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Publications in this series have not been edited; they are released as submitted by the author.

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COMPOSITION OF TILL AND BEDROCK ACROSS THE GREAT BEAR MAGMATIC ZONE: QUATERNARY FIELD DATABASE AND ANALYTICAL RESULTS FROM THE GEM IOCG-GREAT BEAR PROJECT

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INTRODUCTION

An applied Quaternary activity under the Geological Survey of Canada five year Geo-mapping for Energy and Minerals Program (GEM) was started in the Great Bear magmatic zone (GBmz) of the Northwest Territories to characterize the heavy mineral and geochemical signature of iron oxide copper-gold (IOCG) deposits in derived glacial sediments. The GBmz (Fig. 1) is now considered the most prospective setting for IOCG and affiliated deposits in Canada (Corriveau, 2007; Corriveau et al., 2010). It includes two economic IOCG deposits, the magnetite-group NICO Au-Co-Bi-Cu deposit and the nearby magnetite- to hematite-group Sue-Dianne Cu-Ag-(Au) deposit, as well as several other polymetallic occurrences, prospects, and deposits, many of which fall within the larger family of iron-oxide alkali-altered (IOAA) alteration and mineralizing systems (Mumin et al., 2007, 2010; Corriveau et al. 2010; Porter, 2010). An orientation study at the NICO deposit originally completed as part of the TGI-3 initiative showed that the composition of iron oxide grains in till compared to that of bedrock, gold grain abundance, size and shape, as well as pathfinder elements (i.e. As-Bi-Co-Au-Cu-Sb-W-Cd) in surface till, had potential to fingerprint the mineralization at NICO (McMartin et al., 2009a, 2009b, 2011a, 2011b). As a follow up to this initial study, a doctoral research project at McGill University was undertaken to develop a drift prospecting approach to IOCG exploration across the GBmz using pathfinder and alteration-related elements in glacial sediments, and the indicator mineral method. This work is part of the joint government-industry-academia IOCG-Great Bear Multiple Metals GEM project designed to refine IOCG±U exploration criteria and genetic models as well as increase our ability in finding IOCG mineralization in the GBmz and in other Canadian settings. The purpose of this Open File publication is to release the complete Quaternary datasets collected as part of the GEM IOCG-Great Bear Project in 2009 and 2010. Initial results are discussed in Normandeau et al. (2011a, 2011b, 2011c, 2012). Research is ongoing on the characterization of apatite as an indicator of IOCG mineralization and the use of multivariate elemental signatures in glacial sediments (Lypaczewski et al., 2013; Normandeau et al., submitted, in prep.). Iron oxide composition in the ferromagnetic fraction of till from the GBmz is also under study (McMartin et al., 2011c, in prep.; Dupuis et al., 2012a, 2012b; Sappin et al., submitted).

REGIONAL SETTING

Location and physiography

The project area lies between latitudes N 63.5° and 66.7° and longitudes W 116.2° and 118.4°, and includes the community of Gameti (Fig. 2). Drainage is towards the Arctic Ocean via rivers that drain into the MacKenzie River drainage basin. For much of the study area, elevations range from 170 m to 450 m a.s.l (Fig. 2). Supracrustal rocks and the variety of hydrothermal alteration zones they host generally form prominent ridges striking south-southeast/north-northwest. These ridges have relief exceeding 100

m and are dominated by exposed bedrock draped in places by thin, discontinuous till (<2 m thick). Great Bear intrusive rocks form more poorly drained lowlands often covered by thin till. The area lies within the Western Taiga Shield Terrestrial Ecozone of Canada at the northern edge of the boreal coniferous forest (Wiken, 1986). It is part of the Coppermine river Upland Ecoregion of Canada having a mean annual temperature of approximately -7.5° C (summer mean of 9° C; winter mean of -24.5°C) and a mean annual precipitation of 200-300 mm (http://ecozones.ca/english/region/68.html). It is characterized by extensive discontinuous permafrost for much of the area. The northernmost part of the area (north of Port Radium – Echo Bay) is underlain by continuous permafrost. In the southern part of the GBmz, brunisolic static cryosols have developed on the glacial sediments. Vegetation in the latter area is dominated by a mixed deciduous and conifer open forest cover. Turbic and Static Cryosols developed on sandy diamicton and glaciofluvial deposits are the dominant soils in the north where lichen-shrub tundra vegetation is more prevalent.

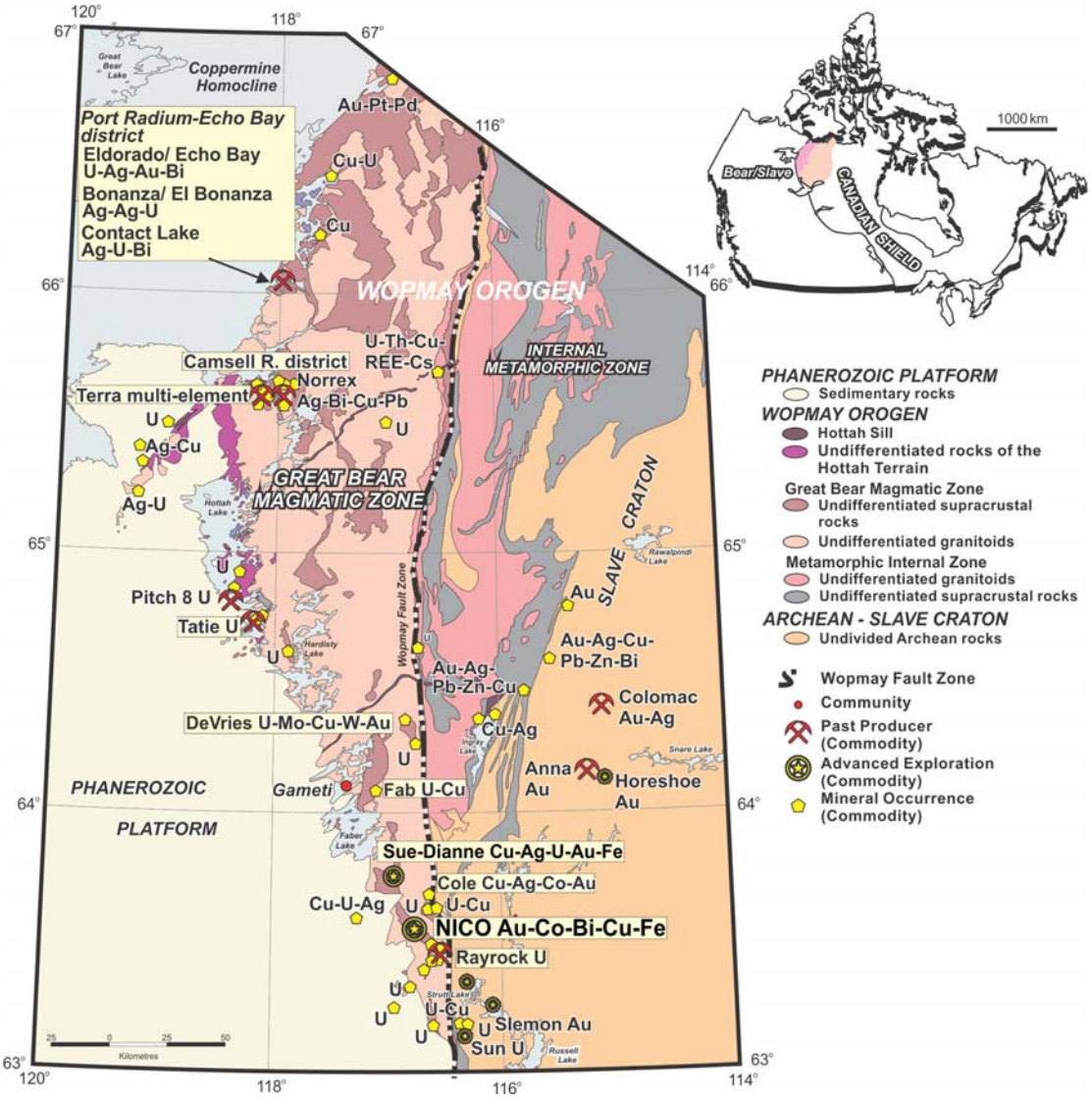

Figure 1. The Great Bear magmatic zone bedrock geology, mineral occurrences and past-producing mines (modified from Corriveau et al., 2010). Inset map locates the Wopmay orogen (Bear Province) and adjacent Slave craton at the western edge of the Canadian Shield.

