



**GEOLOGICAL SURVEY OF CANADA  
OPEN FILE 7174**

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Bathurst Mining Camp, New Brunswick**

**G. Budulan, M.B. McClenaghan, M.A. Parkhill,  
D. Layton-Matthews, and M. Pyne**

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**Contribution to the Targeted Geoscience Initiative (TGI-3) 2005-2010**

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# TILL GEOCHEMICAL SIGNATURES OF THE HALFMILE LAKE Zn-Pb-Cu VOLCANOGENIC MASSIVE SULPHIDE DEPOSIT, BATHURST MINING CAMP, NEW BRUNSWICK

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## ABSTRACT

The Halfmile Lake study was conducted as part of the Geological Survey of Canada's Targeted Geoscience Initiative (TGI-3) Program under the Deep Search Project to document the geochemical and indicator mineral signatures of the till around the Halfmile Lake Zn-Pb-Cu volcanogenic massive sulphide (VMS) deposit in northcentral New Brunswick. Bedrock and till samples were collected in 2007 and 2008 at varying distances up- and down-ice of the deposit. Sampling was focused on the South Upper AB zone because it is the surface expression of the deposit and is capped by a preglacial gossan. Mineralization consists of a Cu-rich stringer zone stratigraphically overlain (structurally underlain) by a Pb-Zn massive sulphide zone. A metal-rich gossan composed of secondary minerals is found at surface.

Till in the Halfmile Lake deposit study area is thin (<2 m), light olive brown to dark brown in colour, and silty sand to sandy silt in texture. Ice flow across the deposit area was towards the east-northeast. The pathfinder elements in the <0.063 mm fraction of till that define the signature of the deposit include Cu, Pb, Zn, Ag, As, Au, Bi, Hg, Sb, Se, and Sn. Elevated concentrations of these elements in till down-ice are consistent with the ore mineralogy of the Halfmile Lake deposit and demonstrate that till geochemistry is a useful tool for detecting VMS mineralization in the glaciated terrain of the Bathurst Mining Camp.

## INTRODUCTION

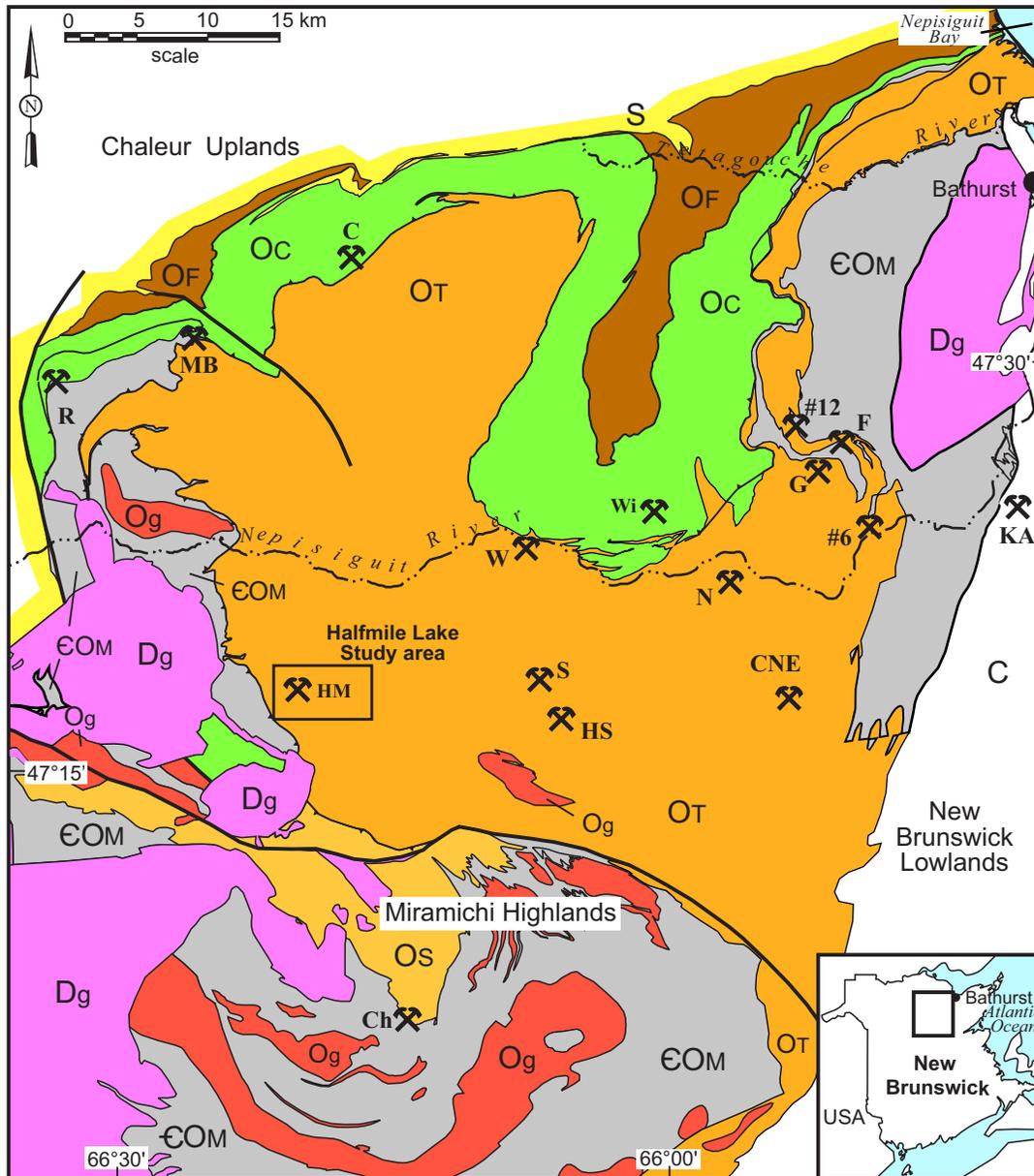
The Bathurst Mining Camp (BMC) in northern New Brunswick hosts 46 volcanogenic massive sulphide (VMS) deposits with defined tonnage. Glacial deposits cover bedrock in the region, thus till sampling can be an important exploration method for base metals here. Till geochemistry is a well established exploration method in Canada for base metals (e.g. Fortescue and Hornbrook, 1969; Ridler and Shilts, 1974; Shilts, 1975, 1976; Kaszycki et al., 1996; Bond and Plouffe, 2002; Lett, 2001; McClenaghan, 2007; McClenaghan et al., 2011), however, little research has been carried out to determine potential indicator minerals of VMS deposits in glaciated terrain. To address this knowledge gap, the Geological Survey of Canada (GSC) conducted a study to document the till geochemical and indicator mineral signatures of one VMS deposit in the BMC, the Halfmile Lake Zn-Pb-Cu VMS deposit (Fig. 1). Till samples were collected around the deposit in 2007 and 2008 for recovery of indicator minerals and geochemical analysis of the till matrix. Results for the till geochemical study are reported here. Results for the indicator mineral part of this study will be reported in a subsequent GSC Open File.

