Be, were at or just above detection limits and their sampling and analytical variability was not significantly lower than between site variability at the 95% confidence level. The remaining data with a confidence level below 95% include Cu, Zn, Nb, LOI, P_2O_5, Cs and Sc. Data for these elements are not suitable for mapping purposes.

Matrix color and texture

Munsell Color codes were determined on dry samples at the GSC Sedimentology Laboratory using a spectrophotometer. For textural analysis of the matrix, approximately 200-300 g from each 3-kg till sample was dry-sieved to obtain the <2 mm (-10 mesh) fraction of the samples. The size classes greater than 0.063 mm are determined using wet sieving followed by dynamic digital image processing using a CAMSIZER Particle Size Analysis System. The classes of sizes smaller than 0.063 mm were determined using a Lecotrac LT-100 Particle Size Analyser. The results of the matrix colour and textural determinations for the >2 mm size fraction, sand (2-0.063 mm), silt (0.063-0.002 mm) and clay (<0.002 mm) are presented in Appendix VII.

Matrix carbon and carbonate contents

Inorganic carbon was determined with a LECO CR-412 Carbon Analyzer instrument on the <0.063 mm fraction of all till samples (1350°C). A small portion of the same fraction of all the 2011 samples and of the two samples from 2010 that had inorganic C > 0% were analyzed for loss-on-ignition (LOI), an approximation of total organic content. Results for LOI are expressed as % weight loss of the dry weight after heating a small portion at 500°C for one hour (Girard et al. 2004). About 1 g of the <0.063 mm fraction of samples was analyzed for carbonate mineralogy using the CM 5014 Coulometer/Acid Evolution Method at the GSC Sedimentology Laboratory (Girard et al., 2004). Total CO_2 was not determined when inorganic C analyzed by LECO was <0.1%. Calcite and Dolomite were not determined when total CO_2 was < 0.05%. Laboratory duplicates and in-house standards were also inserted for the till matrix carbon and carbonate analysis. All results for the inorganic C, LOI and carbonate analysis are given in Appendices VIII and IX.

Clast lithology

The >2.0 mm material from the large till samples (~13 kg) was wet-sieved to separate the 8-30 mm fraction for lithological analysis. For comparison with results from surrounding surveys (TGI-1 Committee Bay and Wager Bay Project - NTS 56G), the 4-8 mm fraction was also prepared on a few samples collected in 2010. Since the results between the 4-8 mm and 8-30 mm fractions were comparable, only the 8-30 mm fraction was examined in 2011. Pebbles were visually examined using a binocular microscope (maximum 200 clasts) by Consorminex Inc. and by Ariane Castagner (Ottawa U.). Pebbles were grouped into the following lithological classes: 1) Paleozoic (dolomitic limestones mainly, minor sandstones); 2) intrusives (granitoids and granite gneisses); 3) supracrustals (metasediments and metavolcanics); 4) mafic and ultramafic volcanics; and 5) any other distinctive lithologies. Results presented in Appendix X include the number of clasts and the percentage (%) of the total in each category. High resolution scanned images of the classified pebbles in each sample are provided in this appendix for future reference.

Heavy mineral processing

The large till samples (~13 kg) were processed at Overburden Drilling Management Ltd. (ODM), Ottawa for recovery of the heavy mineral fraction and indicator mineral counting, including gold grains. No special order was followed for the processing of the samples as the potential for mineralization was unknown in the area. Figure 12 provides a flow sheet which outlines the sample processing for indicator minerals. Samples were disaggregated and sieved to obtain the <2 mm (matrix) fraction, and then, processed using a double-run across a shaking table to ensure a complete recovery of all indicator minerals. The table pre-concentrate was then panned to recover any gold, sulphide and platinum group minerals. After tabling and panning, the pre-concentrate was further refined using heavy liquid (methylene iodide - SG 3.2) and ferromagnetic (FM) separations. The <2 mm non-ferromagnetic (NFM)-heavy mineral concentrates (HMC) of till samples were screened at 0.25 mm. The 0.25-2 mm fraction was used for indicator mineral picking. The total number of gold grains recovered, the weights of table feed, table pre-concentrates, NFM- and FM- HMCs are presented in Appendix XI.

Blank samples consisting of weathered Silurian-Devonian granite (grus) (Plouffe et al., in press) were inserted at the beginning and through the sample batches to monitor potential cross-contamination introduced during heavy mineral separation. No sulphides nor platinum group minerals were found in those samples during the panning except for one single grain of pyrite found at the end of the batch in 2011. No KIMs nor MMSIMs were found in the blanks. Results of gold grain counts are reproducible for the field duplicates collected in 2010 and 2011. Field duplicates collected in 2011 returned comparable KIMs and MMSIMs grain counts while within site variability was more important in the two field duplicate samples collected in 2010, specially for olivine (18 grains versus 0, and versus 5). The variability of the indicator mineral content between the two duplicate samples collected in 2010 reflects a combination of sediment heterogeneity and the precision of the mineral separation and identification method. All picking results for the blank and field duplicate samples are reported in Appendix XI.