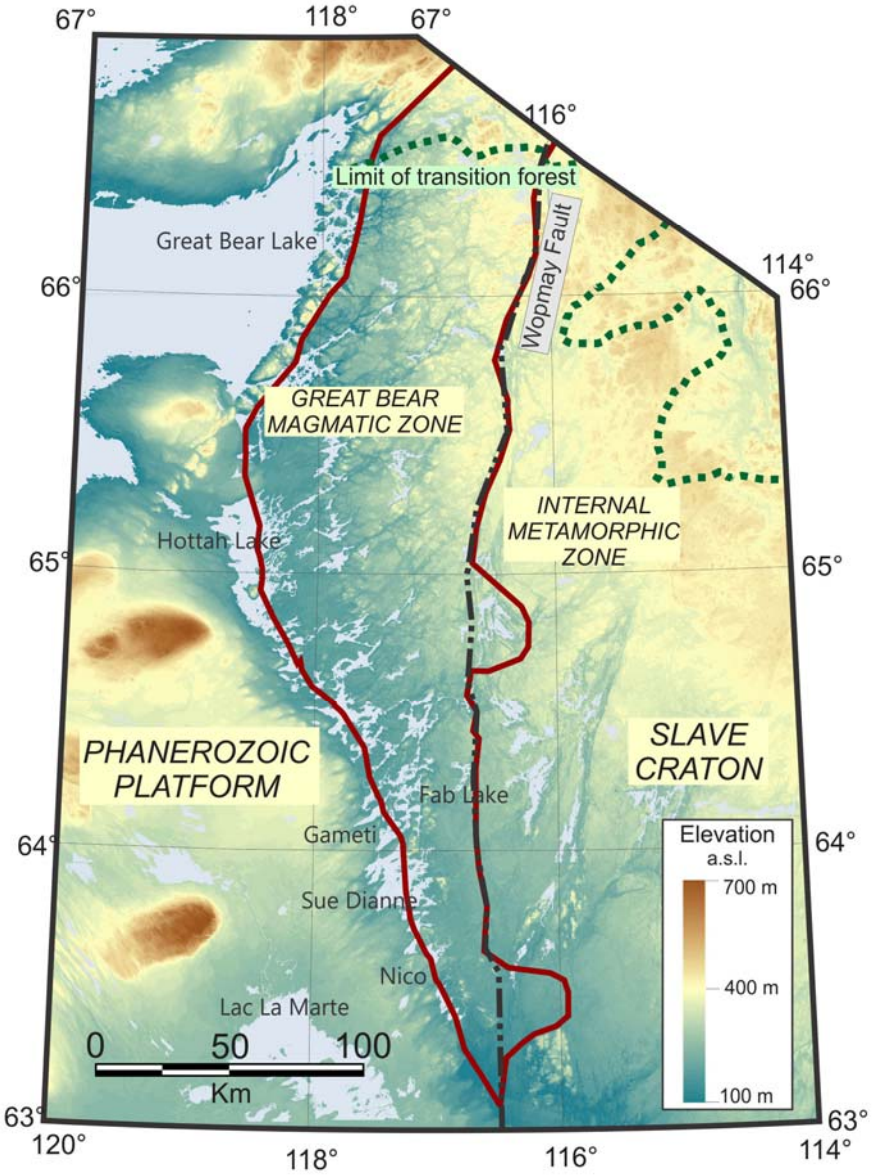

Figure 2. DEM generated from ASTGTM (30 m Aster digital elevation model). Study area is outlined in red. Thick green line represents the limit of transition forest, Atlas of Canada, 2003.

Bedrock geology and mineralization

The Great Bear magmatic zone is a Palaeoproterozoic 1.87-1.85 Ga calcalkaline volcano-plutonic arc accreted to the western margin of the Archean Slave craton during the short lived Calderian Orogeny responsible for the Wopmay Orogen at 1.88 Ga (Bowring and Grotzinger, 1992; Hildebrand et al., 2010). It is exposed between the Archean Slave Craton in the east and the Phanerozoic Cover to the west (Fig. 1). Formerly known for its vein-type uranium and silver mines, the Great Bear magmatic zone is currently the most prospective IOCG mineral belt in Canada (Corriveau et al., 2010). IOCG hydrothermal systems of the GBmz encompass a wide range of hydrothermal alteration types formed at the expense of a variety of volcanic, sedimentary, plutonic and metamorphic rock types. Their evolution history is well constrained within an IOCG alteration sequencing model (i.e. Corriveau et al., 2010).

The magnetite group IOCG NICO deposit is located in the southern part of the GBmz, about 160 km northwest of Yellowknife. It is an economically significant source of Au-Co-Bi-Cu-Fe with pre-production reserves of 33 Mt at 1.02 g/t Au, 0.11% Co, 0.14% Bi and 0.04 % Cu (Fortune Minerals Limited news release, February 02, 2012). Mineralization at NICO consists of three surface and sub-surface tabular zones, up to 1.5 km in length, that are hosted in hydrothermally-altered and locally brecciated marine siltstone and wacke of the ca. 1.88 Ga Treasure Lake Group below their unconformity with overlying 1.87 Ga felsic volcanic rocks of the Faber Group (Goad et al., 2000a, 2000b; Gandhi et al., 2001; Gandhi and van Breemen, 2005). The magnetite to hematite-group IOCG Sue-Dianne deposit is located 25 km north of the NICO deposit. It is an iron-hosted, polymetallic deposit with indicated resources of 8.4 Mt @ 0.8 % Cu and 3.2 g/t Ag (Hennessey and Puritch, 2008). It is hosted in the Faber Lake volcanic sequence and was formed in well-preserved rhyodacite ignimbrite sheets during the development of a structural-hydrothermal diatreme breccia complex. These volcanic rocks are intruded by various felsic porphyry dykes and sills and quartz veins in the vicinity of the deposit.

The Port Radium-Echo Bay district hosts polymetallic mineral showings with typical features of iron oxide-apatite deposits (e.g., K-2 and Mag Hill prospects at depth and the past-producing Echo Bay mine area) and magnetite- to hematite-group IOCG deposits (e.g. K-2, Mile Lake, Breccia Island, Hoy Bay and Birchtree) in the classification scheme of Williams (2010). The Camsell River district is centered on the past-producing Terra (Ag-Ni±Co-Bi) and Norex vein-type deposits (Badham, 1972, 1975; Hildebrand, 1986) hosted among Kiruna-type and IOCG-type alteration and mineralization (Walker and Rajnovich, 2007; Acosta et al., 2011). Other extensive IOAA-type and IOCG hydrothermal systems of the GBmz include Fab, Damp, Hump, Cole, Ham, JLD, Sunil, Peanut, Esther, DeVries, Dennis and Hailstone. Detailed descriptions of these systems are provided in Corriveau and Montreuil (in prep.).

Quaternary Geology

During the last Wisconsinan glaciation, the GBmz was affected by Keewatin Sector Ice of the Laurentide Ice Sheet (e.g. Dyke and Prest, 1987) and lay west of a major ice divide in Keewatin (Dyke, 2004). Only reconnaissance-scale Quaternary mapping with limited field work is available for the study area. The Glacial Map of Canada depicts streamlined forms oriented west-southwest to west, striations predominantly indicating a westerly flow and a handful of esker segments (Prest et al., 1968). Areas of maximum glacial lake coverage located within the depression between Great Slave and Great Bear lakes are also shown on this map. The Surficial Materials Map of Canada (Fulton, 1995) and the 1:1 million scale glacial features compilation of Aylsworth and Shilts (1989) show the study area as a drift-poor area (>80% bedrock outcrop) with small areas of undifferentiated materials, mainly thin till. A series of north-south moraine ridges in the eastern portion of the GBmz, part of the Forcier Moraine identified by St-Onge et al. (1981) and the Rebesca Moraine, indicate major ice recessional positions within the GBmz (Fig. 3).