This study was conducted as part of the GSC's Targeted Geoscience Initiative (TGI-3) Program (2005-2010) in collaboration with the New Brunswick Department of Energy and Mines (NBDEM). The Halfmile Lake (HML) deposit is one of four TGI-3 test sites for base metal indicator mineral and till geochem-

ical studies, which also included the Thompson Nickel Belt (McClenaghan et al., 2009, 2011), the Broken Hammer Cu-(Ni)-PGE deposit in the Sudbury North Range (Ames et al., 2007), and the NICO and Sue Diane iron oxide copper-gold deposits in the Great Bear magmatic zone (McMartin et al., 2011). The Halfmile Lake deposit was chosen as a test site for several reasons: (1) the deposit geology is well known and bedrock samples were available from drill core; (2) the deposit subcrops and thus it was exposed to glaciation; (3) the deposit is till covered; (4) the area is easily accessible; (5) previous regional and local-scale till sampling identified an east-northeast-trending glacial dispersal train of metal-rich till extending down-ice from the Halfmile Lake deposit.

## LOCATION

The Halfmile Lake deposit is located in northcentral New Brunswick, south of the Nepisiguit River (Fig. 1) within the BMC. The property is approximately 60 km southwest of Bathurst and 20 km west of the Heath Steele Cu-Pb-Zn deposit (Fig. 1) and can be accessed via the Otter Brook Road. The area is centred at 47°19'N and 66°19'W (702788 E, 5243847 N; NAD 83; Zone 19). Access to the property was by 4 x 4 truck via gravel logging roads. No known VMS deposits occur west (up-ice) of the Halfmile Lake deposit. The closest landmarks west of the deposit are a north-south-trending road and a parallel river, which are approximately 15 km west of the deposit, and the Mount



**Figure 1.** Location of the Halfmile Lake deposit in north central New Brunswick and regional bedrock geology (modified from Parkhill and Doiron, 2003). Bedrock legend: C = Carboniferous sedimentary rocks; Dg and Og = Devonian and Ordovician (mainly felsic) intrusive rocks, respectively; EOM = Cambrian-Ordovician sedimentary rocks of the Miramichi Group; OF = Ordovician mafic volcanic and sedimentary rocks of the Fournier Group; OT, OC, and OS = Ordovician sedimentary and felsic and mafic volcanic rocks of the Tetagouche, California Lake, and the Sheephouse Brook groups, respectively; S = Silurian and younger rocks. Crossed hammer symbol indicates significant VMS deposit: C = Caribou, Ch = Chester, CNE = Captain North Extension, F = FAB, G = Grandroy, HM = Halfmile Lake, HS = Heath Steele, KA = Key Anacon, MB = Murray Brook, N = Nepisiguit Brook, #6 = Brunswick 6, #12 = Brunswick 12, R = Restigouche, S = Stratmat, W = Wedge, Wi = Willett.

Carleton and Saint Leonard Provincial park boundary, which is 20 km west. The Caribou Zn mine is located 25 km north of the Halfmile Lake deposit (Fig. 1).

