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**Glacial geomorphology and till geochemistry of southern Melville
Peninsula, Nunavut**

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Abstract

This report presents results from field work on southern Melville Peninsula during 2010, part of Geo-Mapping for Energy & Minerals (GEM) Multiple-metals - Melville Peninsula Geoscience Project. Along the coast of the peninsula, ice flow was warm-based and seaward during late-glacial and deglacial time. Across the Rae Isthmus, ice flow was northward and reversed to the south along the southern coast during deglacial time. Ice-flow history and glacial geomorphology show that on the central part of Southern Melville, some cold-based regions persisted during the last glaciation, and elsewhere the glacial regime was permanently or intermittently warm-based during that period. Complementing extensive pre-existing research, a focused drift sampling survey was conducted to assist mineral exploration in regions underlain by prospective bedrock but mantled by glacial deposits of varying thickness. The silt-sized till matrix geochemistry, the heavy mineral concentrates from till mineralogy and mineralized erratic boulders were analyzed for base metals, gold, uranium, gemstone and diamond potential.

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The annexes are in the folder attached to this report. See the metadata file for a list of all the files

contained in the annexes.

Annex A Sample description

Annex B Petrological counts

Annex C Geochemistry

Annex D Heavy mineral content

Annex E Granulometry

Annex F Carbonate content

Introduction

In 2010, the Geological Survey of Canada (GSC) and the Canada-Nunavut Geoscience Office continued Quaternary fieldwork on southern Melville Peninsula as part of the Geo-Mapping for Energy & Minerals (GEM) Melville Peninsula Geoscience Project. Results from Quaternary geology field work conducted in 2009 on central Melville Peninsula were published as GSC Open File 7115 (Tremblay and Paulen, 2012). Quaternary research conducted on southern Melville Peninsula examined in detail the regional and local scale glacial-flow indicators. Reconstructing past glacial trajectories is fundamental for mineral exploration by drift prospecting, as it provides knowledge of former ice flow directions and mineral dispersal parameters of former Pleistocene glaciers. These flow directions are indicated by a variety of erosional and depositional landforms. Attention to the dynamic nature of glacial dispersal centres and related ice-flow history is increasingly important for mineral exploration in northern Canada. Recognition of relict landscapes preserved under ice-divides and cold-based ice terrain can provide further framework for understanding glacial dispersal trains from mineralized bedrock sources, and consequently, this has important implications for interpretation of regional surveys and mineral exploration.

The objective of this work was to augment the considerable amount of existing knowledge on the regional glacial history and surficial geochemistry (Dredge, 1995, 2001, 2002; Day, et al., 2009) with detailed observations, particularly in regions of high mineral potential, to better understand the complex ice-movement chronology. The intent is to provide an enhanced framework for interpreting glacial dispersal of mineralized debris, following data and interpretation already presented at the Nunavut mining symposium (Tremblay and Corrigan, 2011). The 2009 and 2010 field seasons were preceded by analysis of archived till samples from the northern half of Melville Peninsula (Dredge, 2009), as well as re-analysis of approximately 2,200 archived lake sediment samples (Cameron, 1979, Day, et al., 2009) from the central part of the peninsula, using modern analytical techniques.

Location and Geologic Setting

Melville Peninsula is located on the Arctic mainland west of the Foxe Basin, Nunavut (Figure 1). In the central part of this peninsula, the upland areas range from moderate relief (up to 521 m asl in the Prince Albert Hills; Figure 2) in the west to rolling and undulating terrain (200-300 m asl) in the east and south (Hurd Plateau). Rae Isthmus is a low-lying (<100 m asl) area between Committee Bay and Repulse Bay. Numerous rivers are draining the interior of Melville Peninsula, including Aua, Barrow and Wilson rivers (the later was named after Cape Wilson, located to to the river's mouth, for the purpose of this study). The region is affected by continuous permafrost, with active cryoturbation in the glacial sediments. Vegetation at this latitude is typical of mid-arctic tundra, with low shrubs (dwarf willow), grasses and rare presence of arctic ferns. On the plateaus, the vegetation cover is sparse, with only lichen growing on boulders. The Barrow River and Aua River valleys are covered with grass and caribou are frequently observed. The south coast is pristine and populated with numerous marine bird colonies, polar bears, narwhals, belugas, killer whales and seals.

The main part of the peninsula is composed of Precambrian rocks of different ages (Figure 3), metamorphosed to amphibolite facies (Heywood, 1966; Frisch, 1982; Schau, 1993). The Archean Prince Albert Group consists of metavolcanic rocks, ultramafic rocks, gabbros and banded iron formations; and outcrop along small belts, especially around Committee Bay and north of Barrow River. Banded iron formations and ultramafic rocks occur within the belts, and represent economic potential for iron and nickel, in the Prince Albert Hills (Houlé, et al., 2012). The granite and gneiss of the Rae Group and Repulse Bay block (Schau, 1993; Corrigan et al., 2009; LaFlamme et al., 2014) are found throughout the central plateau and contain sparse amphibolites and ultramafic rocks rafts. South of study area, the Paleoproterozoic Penrhyn Group consist of an important metasedimentary belt comprising marbles and various clastic metasediments. The lower member of the Penrhyn Group is particularly rich in marbles and graphite-sulfide-biotite paragneiss, compared to the upper member (Henderson, 1983; Corrigan et al., 2009; Partin et al., 2014). A few unmetamorphosed intrusive bodies (e.g., diabase)

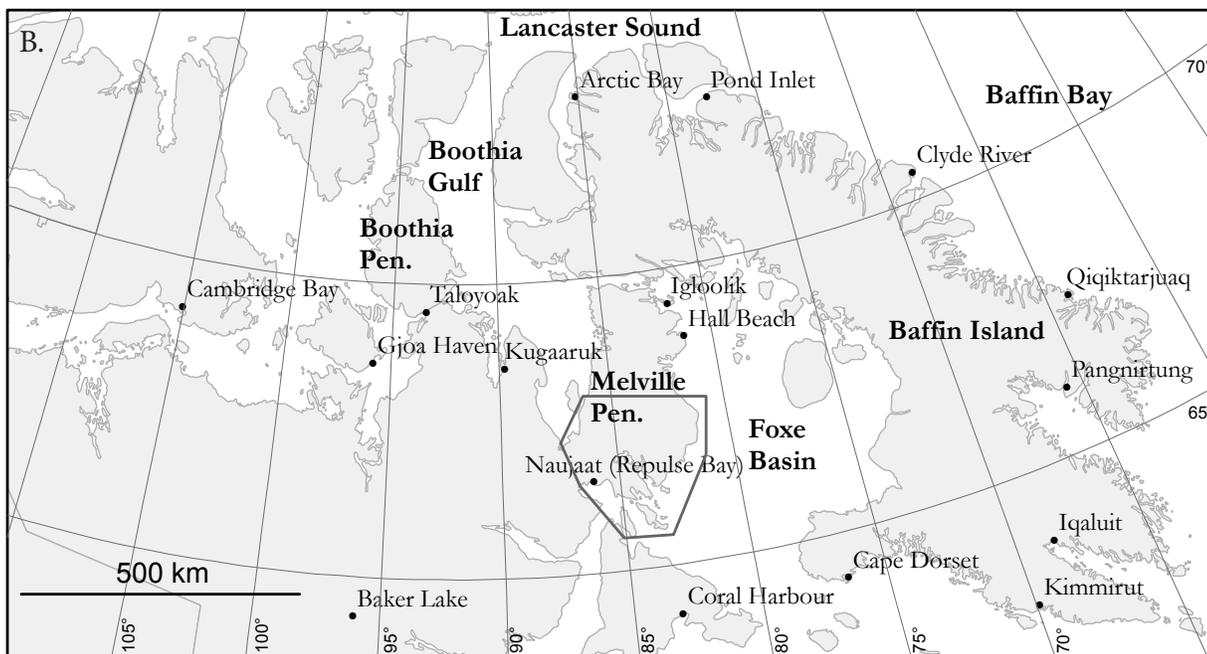
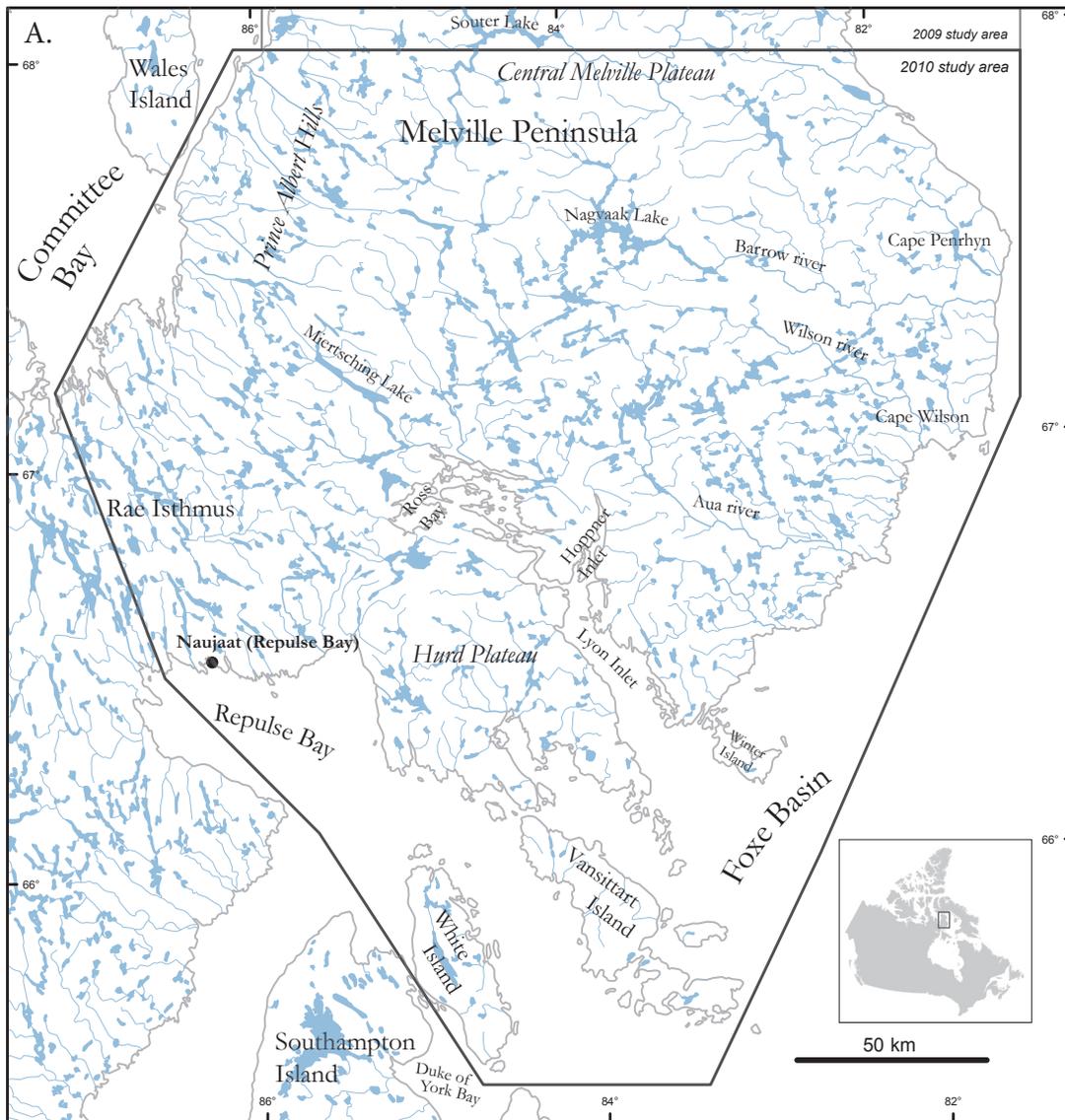


Figure 1. Location maps, with study area outlined in black; A. Southern Melville Peninsula and Canada inset map; B. Central Nunavut Territory.

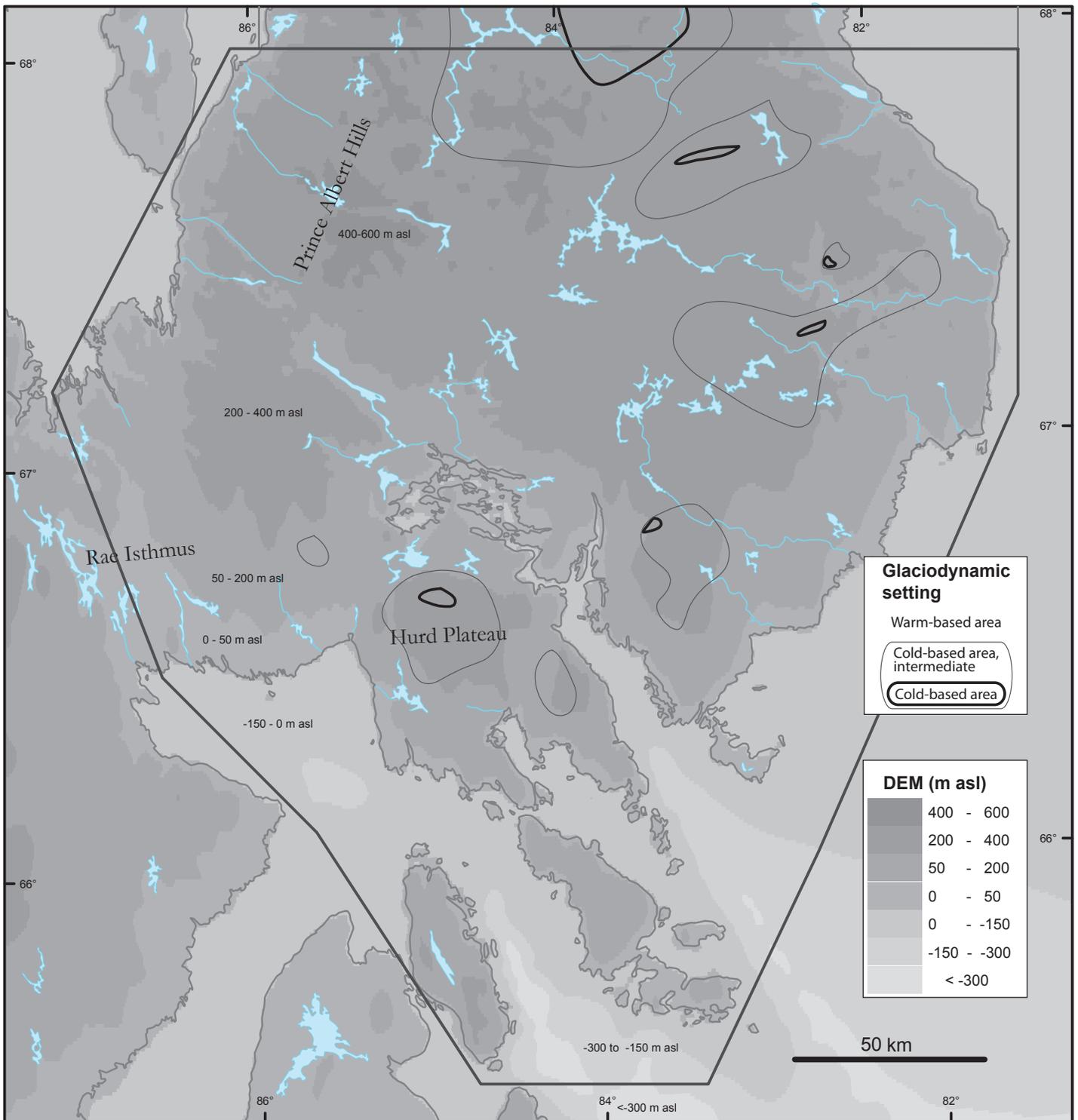


Figure 2. Digital elevation model (DEM, source : National Topographical System 1 : 250 000) and terrain types for southern Melville Peninsula.

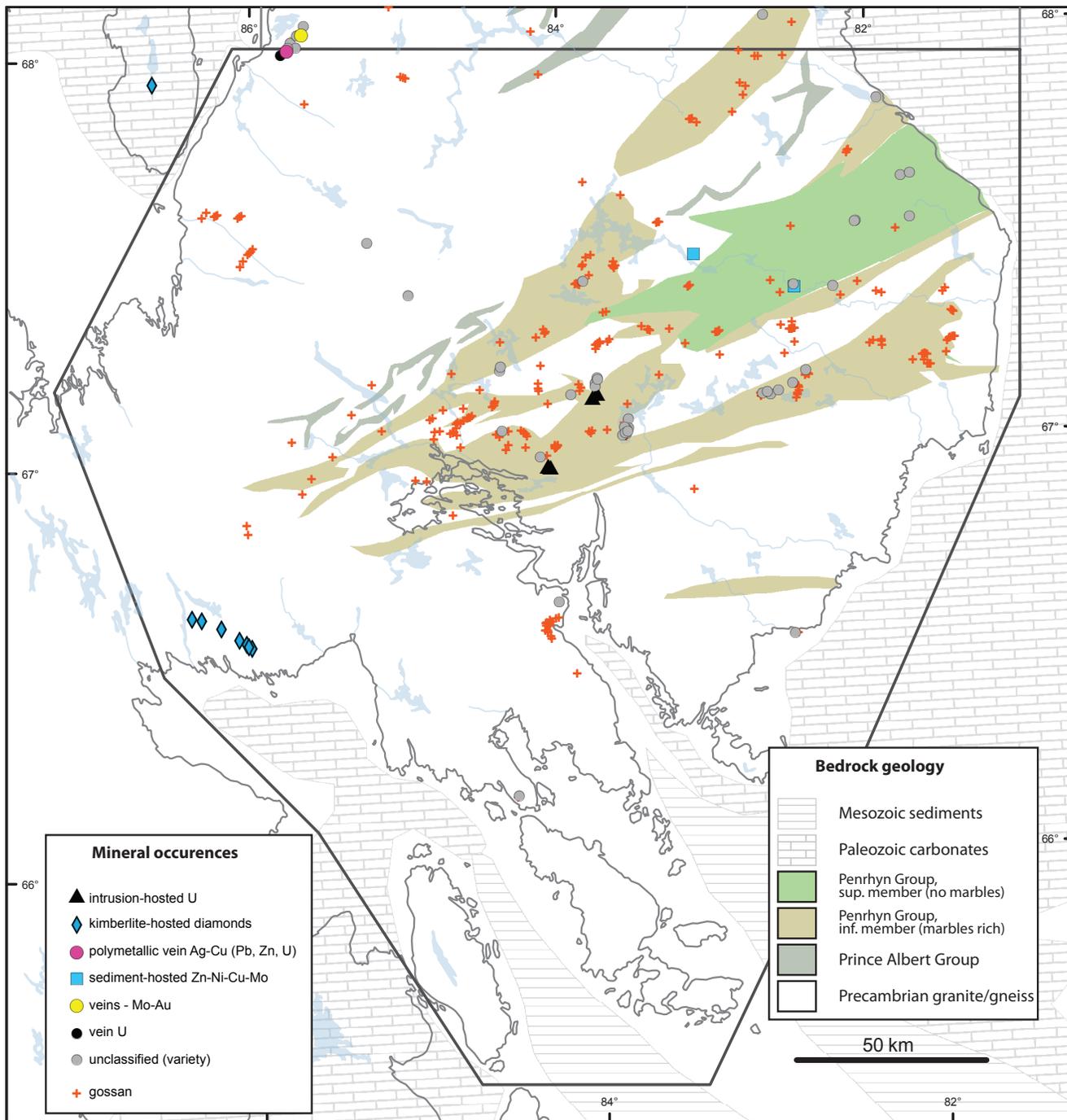


Figure 3. Geological map for southern Melville Peninsula (modified from Schau, 1993; Corrigan, pers comm.). Source of mineral occurrences on NUMIN (2009), and gossans from Dredge (2002).

cross-cut the plateau. In the Repulse Bay area, kimberlites intruded the basement rocks (Armstrong, 2009). The surrounding marine water bodies are underlain with sub-horizontal Paleozoic carbonates from the Arctic platform, principally dolomitic in composition, and younger sediments cover (Mesozoic and Cenozoic; Schau, 1993).

Numerous base and precious polymetallic anomalies and showings are reported in the central Penrhyn Group belt, notably Ni, Zn, U, Ag and Au (Figure 3; Henderson, 1983; NUMIN, 2009; Corrigan, et al., 2010; Houlé et al., 2012). Occurrences of massive sulfides are common, and they form an important series of gossans. Some of these gossans are hundreds of meters in length. Sulfide minerals consist of mostly pyrite, with some occasional chalcopyrite and arsenopyrite. The gossans are rimmed with metamorphosed hydrothermal alteration minerals, and may be considered as SEDEX types mineralization (Corrigan et al., 2010). Mineralized zones within the graphite-sulfides paragneiss contain sphalerite and pyrrhotite (Henderson, 1983), and are associated with Zn, Ni, Au, Cu and other elements in the till (Dredge, 2002) and lake sediments (Day, 2009). Maurice (1979) noted the presence of elevated uranium values in lake sediments, and found the anomaly to be associated with uranium in granitic plutons.