Field observations collected as part of the project indicate that the sediment cover over the GBmz is dominated by discontinuous, thin (<2 m) silty sand till. Above 270 m a.s.l., till is rare but can be found as lee-side deposits of prominent outcrops. Late during deglaciation, Glacial Lake McConnell occupied most of the area below 300 m a.s.l. from ca. 8.5 to 10.5 ka BP (Dyke, 2004) as a result of glacioisostatic depression reversing the regional drainage in the Great Bear, Great Slave and Athabasca lake basins (e.g., Lemmen et al., 1994; Smith, 1994). Evidence for reworking of glacial sediments by glaciolacustrine

processes is present in areas covered by the glacial lake as veneers of silt and clay in topographic depressions, specifically around lake basins up to 10 m above actual water levels, or as veneers of winnowed till and littoral sands overlying the glacial deposits. Multiple shoreline levels indicated by paleobeaches of sorted and well-rounded cobbles (8 to 20 cm in size) were found in certain areas. These are characterized by little to no vegetation cover.

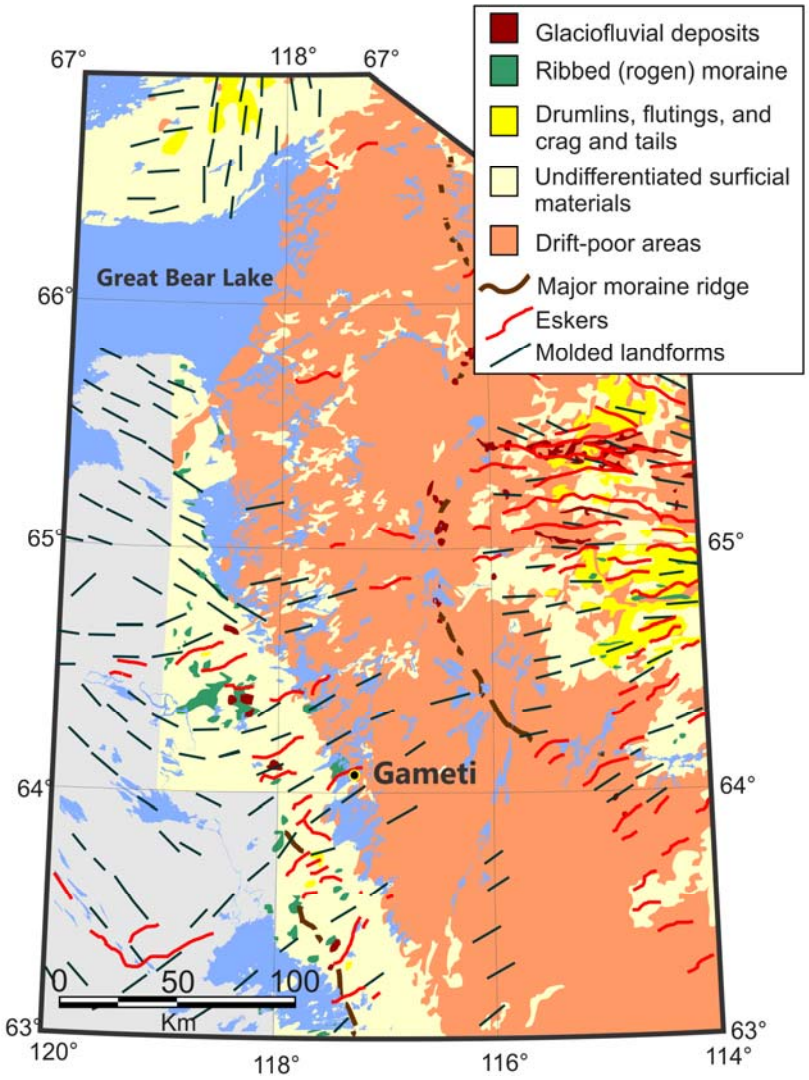

Figure 3. Regional Quaternary map for the study area. Location of major eskers and streamlined forms are derived from Fulton (1995); areas of streamlined drift, ribbed moraine, glaciofluvial deposits, drift-poor terrain and undifferentiated materials are from Aylsworth and Shilts (1989). The location of major moraine ridges are also shown. Areas in grey were unmapped by Aylsworth and Shilts (1989).

Ice-flow indicators measured on bedrock near sampling sites or along lake shorelines indicate that the area was influenced primarily by ice flowing to the west-southwest south of Hottah Lake and to the west-northwest north of the lake (see Appendix II for full datasets). Three distinct ice-flow phases were recorded in the study area (Fig. 4). Ice-flow indicators associated with Phases 1 and 2 consist of relict features preserved on protected (west) sides of outcrops. Phase 1 is better preserved and more commonly observed in the central part of the GBmz, and is concordant with megascale ice-flow indicators present west of the GBmz over the Phanezoic cover (Prest et al., 1968). It is north bound in the southern GBmz and shifts towards the northwest in the central GBmz. Observations of Phase 2 ice-flow indicators, trending towards the south-southwest (210°), are confined south of the 64th parallel. The orientation of Phase 3 indicators range from 225° to 305° across the GBmz, gradually shifting from west-southwestward

in the southern part of the GBmz to west-northwestward in the north. Phase 3 is the dominant ice-flow direction and is consistent with megascale streamlined forms present within and east of the study area.

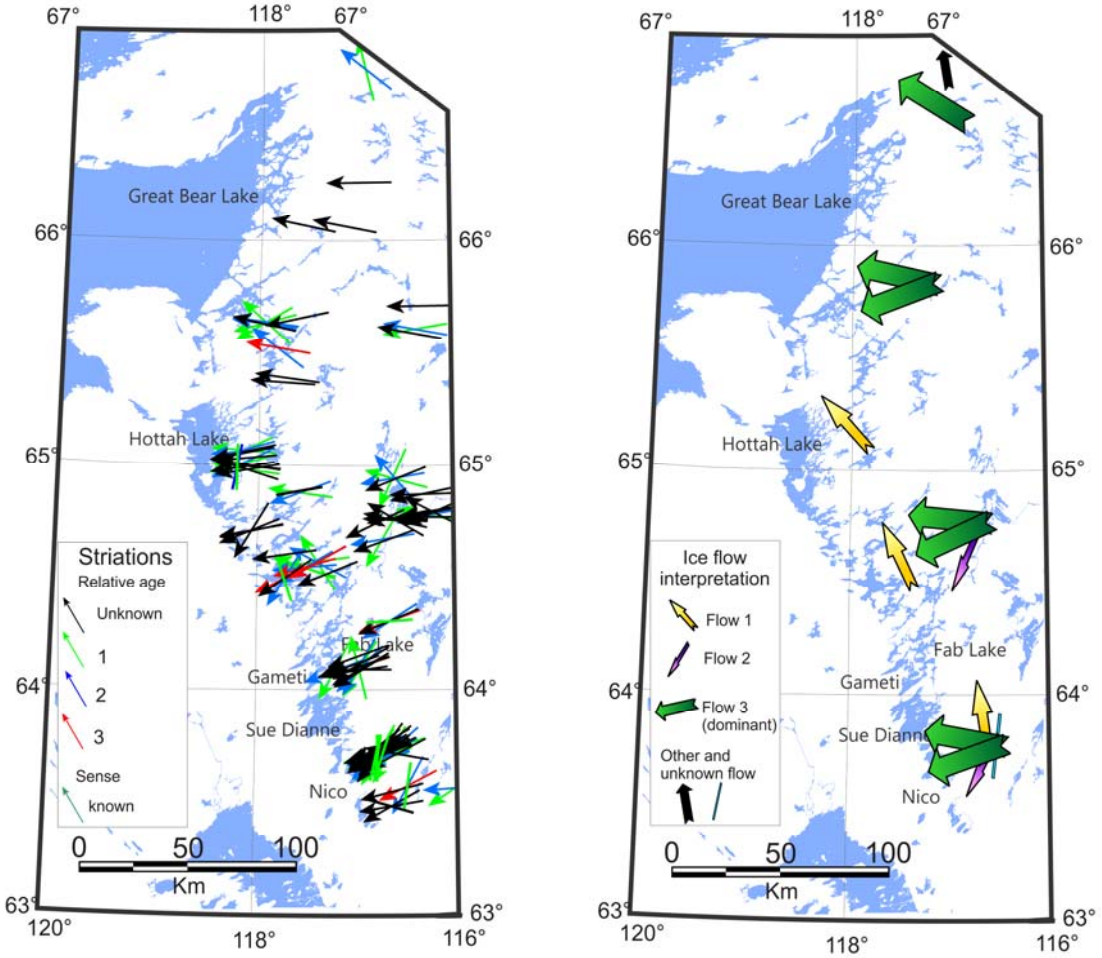

Figure 4. Erosional ice-flow indicator map showing trends and relative ages at each site (left map). Interpreted phases of ice-flow are shown on the map to the right.