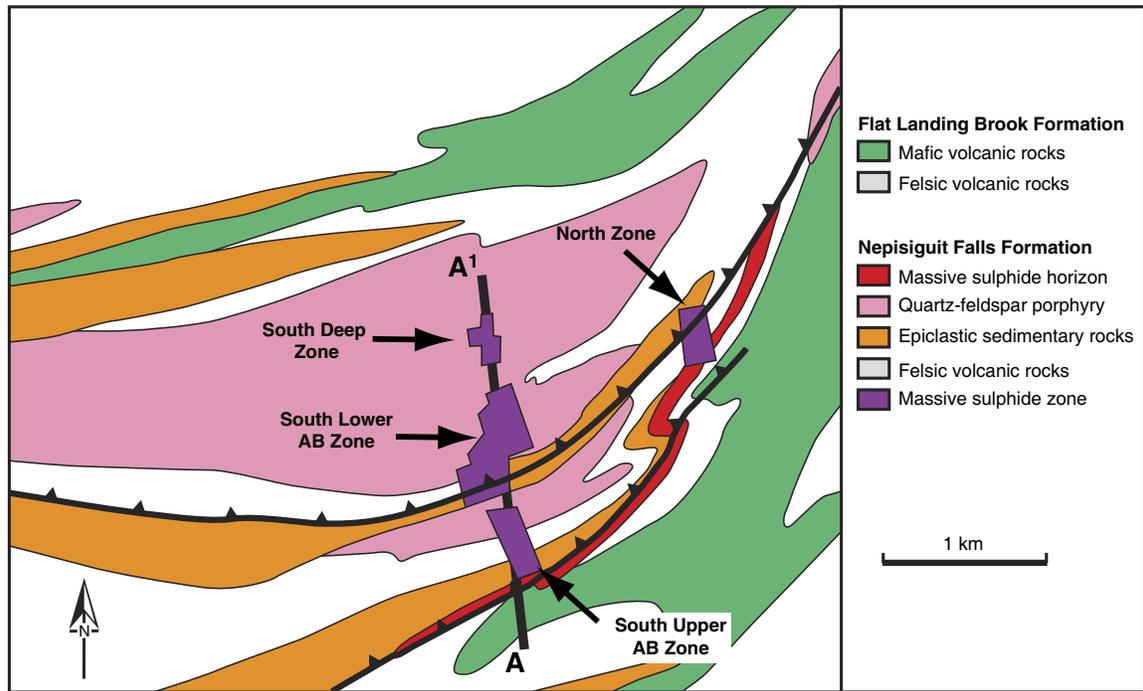
## GEOLOGY

### Bedrock Geology of the Halfmile Lake Area

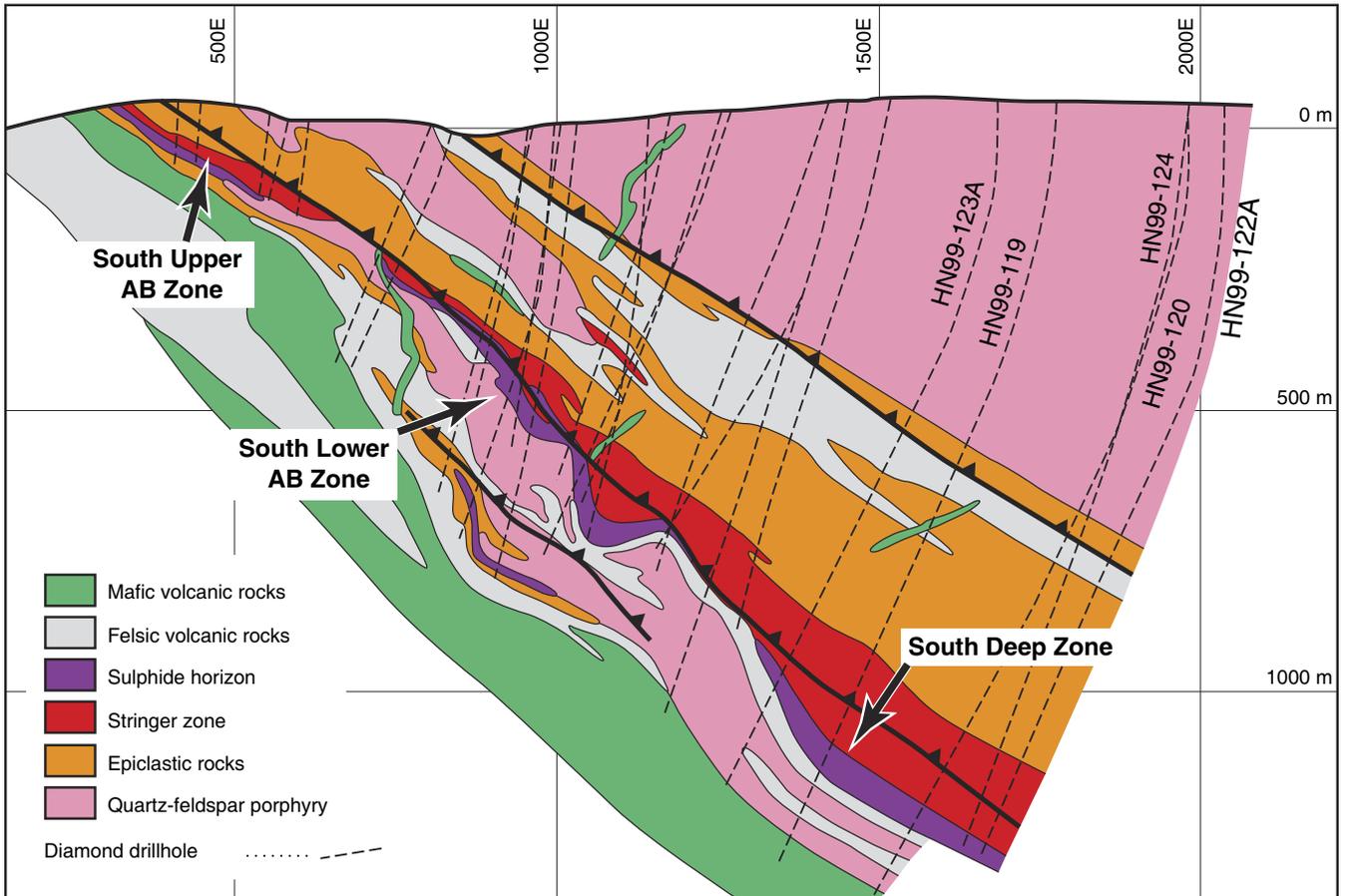
The Halfmile Lake deposit is hosted by the Nepisiguit Falls Formation (Fig. 2) of the Ordovician Tetagouche Group (Adair, 1992; McCutcheon et al., 2000; McCutcheon and Walker, 2001; Mireku and Stanley,