Previous Work

Glacial history was first proposed for the Melville Peninsula by Sim (1962) and the drift dispersal and ice flow around the Foxe Basin was examined by Andrews and Sim (1964). Subsequent regional surficial geology maps and accompanying reports on ice-flow history and glacial dispersion (Dreger, 1989; Dredge and Nixon, 1993; Dredge, 1995; Dredge, 2000a, 2000b, 2001, 2002; Tremblay and Paulen, 2012) provide insight into the nature and sequence of complex glacial and deglacial history of Melville Peninsula. Melville Peninsula is situated immediately north of the ice divide “saddle” between the former Keewatin Ice Divide and Foxe Dome of the Laurentide Ice Sheet (Ives and Andrews, 1963; Dyke and Prest, 1987). The study area was affected by glacial flow from an ice dome centred in the Foxe Basin during the Last Glacial Maximum (LGM). Previous regional mapping in the

area showed a number of erosional ice-movement features and streamlined glacial landforms (Dredge, 2002; De Angelis, 2007). The marine maximum limit typically ranges from 140 to 170 m asl around the peninsula, with the exception of the area north of Lyon Inlet where the marine invasion is around 100 m asl (Dredge, 2002). Glacial ice accumulation on Melville Peninsula was defined as “Melville Ice” (Dredge, 1995), with ice centres at times independent of the Foxe Basin ice centre. Sharp contrasts in glacial erosion led to discovery of paleo-ice streaming and warm-based areas on carbonate till terrains, and cold-based, weakly glacially eroded areas in the core of the bouldery, weathered “regotill” area in the center of the peninsula (Dredge, 2001). Recent interpretation of satellite imagery to map streamlined landforms (De Angelis and Kleman, 2005; De Angelis, 2007; De Angelis and Kleman, 2007, 2008) and topographically-controlled paleo-ice streams (cf., Ross et al., 2010) has brought attention to the dynamics and glacial interaction between cold-based terrain and streamlined glacial terrain around and over Melville Peninsula. Recent work on Rae Isthmus (McMartin et al., 2013; Wityk et al., 2013) has presented an ice flow reversal, and a late-glacial ice flow convergence toward Repulse Bay.

Field Methodology

Field work was focused on ice flow history, geomorphological mapping, and till sampling. Assessment of ice-flow history was carried out and confirmed on the basis of the widest possible range of evidence, from drumlins, flutings and other streamlined landforms to striations, outcrop sculpting and other erosional ice-flow indicators, and glacial dispersal patterns. Landform mapping also encompassed the examination of large subglacial bedforms such as drumlins and flutings from aerial photographs and satellite imagery (Figure 4; Landsat 7 images with bands 1 [blue], 3 [red] and 4 [near-infrared]). Superimposed streamlined landforms were examined and are interpreted to be the result of changes in ice-flow directions, concomitant with adjustments to the overall shape and dynamics of the former ice sheet. Elongated and parallel lineaments observed easily from satellite images were named “glacial lineations”. In detail, they have been observed on the field and on satellite images

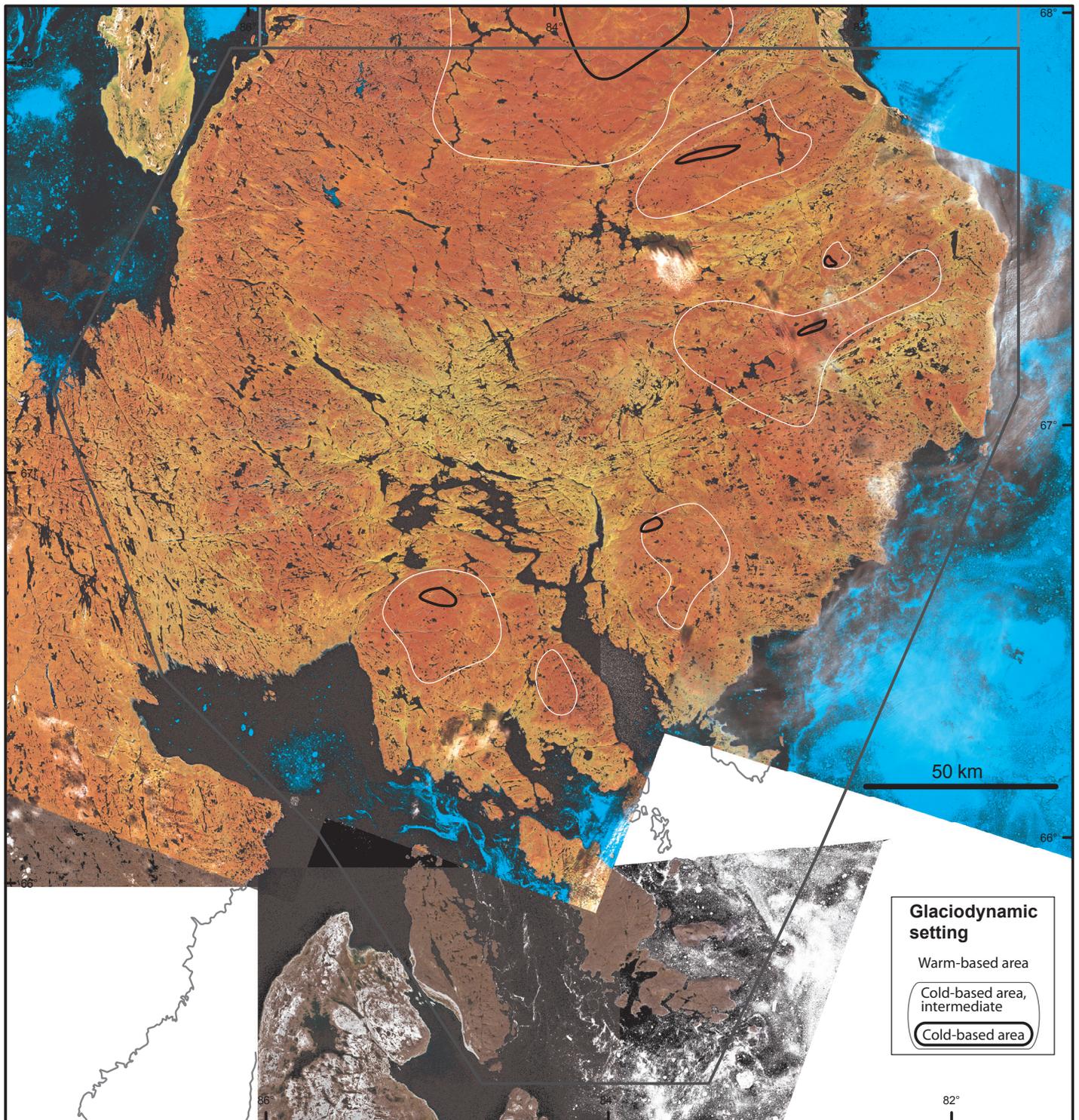


Figure 4. Satellite image (source: Landsat 7, 30 m resolution) and terrain types of southern Melville Peninsula, highlighting zones of cold-based glaciation.

and airphotos, and on the field are marked by lateral differences in till types, granulometry, geochemistry, mineralogy or thickness. The nomenclature of these glacial macroforms will be the focus of future research papers in this area. Furthermore, the final flow phase indicated by glacial landforms may differ from dominant sediment transport paths (e.g., Clarhall and Jansson 2003, Ross, et al., 2010), therefore evidence from the landforms included detailed striation mapping and dispersal trains studies in till.

Detailed examination of outcrops helped understand the complex ice flow history. To unravel the sequence of events, it was imperative to sort out the sense of ice flow direction and the cross-cutting relationship of striae and faceted outcrop surfaces. Relative ages of striated facets are determined (where possible) by evaluating their relative positions on an outcrop according to the following criteria (Lundqvist, 1990, McMartin and Paulen, 2009):

- a) striae located in a lee-side position relative to another, is usually older;
- b) striae touching the top parts of the outcrop will have been formed by the youngest movement; and,
- c) striae preserved only in depressions and other low positions on the outcrop may be interpreted as being older.

Till samples were collected from the active layer of frost boils (McMartin and Campbell, 2009), at a depth of 10 to 50 cm. Bags with 2 kg of till were sampled for geochemical and sedimentological analysis, and 10 kg for heavy mineral analysis. For sample information, see Annex A. At each sample site, observations were made on pebbles and cobbles within the surface tills to document dispersal of visually distinct lithologies to gain a better understanding of bedrock erosion and subsequent debris comminution, transport and deposition under varying basal ice environments.

Lithological counts on pebbles of 5-15 cm diameter observed in mudboils (see worksheet PETRO_FIELD_TM10 in Petro_10_field and lab.xls in Annex B) were conducted. Because of time limits and the uncertain affiliation of rocks, the lithology of pebbles was confirmed by visual estimates in a

defined area of mudboils. The estimate was visually assessed within 10% for major rock types, and while quite uncertain it is thought to represent the real values with fair accuracy. The lithology categories include Paleozoic carbonates, Prince Albert Group rocks (amphibolites, intermediate to felsic volcanics, ultramafic and banded iron formations), granite and gneiss of the Rae Group, gabbro and Paleoproterozoic Penrhyn Group (marble, coarse-grained metasediments, fine-grained metasediments, quartzite).

Additional lithological countings were performed under binocular in laboratory on 4 - 8 mm gravel from the 10 kg samples (see worksheet PETRO_LAB_TM10 in file Petro_field and lab_CXAT2010.xls, Annex B). They provide larger samples (e.g., n=300 in 100g sub-samples) to support the interpretations (i.e. Annex B, which also includes previously unpublished 2-4 mm pebbles from central Melville Peninsula. The petrographic fractions were individually weighted to provide a percentage relative to the total weight of the sample. The lithology categories include Paleozoic carbonates, Prince Albert Group rocks (amphibolites), granite and gneiss of the Rae Group, gabbro and Paleoproterozoic Penrhyn Group (marble, metasediment, metasediment with graphite). In that small clast-size it can be difficult to distinguish granite/gneiss from metasediments, however graphitic metasediments, amphibolite, marbles and Paleozoic carbonates are easily distinguishable. Thus the 4-8 mm (in laboratory) and 5-15 cm (on the field) petrographical countings are complementary tools to characterize till composition and glacial transport.

Laboratory Methodology

Geochemistry and Sedimentology Sample Preparation

A total of 297 till matrix geochemistry samples (2 kg) were processed at the GSC sedimentology laboratory in Ottawa. A portion of the matrix (< 2 mm) of each sample was wet-sieved to 63 µm for geochemical analysis (Annex C). Analytical accuracy and precision was monitored by including GSC blind CANMET standards in the analytical analysis. Preparation laboratory duplicates of

samples, and ACME Analytical limited laboratories blanks, reference standards and analytical duplicates, were analyzed. Another <2 mm portion was sent for matrix granulometry and carbonate content analysis. Lastly, a portion was saved for archival purpose.

A total of 102 rusty and/or mineralized boulder samples were sampled during field seasons of 2009 and 2010, in both central and southern Melville Peninsula; the least weathered portions were manually sub-sampled, and then crushed and analysed at ACME laboratories. They generally range from 20 to 200 cm in size, and displays various shapes indicating variable glacial transport.

Geochemical Analysis

A split of each 2 kg sample was dried and sieved at the GSC Sedimentology Laboratory in Ottawa and then submitted to ACME Analytical Laboratories in Vancouver for analysis on the <0.063 mm fraction (till matrix, Annex C). A 30 g split was digested by aqua regia and analyzed by inductively coupled plasma mass spectrometry (ultra-trace ICP-MS, following aqua regia digestion) for 65 elements, including Au, base metals, Pt and rare earth elements.

Quality control and assurance data (QC/QA) are provided along with the results. Duplicates quality control for till samples provide an assessment the precision of the analysis (Annex C, QCQA assessment.xlsx file in till/QCQA folder). The statistical analysis shows that Au have a RSD (relative standard deviation, a measure of the spread of the data within the population) of 65% (probably indicating the presence of silt-sized gold grains, introducing variability in the results), and Se, Sb, Be, Cd and Nb have RSD between 10 and 20% (moderate imprecision within the data). Standard quality control for till samples (Annex C) is a measure of the accuracy of the analysis. The statistical analysis indicates that Au, As, S and W displays occasional important deviation relative to the expected standard value (on one or two samples where error is greater than 25%; expected values are estimated from data compiled at the GSC laboratory by Madore, pers. comm. 2015). The samples are affected by the occasional presence of mineralized grains influencing individual samples (nugget effect). Elements B, Ge, In, Pt, Pd, Re, Ta and Te display high relative error (greater than 25%), but this statistical result is inconclusive because

they have values close to measurement background levels. Isolated results may be considered unreliable to some extent, confidence in the results will increase with increasing amount of samples located within a given area.

The mineralized boulders samples were analyzed after crushing and 4-acid digestion, by inductively coupled plasma emission spectrometry (ICP-ES) for 24 elements on 0.5g splits. Fire assay on 30g splits was conducted mainly to detect the presence of Au. Standard and duplicates analysis were provided by the ACME Analytical Laboratories for the boulders geochemical analysis.

Mineralogical Analysis

A total of 206 bulk samples (~10 kg) were sent to Overburden Drilling Management Limited (ODM, see Figure 5 and Annex D) in Nepean, Ontario, for heavy mineral analysis (cf. McMartin, et al., 2002; McClenaghan et al., 2012). Field sample duplicates and GSC blanks from granite grus were inserted for quality control and quality assurance. Field sample duplicates were sampled from the same location but spaced 5 to 10m apart (10CXAT371 and 10CXAT361, and 10CXAT372 and 10CXAT364 are field duplicates, see appendices B, C and D). GSC blanks are samples from Siluro-Devonian granite grus as described in Plouffe et al. (2013), are sample numbers 10CXAT373 and 10CXAT374 (see appendices B, C and D). The standard pre-analysis treatment was applied to all samples, which includes sieving of pebbles at <2 mm (the 4-8 mm fraction were separated for lithological counting), and subsequent pre-concentration of heavy minerals by shaking table. Native gold, thorianite/uraninite and sperrylite grains were counted from a panning concentrate, described and replaced in the same fraction. One hundred forty-six samples were selected to be processed further into kimberlite indicator minerals (KIMs) and metamorphic massive sulfides indicator minerals (MMSIMs) identification analysis. The heavy mineral pre-concentrate is sieved to 0.25 to 2.0 mm, and then submitted to heavy liquid separation (methylene iodide, specific gravity=3.2) and ferro-magnetic separation. The complete fractions sub-samples were processed, except for 2 large samples where only 50% of the material was processed, however the results are reported as proportionnal

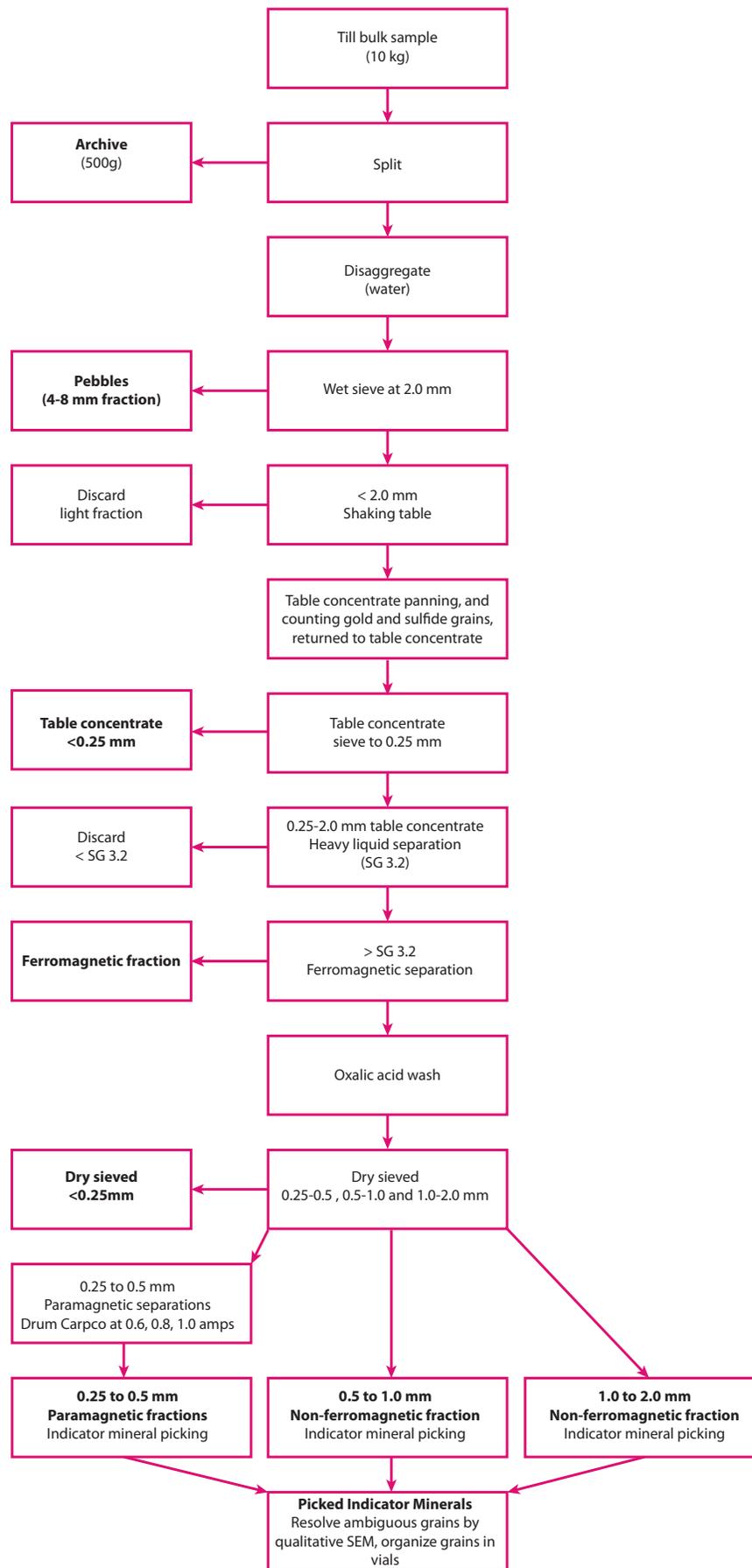


Figure 5. Flow sheet outlining the till sample heavy mineral analysis process at Overburden Drilling Management Limited (adapted from McClenaghan et al., 2012). Bold characters indicate fractions destined for storage and/or analysis.

to the original whole fraction size. The results are reported on three different fractions (0.25-0.5 mm, 0.5-1 mm and 1-2 mm). The 0.25-0.5 mm fraction was divided into distinct paramagnetic separations using a Carpc® magnetic separator at 0.6, 0.8 and 1.0 amps to help picking this fraction. Following further preparation, binocular identifications of MMSIMs and KIMs were undertaken and supported in some case by scanning electron microscope analysis (SEM). On 146 samples, the >0.250 mm fraction of non-ferromagnetic heavy mineral concentrate (NFHMC) was examined by binocular microscope for the identification of various distinctive mineral species, namely, KIMs and MMSIMs which notably include gahnite, red rutile, pyrite, chalcopyrite and arsenopyrite (Averill, 2001).

In addition to the internal laboratory quality control procedure, we have submitted a number of duplicates and blanks within the sample batch. For gold grains, all the duplicates and the blanks returned no grains. The carry-over between the analysis seems to be constantly low. All duplicates and blanks show no KIMs or pseudo-KIMs grains (except 1 Cr-diopse grain for field duplicate 10-CXAT-371; it is a pseudo-KIM). For MMSIMs found in the duplicates, most are detected in both duplicates in similar amounts (thorianite/uraninite, pyrite, goethite, spinel, sillimanite, tourmaline, staurotide, monazite). Very small quantities (most of the time in traces or a few grains) of some minerals were not replicated in both duplicates: low-chrome diopside, apatite, monazite, epidote, chondrotite and red rutile; natural variability might be a factor in explaining this inconstancy. All blanks show no MMSIMs, except traces of sillimanite. In conclusion, the data on blanks and duplicates shows that carry-over between heavy mineral analysis seems to be limited to absent during the process of the samples.

Texture

Till sample granulometry (sand, silt and clay) was determined by use of a laser particle size analyzer in conjunction with sieving or digital image analysis instrumentation (Camsizer & Lecotrac LT100; for 297 samples, in Annex E, including data from 2009 and 2010 field seasons). The results as reported as % of the less than 2 mm fraction. The clay content refers to the < 0.002 mm fraction.

Carbonate content

The total carbonate content and calcite/dolomite ratio were determined by titration with CM 5015 Coulometer / Acid Evolution on the less than 63 µm fraction, on maximum 2 g samples, for 219 samples (Annex F, including data from 2009 and 2010 field seasons). The carbonate content in till matrix data from samples taken on Melville Peninsula (Dredge, 1995, 2002) was used in this paper. For these samples, carbonate content of the matrix was determined using the LECO method on the <63 µm fraction. With the LECO method, carbonate is calculated by carbon loss-on-ignition, and expressed as calcium carbonate equivalent.