Pebble lithology data show that till has a local provenance with a short distance of glacial transport (see Appendix XI for full datasets). For example, dispersal of heavily metasomatized clasts is observed less than 800 m down-ice of the Sue-Dianne deposit (Normandeau et al., 2011a). Dispersal train orientations are coherent with the dominant flow directions.

METHODS

Field procedures

Field data collection

Field work was completed from June 10 to July 24 in 2009 and June 29 to July 30 in 2010 by Philippe Normandeau with assistance from Isabelle McMartin and Louise Corriveau, as well as from a number of project participants from the GSC and the NTGO, students and local hires. Field activities in 2009 were concentrated around the Sue Dianne and NICO deposits, and showings at Hardisty, Fab, Isabelle, Grant and Little Crapeau lakes, and in 2010 around showings and hydrothermal systems at Fab, DeVries, Hottah and Grouard lakes, and in the Terra-Mine area (Fig. 1). Access was by helicopter, float

plane, boat or foot from Fortune Minerals Ltd. NICO camp, Gameti community, Grouard Lake GSC camp and NTGO field camps. Field work involved sampling site description, ice-flow indicator mapping, and till and bedrock sampling. A total of 270 sites were visited and are described in Appendix I.

Ice-flow indicator mapping

The orientation and sense of 165 small-scale erosional ice-flow indicators were measured from 106 sites in 2009 and 2010 (Fig. 4). Indicators included striations, grooves, moulded outcrop, crescentic fractures, and roches moutonnées (Fig. 5a). The sense of ice flow movement was derived from crescentic fractures and roches moutonnées, where present, or from stoss and lee topography (general shape of outcrop). Relative ages of striated facets were established at 30 sites. Detailed ice-flow indicator measurements and descriptions are provided in Appendix II.

Till sampling

A total of 101 till samples were collected across the entire GBmz in 2009 and 2010 in the vicinity of known deposits and showings hosted within large IOCG-type alteration systems (Fig. 6). Samples were collected proximal to, up-ice, and down-ice from mineralization, hydrothermally-altered host rocks and least-altered bedrock. Detailed sampling was completed around the Sue Dianne deposit and the Fab Lake showing. Samples were collected in the upper C-horizon soils developed on till from hand dug pits, at an average depth of 50 cm, to obtain relatively unaltered material (Fig. 5b). At each site, one small sample (~3 kg) and one large sample (8-26 kg; mean=16 kg) were collected. Permafrost or sometimes bedrock was encountered at the bottom of holes. Special care was taken to exclude layers of organic material or heavily oxidized clasts. Winnowed and modified tills were avoided as much as possible during sampling. One sample per block of about 25 samples was collected as a field duplicate to test site variability; it was taken randomly within each block (total of two samples per year). Of the 101 samples, 6 samples were collected <25 km up-ice (east) from the GBmz, in the Wopmay internal metamorphic zone and in the Slave Province and represent non-altered background sites. Detailed till sample locations and descriptions are provided in Appendix III.

Figure 5. Photographs of 1) southwestward (208°) deep striae preserved on the lee side of surface striated by younger west-southwestward flow (249°) near Gameti. Arrows indicate sense of flow (left photo); 2) hand-dug hole in C-horizon till with small and large sample bags collected at sample site (right photo).

Bedrock sampling

A total of 71 representative 1 to 3 kg surface bedrock samples were collected in 2009 and 2010 for indicator mineral recovery at most till sample sites, in the vicinity of and at nearby surface deposits and showings (Fig. 6). In addition, 24 smaller (118 to 1313 g) leftover crushed bedrock samples collected in 2009 and 2010 by project participants for lithogeochemistry were selected in 2011 for indicator mineral processing and recovery. Detailed bedrock sample locations and descriptions are given in Appendix III.

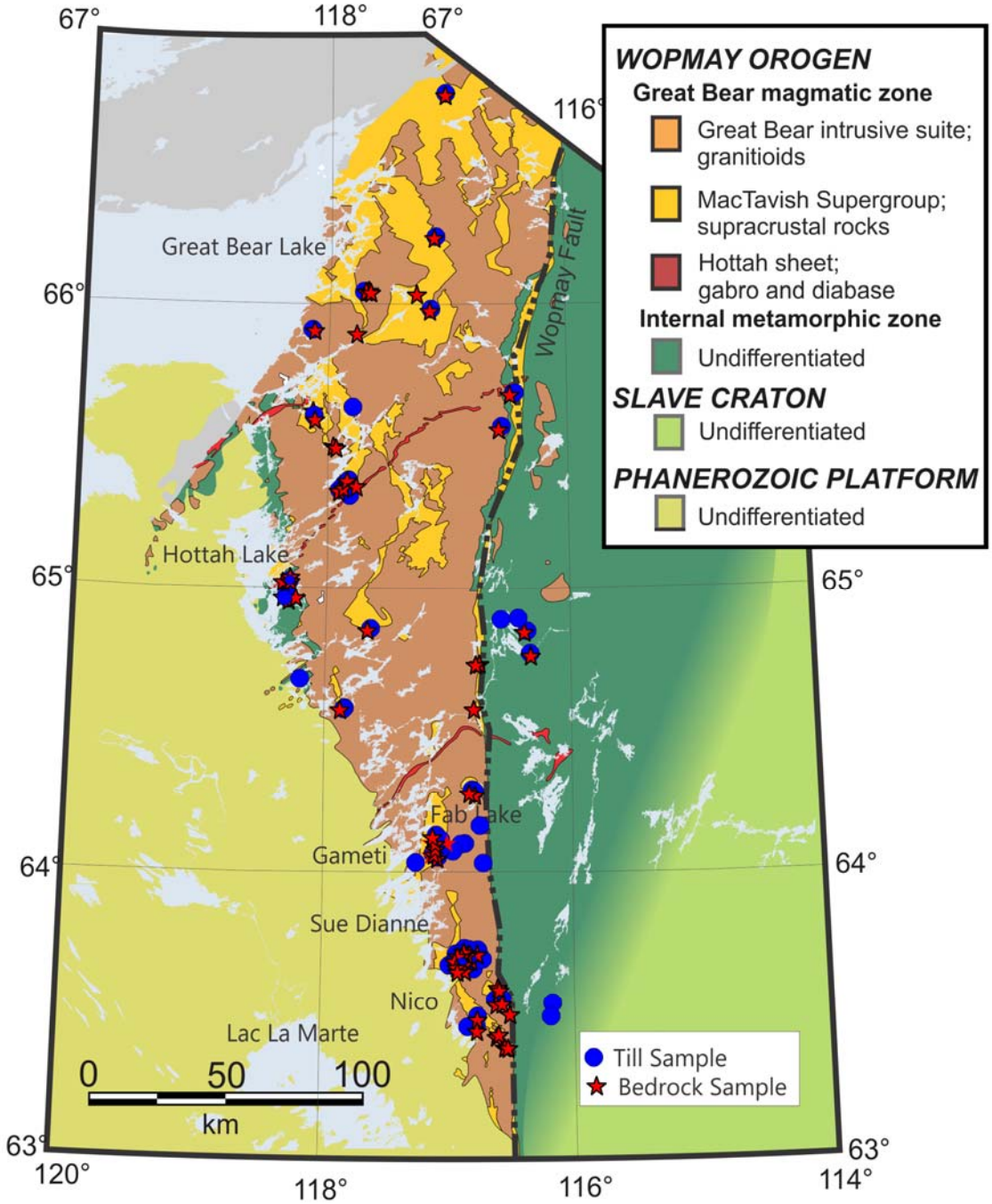

Figure 6. Sample location map. Detailed description and location of the samples are given in Appendix III.