2006). The Nepisiguit Falls Formation ( $469 \pm 2$  Ma) is characterized by intrusions of quartz-feldspar porphyry, felsic volcanic rocks, epiclastic rocks (sedimentary rocks derived from volcanic rocks), and minor intermediate to mafic volcanic rocks. Pyroclastic and epiclastic rocks are commonly intercalated with chloritic and Fe-rich mudstone (McCutcheon and Walker, 2001; Mireku and Stanley, 2006).

The structural geology of the Halfmile Lake region has been described in detail by de Roo and van Staal



**Figure 2.** Bedrock geology map of the Halfmile Lake deposit area, showing surface projections of the massive sulphide zones and the location of the South Upper AB zone subcrops, the focus for till sampling in this study (modified from Mireku and Stanley, 2006; modified from a Noranda Inc. company map). Cross-section A-A' is shown in Figure 3.



**Figure 3.** South-southwest to north-northeast composite cross-section of the Halfmile Lake deposit along A'-A (see location in Fig. 2) (modified from Mireku and Stanley, 2006; also modified from a Noranda Inc. company map).

## Till Geochemical Signatures, Halfmile Lake Zn-Pb-Cu VMS Deposit, Bathurst Mining Camp, New Brunswick

**Table 1.** Summary of ore minerals in bedrock and till for the Halfmile Lake deposit (summarized from Adair, 1992; Boyle, 2003; Mireku and Stanley, 2006; and this study).

Minerals in the Deposit	Formula	Present in Till in this Study?
<b>Major and minor minerals</b>		
pyrite	FeS <sub>2</sub>	yes
pyrrhotite	FeS	yes
sphalerite	(Zn,Fe)S	yes
galena	PbS	yes
chalcocite	Cu <sub>2</sub> S	yes
magnetite	Fe <sub>3</sub> O <sub>4</sub>	yes
marcasite	FeS <sub>2</sub>	
<b>As-bearing minerals</b>		
arsenopyrite	FeAsS	yes
cobaltite-gersdorffite	CoAsS-NiAsS	
<b>Sn-bearing minerals</b>		
cassiterite	SnO	
<b>Bi-bearing minerals</b>		
native bismuth	Bi	
<b>Precious metal minerals</b>		
native silver	Ag	

Minerals in Gossan	Formula	Present in Till in this Study?
goethite	FeO	yes
beudantite	PbFe <sub>3</sub> (AsO <sub>4</sub> )(SO <sub>4</sub> )(OH) <sub>6</sub>	yes
electrum	Au <sub>60</sub> Ag <sub>40</sub>	yes
cassiterite	SnO	
pyrite	FeS <sub>2</sub>	
arsenopyrite	FeAsS	
jarosite	KFe <sup>3+</sup> <sub>3</sub> (SO <sub>4</sub> ) <sub>2</sub> (OH) <sub>6</sub>	yes
cinnabar	HgS	yes

(1991), Adair (1992), and Wilson (1993). Structurally, the entire sequence is overturned, with a stratigraphic footwall (structural hanging wall) to the massive sulphide zone dominated by quartz-feldspar porphyritic intrusions, felsic volcanic rocks, and epiclastic rocks (Fig. 3). The stratigraphic hanging wall (structural footwall) consists predominantly of felsic volcanic rocks and minor epiclastic rocks (Mireku and Stanley, 2006). The deposit has been metamorphosed to lower greenschist facies (Adair, 1992), characterized by the presence of phengitic muscovite and chlorite in felsic volcanic and epiclastic rocks, and a chlorite-epidote±biotite assemblage in intermediate to mafic rocks (Adair, 1992; Mireku and Stanley, 2006).