Results and interpretations

Glacial Geomorphology

Glacial geomorphology was compiled mainly from previous surficial geology maps (Dredge, 1995; 2002) originally mapped using aerial photographs, field observations and petrographic analysis. The geomorphological features for the study area are mapped (generally representing features to their actual scales) in Figure 6, and photos are presented in Figure 7. Recent regional satellite image analyses and interpretations (De Angelis, 2007) assisted in focusing field observations useful in deciphering various geomorphological features. A number of features depicted in Figure 6 were added from recent field observations and satellite image interpretations conducted following field season 2010.

The geomorphological features (glacial macroforms) that were mapped are indicative of ice flow direction(s), the pattern and trajectories of ice retreat or the standstill of ice fronts at certain positions (i.e., moraines). Among the macroforms, the ice-sculpted bedrock forms (Figure 7B), the product of erosive forces of glacial ice, are present as elongated and streamlined features. Depositional and erosional macroforms were also mapped, as mainly till-formed (drumlins) or having a rocky apron (crag-and-tails, Figure 7C). A set of symbols ('glacial lineation') described linear, sometimes streamlined landforms observed from satellite images, thought to be of subglacial origin, sometimes over 10 kilometers in length. On the ground, they commonly appear as zones that display thicker or finer-grained patches

Figure 6. Glacial geomorphology, including new satellite image interpretation, and elements from Dredge (1995, 2002) and De Angelis (2007). Northern part of Southampton Island glacial geomorphology is modified from Ross (2010) and De Angelis (2007).

Geomorphology

Macroforms

-  Streamlined till form (drumlin, fluting)
-  Glacial lineation
-  Crag and tail
-  Ice-moulded bedrock form
-  Esker
-  Moraine

Glaciodynamic setting

-  Warm-based area
-  Cold-based area, intermediate
-  Cold-based area

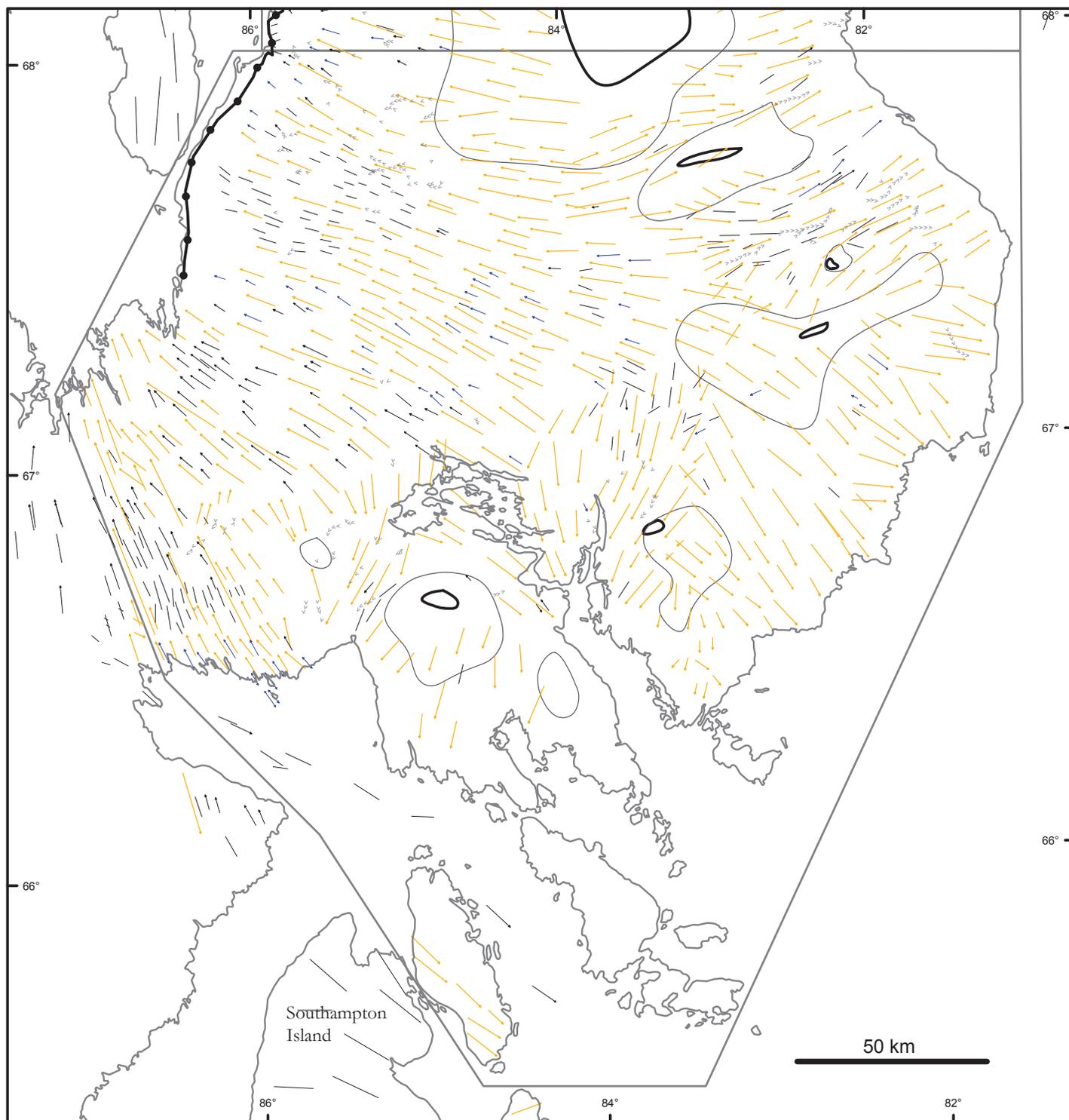




Figure 7. Geomorphological features in the study area; arrows indicate direction of glacial flow.
 A. Penrhyn Group rocks, with gossans and metal-enriched blue lake waters, in warm-based glacial terrain.
 B. Double-sided giant roches moutonnées in Penrhyn Marbles, in warm-based terrain.
 C. Crag-and-tail in Rae Isthmus medium-grained till, in warm-based terrain.
 D. Sheeted bedrock outcrop and felsemeer in granite-gneiss terrain, on cold-based terrain of Central Melville Plateau.
 E. Polygons formed on cold-based terrain till over granite-gneiss terrain, Hurd Plateau.
 F. Double-sided roche moutonnées in warm-based terrain, granite-gneiss terrain, Repulse Bay area.

of till, relative to surrounding boulder fields, till or thin till areas. These linear forms are not necessary drumlins, in the sense that they are not always elevated relative to their surroundings.

Mapped ice-marginal glaciofluvial sediments (Dredge, 1995, 2002) are indicative of direction and processes of glacial retreat. These landforms contain sediments ranging from ice-thrusted diamicton (push moraine) to juxtaposed glacial sediments of glaciofluvial origin. These ice-marginal sediments and landforms are present along the west coast of the Melville Peninsula, predominately in a large feature mapped as the Melville Moraine (Dredge, 1990). Eskers were also mapped, and typically are landforms that occur as elongated, sinuous ridges of sand and gravel, demarking former subglacial meltwater drainage. Eskers are uncommon, except in the vicinity of the Melville Moraine and in Barrow river valley. A few eskers are scattered around the east and south coastal areas, and in the edge of Rae Isthmus lowlands.

Glacial History

The glacial history presented in this report is built on the previous interpretations by Dredge (1995 and 2002) and Tremblay and Paulen (2012).

In this report, glacial history is summarized from previous work and newfield observations of ice flow trajectories, glacial transport, glacial dynamics and marginal positions of the former ice sheet. Striation measurements and other erosional ice-flow indicators are particularly important for the understanding of the successive ice flow episodes (Figure 8). The ice-flow history can be summarized into two main ice flow phases, but locally a more complex pattern may appear (Figure 9). Prior to the glacial events presented in this synthesis, at the beginning of the last glaciation, Melville Peninsula might have been a centre of cold-based ice accumulation (Melville Ice; Dredge, 2002); during that time, ice might have flowed radially, notably with an ice flow to the southwest in the Lyon Inlet area.

1. Early Flow

This ice-flow episode is directed toward N and W in the northwestern area, and toward S and E in the southeastern part of the Melville Peninsula.

On Rae Isthmus, from the record that is currently available, ice flow was continuously flowing to the north toward Committee Bay. Most striated and sculpted outcrops display this ice flow movement either as the dominant ice flow phase or as an older striation set on protected surfaces. It probably occurred during LGM to deglaciation, when central southern Melville was mostly cold-based, and is interpreted to have hosted a subsidiary ice divide area that separated ice masses flowing toward Committee Bay and toward Hudson Strait (Dredge, 2002). Furthermore, during LGM, the Foxe Basin coast of Melville Peninsula was cold-based with no glacial flow recorded on the land surface. Based on new field evidence, it is interpreted that no warm-based, erosive ice flow crossed from Foxe Basin over south-central Melville Plateau during the last glaciation or earlier glaciations, because many Paleozoic carbonate erratics on the southern plateau probably are derived from unmapped, small outliers of Paleozoic carbonate rocks located on the Melville Peninsula (especially along Barrow River, see next section).

2. Late Flow

This ice flow episode generally radiates from the center of the Peninsula, but differs from Phase 1 by its more progressively more vigorous flow on the south and east coast of the Peninsula, and the ensuing time-transgressive migration of ice divide location toward a general northwest direction. Except for some isolated pockets, most of southern Melville Peninsula was warm-based at that time, with a mostly radial ice-flow pattern, although on the east coast of Foxe Basin, some coast-parallel ice flow occurred. Ice flow reversal is observed from striations and macroforms record (figures 7, 8 and 9) in the areas where ice divide migrated. In the northeast portion of study area, and on the Rae Isthmus (Campbell and McMartin, 2011; McMartin et al., 2013; Figure 7F), the ice flow reversal was complete as the ice divide moved from the sea (where it was located during ice flow phase 1) to the land. The ice flow Phase 2 westernmost ice reversal limit is the last to be observed in most places, and probably occurred gradually as ice was retreating from Hudson Strait and Foxe Basin and eventually on the shores of Melville Peninsula (Dyke and Prest, 1987).

Figure 8. Striation measurements; glacial geomorphology (including new satellite image interpretation, and elements from Dredge 1995, 2002; and De Angelis, 2007). Numbers indicate relative age relationship (1 = oldest).

Striae
 ↑ Dredge, 1995 and 2002
 ↑ This paper
 Macroforms

Glaciodynamic setting

Warm-based area

Cold-based area, intermediate

Cold-based area

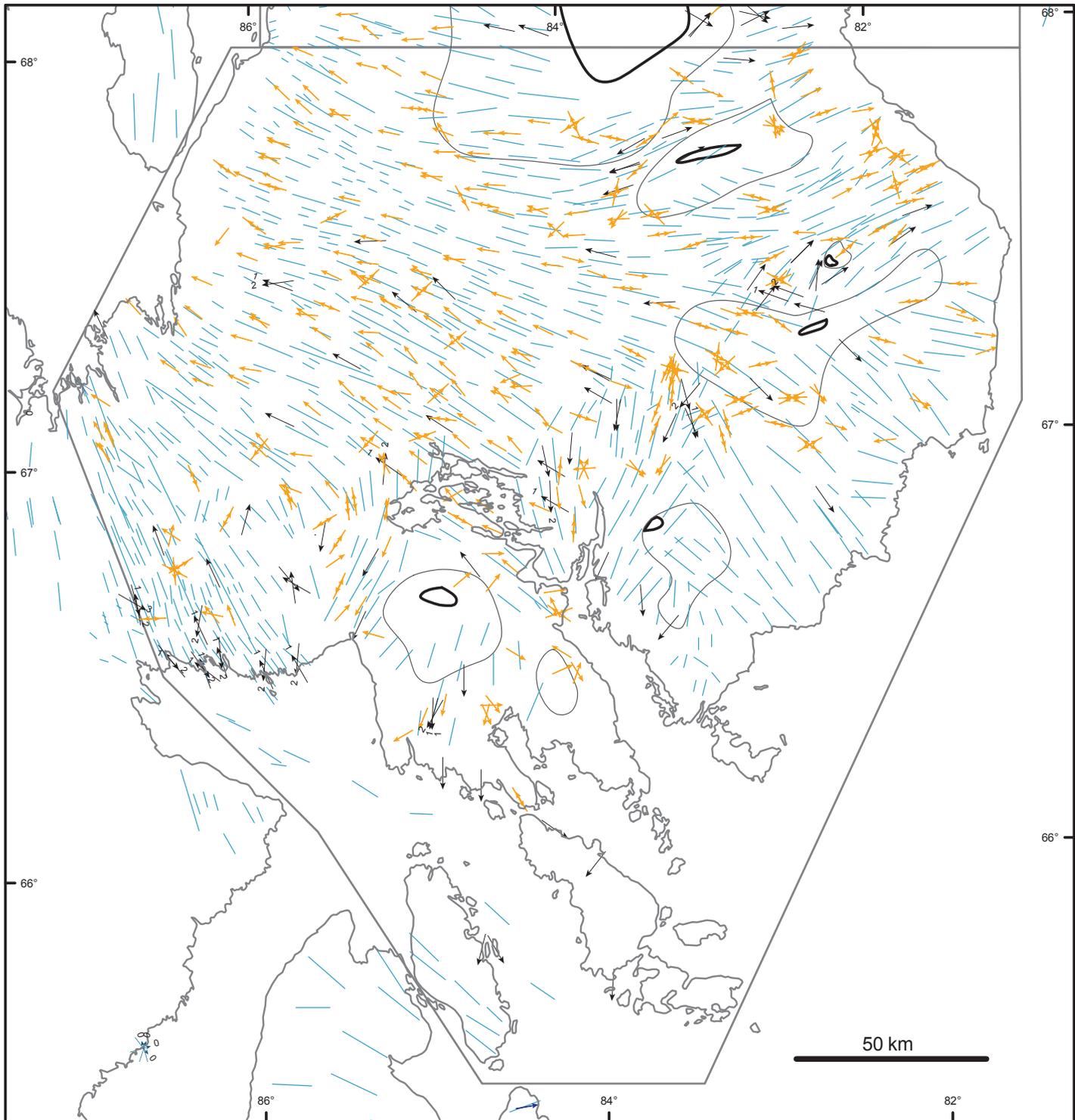


Figure 9. Ice flow lines in study area, with glacial geomorphology (including new satellite image interpretation, and elements from Dredge 1995, 2002; and De Angelis, 2007).

Glaciodynamic setting

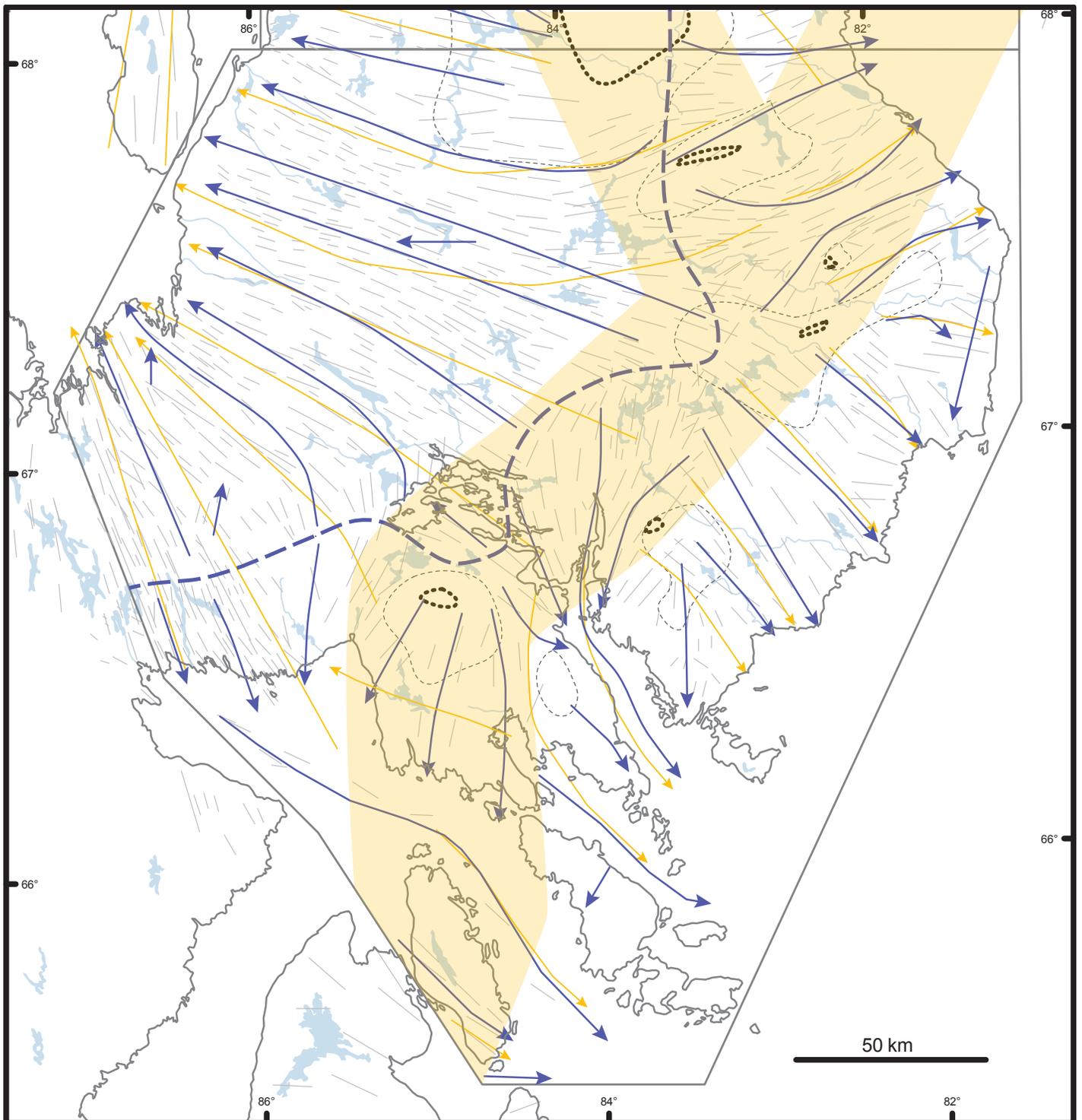
- Warm-based area
- Cold-based area, intermediate
- Cold-based area

Ice flow chronology

- ← Ice flow 2
- Westernmost limit of Ice flow 2 extension
- ← Ice flow 1
- Ice divide 1

Geomorphology

- Macroforms



Deglaciation

On the northwest coast, the ice flow was directed toward the Melville Moraine at the beginning of deglaciation on Melville Peninsula (8.4 ka ¹⁴C BP; Dredge, 2002). When the ice front reached the south and east coasts, deglaciation became terrestrial-based (around 7 ka ¹⁴C BP, from Dredge, 2002), and glacial dynamics gradually diminished, probably due to the thinness of ice and lack of major driving forces (i.e., streaming ice and calving ice front). The ensuing land-based deglaciation left little traces except for a few eskers, while ice flow directions probably locally shifted as ice retreated toward the centre of the Melville Peninsula. From the striation record presented by Dredge (1995, 2002) north of Lyon Inlet, some SW striae measurement are parallel to Penrhyn Group rocks foliation. Ice flow dynamic was probably sluggish and mostly cold-based, and thickness of ice was relatively small compared to the mainland on the western side of Rae Isthmus where relatively thicker ice from the Keewatin Ice Divide was driving the glacial dynamic during land-based deglaciation, with some cold-based patches occurring in highlands south and north of Wager Bay (McMartin et al., 2012; McMartin and Dredge, 2005). On Melville Peninsula, the remaining glacial ice in the upper elevations stayed cold-based, and glacial meltwater formed a well-developed set of ice-marginal channels in the cold-based areas (Dredge, 2002). In association with this glacial meltwater episode during deglaciation, some ice-marginal glacial lakes features (spillway channels, deltas) were formed on the plateau. Deglaciation was probably complete by 6.5 ka ¹⁴C BP (Adams and Finkelstein, 2010). Overall, the glacial history depicted in this paper is similar to Dredge (2002), as it suggest that during most of the last glaciation a subsidiary ice divide existed over Melville Peninsula. However, the locations of subsidiary ice divide through time are slightly different compared to Dredge (2002), partly because more data was acquired from striations and satellite images interpretations.

Terrain And Till Types

The glacial imprint of glaciers is marked by various geomorphological indicators, observed in the field and by remote mapping (Dredge, 2002; Tremblay

and Paulen, 2012). The composition of till and the geomorphological indicators of glacial erosion are summarized into a broad classification of terrain and till types. The basal thermal condition character of the former ice sheet (cold- versus warm-based) can be inferred from this classification, and can therefore help to understand and outline the nature of glacial transport. Figures 10, 11 and 12 show the location of samples and sedimentological characteristics (carbonate content of till matrix and granulometry) upon which some of the interpretations are based.