Analytical procedures

Sample preparation

Preparation of each of the two till sample sizes was different (Fig. 7). The clay-sized fraction (<0.002 mm) of about 300-500 g from the small 3-kg samples was separated by centrifugation and decantation in GSC's Sedimentology Laboratory using the methods described in Girard et al. (2004). A 2-kg split of all 3-kg samples was air-dried and dry-sieved in the Sedimentology Laboratory using a stainless steel 230 mesh screen to obtain the <0.063 mm fraction for geochemical analysis. An order of processing from the potentially least metal-rich to the most metal-rich samples was given and followed in each sample batch (2009 and 2010) to limit cross-contamination. The remainder (<800 g) of the original 3-kg till samples was archived at the GSC, Ottawa. The large till samples were shipped to Overburden Drilling Management Ltd (ODM) for processing and the production of heavy mineral concentrates. Samples were disaggregated in water and screened at 2 mm to produce a non-ferromagnetic heavy mineral concentrate (NF-HMC) for picking indicator minerals and a ferromagnetic fraction (FM-HMC) for further studies on iron oxides. The oversize material was wet-sieved to collect the 4-9 mm fraction for lithological analysis. Samples collected near mineralized zones with potentially high concentrations of sought indicator minerals were processed at the end of the batch in each year to limit cross-contamination, and results are given in the order they are listed in the ODM raw data file in Appendix XII. Sample preparation and analytical procedures for all till samples are summarized in Figure 7.

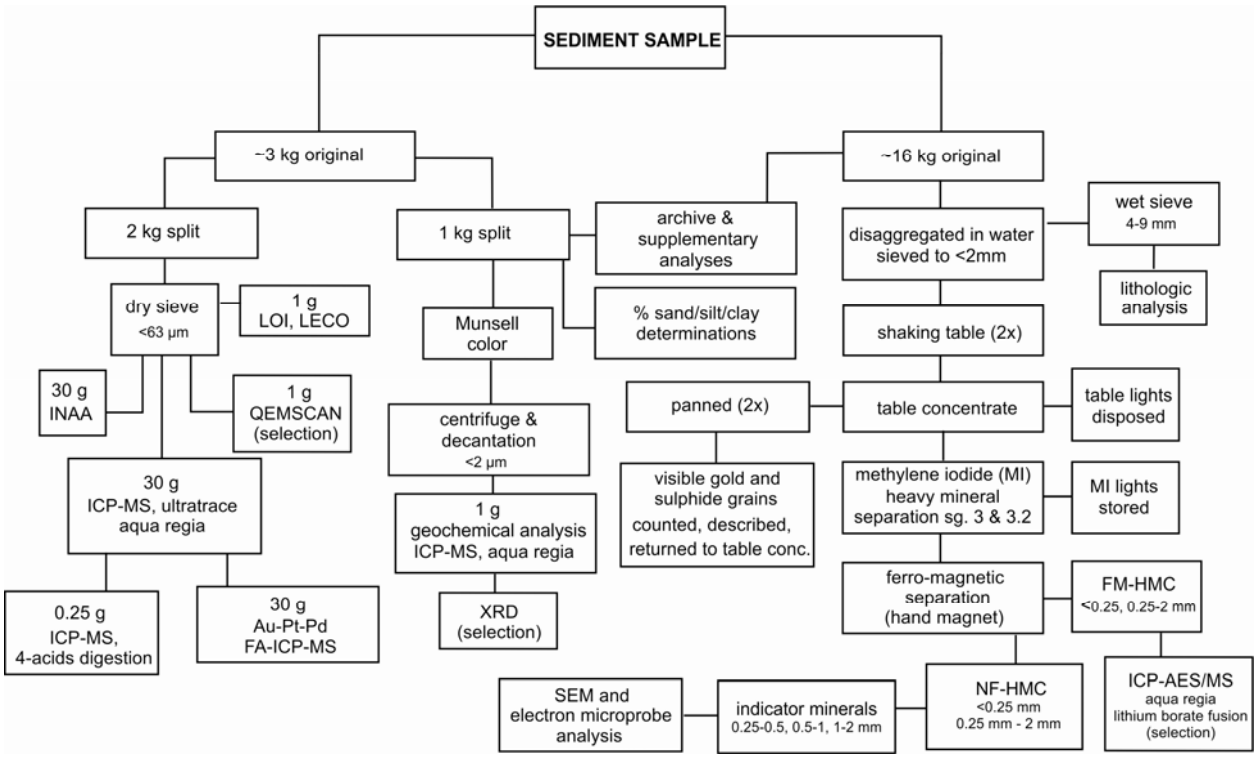

Figure 7. Generalized flow sheet showing steps in till sample processing.

Bedrock samples were examined at ODM and described, to determine processing characteristics, optimum sample size and processing sequence (See Appendix III for ODM bedrock logs). All bedrock samples were disaggregated to reduce rock fragment/mineral grain size to <2 mm using an electric pulse disaggregator (EPD Spark-2) (e.g. Cabri et al., 2008). Highly mineralized samples were processed at the end of the batch in each year to limit cross-contamination, and results are given in the order they are listed in the ODM raw data file in Appendix XII. All disaggregated bedrock samples were processed at ODM for heavy mineral separation, panning and indicator mineral picking (Fig. 8).

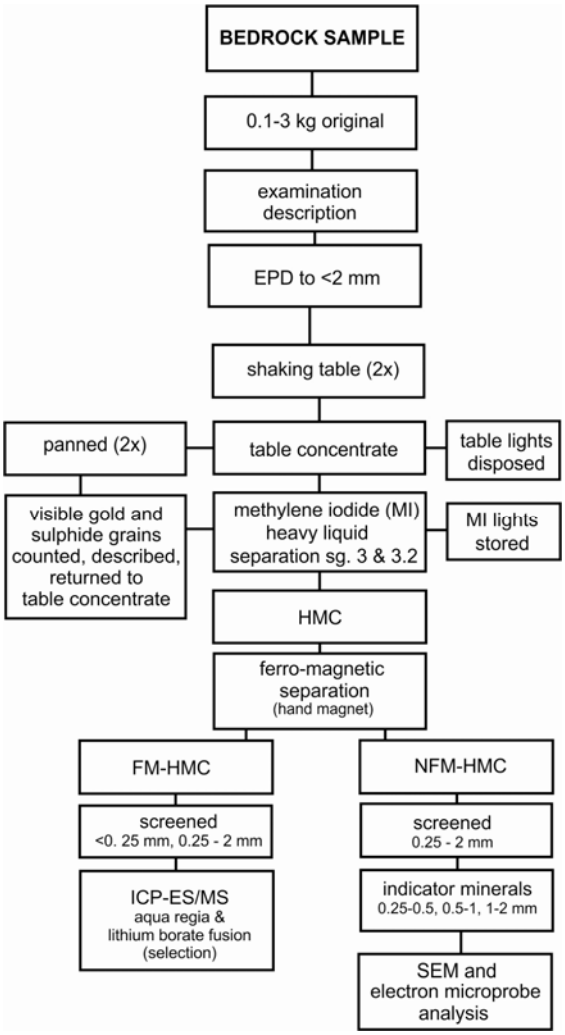

Figure 8. Generalized flow sheet showing steps in rock sample processing for indicator mineral analysis.