Indicator mineral identification and picking

Prior to indicator mineral identification and picking, the 0.25-2 mm NFM-HMCs recovered from till samples were sieved to 0.25-0.5 mm, 0.5-1 mm and 1-2 mm. The 0.25-0.5 mm fraction of the samples was further refined using a Carpco® electromagnetic separator to produce fractions with different paramagnetic characteristics to help reduce the volume of concentrate to be visually examined (Averill and Huneault, 2006). All fractions were examined under a stereoscopic microscope at ODM to determine the abundance of potential kimberlite indicator minerals (KIM) and metamorphosed or magmatic massive sulphide indicator minerals (MMSIM®). For each sample, the complete concentrate was examined. ODM performed checks on selected grains using SEM-energy dispersive x-ray spectrometer (EDS) to confirm mineral identification. Selected grains considered having possible KIM and MMSIM affinities were mounted for further study. Because of their high abundance in some samples, only a few representative grains of certain mineral species were picked for further study (i.e. forsterite, fluorite). Appendix XI includes all raw grain counts from the visual identification of possible indicator minerals for the 0.25-2 mm NFM-HMCs.

Electron microprobe analysis

Selected visually identified indicator minerals and some background grains (total of 301 grains from 2010 and 848 grains from 2011) were mounted on 25-mm epoxy-impregnated stubs at SGS Mineral Services, Lakefield, ON (2010 samples) and at Geoscience Laboratories, Sudbury, ON (2011 samples). All mounted grains from the 2010 samples were analyzed to confirm their identity and quantify their chemical composition at Geoscience Laboratories using a CAMECA SX-100 Electron Probe Micro Analyzer (EPMA). The 2011 microprobe results are still pending and will be released with the 2012 sample results. Major elements were analyzed under normal operating conditions (20 kV and 20 nA), whereas minor/trace element analyses were carried out using a higher beam current (20 kV and 200 nA) and, where possible large surface area crystals (LLIF and LPET) were employed, to improve the limits of detection. Quality control data including standards, analyzing crystals, counting times, operation voltage, beam current, limits of detection, and limits of quantifications are given in Appendix XII. The analyzed grains were classified (or re-classified when necessary) by Dave Crabtree (Geoscience Laboratories) on the basis of their chemical composition. The final mineral classification and chemistry results for the 0.25-2 mm NFM-HMC are provided in Appendix XII. In appendix XII, “Picked I.D.” refers to the visual mineral identification and “Mineral classification” to the identification based on EPMA analysis provided by the Geoscience Laboratories.

SUMMARY

This Open File report releases the field database and analytical results from the 2010 and 2011 field seasons of the GEM Wager Bay Surficial Geology Activity. The datasets are presented in a format easily importable in a geographic information system (GIS). Quaternary field observations were recorded at 282 field stations; 187 of these included ice-flow indicator measurements. Observations reported for each station include date of collection, location (lat-long and easting-northing, NTS), elevation, observation type, surficial mapping legend unit, landform interpretation and detailed field notes. Ice-flow indicator observations provide information on azimuth, feature type, sense of flow, definition, relative age and relation type (where determined), number of indicators and field notes.

Regional surface till samples were collected at 140 of the field observation sites (average 10 km spacing) primarily for both geochemical and indicator mineral analysis. The exceptions were; samples consisting of clayey diamictic layers were collected at three of these sites for only geochemical determination; one beach sample was collected for indicator minerals; and marine mollusk shell samples were collected at 8 sites for radiocarbon age determination. Sample information include location, lithotype, sample depth, soil horizon, purpose and sample size, oxidation state, field colour, matrix and matrix modifier, compaction, water content, HCl reaction, clast %, clast notes, clast roundness, sorting, and additional field notes.

Analytical results include till matrix texture and colour, matrix carbon and carbonate contents, pebble count analysis, as well as till matrix geochemistry performed on the <0.063 mm fraction using ICP-MS aqua regia digestion, ICP-MS 4-acid digestion, and ICP-ES/MS lithium borate fusion. Till matrix geochemistry QA/QC analysis was determined using field and analytical duplicates as well as control reference samples (silica blanks and primary standards). The analytical and QA/QC procedures follow the protocols for till samples collected as part of GEM projects (Spirito et al., 2011). Analytical precision indicates results to be reproducible with precision generally classified as good to very good for most elements in results from both years. Limitations include many elements with values too close or below detection limits in the analytical duplicates. Accuracy analysis shows that results are generally within 10% of the mean standard value available for most elements. Blank sample analyses show minimal contamination between samples. Site heterogeneity in geochemical composition was evaluated using field duplicates. Results indicate minor sediment heterogeneity at the sample site and a good reproducibility. With a few exceptions, the analysis of variance for all three geochemical methods indicates that the combined sampling and analytical variability between field duplicate pairs is significantly smaller than the variability between the till sites where the duplicates were collected. This indicates that most elements are suitable for mapping purposes.

Heavy mineral processing, precious metal grain counts and indicator mineral picking of potential KIM and MMSIM affinities were completed for each till sample. Contamination, grain carryover, reproducibility and site heterogeneity were evaluated using blanks and field duplicates. Results indicate minor sediment heterogeneity at the sample site and a good reproducibility. Picked grain composition of 301 grains from 2010 was determined using electron microprobe through single point per grain analysis. The 2011 microprobe results as well as the field datasets and analytical results from the 2012 field season will be compiled in a forthcoming second Open File report which will provide an interpretation of till provenance and glacial history, and discuss implications for mineral exploration and land-use management for the entire area north of Wager Bay.

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