1) Cold-based (or total cold-based, in Tremblay and Paulen 2012): a zone where only features indicative of cold-based ice are present, and thus where glacial erosion is assumed to be inexistent or minimal throughout the last glaciation and the Quaternary. These features include the absence of striations on bedrock, the absence of glacial macroforms and the development of mature permafrost polygons in surficial deposits. The ground is typically covered with felsenmeer, rough bedrock outcrops or bouldery deposits (with dominantly sandy, brown to red-hued weathered matrix, Figure 12). Dredge (2002) is referring to those materials as being issued at least partly from non-glacial regolith, and supposes a Sangamonian or older ages for those materials. Ice-marginal parallel channels are incised into this terrain, and associated with subaerial or marginal meltwater sediments and landforms. Outcrops are moderately to extensively weathered, often exhibiting millimetre to centimetre scale differential weathering of minerals and/or lithologies. Landscape features include an absence or rarity of small lakes, and dendritic river drainages are dominant over deranged river systems. The cold-based zone is controlled by topography, often occurring in area located in shielded, up-ice position relative to the highest hills in the west of the Peninsula, and on the southern plateau. There are evidence of earlier ice-flow erosion at the margins of the cold-based areas of south-central Melville Peninsula.

2) Intermediate cold-based: a transition zone where at least one or more of the aforementioned criteria for cold-based glaciation are absent. It approximately corresponds to the areas Dredge (2002, p.16) and De Angelis and Klemm (2007) mapped as regotill or cold-based zone area. In this setting, the presence of important boulder cover is still ubiquitous, and constitutes one of the principal

Figure 10. Location map of field stations and samples, from this paper and published data.

- ▲ Till geochemistry (this paper, or Tremblay and Paulen 2012)
- Till heavy mineral (this paper, or Tremblay and Paulen 2012)
- ▲ Till geochemistry (Dredge, 1995 and 2002)
- Lake sediments (Day, 2010)
- Sample located close to gossan, many rusty boulders and/or red diamicton

Bedrock geology

- Mesozoic sediments
- Paleozoic carbonates
- Penrhyn Group, sup. member (no marbles)
- Penrhyn Group, inf. member (marbles rich)
- Prince Albert Group
- Precambrian granite/gneiss

Glaciodynamic setting

Warm-based area

Cold-based area, intermediate

Cold-based area

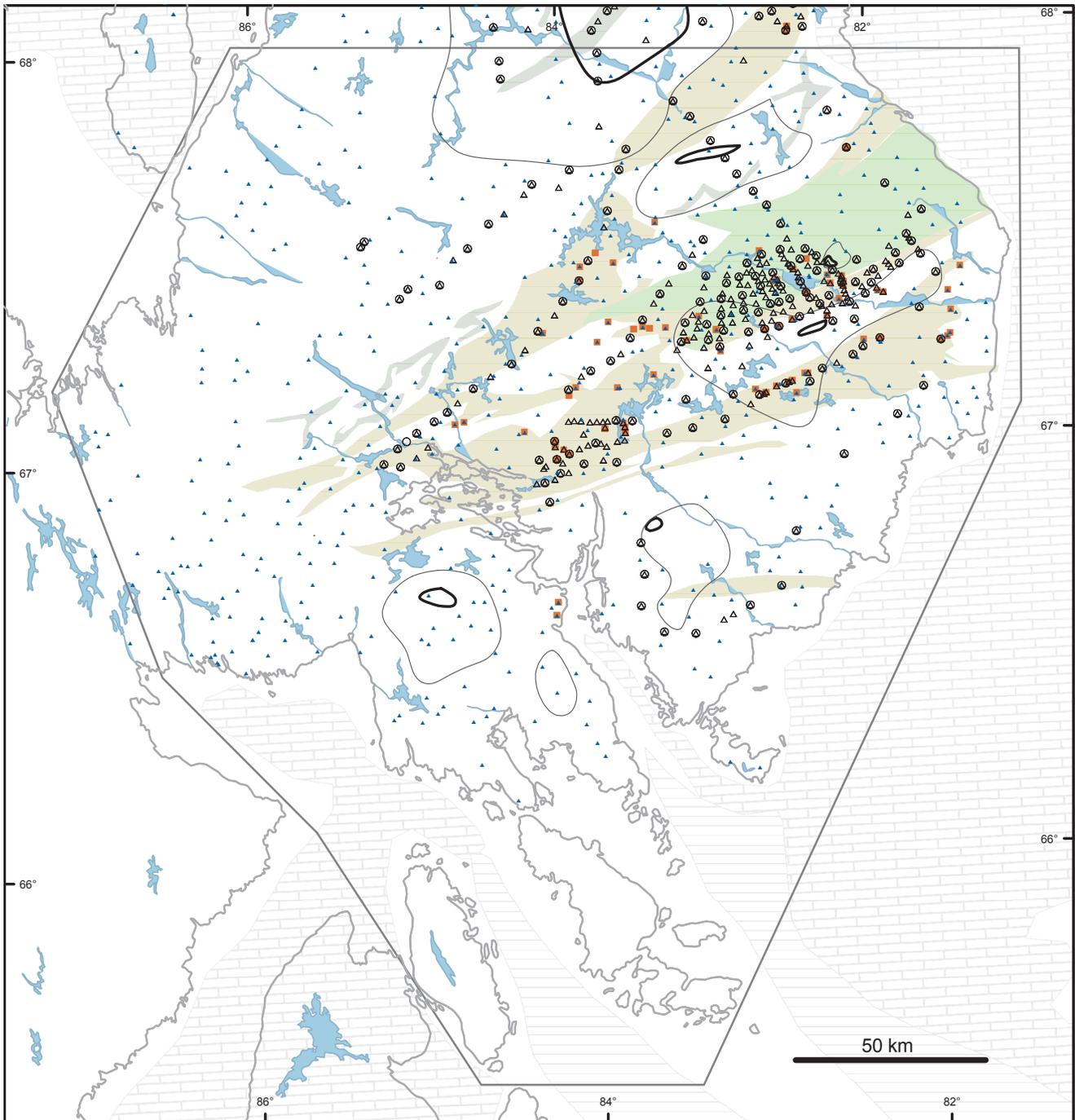
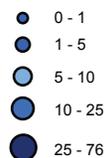
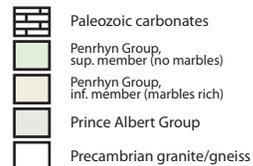


Figure 11. Carbonate content in till (includes new data identified with white dots, and data from Dredge 1995, 2002 and 2009).

Carbonate in till matrix
(%, less than 63 μm fraction)



Bedrock geology



--- Over 10% carbonate in till matrix, from Paleozoic carbonate rocks
 --- Over 10% carbonate in till matrix, from Penrhyn group marbles

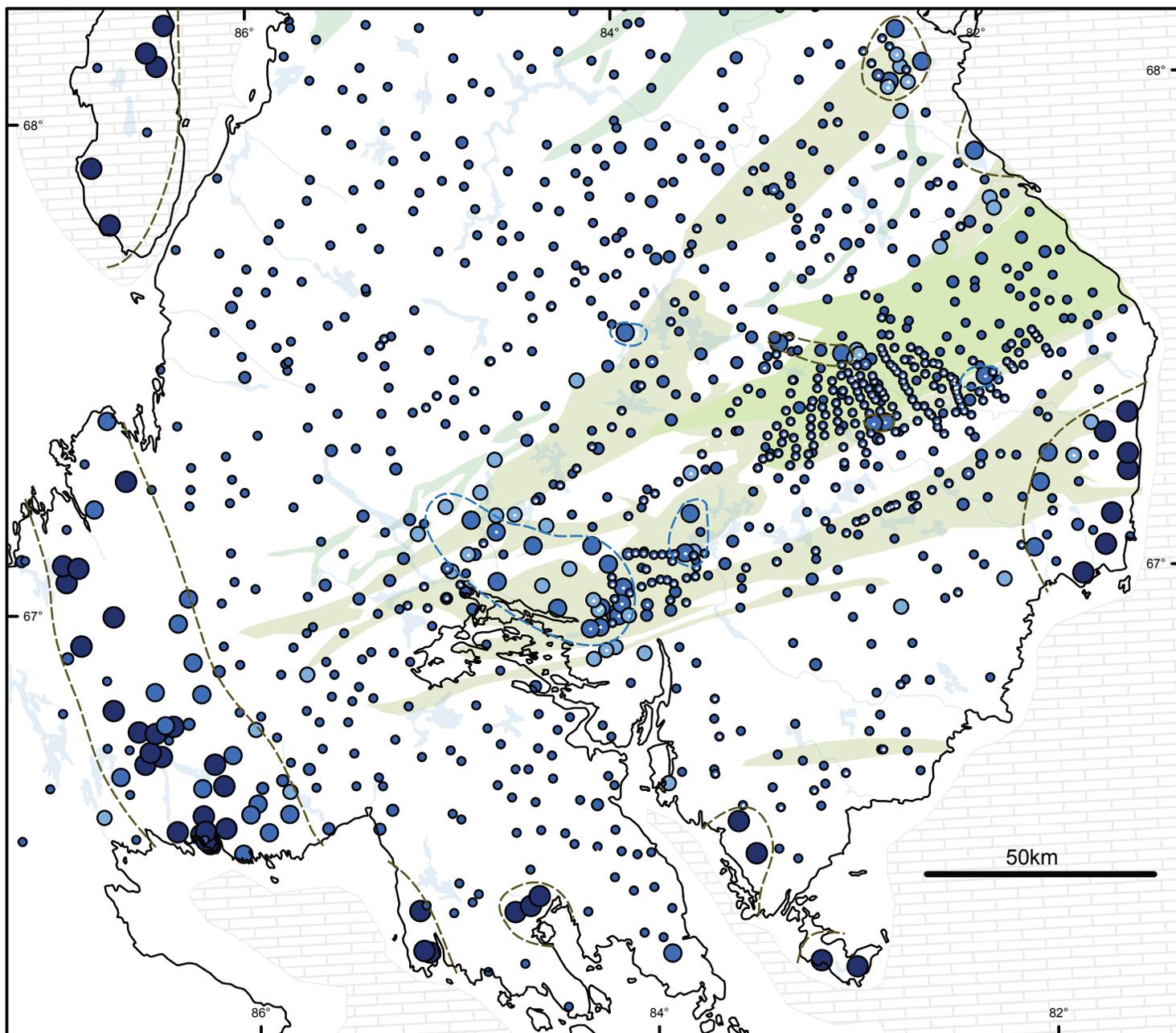


Figure 12. Proportion of less than 63 μm fraction in till matrix (0-2 mm) (includes new data identified with white dots, and data from Dredge 1995, 2002 and 2009 with no white dots).

Less than 63 μm fraction
% in till matrix (0-2 mm)

- 2 - 26
- 26 - 37
- 37 - 47
- 47 - 61
- 61 - 100

Bedrock geology

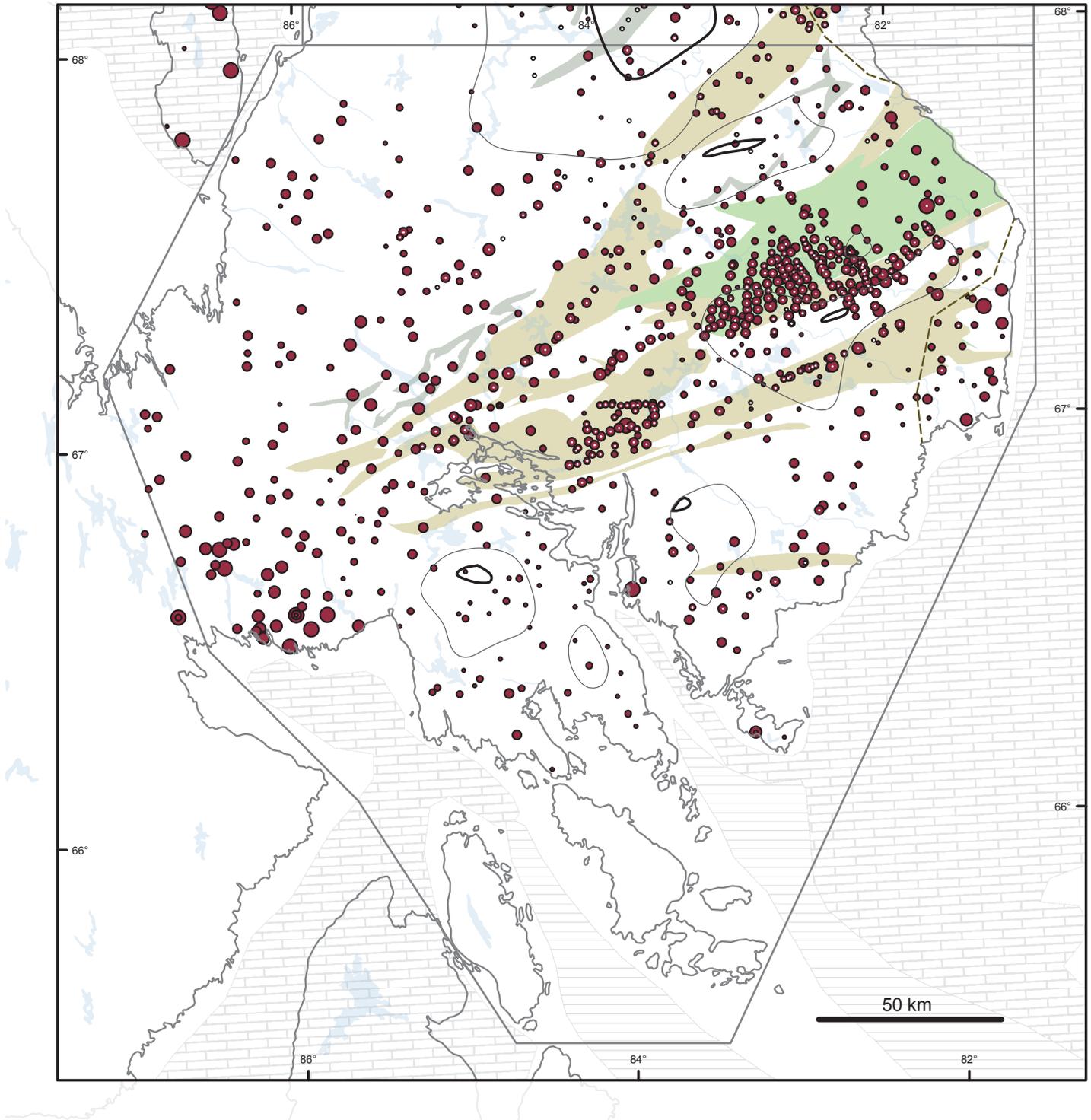
-  Paleozoic carbonates
-  Penrhyn Group, sup. member (no marbles)
-  Penrhyn Group, inf. member (marbles rich)
-  Prince Albert Group
-  Precambrian granite/gneiss

Glaciodynamic setting

Warm-based area

Cold-based area, intermediate

Cold-based area



characteristics. Outcrop weathering is developed, but to a lesser degree than in the cold-based zone. Macroforms frequently occurs as parallel linear features observed from satellite images, often not particularly elevated relative to surroundings. Striae, where present, occurs in sparsed patches among unstriated, weathered bedrock surfaces. Where striae are present, outcrops occasionally have a vague, weathered and rounded asymmetrical shape, evocating either incipient roches moutonnées or weathered old roches moutonnées. The degree of development of the above features typically grades out toward the outer margins of this zone, to reach conditions similar to those observed in the warm-based area described below. The ground cover is similar to cold-based areas. The characteristics of intermediate cold-based terrains are similar to those found on Hall Peninsula, Baffin Island, and described in Tremblay et al. 2013 and 2014.

3) Warm-based zone in till from granite-gneiss terrain: The land surface is at least locally affected by glacial macroform development, and where marks of glacial erosion on bedrock are widespread (Figure 7 C). The boulder cover is variable. The glacial sediment cover is dominated by till, of variable thickness, typically grey to light brown in color, sandy-silty in grain size (Figure 12).

4) Warm-based zone in till from Penrhyn Group metasediments: In this zone, till originates dominantly from incorporation of metasediments and marbles debris, mixed with granite and gneiss tills. Carbonate content is occasionally higher than in granite-gneiss till area, and Figure 11 outlines specific areas where the carbonate content in till matrix is higher than 10% CaCO_3 . Glacial macroform development is generally strong (Figure 7B), and carbonate content is consistently high in elongated glacially-transported features referred to as “carbonate plumes” by Dredge (2000b). The matrix color of the till is generally gray to reddish, colored by altered iron minerals. The granulometry is noticeably finer than the surrounding granitic-source till (Figure 12).

5) Warm-based zone in carbonate till: In this zone, till originates from Paleozoic carbonates rocks, mixed with granite and gneiss tills. The carbonate content in till is moderately elevated (contoured to 10% matrix CaCO_3 content in till, Figure 11). Glacial

macroform development is generally strong (Figure 7E), and carbonate content is consistently high in elongated glacially-transported features referred to as “carbonate plumes” by Dredge (2000b). The matrix color of the till is increasingly paler and yellower in proportionality with the increased amount of carbonate present in the till matrix. The granulometry is finer grained than in the granite-gneiss and the Penrhyn Group metasediments tills (Figure 12). Where moderate relief is present, the till surface is affected by moderate solifluction, and vegetation-denuded surfaces are not as common as on northern Melville Peninsula carbonate till terrains (Tremblay and Paulen, 2012).

Glacial Transport Of Erratics

The lithological counts (figures 13, 14 and 15) are useful for understanding the direction and intensity of glacial transport, as well as the relative importance of the various ice flow phases on glacial transport (Parent et al., 1996, Klassen, 1999, Tremblay et al., 2007). Potential errors include non-source area lithology provenance, pebble shattering, size variation and uncertain lithologic affiliation.

The Paleozoic carbonate and Penrhyn marble pebble counts (4-8 mm and 5-15 cm) and erratic boulder observations (Dredge, 1995 and 2002) are presented in Figure 13. Marble clasts in till 4-8 mm and 5-15 cm fractions are not as common as marble outcrops local abundance would suggest, probably because they are easily crushed to finer grains during glacial and periglacial processes. Paleozoic carbonates erratics are found near the coast, indicating glacial transport from the Foxe Basin Paleozoic carbonates outcrops to the land. Some limestone clasts might also have been ice-rafted as some of them are located under the marine maximum limit. Close to Barrow River, two small areas with Paleozoic carbonate clasts were found in till within the 4-8 mm and 5-15 cm fractions, and in erratic boulders. Dredge (2002) shows limestone clasts found mainly in the upstream section of Barrow River. Altogether, since Paleozoic carbonates appear to have a spatially grouped distribution, we suggest they originate from unmapped local Paleozoic carbonate rocks outliers, hypothetically hidden under till cover in topographically lower drift-covered areas (in the Barrow River valley). East of Barrow River, the

Figure 13. Petrographic counts in till pebbles and erratic boulders observations, for Paleozoic carbonate rocks and Penrhyn Group marbles.