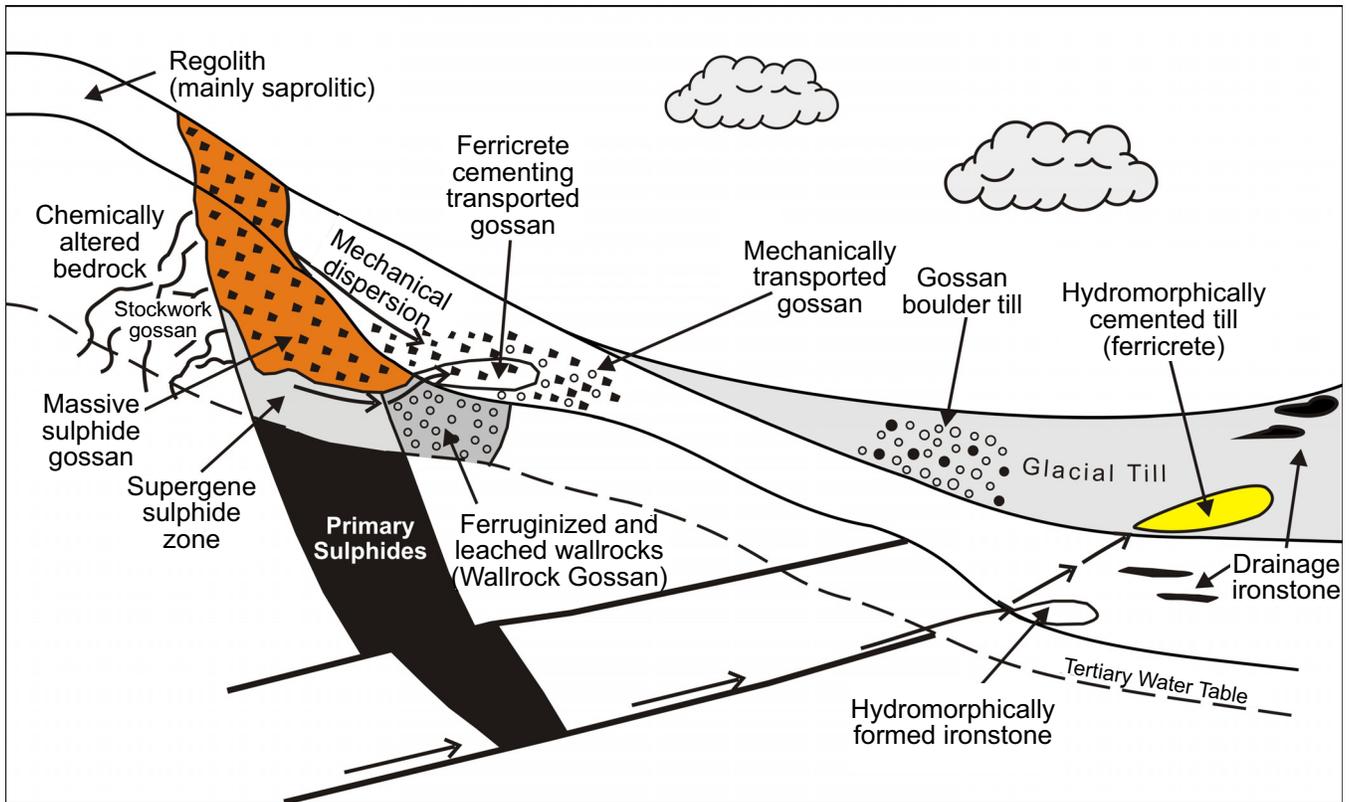
The Halfmile Lake deposit contains four metal sulphide-bearing zones: 1) North, 2) South Upper AB, 3) South Lower AB, and 4) South Deep zones (Figs 2, 3). The South Upper AB zone was selected for this till dispersal study because it is the surface expression of the deposit and is covered by thin till. Mineralization consists of a Cu-rich stringer zone stratigraphically overlain (structurally underlain) by a Pb-Zn massive sulphide zone, both of which are inclined approximately 35° at depth (Adair, 1992; Mireku and Stanley, 2006). The major and minor ore minerals present in the Halfmile Lake deposit are summarized in Table 1.

The Halfmile Lake deposit is capped by a preglacial gossan that subcrops over the South Upper AB zone and is at an approximate depth of 200 m. The gossan consists primarily of vuggy and boxwork-textured goethite with lesser amounts of other secondary minerals and is considered by Boyle (2003) to be a massive sulphide gossan. Minerals present in the gossan at the Halfmile Lake deposit are listed in Table 1. The gossan cap was formed in situ during the late Pliocene up to the onset of Pleistocene glaciations (105-23 Ma), i.e., prior to Quaternary glaciation, as the result of surficial chemical weathering. A gossan cap can show evidence of primary bedrock structures, such as banding, folding, and brecciated fault zones, and is typically found in sharp contact with an underlying supergene sulphide zone (Boyle, 2003). Figure 4 shows a schematic diagram from Boyle (2003) illustrating a typical preglacial gossan capping a sulphide zone and various environmental conditions that can determine gossan characteristics, most of which are evident in the BMC. The presence of a gossan at the Halfmile Lake deposit is of significant economic importance because at other locations in the BMC these gossans are known to contain economic concentrations of Au and Ag (Boyle, 2003). In general, gossans in the BMC contain goethite, jarosite, beudantite, cassiterite, cinnabar, native Bi, and native Ag, are enriched in Au, Ag, and Sb, and are depleted in Fe, Mn, Mg, Ca, Sr, S, Cu, Pb, Zn, Cd, In, Ag, and Tl (Boyle, 2003).