Till matrix geochemistry

Approximately 1 g of the clay-sized fraction (<0.002 mm) of till was analyzed at Acme Analytical Laboratories Ltd., Vancouver, for a suite of trace and major elements using ICP-MS, following a hot (95°C) aqua regia digestion (HCl-HNO_3, 3:1) (Group 1DX: 37 elements). In addition, approximately 30 g of the silt+clay-sized fraction (<0.063 mm) were analyzed at Acme 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); 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). Gold, Pt and Pd concentrations were also determined on 30 g of the

silt+clay-sized fraction at Acme by Pb-fire assay/ICP-MS (Group 3B-MS). About 30 g of the same fraction was analysed at Activation Laboratories Ltd. for Au and a suite of trace, major and rare earth elements using INAA (Group 1D Enhanced: Au + 34 elements). Detection limits and analytical results are presented by the respective analytical methods in Appendices IV, V, VI and VII.

QA/QC analysis of till geochemical determinations

Reliability (accuracy and precision) of analytical data returned from commercial laboratories was determined by including analytical ('blind') duplicates, primary standards and silica blanks within the till sample suite submitted to the labs. To monitor potential cross-contamination and to purge the sieves, silicic acid blanks were inserted and sieved during the sieving process and sent for analysis (with <0.063 mm pulps only). Field duplicates were submitted to evaluate sediment heterogeneity within a site. QA/QC procedures generally followed the protocols developed for till samples collected as part of GEM projects and implemented in 2010 (Spirito et al., 2011). Results of the QA/QC statistics and plots discussed below are included in the respective appendices for the geochemical results.

Precision

Analysis of analytical duplicate samples was used to monitor analytical precision of the till matrix geochemical results. In every analytical batch (2009 and 2010), 2 to 4 laboratory duplicates prepared by the GSC Sedimentology Laboratory were inserted randomly. The results for the two laboratory duplicate samples inserted with the 2010 clay fraction pulps indicate that the analytical precision is very good to excellent for all elements analyzed by ICP-MS after an aqua regia digestion (RSD≤10%), except for Na (RSD=15%) and Au (RSD=21%). In contrast, the precision in 2009 was only high for Ba, La and Zn (RSD<10%) using the same method; the four laboratory duplicates inserted with the 2009 samples indicate that this method was less precise for all the other elements (RSD=10-20%), and not precise for Al, Au, Ti and W (RSD=21-29%). There may have been a problem with the laboratory instruments in that batch although Acme's internal laboratory duplicate results were reproducible; alternatively, a mistake in the laboratory duplicate preparation and labelling at the GSC may have happened in 2009. Ag, B, Cd, Hg, S, Se, and Te levels are near or below the lower detection limit in the laboratory duplicates for both years, therefore the precision cannot be properly evaluated for these elements.

The results for the laboratory duplicate samples inserted with the silt+clay fraction pulps indicate that the analytical precision is good to very good for many elements analyzed by ultratrace ICP-MS after an aqua regia digestion (RSD≤10%). This method is somewhat less precise (RSD=10-20%) for Be, Bi (2010), Dy, Er, Gd (2009), Hf (2009), Ho (2010), Lu (2009), Na (2010), Nb (2010), Ni (2010), Sb (2010), Tb (2010), Tm (2009), U (2009) and Yb (2009), and even less so (RSD>20%) for Ag, Au, Mo and Sn (2009). Au (2009: 210%) and Mo (2010: 45%) are specially not reproducible. B, Cd, Ge, Hg, In, Pd, Pt, Re, S, Se, Ta, Te levels are near or below the lower detection limit in laboratory duplicates, therefore the precision for these elements cannot be properly evaluated with this method. For the 4-acid digestion, laboratory duplicates indicate that the analytical precision is very good to excellent for most elements, but somewhat less precise (RSD=10-20%) for Ag, As (2010), Cd (2010), Nd (2010) and Tb (2009). This method is not very precise for Cd (2009), Mo (2010), Sn (2009) and W (RSD=26-40%). Au, Be, Bi, In, Lu, Re, S, Sb, Se, Tm and W levels in laboratory duplicates are near or below the detection limit with the 4-acid digestion, therefore the precision cannot be properly evaluated for these elements. With the neutron activation method, reproducibility appears to be good for most elements (RSD<10%). This method is

somewhat less precise for As (2010), Cr (2009), Eu (2010), Nd (2009), U and Yb (2009) (RSD=15-24%), and even less so for Ba (2009: 32%), Cs (2010: 47%) and Rb (2009: 69%). It is not very reliable (RSD>97%) for Au, Mo (2010) and Ta although levels detected for these elements were close to their lower detection limits in the duplicates. Precision for Ag, Br, Ca, Cs, Hg, Ir, Ni, Sb, Se, Sn, Sr, Tb, W and Zn cannot be properly evaluated since the results of the lab duplicate analysis are below or near the lower detection limit. For the FA-ICP-MS method, Au and Pd levels in laboratory duplicates are too close to the detection limit for the precision to be properly evaluated. Precision of Pt determinations are good in 2009 (RSD=14%) and poor in 2010 (RSD=53%) although Pt levels are rather low in the laboratory duplicates.

Accuracy

Analysis of primary standards was used to monitor analytical accuracy of the geochemical results. In every analytical batch (2009 and 2010), 2 to 3 control reference samples (CANMET Standards TDB-1, UM-2, UM-4, Till 4) were inserted. Some of the standards had insufficient material for analysis (noted "not/ss" in results files), and others had no certified, provisional or informational values for comparison. The evaluation of the accuracy is therefore largely qualitative for some methods. 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 informational analysis available for TDB-1 and Till 4 (GSC internal database). Values above 10% of the mean are shown in red in the QA/QC report standard sheets. Al, Na and Pb are less accurate using this method. The accuracy in the ultratrace ICP-MS analysis by aqua regia digestion is very good (based on TDB-1, Till 4 and UM-4 standard results), except for a few elements such as Ag, Au, Fe, Hg, Pd and Sb which are somewhat (but inconsistently) less accurate between batches. The 4-acid digestion is generally very accurate except for Cd, Mo, Nb, P and W which are less accurate, mainly when comparing results of the TDB-1 standard with the certified values. The accuracy in the INAA analysis is generally good for most elements except for Au, Ba (with TDB-1), Br, Rb and U, elements that are consistently less accurate (above 10% of certified, provisional or mean of informational values). For the FA-ICP-MS method, the accuracy is very good using the results of the UM-4 standard which contains more PGMs. Results of silica blanks are very low for all elements using all methods indicating that contamination was minimal during the various batch analyses. Only Zr was higher reaching as much as 52 ppm in some samples (ICP-MS, aqua regia), likely the result of zircon grains in the silica blanks.

Field variability

Results of the two field duplicate samples collected each year within 5-10 m of the original sampling sites indicate that the sediment is fairly homogeneous in composition within a site. The low number of field duplicates per year (n=2) does not permit to do a full measure of the variance due to sediment heterogeneity within a site versus between sites (Garrett, 1969, 1983).

Till matrix color and texture

Munsell Color codes were determined on dry samples at the GSC Sedimentology Laboratory using a Munsell Soil Color Chart for the 2009 samples and a spectrophotometer for the 2010 samples. In addition, approximately 200-300 g from the 3-kg till samples was used for textural analysis of the till matrix: the <2 mm (-10 mesh) fraction of the samples was separated by dry-sieving; the classes of sizes 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 are

determined using a Lecotrac LT-100 Particle Size Analyser. The results of the matrix colour and textural determinations (>2 mm, 2-0.063 mm, 0.063-0.002 mm, <0.002 mm) are presented in Appendix VIII.

Till matrix organic and inorganic carbon content

Total, inorganic and organic carbon were 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 samples that had total C > 0.1% was analyzed for loss-on-ignition (LOI). LOI helps to give a measure of the degree to which the sample geochemistry has been modified by post-depositional weathering and/or organic matter incorporation. 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). The results of the LOI and LECO analysis are given in Appendix IX. Laboratory duplicates and in-house standards were also inserted for the till matrix carbon analysis at GSC's Sedimentology Laboratory. Results for these and for laboratory repeats are part of Appendix IX.