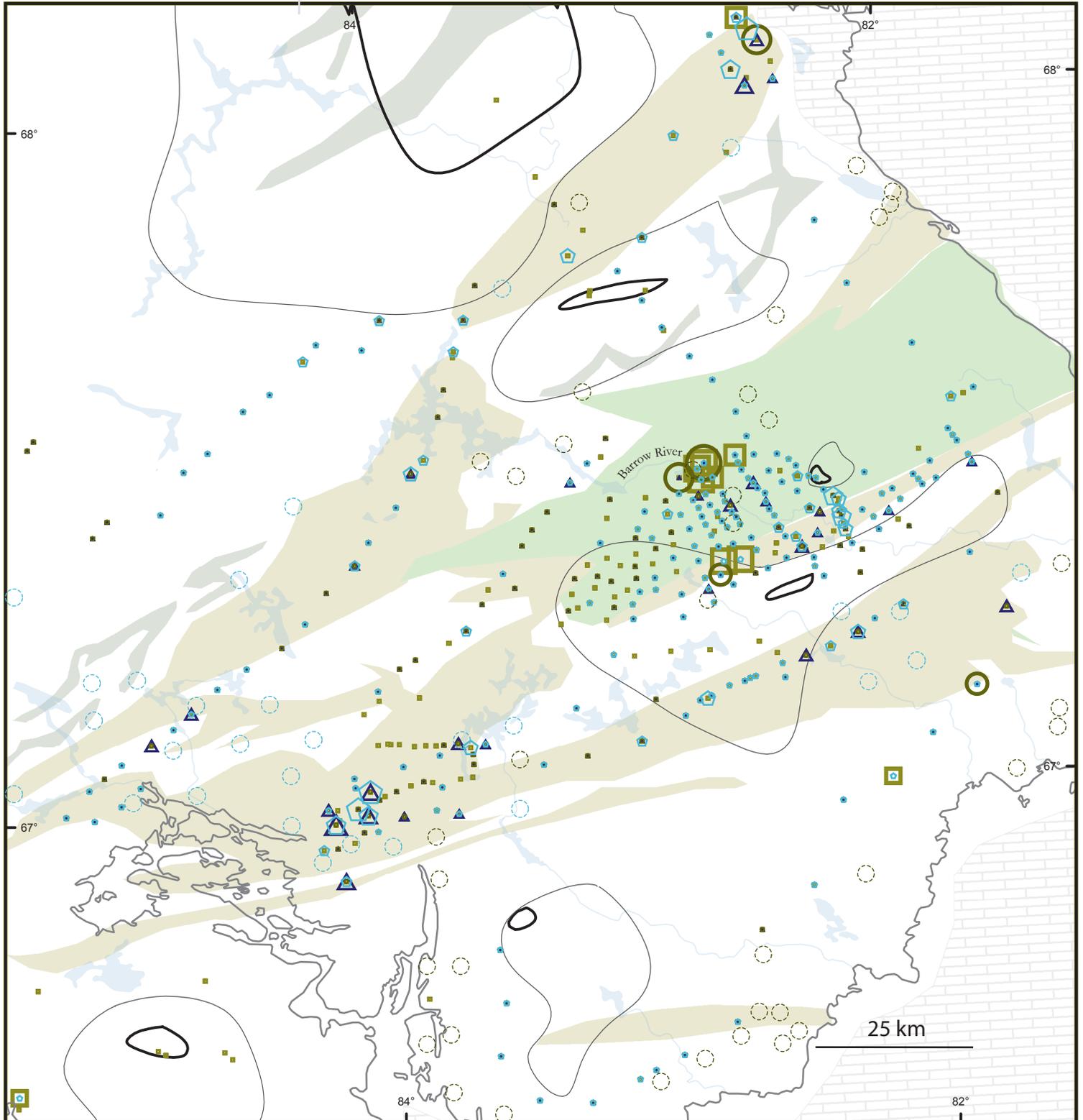
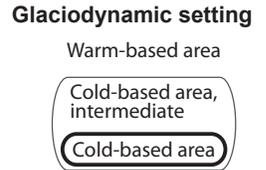
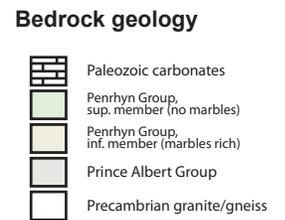
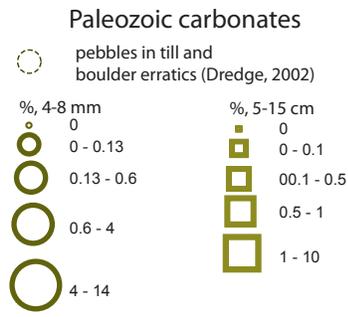


Figure 14. Pie diagrams map displaying petrographic countings in 5-15 cm fraction of surface till (visual estimates).

Petrographical counts (% , 5-15 cm)

- Paleozoic carbonates
- Precambrian granite/gneiss
- Penrhyn Group (metasediments)
- PAG (greenstone belt)

Bedrock geology

- Paleozoic carbonates
- Penrhyn Group, sup. member (no marbles)
- Penrhyn Group, inf. member (marbles rich)
- Prince Albert Group
- Precambrian granite/gneiss

Glaciodynamic setting

Warm-based area

Cold-based area, intermediate

Cold-based area

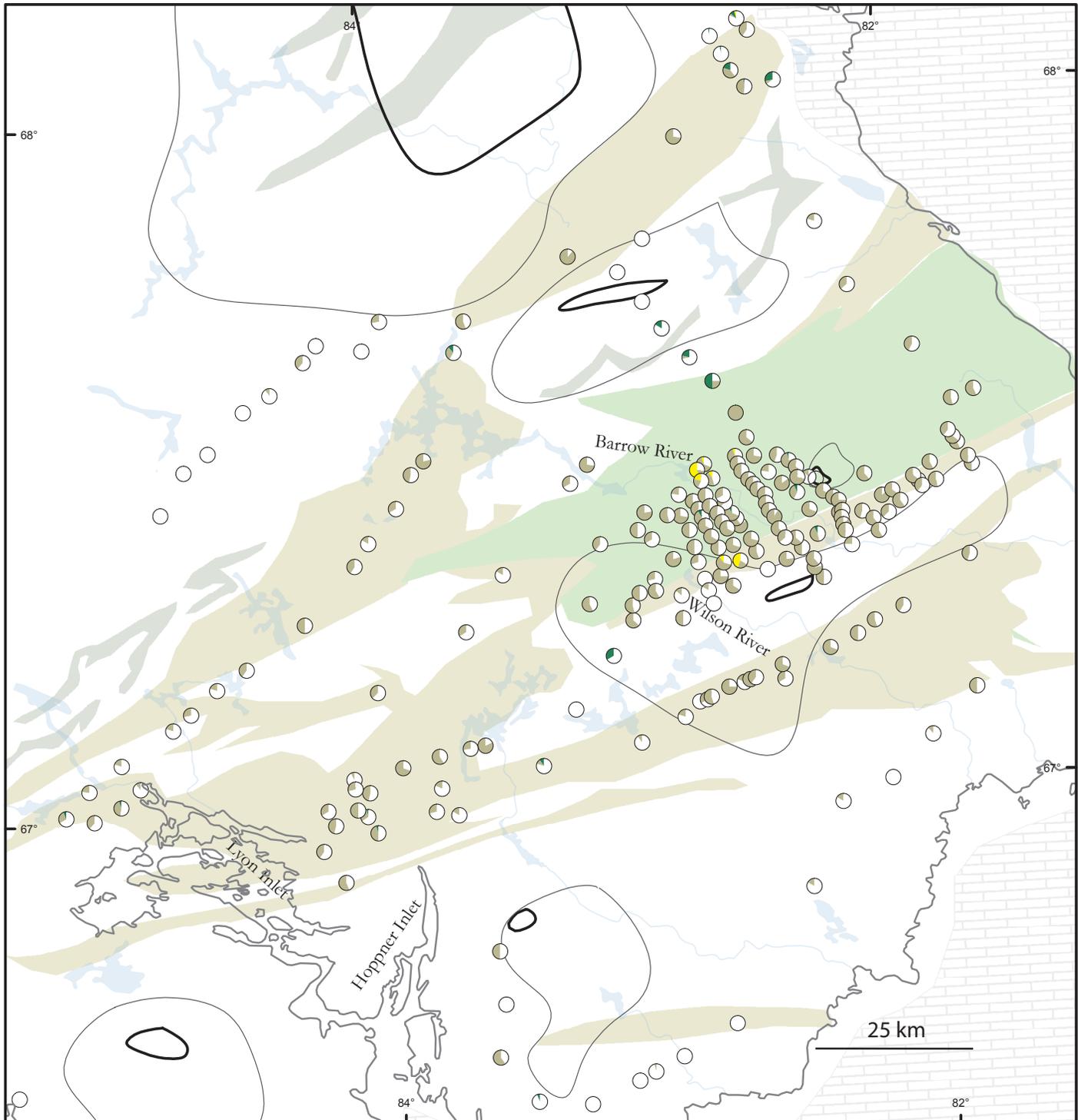


Figure 15. Graphitic metasediments pebbles counted in till (% weight on 95 to 115 μ m of 4-8mm pebbles).

Penrhyn Group
graphitic metasediment
(% weight, 4-8 mm fraction)

- 0 - 1
- 1 - 5
- 5 - 11
- 11 - 19
- 19 - 68

Bedrock geology

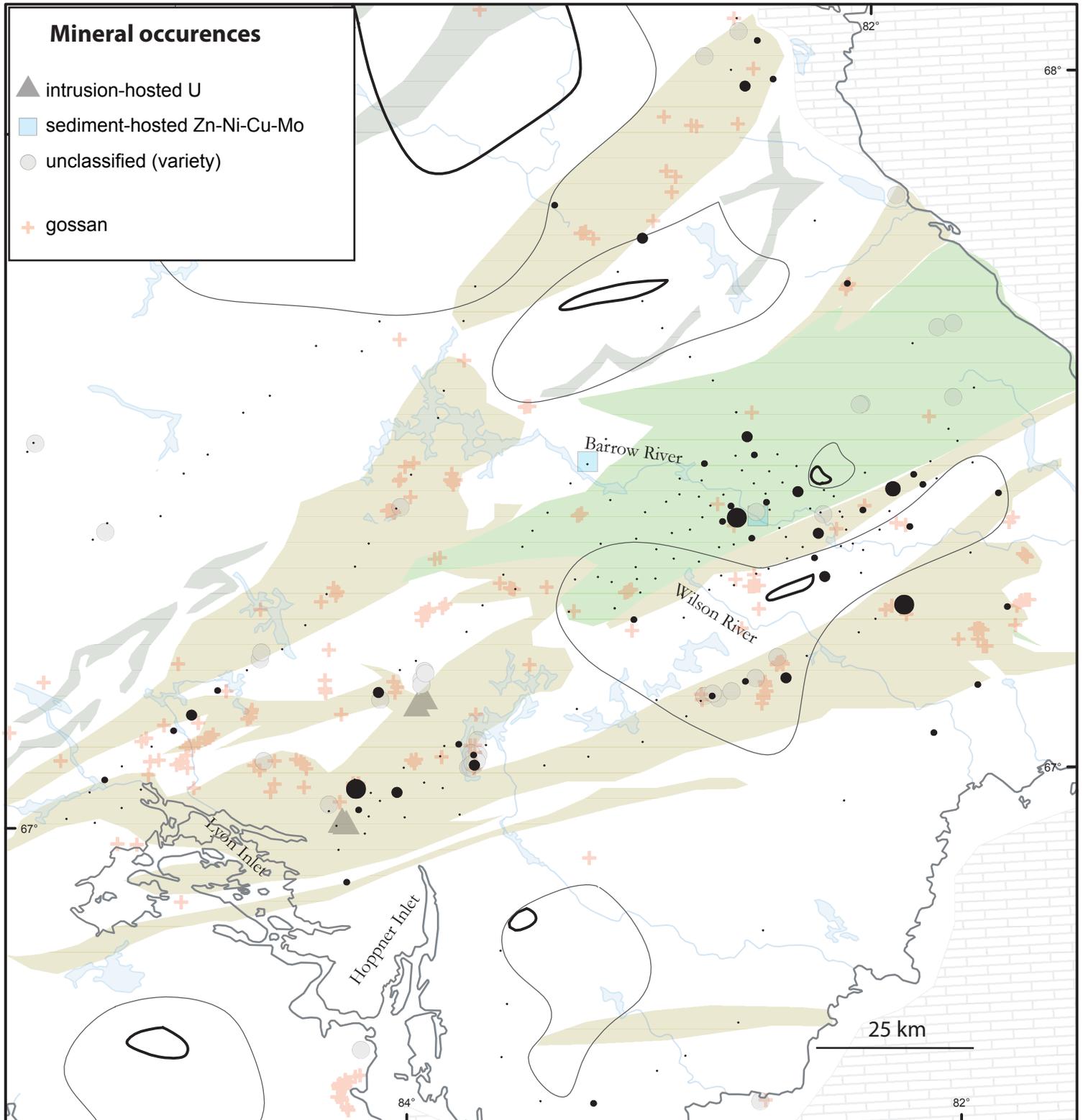
- Paleozoic carbonates
- Penrhyn Group, sup. member (no marbles)
- Penrhyn Group, inf. member (marbles rich)
- Prince Albert Group
- Precambrian granite/gneiss

Glaciodynamic setting

Warm-based area

Cold-based area, intermediate

Cold-based area



limestones clasts found in till might have been glacially transported from the outliers toward Foxe Basin. Elsewhere within the central part of the Melville Peninsula plateau, the Paleozoic carbonate clast content of the surface tills is mostly absent, and therefore it is interpreted that no ice from the Foxe Basin crossed the central part of Melville Peninsula, which might have been a cold-based glacial zone during the last glaciation. This interpretation differs from the view that limestones have been transported on Melville Peninsula by warm-based glaciers flowing from Foxe Basin toward Committee Bay (Dredge; 2002). The higher density of data for limestones erratics and pebbles published here explains the difference in the interpretation between our work and Dredge (2002).

The most abundant lithology in the surface clast counts is the undivided, felsic-dominated Archean granite and gneiss. These rocks, observed in 5-15 cm clast sizes (visually estimated on the field, Figure 14), range from 100% in some parts of the plateau to less than 10% in the central Penrhyn Group. Because their outcrops occupies small area, the Archean Prince Albert Group rocks, which consist of felsic, mafic and ultramafic metavolcanic rocks, gabbros and iron formation, are not commonly observed in till samples from the study area, except close to Prince Albert Group outcrops located in the northern part of study area.

The Penrhyn Group metasediments form more than half of clasts in tills over most of Penrhyn Group rocks, reflecting local provenance. The accuracy of detection of metasediments versus granite/gneiss is better in 5-15 cm than in 4-8 mm, as the rusty and bedded characteristic aspects of the metasediments are enhanced in the 5-15 cm fraction observed on the field relative to the 4-8 mm fraction observed by binocular in laboratory. Figure 15 shows that Penrhyn group graphitic metasediments are spatially associated with gold (see further sections), and are easily observed by binocular in the 4-8 mm fraction. Their distribution seems to reflect local to distal provenance, and little to moderate glacial transport (Figure 15).

Economic Geology

A number of till samples were collected on Melville Peninsula, and analyzed for economic mineral

content. The following section discusses the results of the till matrix geochemistry and heavy mineral content and chemistry selected from the new sample dataset (Figure 10), and previous data from Dredge (1995, 2002 and 2009). For a full list of new sample location and geochemical and mineral composition, see Annexes A, C and D.

Numerous till geochemistry results have been previously published for this area, for till matrix <2 μm and <63 μm fraction analysis (Dredge, 1995, 2002 and 2009). The geochemical content of the till fine particles fraction is a combination of elements inside the mineral grains, of the method of analysis (dissolution), and of elements adsorbed on individual grains, previously leached from dissolvable crystals, chiefly sulfides (Shilts, 1977). In this report, all data reported from Dredge (2002) is on <63 μm fraction, and samples collected by Dredge (2002) from gossans were excluded from the maps.

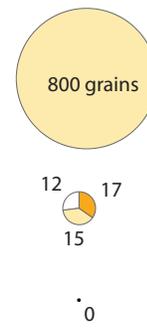
In an effort to synthesize the presentation of <63 μm fraction geochemical results, pie diagrams have been drawn to illustrate multiple deposit-related elements in on a single map (figures 17 and 20). To allow the comparison of multiple elements within a single pie diagram, the geochemical values have been normalized relative to the standard deviation of all results for a specific element (σ). It is possible to pinpoint the location of anomalies for several elements on the same map, with pie diagrams normalized to σ scale. Comparison is thus made on a common basis and the output is unitless; for example, an output value of 1 for a specific element indicates that the sample has a value equal to the σ of the population for that same element. Values above one means they are more abundant than the σ of the population for that same element, and values below one means they are less abundant than the σ of the population for that same element. The visual aspect of the pie charts thus allows a quick understanding of anomalies importance for multiple elements on the map. Till matrix (<63 μm) are presented using normalized data pie diagrams for base metals (figures 17,18 and 19) and gold-related (Figure 20) elements.

It is important to constantly bear in mind the importance of context in the interpretation of geochemical, sedimentological and mineralogical results in tills, such as locally important meteoritic

Figure 16. Total number of sulfides grains counted in NFHMC (>250 μm). Data is standardized to a sample weight of 10kg (table feed). The size of the pie circle is proportionnal to the sum of the grains picked for each sample. Blue arrows indicate generalized ice flow direction.

Sulfides
(grains, 10 kg samples)

- Chalcopyrite
- Pyrite
- Arsénopyrite



Bedrock geology

- Paleozoic carbonates
- Penrhyn Group, sup. member (no marbles)
- Penrhyn Group, inf. member (marbles rich)
- Prince Albert Group
- Precambrian granite/gneiss

Glaciodynamic setting

- Warm-based area
- Cold-based area, intermediate
- Cold-based area

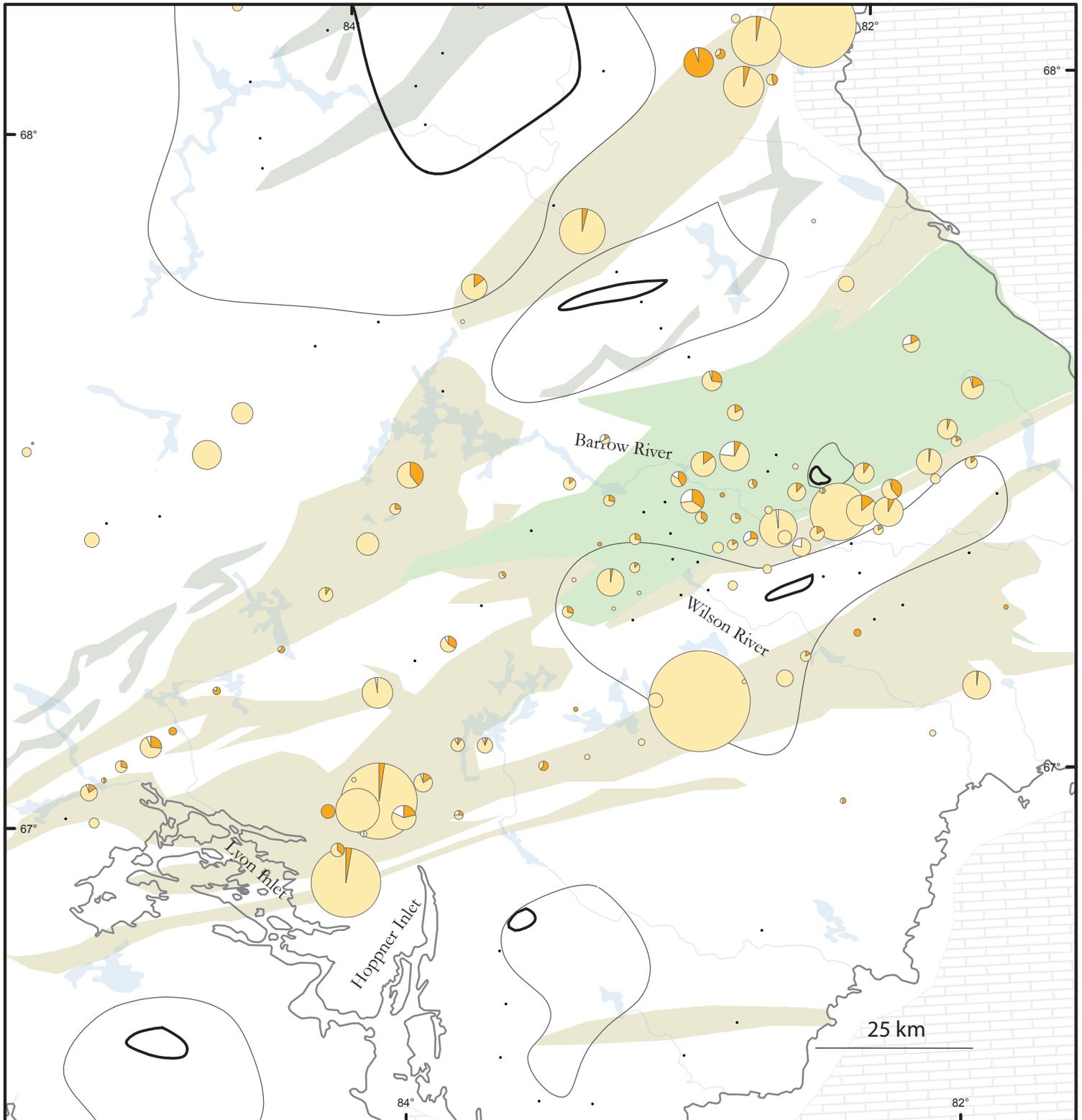
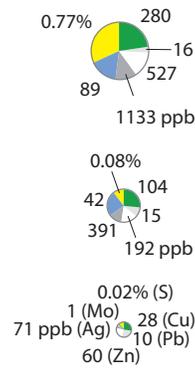
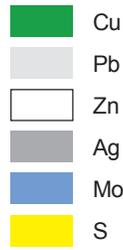
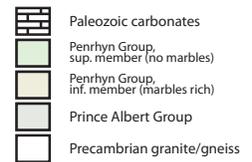


Figure 17. Pie plots showing important base-metals elements analyzed in 63 μm till matrix (Cu, Zn, Pb, Mo, Ag). Data is normalized to their respective 1σ to allow graphical comparison between elements, therefore the pie sizes values are unitless. The size of the pie circle is proportionnal to the sum of the normalized values for each sample. The absolute values are in ppm, unless otherwise indicated. The star symbol indicates that the pie segment is too small to be displayed on the diagram.