The Halfmile Lake deposit is currently held by Trevali Mining Corporation and as of January, 2012 is being mined. The deposit has a NI 43-101-compliant indicated mineral resource estimate of 626 Mt grading 8.13% Zn, 2.58% Pb, 0.22% Cu, and 30.78 g/t Ag (Daigle et al., 2009) and is capped by approximately 13,600 Mt of gossan, grading 168 g/Mt Au and 428 g/Mt Ag (Boyle, 2003).

### Surficial Geology of the Halfmile Lake Area

Generally, a thin (<2 m) layer of silty sand, grayish-yellow to yellowish-brown, locally derived subglacial till covers most of the deposit area (Fig. 5). It is found on the lee sides of hills, usually in valleys, and may be Early Wisconsinan to pre-Late Wisconsinan (Parkhill and Doiron, 2003). Till in the deposit area contains 20-40% pebble- to cobble-sized clasts that are angular to subangular. Ice-flow indicators (striations, grooves, and roche moutonnées), together with till fabric analyses, till clast provenance studies, till geochemistry, and the distribution of boulder erratics, indicate that the dominant ice-flow direction associated with this surface till was to the east (070–110°), followed by a northeast ice flow (Parkhill and Doiron, 2003). Upon closer examination of pit stratigraphy on the Halfmile Lake property, Parkhill and Doiron (2003) that sug-



**Figure 4.** Schematic diagram of a supergene sulphide zone capping a massive sulphide deposit. Also noted are the different types of gossans associated with the deposit and the effects of environmental factors on gossan formation (from Boyle, 2003).

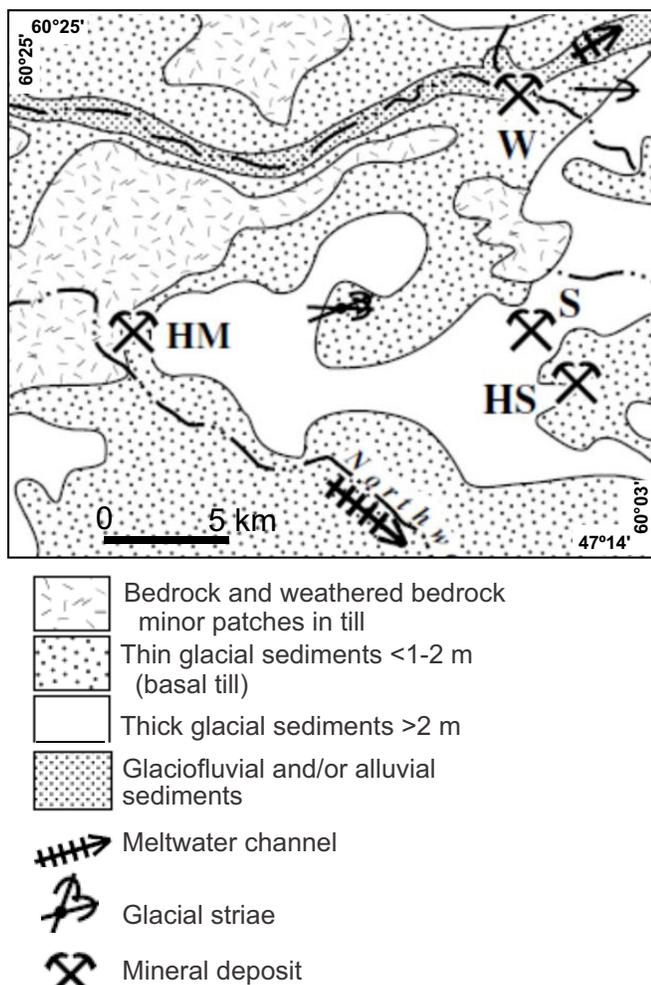
gested the presence of two types of till: an upper till, which consists of fine- to coarse-grained, sandy-clay basal till containing up to 40% clasts, and a lower till, which is more locally derived (closer to bedrock), yellowish, and talc-rich with up to 70% clasts. The contact between these two tills can be sharp or gradational (Parkhill and Doiron, 2003).

### Exploration History

The early history of the BMC, from the mid-1800s to 1956, was summarized by MacKenzie (1958) and a subsequent more comprehensive history of exploration and mining in the area has been recorded by McCutcheon et al. (2003). The BMC is one of Canada's oldest VMS mining districts and drift prospecting has played an important role in the discovery of its mineral potential. The presence of massive sulphide boulders in the Armstrong Brook area, 20 km east of the Caribou mine, had been known since 1860 (Rose and Johnson, 1990) and through extensive tracing of these mineralized glacial erratics up-ice to their bedrock source led to the discovery of the Orvan Brook massive sulphide deposit in 1937; the first discovery of massive sulphides in the BMC (Tupper et al., 1967). Although the Austin Brook deposit was mined for iron as early as 1911, the base metal potential of the BMC was not appreciated until 1952 when the nearby Brunswick 6

massive sulphide deposit was discovered during drilling of an electromagnetic anomaly (McCutcheon et al., 2003). This discovery set off a staking rush that turned the BMC into one of the most productive and economically important mining districts in the world. The BMC is host to 46 massive sulphide deposits and approximately 70% of these were discovered in the 1950s using geological, geophysical, and geochemical methods (Goodfellow et al., 2003). Almost every deposit and occurrence was found at the surface or subcropping below a generally thin and discontinuous cover of glacial sediment (McCutcheon et al., 2003).