Till matrix mineralogy

To evaluate the potential for finer-grained and/or lighter-weight indicator minerals in till, and to gain a better understanding of the fine till fraction geochemistry, an experiment using Quantitative Evaluation of Materials by Scanning Electron Microscopy (QEMSCAN^{TM}) of ten selected till samples was completed in collaboration with SGS Mineral Services in Lakefield, Ontario (de Souza et al., 2011). Samples were collected from the Sue-Dianne deposit area except for one which was collected near Hottah Lake. Approximately 1 g of the silt-and-clay sized fraction (<0.063 mm) of till was mounted on 30 mm polished section and coated with a thin layer of carbon to ensure conductivity while in the SEM chamber. QEMSCAN utilizes both the back-scattered electron (BSE) signal intensity as well as an Energy Dispersive X-ray Signal (EDS) at each measurement point. EDS signals are used to assign mineral identities to each measurement point by comparing the EDS spectrum against a mineral species identification program (SIP) or database. A bulk modal analysis (BMA) giving mineral identities and proportions (% mineral mass) and mean grain size by frequency (μm) for each mineral identified, and the grain size distribution (% mass of grain size) in each sample are given in Appendix Xa.

The mineralogy of the clay-sized fraction (<0.002 mm) of 14 selected till samples was determined by X-ray powder diffraction analyses at the Geological Survey of Canada, using a Bruker D8 Advance Powder Diffractometer equipped with a Lynx-Eye detector, with Co Kα radiation set at 40 kV and 40 mA. The samples were also x-rayed following saturation with ethylene glycol (24 hours in desiccator) and heat treatment (2 hours at 550 °C). The selection included samples collected down-ice from the Sue-Dianne deposit, and various showings across the GBmz. Initial identification of minerals was made using EVA software with comparison to reference mineral patterns using Powder Diffraction Files (PDF) of the International Centre for Diffraction Data (ICDD) and other available databases. Quantitative analysis was carried out using TOPAS, a PC-based program that performs Rietveld refinement (RR) of XRD spectra. Detailed methods and results of the XRD analysis are presented in Appendix Xb.

Till clast lithology

The >2.0 mm material from the large bulk till samples was wet-sieved to separate the 4-9 mm fraction for lithological analysis. Pebbles from all till samples were visually examined using a binocular

microscope (minimum of 170 clasts counted per sample) at McGill University. Pebbles were grouped into the following lithological categories: intrusive, metamorphic (2009 samples only), non-metamorphosed sedimentary, supracrustal, magnetic, altered (visible metasomatic alteration), quartz, gabbro, schist, concretion, heavily weathered, hematite breccia, or others undifferentiated (2010 samples only). Results were calculated by % clasts counted of the total sample and are presented in Appendix XI.

Till and bedrock heavy mineral processing

The large bulk till and the bedrock samples were processed at Overburden Drilling Management Ltd. (ODM), Ottawa, for recovery of the heavy mineral fraction and indicator mineral picking, including gold grains. The <2 mm (matrix) fraction of the disaggregated till samples were processed using a double-run across the shaking table. The table preconcentrate was then panned to recover any gold, sulphide and platinum group minerals. After tabling and panning, the preconcentrate was further refined using heavy liquid (SG 3.0 and 3.2) and ferromagnetic (FM) separations. The non-ferromagnetic heavy mineral concentrates (NF-HMC) were screened at 0.25 mm. The 0.25-2 mm fraction NF-HMC (S.G. >3.2) was used for indicator mineral picking. The ferromagnetic fraction (FM-HMC) was also screened at 0.25 mm and the 0.25-2 mm fraction FM-HMC was used for the study of iron oxides (i.e. Dupuis et al., 2012a, 2012b).

Bedrock samples were processed to recover heavy minerals, using a method similar to that used for the till samples. The disaggregated bedrock samples were pre-concentrated with respect to density using a shaking table. Samples were tabled twice to increase gold recovery. Visible gold, sulphide and platinum group grains recovered from this table concentrate and/or by subsequent panning were counted and described, then returned to the table concentrate after examination. Heavy liquid separation using methylene iodide (SG 3.0 and 3.2) was used to produce a final heavy mineral concentrate (HMC) from the table concentrate. After a ferromagnetic separation, the NFM-HMC was sieved to obtain the sand fraction (0.25-2 mm) for picking. The 0.18 mm-0.25 mm fraction was also prepared for future reference. The ferromagnetic fraction (FM-HMC) was sieved (0.25-2 mm) for further examination. The total number of gold grains recovered, the weights of table feed, table preconcentrates, NFM- and FM- HMCs for both bedrock and till samples are presented in Appendix XII.

The FM-HMC fractions of selected bedrock and till samples collected in 2007 (McMartin et al., 2011b) and in 2009 (this report) were analyzed for geochemistry to evaluate the metal contents and potential pathfinder elements in this fraction. The <0.25 mm and pulverized 0.25-2 mm FM-HMC fractions were analyzed at Acme Analytical Laboratories Ltd. for a selected suite of base metals using ICP-MS after a hot aqua regia digestion (Group 1DX: 14 elements), and for whole rock analysis by ICP-ES and total trace elements by ICP-MS following a lithium metaborate/tetraborate fusion and dilute nitric digestion (Group 4A-4B: 46 elements). Results for the geochemical analysis of the <0.25 mm and pulverized 0.25-2 mm FM-HMC of all samples, together with laboratory duplicate results, are presented in Appendix XIIIa and XIIIb. Interpretation of these results is currently under study (McMartin et al., in prep.)

Indicator mineral picking

Prior to indicator mineral examination and selection, the 0.25-2 mm NFM-HMCs (SG>3.2) recovered from till and bedrock 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 bedrock and till 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 IOCG and metamorphosed or magmatic massive sulphide (MMSIM®) indicator minerals. Bedrock samples were examined first. Checks were performed on selected grains using SEM-energy dispersive x-ray spectrometer (EDS) to confirm mineral identity. Selected grains considered having possible IOCG affinities (mainly sulphides, silicates, some oxides) were picked and mounted for further study. Because of their abundance in some bedrock samples, no more than 20 to 50 representative grains of the same mineral species were selected per sample for further study (mainly allanite, andradite, apatite, actinolite, hematite, chalcopyrite, polymineralic grains). Selected iron oxide grains from the ferro-magnetic fraction of selected bedrock and till samples were picked, mounted and microprobed at Laval University. These results are reported elsewhere (Dupuis et al., 2012a, 2012b; Sappin et al., sub.). Appendix XII includes all raw grain counts from visual identification of possible IOCG indicator minerals for the 0.25-2 mm NFM-HMCs (SG>3.2).

QA/QC analysis of heavy mineral processing and indicator mineral picking

Following the new QA/QC protocols developed for till samples as part of GEM Projects (Spirito et al., 2011), 'blank' samples consisting of weathered Silurian-Devonian granite (grus) (Plouffe et al., in press) were inserted at the beginning and through the till sample batch in 2010 to monitor potential cross-contamination introduced during heavy mineral separation. 'Blind' duplicates (sub-split of field duplicates) were also used to evaluate the precision of the mineral separation and identification method. One to two gold grains were found in 5 of the 6 blanks during panning and gold grain counts in 2010, in agreement with known values of gold grains in this blank material (Plouffe et al., in press). Expected hornblende/titanite-zircon assemblages with no PGMs nor specific potential indicator minerals were found in the blanks. Results for the blind and the field duplicates indicate that gold grain counts are reproducible, and that the sediment collected 5-10 m apart is fairly homogeneous. The results of potential indicator mineral picking in the blind and field duplicate samples indicate minor sediment heterogeneity at the sample site, and a good reproducibility of the results. Although the mineral assemblages are similar, single grains of andradite, Mn-epidote, sapphirine, red rutile, loellingite, chalcopyrite and gahnite were sometimes found in the field duplicate, in the blind duplicate or in the original. All panning results and weights for the blanks, blind and field duplicate samples are reported in Appendix XII.