Geochemistry (normalized value)



Bedrock geology



Glaciodynamic setting

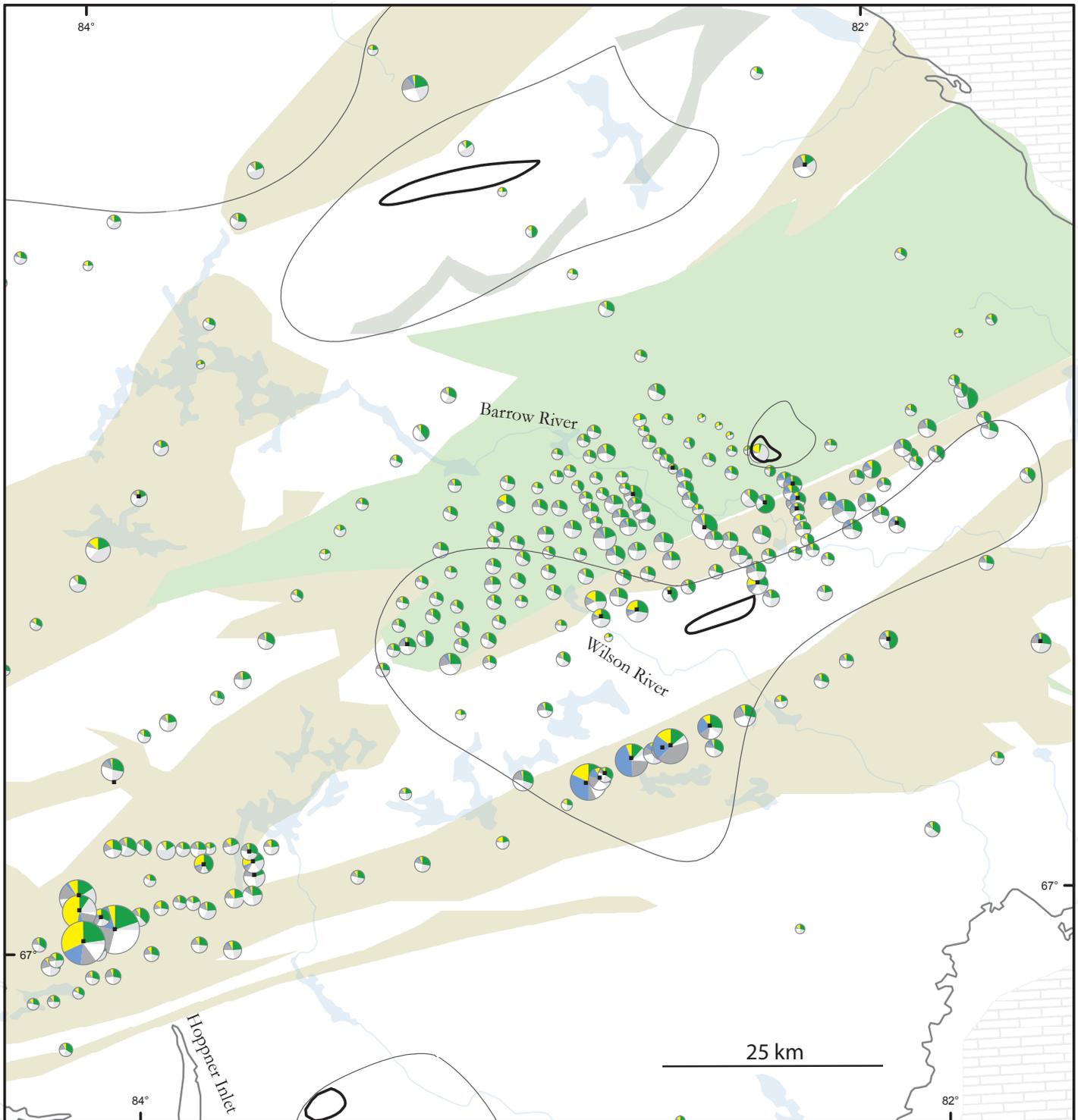
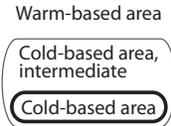


Figure 18. Composite map showing zinc geochemistry in till <math><63 \mu\text{m}</math> fraction (Dredge, 1995, 2002 and 2009; Tremblay and Paulen, 2012 and this paper, indicated by white dots), and zinc geochemistry in lake sediments (interpolated by kriging with data from Day, et al., 2009; see Fig. 10 for sample locations). GR/GN: Precambrian granite and gneiss; PAG: Prince Albert Group Archean supracrustal rocks; PEN: Penrhyn Group Paleoproterozoic supracrustal rocks; CARB: Paleozoic carbonate rocks.

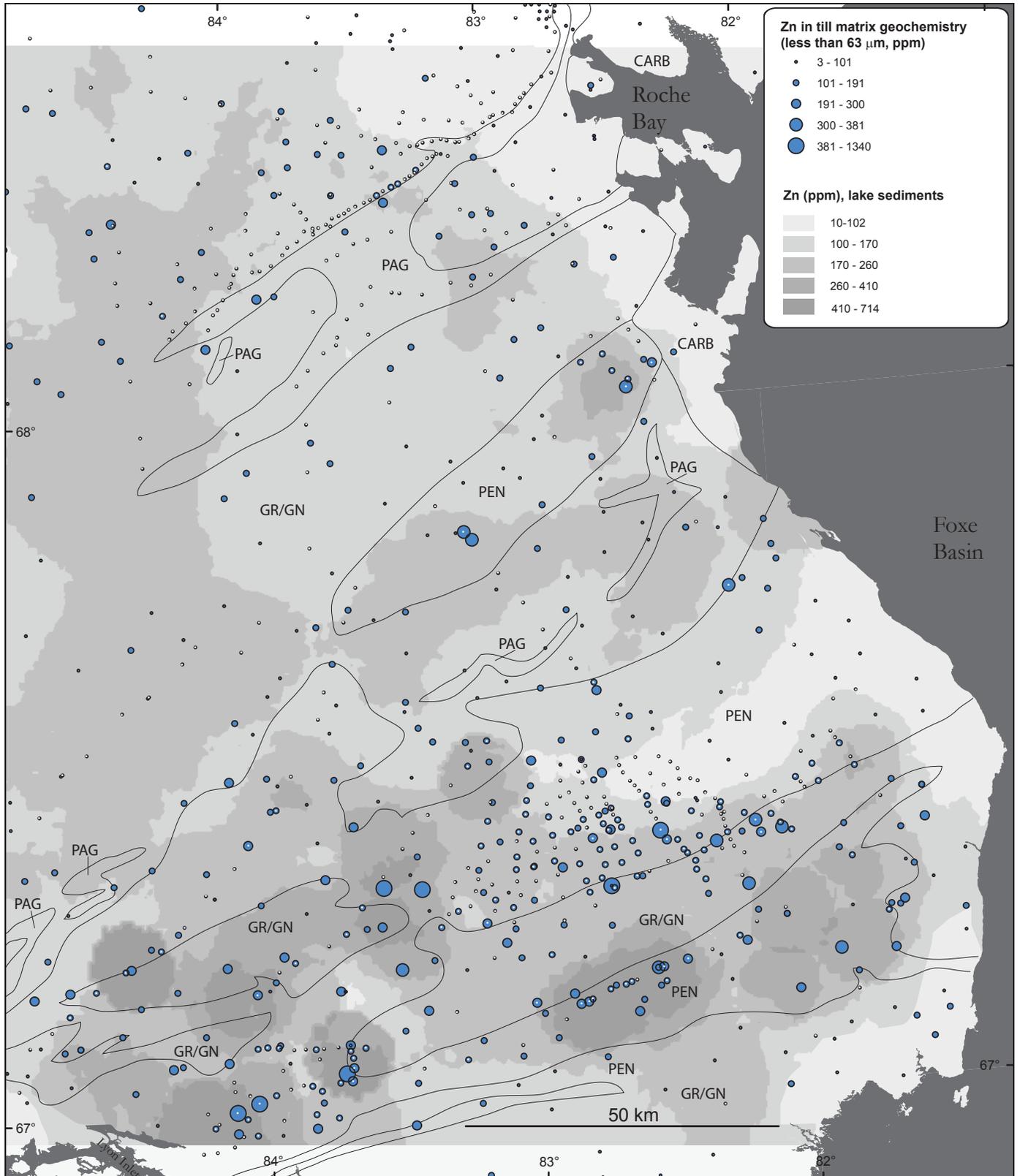


Figure 19. Composite map showing nickel geochemistry in till <math><63 \mu\text{m}</math> fraction (Dredge, 1995, 2002 and 2009; Tremblay and Paulen, 2012 and this paper, indicated by white dots), and nickel geochemistry in lake sediments (interpolated by kriging with data from Day, et al., 2009; see Fig. 10 for sample locations). GR/GN: Precambrian granite and gneiss; PAG: Prince Albert Group Archean supracrustal rocks; PEN: Penrhyn Group Paleoproterozoic supracrustal rocks; CARB: Paleozoic carbonate rocks.

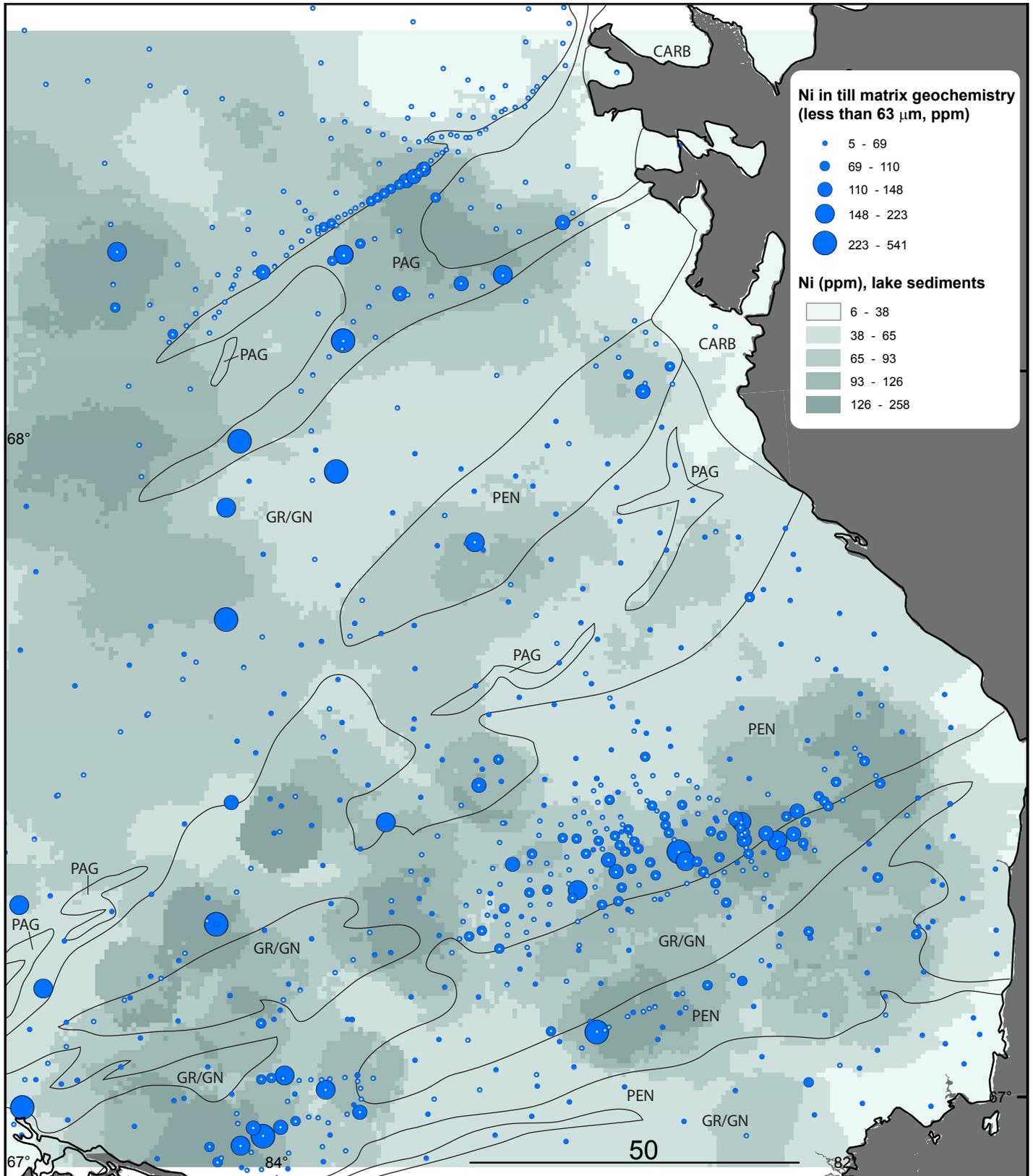
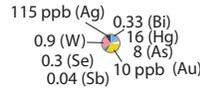
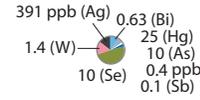
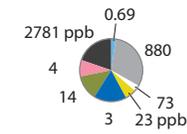


Figure 20. Pie plots showing important gold deposits -related elements analyzed on less than 63 μm till matrix geochemistry (Au, Bi, As, Sn, Se, Hg). Data is normalized to their respective 1σ to allow graphical comparison between elements, therefore the pie sizes values are unitless. The size of the pie circle is proportionnal to the sum of the normalized values for each sample. The absolute values are in ppm, unless otherwise indicated. For As, the highest value is shown as being smaller (500 ppm shown, 20 times bigger in reality, exceeding 10 000 ppm) and is represented by a star on the map. The black dots indicates that the samples were taken close to a gossan.

Geochemistry (normalized value)

- Bi
- Hg
- As
- Au
- Sb
- Se
- W
- Ag



Bedrock geology

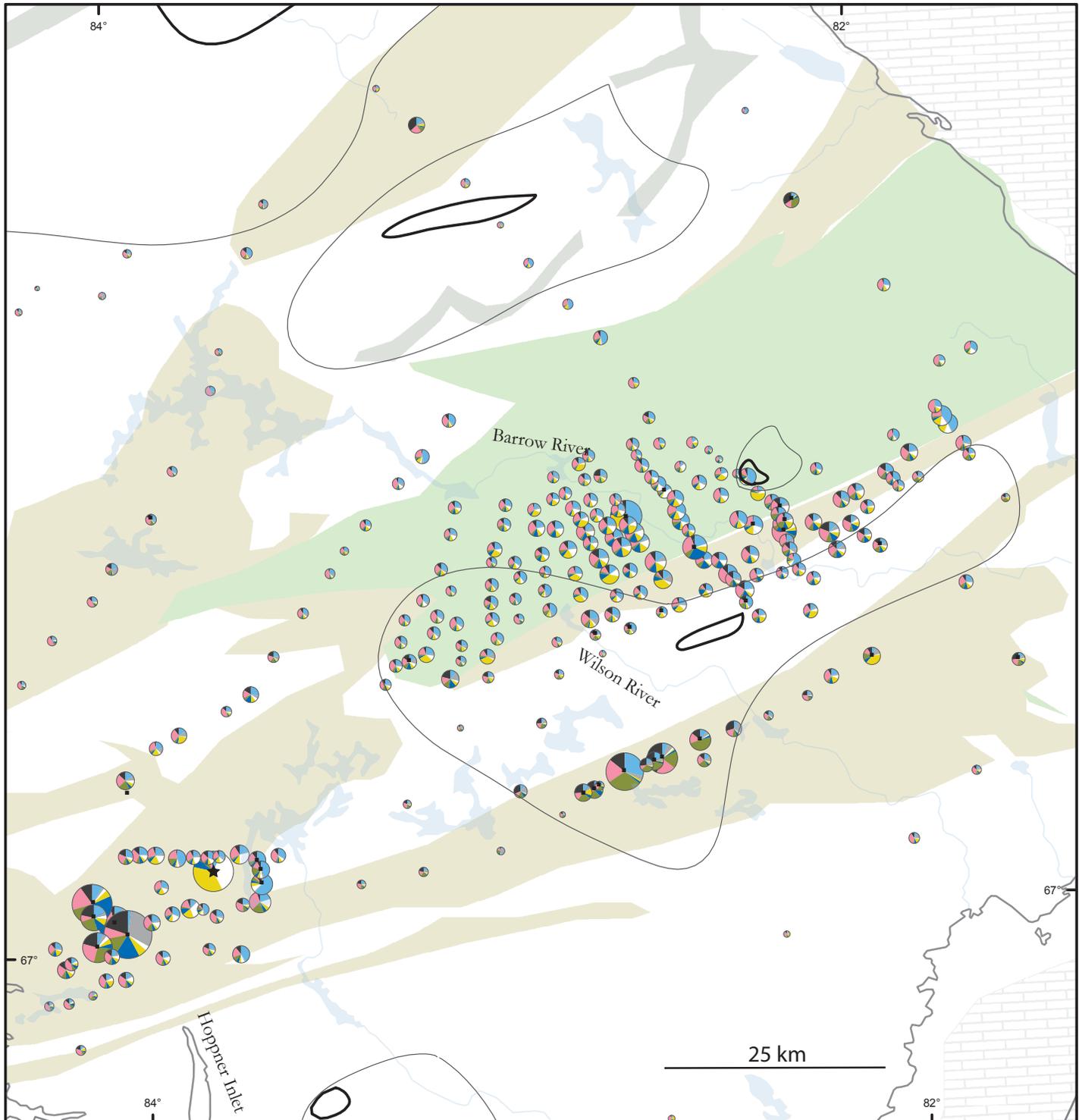
- Paleozoic carbonates
- Penthy Group, sup. member (no marbles)
- Penthy Group, inf. member (marbles rich)
- Prince Albert Group
- Precambrian granite/gneiss

Glaciodynamic setting

Warm-based area

Cold-based area, intermediate

Cold-based area



alteration (presence and preservation of sulfides, and leaching of base metals from mineralized bedrock and tills; Cameron, 1979; Henderson, 1983;), carbonate content, bedrock provenance and glaciofluvial reworking (Tremblay and Paulen, 2012). Also, it is important to consider the direction and chronology of ice flows (fig. 9), the glacial terrain and the till types (figures 6, 11 and 12) in the interpretation of provenance of till anomalies. A particular issue with the interpretation of glacial transport and till geochemical and mineralogical contents is the coarse and/or weathered nature of till occurring within the cold-based (and intermediate) zones (defined as 'regotill' in Dredge, 2002; Tremblay and Paulen, 2012). It arises from a combination of prolonged weathering, polygonization (periglacial sorting), weak glacial attrition, and glaciofluvial reworking during deglaciations. In these specific areas, the short glacial transport distance and the uncertain direction of provenance due to the paucity of glacial erosional indicators demand great care in the interpretation of the pending results from geochemistry and heavy mineral analysis.

Sulfides grains

The amount of sulphide grains found in NFHMC is a function of both the source rocks (i.e. the initial amount of sulphides), the glacial transports characteristics, and the degree of weathering of the till (see Tremblay and Paulen, 2012 on northern Melville Peninsula). Sulfide grains are present in higher amounts from Penrhyn Group area tills (up to 635 grains of pyrite and up to 45 grains of chalcopyrite, 9 grains of arsenopyrite on different samples, Figure 16) than in granite/gneiss derived tills, where the background concentration is close to zero grains per sample. Once the sulfide grains are comminuted in the till and subjected to post-glacial weathering, the till type has an important control on the preservation of sulfides grains. In the cold-based and intermediate cold-based areas, fewer sulfide grains are found in the heavy mineral fraction than in the warm-based zone. In the carbonate till zones (both from Paleozoic and Proterozoic sources) the combination of fine-grained matrix and buffering effect of carbonate reduces the rate of weathering of sulphide minerals (Shilts, 1993, Tremblay and Paulen, 2012), and therefore relatively more sulfides grains are possibly found. Also, chalcopyrite/

pyrite ratios tend to increase with the level of alteration of the till (Averill, 2001), as observed notably on Northern Melville Peninsula (Tremblay and Paulen, 2012). In the host rocks, especially in most of the mineralized areas, pyrite is observed to be more abundant than chalcopyrite. In the tills, the chalcopyrite/pyrite ratio is observed to be higher than in the surrounding rocks. The weathering of the tills is probably an important factor on southern Melville Peninsula. In a similar manner, the pyrite/arsenopyrite ratio should increase with weathering (McMartin, et al., 2009, 2011) because pyrite is less soluble than arsenopyrite. Arsenopyrite is common in the metasedimentary tills, and especially high in some samples in the central Penrhyn Group near Barrow river (up to 9 grains per sample). These high concentrations are spatially linked with continental-scale As anomaly in the Penrhyn Group area in lake sediment geochemistry (Corrigan et al., 2009, Day, et al., 2009).