The Halfmile Lake property has been extensively explored by a number of exploration companies since it was first staked in 1954. Many surveys have been conducted over the years including surficial surveys (soil, till, water, and stream sediment sampling), geophysical surveys (airborne and ground electromagnetic (EM) surveys, bore hole pulse EM, and IP), surficial and bedrock mapping, trenching, diamond drilling, and seismic reflection surveys. A summary of the historical work completed on the Halfmile Lake property is described by Daigle et al. (2009) and Walker and McCutcheon (2011). The Middle River Mining Co. (Texas Gulf Sulfur Co.) was first to discover the South Upper AB zone of the Halfmile Lake deposit in 1955 from airborne electromagnetic and magnetic surveys,



**Figure 5.** Surficial geology map of the area surrounding the Halfmile Lake (HM) deposit, simplified from Parkhill and Doiron (2003). The map shows the location of other VMS deposits in the area (modified from Doiron, 2000a,b). Abbreviations of deposit names: HM = Halfmile, HS = Heath Steele, S = Stratmat, W = Wedge.

followed by a ground electromagnetic and soil geochemical survey. Based on data from aeromagnetic maps, aerial photographs, and reconnaissance geology, the Halfmile Lake area was a likely target (Holyk, 1957) and their first drillhole intersected the Halfmile Lake deposit (McCutcheon et al., 2003). Later that year, Great Sweet Grass Oils Co. and Bay Copper Mines discovered the North and South Lower AB zones, respectively (Adair, 1992; Mireku and Stanley, 2006). In the 1960s and 1970s, additional holes were drilled by Texas Gulf Sulfur and then Billiton (Walker and McCutcheon, 2011). Throughout the 1980s and 1990, the property was owned by several companies and additional diamond drilling was carried out. The gold potential of the gossan at Halfmile Lake South was assessed in 1985 by Kidd Creek Mines Ltd. (Hassard and Gardiner, 1986 in Walker and McCutcheon, 2011). The South Deep zone was discovered in 1999 by Noranda Exploration Ltd. after con-

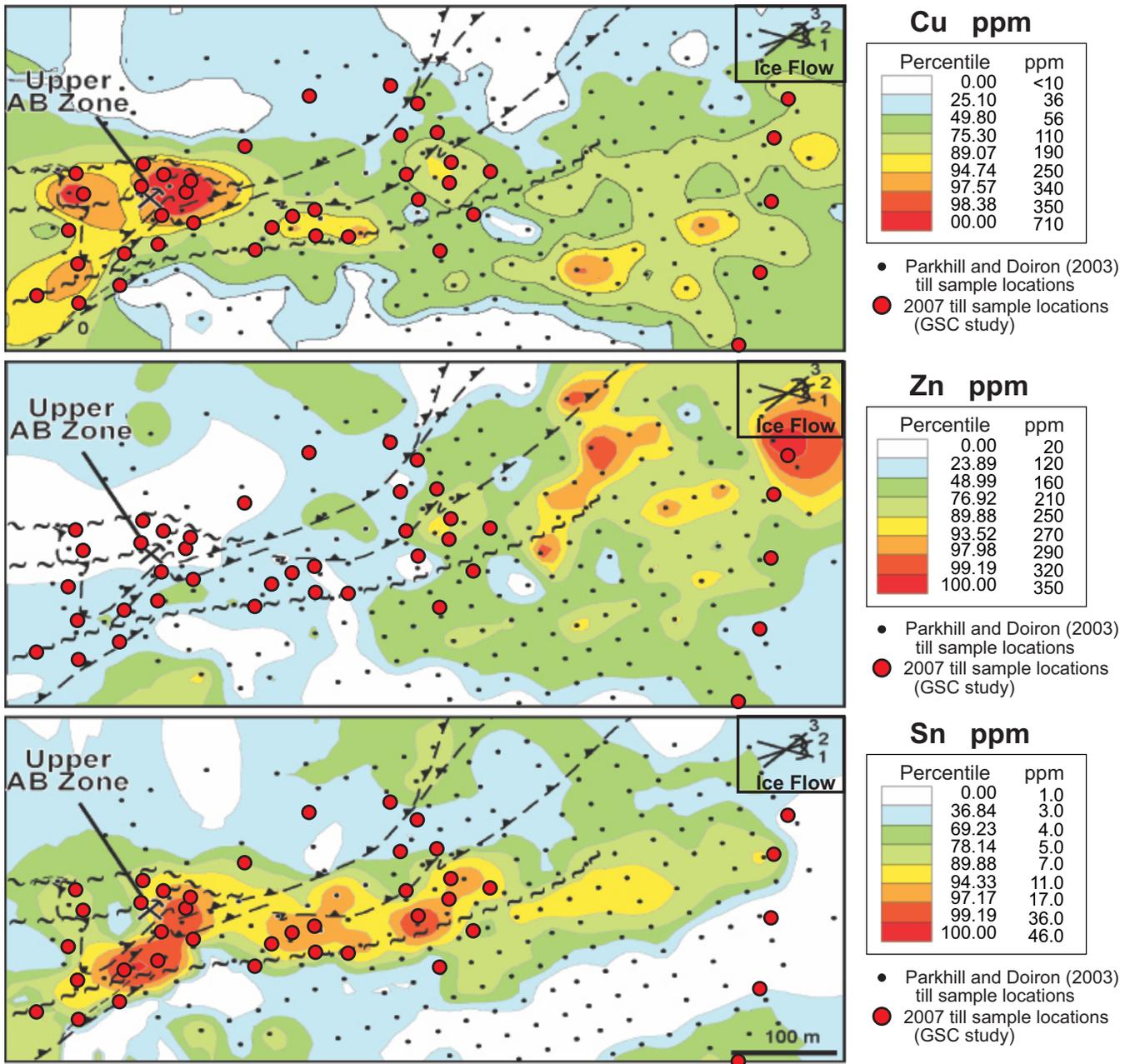
ducting a 3-D seismic survey followed by subsequent drilling (Mireku and Stanley, 2006; Walker and McCutcheon, 2011).