With the 2009 bedrock samples, crushed vein quartz (i.e., mineral blank) was processed at the beginning, and through the sample batches to monitor contamination from laboratory equipment and carryover. Unfortunately, four heavily mineralized samples from Voisey's Bay (Ni-Cu) and Nevada (Au) were introduced in one of the 2009 bedrock sample batches on the EPD at ODM (batch # 4761). This resulted in significant carryover contamination in the quartz blanks (QC-1 to QC-4) and in some of the samples. This contamination included >0.25 mm chromite grains from Voisey's Bay and ruby corundum from Nevada. In addition, minor carryover contamination occurred in the same batch in heavy silicate minerals (almandine, hornblende and pyroxene) from the large number of till samples processed in this laboratory. In the end however, none of these grains were picked as potential indicator minerals. The suspected chromite grains resulting from contamination were removed in a separate bedrock sample results sheet for that batch in Appendix XII ("MMSIM Chromite Removed") and highlighted in the final

results sheet ("Bedrock – MMSIM").

The micropanning results were even more susceptible to inter-sample EPD contamination than the >0.25 mm sand-sized fraction picked for indicator minerals. The QC quartz blanks contained fine grained chalcopyrite and pyrite as a result of carryover contamination from other bedrock samples and one sample contained a single grain of cinnabar probably as a result of carryover from the Nevada sample. The second batch of bedrock samples submitted to ODM in 2009 (#4937) showed no contamination related to EDP processing in the fine fraction. One to three silt-sized pyrite grains were found in each blank of the second batch but these could have been introduced during panning and are considered insignificant.

To better monitor the carryover contamination experienced in 2009 with the EPD, quartz blanks were inserted between each single bedrock sample collected in 2010, and between the leftover crushed bedrock samples collected in 2009 and 2010. No mineralized samples from outside sources were introduced between these sample batches. Carryover from inter-sample contamination during sample processing still occurred in the very fine fraction of bedrock samples as shown in the micropanning results of the quartz blanks (mainly pyrite and arsenopyrite). More importantly, a significant fine grained galena contamination occurred from the EPD carryover of a previously processed galena ore sample in the batch of coarsely crushed bedrock samples (leftover lithogeochemistry samples). All galena counts within this batch (quartz blanks and regular samples) should therefore be disregarded (batch #5730). It is important to note that the coarser >0.25 mm fraction was not affected by this carryover. A single grain of chalcopyrite was found in a quartz blank processed in 2010. All picking results for the blank samples processed with the bedrock samples are reported in Appendix XII.

Binocular and SEM photographs of selected grains

Picked grain morphology from selected indicator mineral species from till and disaggregated bedrock samples was studied under binocular and scanning electron microscope (SEM). Backscatter electron images (BSE) and energy dispersive X-ray spectroscopy analysis (EDX) were taken using the Hitachi S-3200N variable pressure SEM at the GSC Microbeam Laboratory for the 2009 samples and using the Hitachi S-3000N variable pressure SEM at the Facility for Electron Microscopy Research (FER) at McGill University for the 2010 samples. The beam was set at 25 kV in variable pressure mode (set at 20 Pa). Single-point, non-quantitative compositional data was obtained using EDX with the INCA analysis software. Readings were averaged over a live time period of 50 seconds and taken at multiple locations as to provide complete identification of polymineralic grains. Representative binocular and BSE data as well as an observation summary document are provided in Appendix XIV.

Electron microprobe analysis

Selected visually identified indicator minerals and some background grains (total of 433 grains from 2009 and 496 grains from 2010) were mounted on 25-mm epoxy-impregnated stubs at SGS Lakefield Research Laboratory. In the 2010 batches, only the Cr-pyrope, Cr-diopside, olivine, chromite, hematite, apatite and malachite grains were selected for microprobe analysis. The rest of the grains were mounted but are archived for further studies. The grains were analyzed to confirm their identity and quantify their chemical composition. Analyses were conducted at the GSC Microbeam Laboratory using a CAMECA SX50 electron microprobe (EMP) equipped with four wavelength-dispersive spectrometers.

Operating conditions were 20 kV accelerating voltage, and 10 nA beam current using a focused spot. Count times on peak were 10 seconds, with 5 seconds off-peak. The raw data were processed with the ZAF matrix correction. Standards comprise a range of natural and synthetic pure metals, simple oxides and simple compounds. The analysed grains were classified (or re-classified when necessary) by K. Venance (GSC) and I. Kjarsgaard (2009 results only) on the basis of their chemical composition. Theoretical chemical compositions of mineral end-members (LeMaitre, 1982) were used to calculate cut-off values (at approximately 50:50 mol %) for members of binary solid solution series. Some of grain mounts were not suitable for work on a per-grain basis. Grain mounts work at the GSC is done in automated mode: the coordinates are loaded off-line, simply placed on a clean spot away from cracks/impurities etc. Some of the grains were heterogeneous (comprised of multiple phases) or the phase of interest comprised only a minor component of the grain. Therefore the totals are sometimes too low or too high and re-classification was not possible or approximate. The final mineral classification (2009 sample only) and chemistry results for the 0.25-2 mm NFM-HMC are provided in Appendix XV.

SUMMARY

This Open File report releases the Quaternary field database and analytical results from the 2009 and 2010 field seasons of the GEM IOCG-Great Bear Project. The datasets are presented in a format easily importable in a geographic information system (GIS). Quaternary field observations were recorded at 270 field stations; 154 of these included either surface expression and/or material modifier description and/or ice-flow indicator measurements (n=165). They depict a discontinuous till cover, sparingly affected by glaciolacustrine reworking below 300 m a.s.l., and a dominant ice-flow direction gradually shifting from west-southwestward in the southern part of the GBmz to west-northwestward in the north.

Samples collected include 101 till samples from C-horizon soils, primarily for geochemical and indicator mineral analysis, taken in relation to known mineralization, alteration zones and least altered bedrock, as well as 95 surface bedrock samples for indicator mineral recovery purposes. Analytical results include till matrix texture and color, matrix carbon, pebble analysis, as well as extensive till matrix geochemistry performed on the <0.002 mm and/or <0.063 mm fraction using ICP-MS aqua regia digestion, ICP-MS 4-acid digestion, INAA, and fire assay/ICP-MS. Till matrix geochemistry QA/QC analysis was determined using field and analytical duplicates as well as control reference samples (silica blanks and primary standards). Analytical precision analysis 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. Problematic elements recurring over multiple analytical techniques include: Ag, Au, B, Cd, Hg, In, S, Sb, Se, Re and W. Measurement accuracy analysis shows that results are generally within 10% of the mean standard value available for most elements. Limitations include insufficient material for analysis of some standards. Blank sample analyses show minimal contamination between samples. Field duplicate geochemical analyses suggest the sediment is fairly homogeneous within a site although insufficient data is available to do a full analysis of variance.

Mineralogy of the till <0.063 mm fraction of 10 selected samples was determined using QEMSCAN^{TM}, giving mineral species identity and proportion under bulk modal analysis, mean grain size frequency per species and grain size distribution per sample. Mineralogy of the till <0.002 mm fraction of 14 selected samples was determined using XRD, giving mineral species identity and proportions.

Heavy mineral processing, gold grain counts and indicator mineral picking of potential IOCG affinities were completed on all till and disaggregated bedrock samples. Contamination, grain carryover, reproducibility and site heterogeneity were evaluated using blanks, as well as laboratory and field duplicates. Results indicate minor sediment heterogeneity at the till sample site and a good reproducibility. However, low abundance of some mineral species in till samples may allow for single grain occurrence in only one of both duplicate samples. In 2009, carryover contamination during EPD processing in a specific quartz blank, and to a lesser extent in the following sample, was caused by four heavily mineralized samples from Voisey's Bay (Ni-Cu) and Nevada (Au) introduced in one of the bedrock sample batches. Results suspected to have been affected were removed in a separate sheet.

Morphological analysis of representative grains from selected species was performed using binocular, SEM-EDX and SEM-backscatter imagery. Picked grain composition of 433 grains from 2009 and selected species from 496 grains from 2010 was determined using electron microprobe through single point per grain analysis. All presented data is currently being used under a graduate research project by P. Normandeau at McGill University (Normandeau et al., in prep).

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