Base Metal Elements (Cu, Pb, Zn, Ni, Mo and S)

Two important anomalies in base metals elements are observed in tills located in Penrhyn Group rocks area (Figure 17: north of Hoppner Inlet, and between Barrow River and Wilson River. The anomalies add detail to those previously found by Dredge (2002) in till and Day et al. (2009) in lake sediments. An important anomalous base metal element is Zn, with many samples shown on Figure 18 with more than 300 ppm of Zn. Several samples with elevated values of copper (between 50 and 300 ppm) and nickel (between 50 and 500 ppm) are located within these base metals anomalous zones. Some of the anomalous samples were taken in areas proximal to gossans (see Figure 15 for locations of gossans), and this is reflected in the high amount of sulfur in the samples (Figure 17). These till samples may show a local geochemical enhancement due to proximity to mineralized source rocks. These geochemical anomalies might be linked with sulphidic, often graphitic, paragneiss and schist (chiefly sphalerite and pentlandite, with pyrrhotite, pyrite and chalcopyrite) in the Penrhyn Group rocks (Cameron; 1979).

Gold-related Elements (Au, As, W, Ag,

Sb, Bi, Se, Sb and Hg)

Elevated values in Au-related elements (Au, As, W, Ag, Sb, Bi, Se, Sb and Hg; Figure 19), and in particular As are located in till overlying (or derived from?) the Penrhyn Group rocks: a) south of Barrow River, b) south of Wilson river valley and c) north of Lyon Inlet. In these areas, Au values range mainly between 15 and 100 ppb. South of Wilson River, the samples show high values for various elements but gold content is low (<10 ppb Au); instead it is associated with base metals anomalies (Figure 17). While every Au-related element seems to be associated with each gold anomaly (Fig. 20), As (and associated arsenopyrite grains, Figure 16) is the element that seems to show the closest spatial correlation with gold. One sample collected near a gossan exceeds the upper detection limit of 10000 ppm of As (shown as a star on the map).

Gold Grains Counts

Visible gold grain counts in the till panned concentrate are of acute interest for gold exploration (Averill, 2001; McClenaghan, 2009; McClenaghan and Cabri, 2011) as they provide direct, unequivocal testimony of the occurrence of gold as well as the estimated distance of transport from the shape of grains (Figure 21; see Annex D for more details). Results were normalized to a 10 kg sample (labeled '10k' in Annex C and D), based on the original Table feed weight. The background gold grains content in till is very low (close to zero), and important anomalies are located: a) south of Barrow River and b) north of Hoppner Inlet. A concentration of 3 to 60 grains of gold per 10 kg till sample are typical in these two areas. Most of the grains have reshaped or modified shape, and only a few are pristine (cf., DiLabio, 1990); this in contrast with the observation that glacial transport is limited in these areas from different data. Original gold grain shape modifications by pedochemical alteration might explain the lack of pristine gold grains close to assumed sources. Also, gold and silver -rich spherical grains were found in gold grain-rich tills located in one of the main gold anomalies area (Averil, pers. comm. 2011). These spherical gold grains occurs in an area where gold grains are commonly found, but the natural process responsible for the formation of these spherical grains is unknown.

A compilation of Au data from till geochemistry is shown in Figure 22 (including data from this project and from Dredge, 1995; 2002), gold grains (this paper) and lake sediments (Day et al., 2009; authors mention that normally sample size is in majority under 30 g, therefore important variance is expected in the Au results). The same gold anomalies (south of Barrow river and north of Hoppner Inlet) are found in each sample media. In the northernmost Penrhyn Group area, a gold anomaly found in lake sediments is not observed in either gold grains or till geochemistry. This is an exceptional situation, and the explanation for the lack of coherence of till and lake sediment data is unknown. Also, some lake sediment anomalies in the eastern part of Penrhyn Group were not till-sampled by the present survey and still represent unknown potential area for Au. The Penrhyn Group Au anomalies presented in this report seem to be considerably higher in size and magnitude relative to the Prince Albert Group belt anomalies presented in the north of Figure 22 and detailed in Tremblay et Paulen (2012).

Metamorphosed or magmatic massive sulfides indicator minerals (MMSIM)

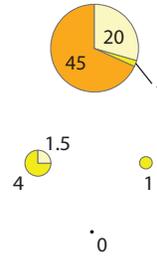
A diverse set of MMSIMs was picked by ODM in the till NFHMC (figures 23 and 24; see Annex D). Specific zones of interest, possibly linked with the presence of base metals (Averill, 2001) and gemstones, are delimited by the abundance of these minerals grains. The MMSIMs present in the mineralized areas of Penrhyn Group rocks (Barrow and Wilson rivers areas) are characterized by both their quantity and diversity relative to surroundings rocks (Figure 23). Gemstone minerals are also present in till. While being considered as potential MMSIMs, they represent economical potential on their own (Figure 24). The gem minerals found in till seems to be spatially linked with the MMSIMs-rich, gossaneous areas of the Penrhyn group rocks.

The samples with high MMSIMs counts spatially correlated to gold and/or base metals anomalies areas are different for each area. South of Barrow river, the most common MMSIMs are: tourmaline, red rutile, monazite, chondrotite, Cr-V grossular, sapphirine (gem: ruby and CrV grossular). In the Wilson river valley, MMSIMs comprised: Red rutile, spinel (non-gahnite), chondrotite, monazite (gem: topaz).

Figure 21. Pie plots showing gold grains in till counted in heavy mineral pre-concentrates. Data is normalized to a sample weight of 10 kg (table feed). The size of the pie circle is proportional to the sum of the grains picked for each sample.

Gold grains in till (10 kg samples)

- Reshaped
- Modified
- Pristine



Bedrock geology

- Paleozoic carbonates
- Penrhyn Group, sup. member (no marbles)
- Penrhyn Group, inf. member (marbles rich)
- Prince Albert Group
- Precambrian granite/gneiss

Glaciodynamic setting

Warm-based area

Cold-based area, intermediate

Cold-based area

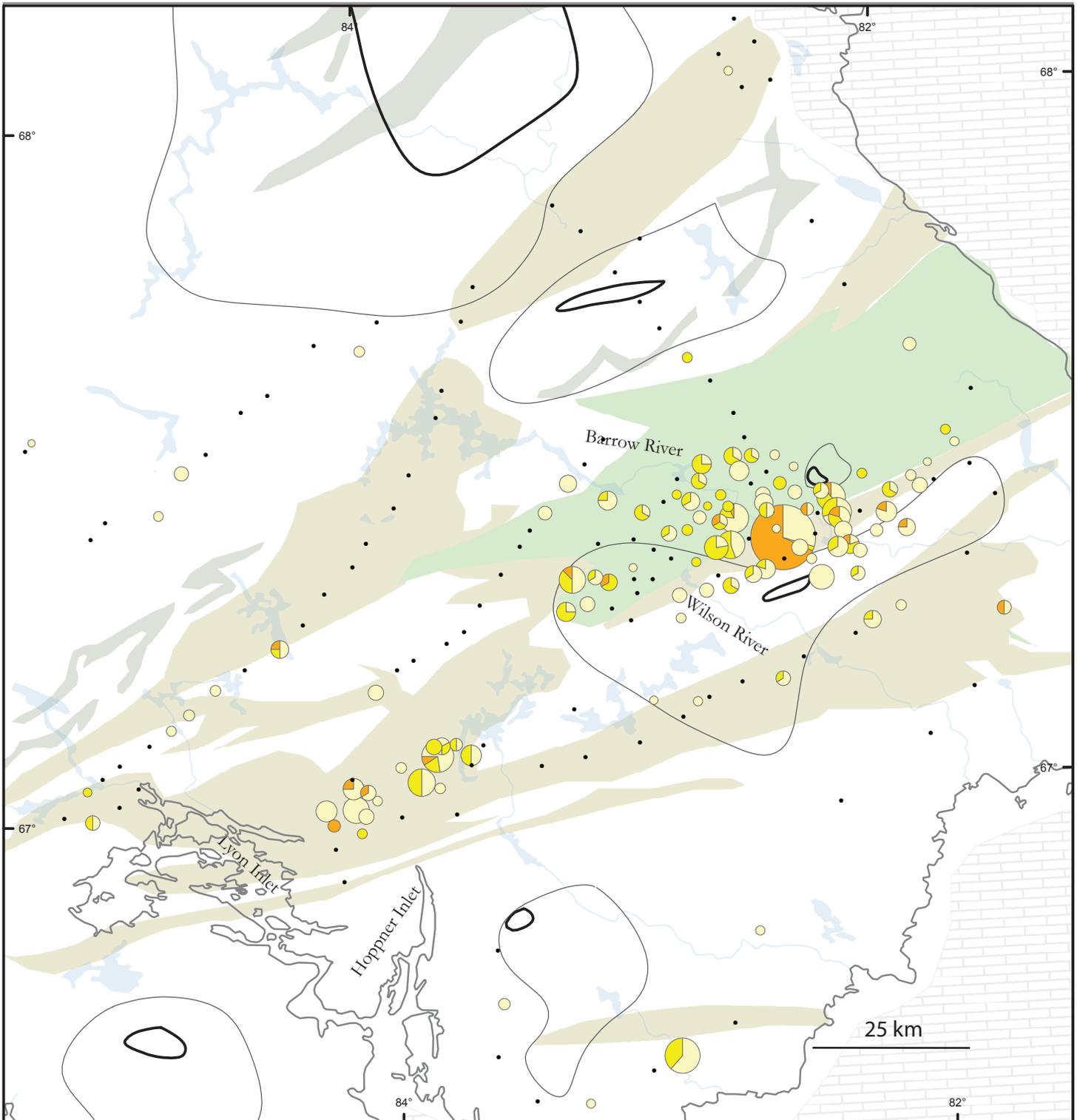


Figure 22. Composite map showing gold grains in till counted in heavy mineral pre-concentrates (normalized to a sample weight of 10 kg [table feed]), gold geochemistry in till <63 μm fraction (Dredge, 1995, 2002 and 2009; Tremblay and Paulen, 2012 and this paper, indicated by white dots), and gold geochemistry in lake sediments. GR/GN: Precambrian granite and gneiss; PAG: Prince Albert Group Archean supracrustal rocks; PEN: Penrhyn Group Paleoproterozoic supracrustal rocks; CARB: Paleozoic carbonate rocks.

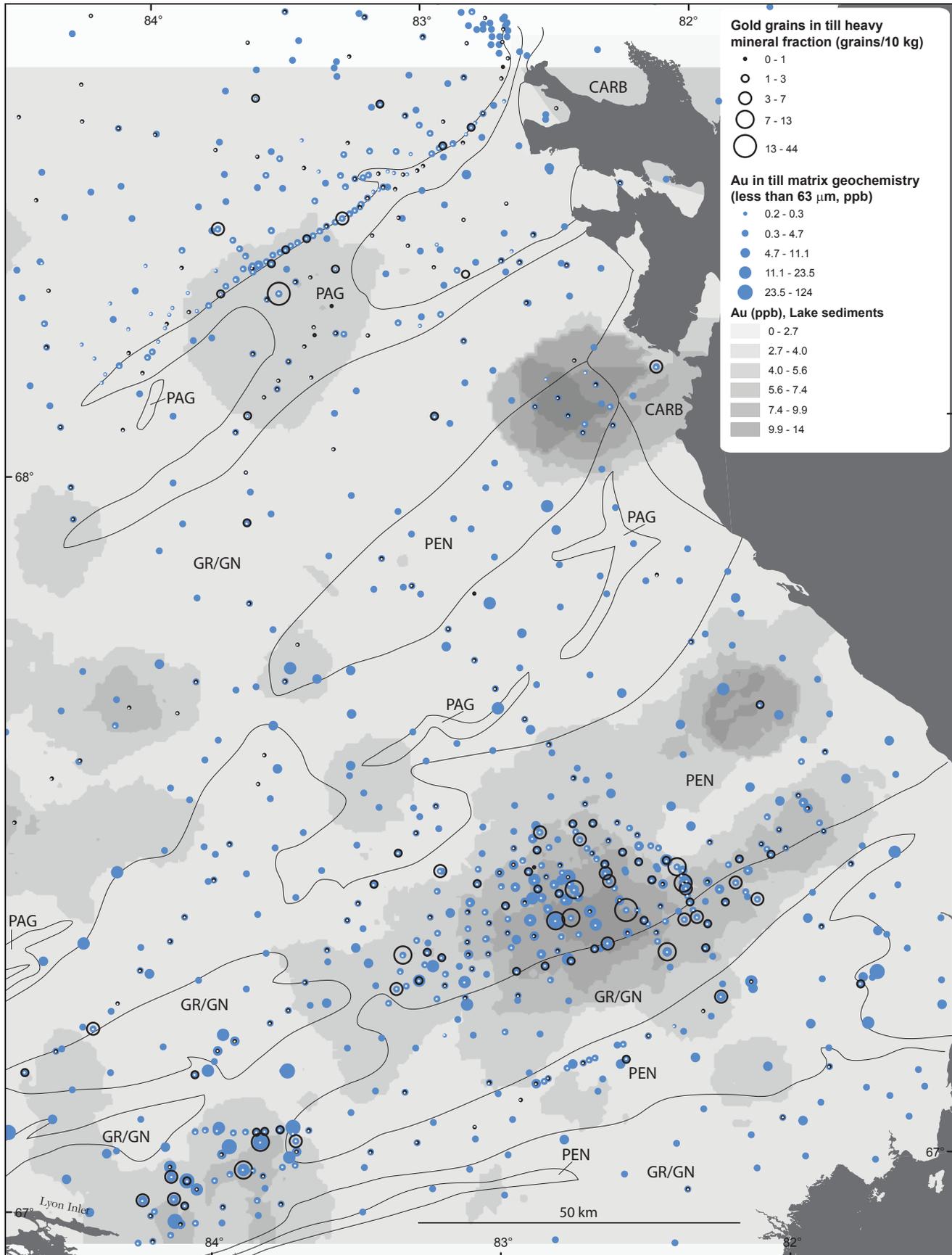


Figure 23. Pie plots showing MMSIMs grains in till counted in NFHMC (excluding gem minerals). Data is standardized to a sample weight of 10 kg (table feed). The size of the pie circle is proportional to the sum of the grains picked for each sample. For easier display, spinel (non-gahnite) is divided by a factor of 4 (number in brackets).

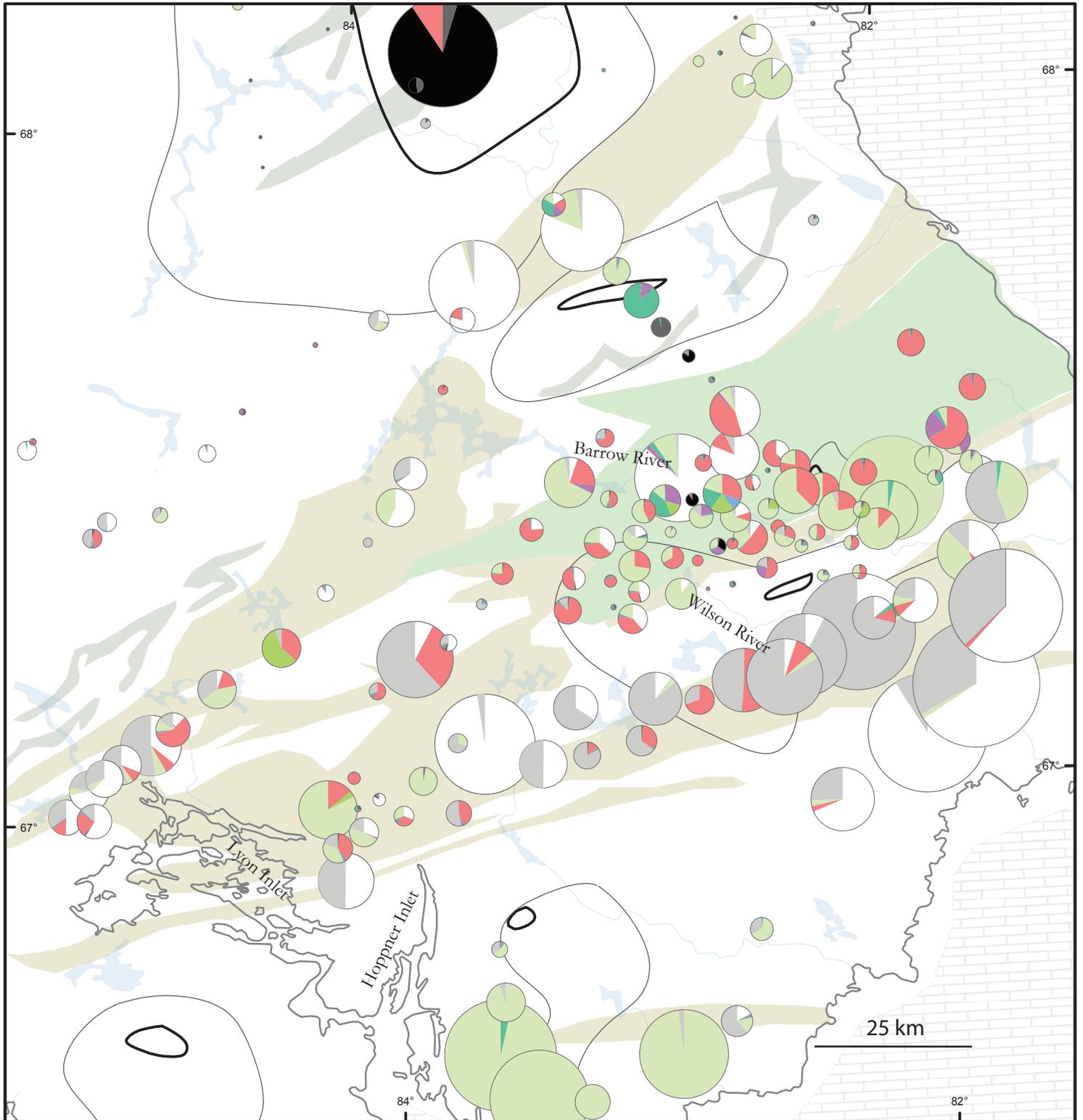
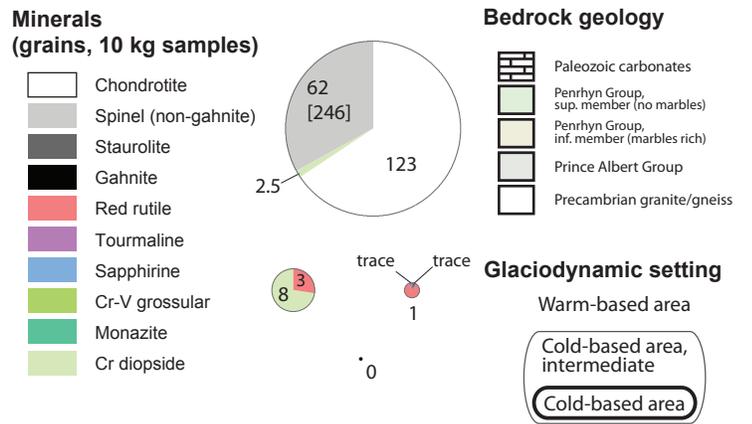


Figure 24. Pie plots showing gem minerals within MMSIMs in till counted in NFHMC. Data is standardized to a sample weight of 10 kg (table feed).

Minerals (grains, 10 kg sample)

- Topaz
- Sapphire
- CrV grossular
- Ruby



0

Bedrock geology

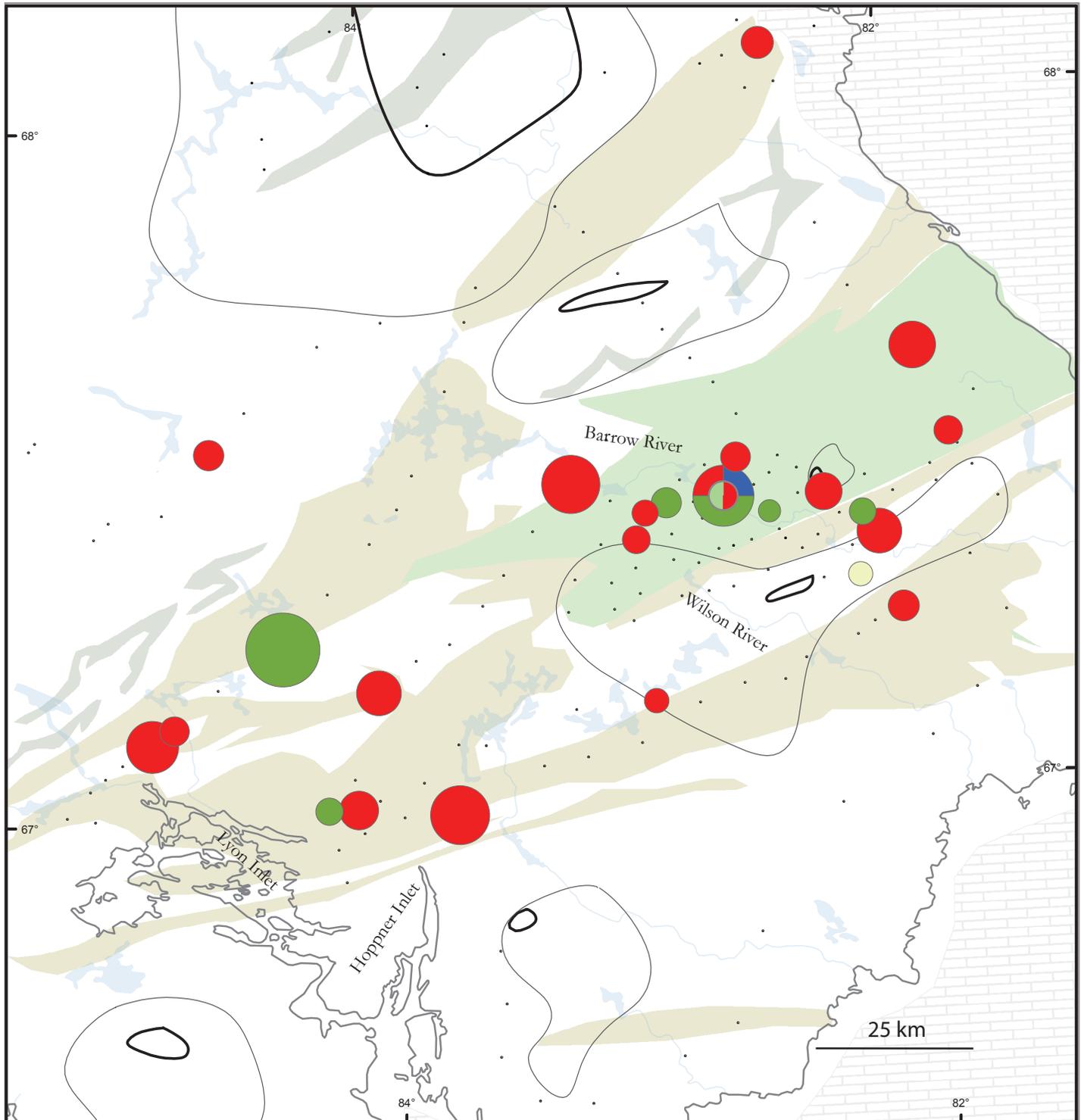
- Paleozoic carbonates
- Penrhyn Group, sup. member (no marbles)
- Penrhyn Group, inf. member (marbles rich)
- Prince Albert Group
- Precambrian granite/gneiss

Glaciodynamic setting

Warm-based area

Cold-based area, intermediate

Cold-based area



Finally, north of Lyon Inlet gems are found: ruby and Cr-V grossular.

Field and laboratory geological observations of the MMSIMs minerals in Melville Peninsula rocks from David Corrigan (pers. comm. 2011) links the MMSIMs minerals found in till (Figure 23) with various possible source rocks and associated mineralizations. Gahnite is typically associated with metamorphosed VMS deposits and Sedex deposits (Spry and Teale, 2009) and are found in the central Melville Prince Albert Group rocks and tills (Tremblay and Paulen, 2013). Red rutile is common in metamorphosed pelite from the Penrhyn Group, explaining its presence in the overlying tills. Chondrotite is typically common in the marbles and the skarns (replacing olivine), and is common in Penrhyn group rocks where marbles are present, they also are found in nearby tills. Cr-diopside found in tills located south-east of Hoppner Inlet may be related with the occurrence of mafic (opx-cpx-plag) xenoliths found in charnockites, where they are found to be bright green indicating the presence of chrome. South of Barrow river, the diversity of MMSIMs (tourmaline, red rutile, monazite, chondrotite, Cr-V grossular, sapphirine, as well as ruby) might indicate metamorphosed hydrothermal alterations.

Kimberlite indicator mineral (KIM)

Potential KIMs recovered from till heavy mineral fractions (Figure 25) are key components in diamond exploration in the glaciated terrain of northern Canada (Armstrong, 2009). Except for olivines (forsterite) in several samples and 1 Cr-diopside (Sample 10CXAT-188, identified by SEM), no other KIMs were found in the samples from study area (see Annex D). The olivines and Cr-diopsides could alternatively originate from non-kimberlitic rocks such as mafic or ultramafic intrusive (Averill, 2001, 2009). Olivines could also originate from marbles of the Penrhyn Group. Close to the hamlet of Naujaat (Repulse Bay), where no samples was taken, kimberlites pipes were found by exploration companies (Armstrong, 2009; Stornoway Diamonds, 2013).

Other minerals of interest for mineral exploration

Small-sized thoriumite/uraninite grains were found

in 53 samples in the study area, with sometimes up to several thousand grains found in some samples located north of Hoppner Inlet (Figure 26, see ODM report in Annex D). The U content of the thoriumite/uraninite grains is typically 30-40%, from SEM analysis. Potential for uranium is well known from past mineral exploration activities, U anomalies in lake sediments (Maurice, 1979; Day and al., 2009) and radiometric aerial survey (Corrigan, et al., 2010). Sperrylite is also found in 6 samples (1 or 2 grains per samples), indicating potential Pt anomalies north of Hoppner and Lyon Inlet, and south and east of Barrow River. Sperrylite is also an occasional indicator mineral of gold deposits (McClenaghan, 2009).

Mineralized boulders

In the course of field seasons 2009 and 2010, 102 mineralized float boulders were sampled and sent to the laboratory for assay (See Annex C). Rusty mafic, ultramafic and banded iron-formation rocks were sampled in central Melville Peninsula, and rusty metasediments and gossaneous rocks were sampled in the Penrhyn Group area in southern Melville Peninsula. The results shown on Figure 27 highlight the anomalous results in boulders geochemistry of Ni, Cu, Ag, Au and Mo. They are confirming the mineral potential of the mafic and ultramafic rocks of Prince Albert Group central belt (with notably one sulfide-bearing ultramafic boulder at 1.3% Ni and 0.3-0.4% Cu). This boulder was sampled in a zone with moderate glacial transport distance (Tremblay and Paulen, 2012) in warm-based terrain, it probably comes from nearby Prince Albert Group rocks within a few kilometers. In the Penrhyn Group belt, metasediment and quartz vein samples assayed notable amounts of Zn (0.2-0.3%) and Cu (0.01-0.1%), and one metasediment sample assayed high values of Ag and Mo. Au results were general quite low (under 100 ppb), and not easily spatially correlated with till or lake geochemical anomalies, probably because the gold-bearing rocks were not easily identified on the field amongst the other, non-gold-bearing mineralized boulders.

Conclusions

- The mapping of geomorphological and

Figure 25. KIMs or pseudo-KIMs grains counted in till. Data is standardized to a sample weight of 10 kg (table feed).

Minerals (grains, 10 kg sample)

- high Cr-diopside
- Olivine (fosterite)



Bedrock geology

- Paleozoic carbonates
- Penrhyn Group, sup. member (no marbles)
- Penrhyn Group, inf. member (marbles rich)
- Prince Albert Group
- Precambrian granite/gneiss

Glaciodynamic setting

Warm-based area

Cold-based area, intermediate

Cold-based area

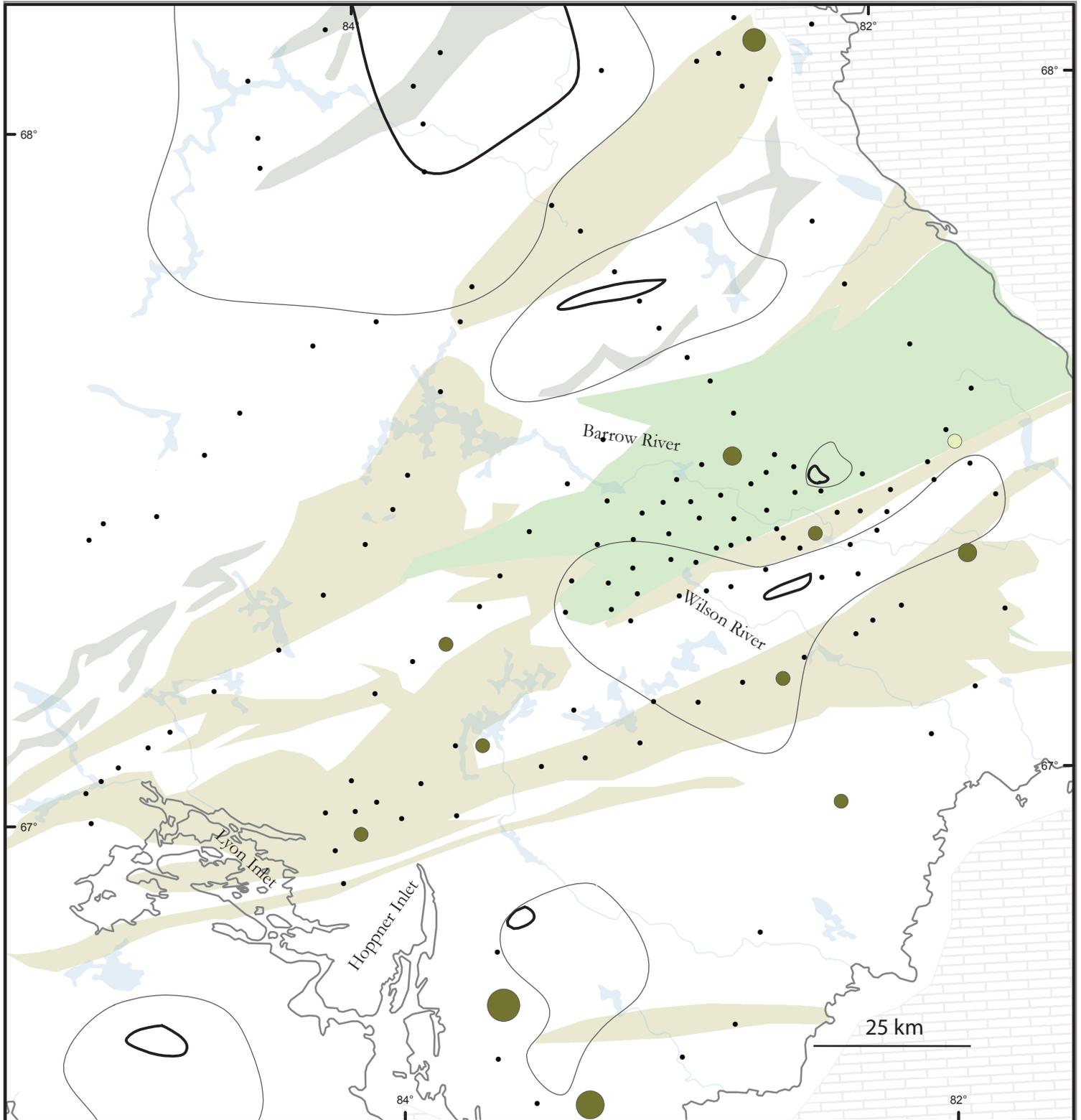
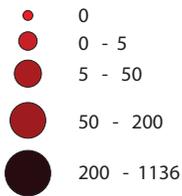


Figure 26. Thorianite and sperrylite grains counted in till. Data is standardized to a sample weight of 10 kg (table feed).

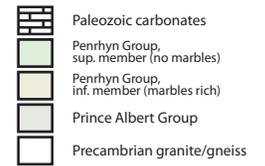
**Thorianite grains
(10 kg samples)**



**Sperrylite grains
(10kg samples)**



Bedrock geology

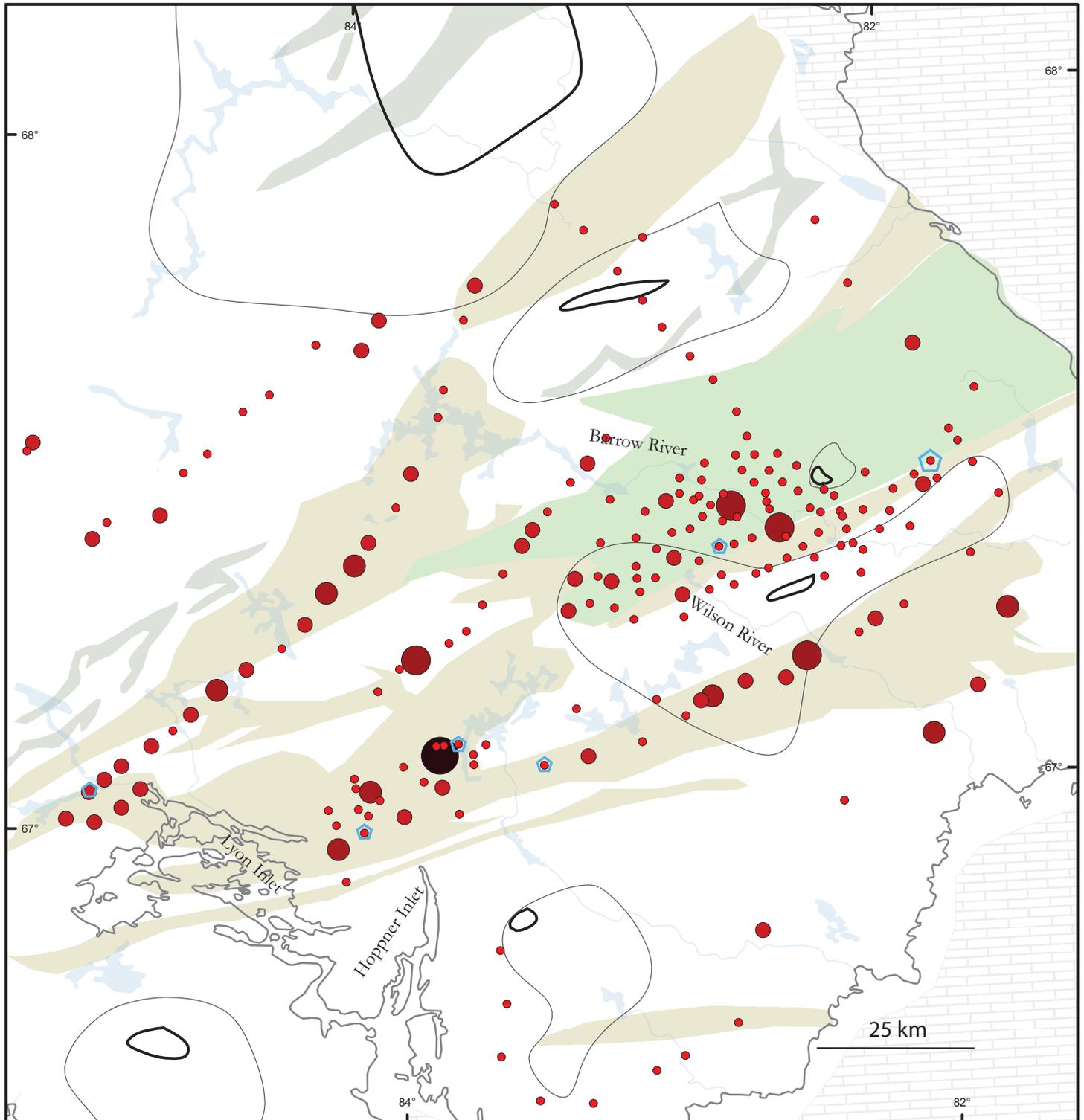


Glaciodynamic setting

Warm-based area

Cold-based area, intermediate

Cold-based area



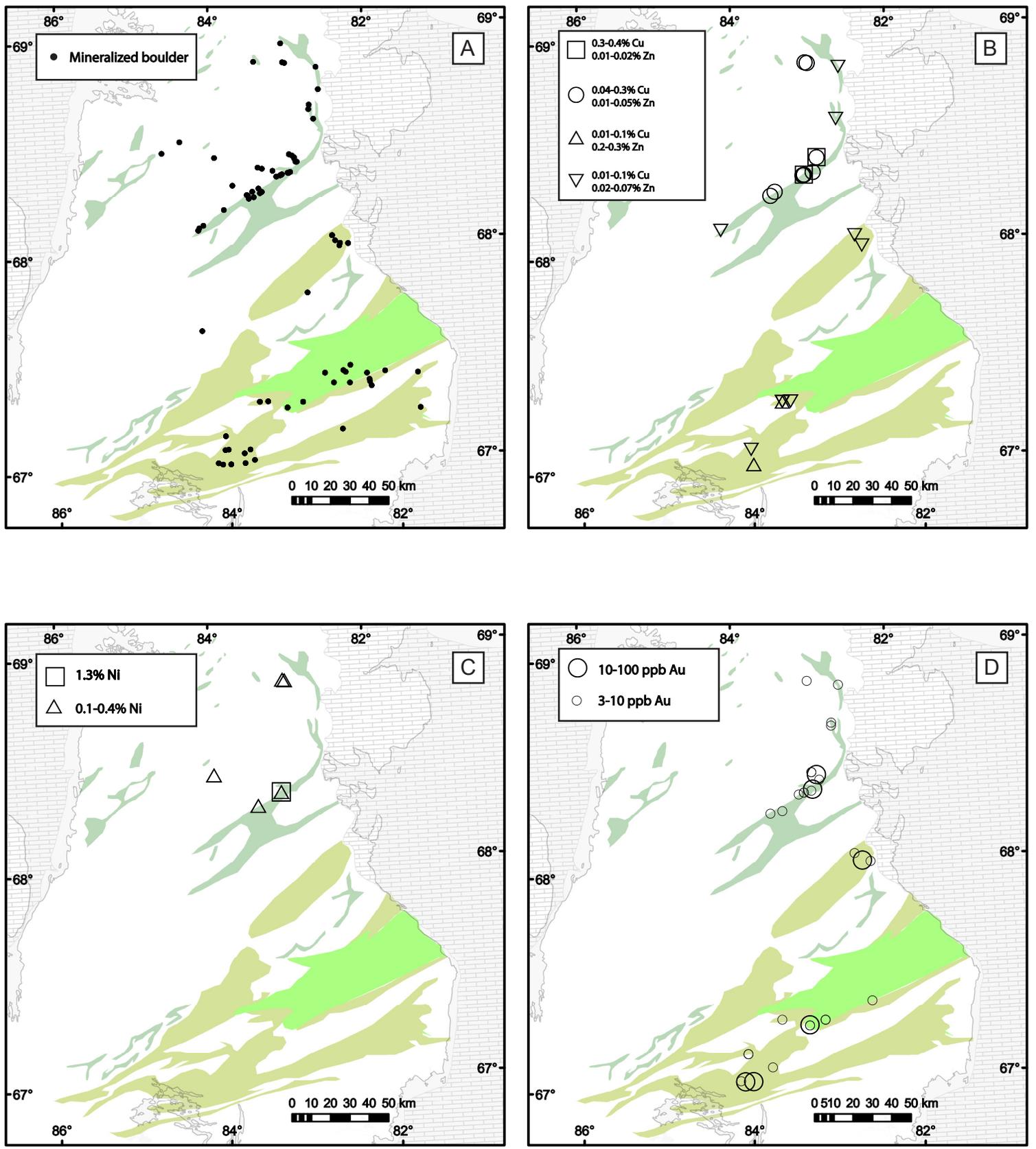
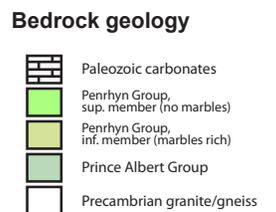


Figure 27. Mineralized boulders maps, showing anomalous values for Au, Cu-Zn and Ni. A. Mineralized boulders location; B. Cu and Zn anomalies; C. Ni anomalies; D. Au anomalies.



sedimentological indicators identified tills from warm-based areas (dominated by different characteristics depending on provenance from granite-gneiss rocks, metasediments, marbles and/or Paleozoic carbonates rocks), and cold-based areas. The cold-based zones are divided into the pervasive and intermediate zones, associated with drastic reduction of glacial transport distances, especially within the pervasive cold-based zones. The occurrence of weathered, formerly glaciated surfaces on some cold-based areas might indicate these surface are pre-last glaciation in age.

- The glacial transport of erratics (i.e., Penrhyn Group rocks, Paleozoic carbonate rocks) indicates moderate to little glacial transport for most of southern Melville Peninsula, except close (within 10km) to the coast and near Rae Isthmus and Lyon Inlet.
- On southern Melville Peninsula, the LGM and post-LGM ice flow history is divided into two main phases:
 1. Early flow, possibly occurring during the last glaciation (from LGM to early deglacial).
 2. Late flow, occurring while ice retreated from Foxe Basin and Hudson Strait.
- New data from analysis of till matrix geochemistry and heavy mineral mineralogy (i.e., gold grains, KIMs, MMSIMs) illustrate mineral prospectivity in southern Melville Peninsula for Au, base metals (notably Zn, Ni and Cu), uranium and gemstone minerals, focusing mainly in the Penrhyn Group rocks. Au in less than 63 μm fraction geochemistry in till is spatially correlated with graphitic metasediments clasts content, As in till geochemistry, arsenopyrite grains in heavy mineral fraction, various MMSIMs (notably red rutile and tourmaline), sperrylite grains, gold grains in till and Au in lake sediments geochemistry.

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