### Previous Surficial Geochemical Studies in the Bathurst Mining Camp

Massive sulphide boulders have been known in the Armstrong Brook area, 47 km northeast of the Halfmile Lake deposit, since the 1860s (Dreimanis, 1958; Rose and Johnson, 1990; Parkhill and Doiron, 2003). The earliest applications of drift prospecting methods in the BMC is documented in Dreimanis (1958), who summarized some of the earliest boulder tracing in the region, including the discovery of the Orvan Brook deposit (Fig. 1) in the 1930s and the Nigadoo boulder train that led to the discovery of the Nigadoo deposit. More recently, Boyle (2003) described how the chemical composition of gossan boulders in the Fly Tent Creek area was used to determine that these boulders were not derived from the up-ice Devil's Elbow deposit, but from a deposit yet to be discovered.

Dreimanis (1960) notes that, in the 1950s and 1960s, prospecting for base metals by soil geochemistry was optimal for residual soils overlying orebodies, but that most residual soils in Canada have been eroded and incorporated into glacial sediments and transported away. Based on case studies in the BMC, as well as Ontario and Quebec, he demonstrated that determining the abundance of base metals and ore particles in overlying and down-ice glacial deposits was better suited to prospecting in the glaciated terrain of Canada. Presant (1966) reported that concentrations of Cu, Pb, Zn, Fe, Mn, As, Sb, Ag, Sn, and Cd are up to 100x higher in soils developed on glacial sediments over sulphide deposits than soils above non-mineralized bedrock in the BMC. Pilch (1970) and Govett et al. (1974) reported anomalous concentrations of Pb (in excess of 1000 ppm) and Hg in B horizon soils that had developed on till overlying mineralization. In a more recent example, the BOG VMS prospect was discovered in 1983 by following-up on a Cu-Pb-Zn anomaly (up to 3000 ppm Pb) in soils developed on glacial sediments, and in till subsequently sampled in deep overburden drillholes (Hoffman and Woods, 1991). More recently, Hall et al. (2003) have demonstrated the use of selective leaches on soils as an exploration method for buried massive sulphide deposits in the BMC.

Since the mid-1980s, the GSC and the NBDNR have carried out several Quaternary mapping and till sampling programs in the BMC to study the nature and type of surficial materials, determine the ice-flow history and patterns of glacial dispersal, examine mineralogy of glacial sediments, and to determine till geochemical signatures around known massive sulphide deposits (Pronk, 1986, 1987; Lamothe, 1990a,b, 1992;



**Figure 6.** Distribution of Cu, Zn (4-acid/ICP-ES), and Sn (4-acid/ICP-MS) in the <0.063 mm fraction of till in the area surrounding the Halfmile Lake Zn-Pb-Cu deposit (Upper AB Zone) as reported by Parkhill and Doiron (2003). Ice-flow direction is to the east. Location of GSC 2007 till sampling sites from the current study are shown as large red dots.

Doiron, 1993a,b, 2000a,b; Parkhill, 1994; Parkhill and Doiron, 1995; Doiron and Boisvert, 1999; Parkhill and Dickson, 1999; Klassen, 2003). This more recent work has shown that till containing elevated concentrations of one or more elements associated with sulphide deposits (i.e. Cu, Pb, Zn, Au, Ag, As, Sn) forms dispersal trains that can be traced back to their mineralized bedrock source and that dispersal trains are generally short (>0.5 to 1 km). Indium, Sn, As, Cu, Pb, Sb, Au, and Zn in the <0.063 mm fraction of till were identified by Parkhill and Doiron (2003) as the optimal pathfinder elements for defining glacial dispersal from

the Halfmile Lake deposit at least 600 m down-ice (Fig. 6). Hussein et al. (2003) demonstrated the application of Pb isotope ratios for identifying glacial dispersal of metal-rich till from the Halfmile Lake deposit using the <0.063 mm till matrix.

Recent studies of the hydrogeochemical signatures of massive sulphide deposits in the BMC included a regional hydrogeochemical survey of the northern part of the BMC (Leybourne et al., 2003) as well as detailed hydrogeochemical studies of the Halfmile Lake deposit (Leybourne, 2001; Leybourne et al., 2002, 2003, 2006; Leybourne and Goodfellow, 2003).

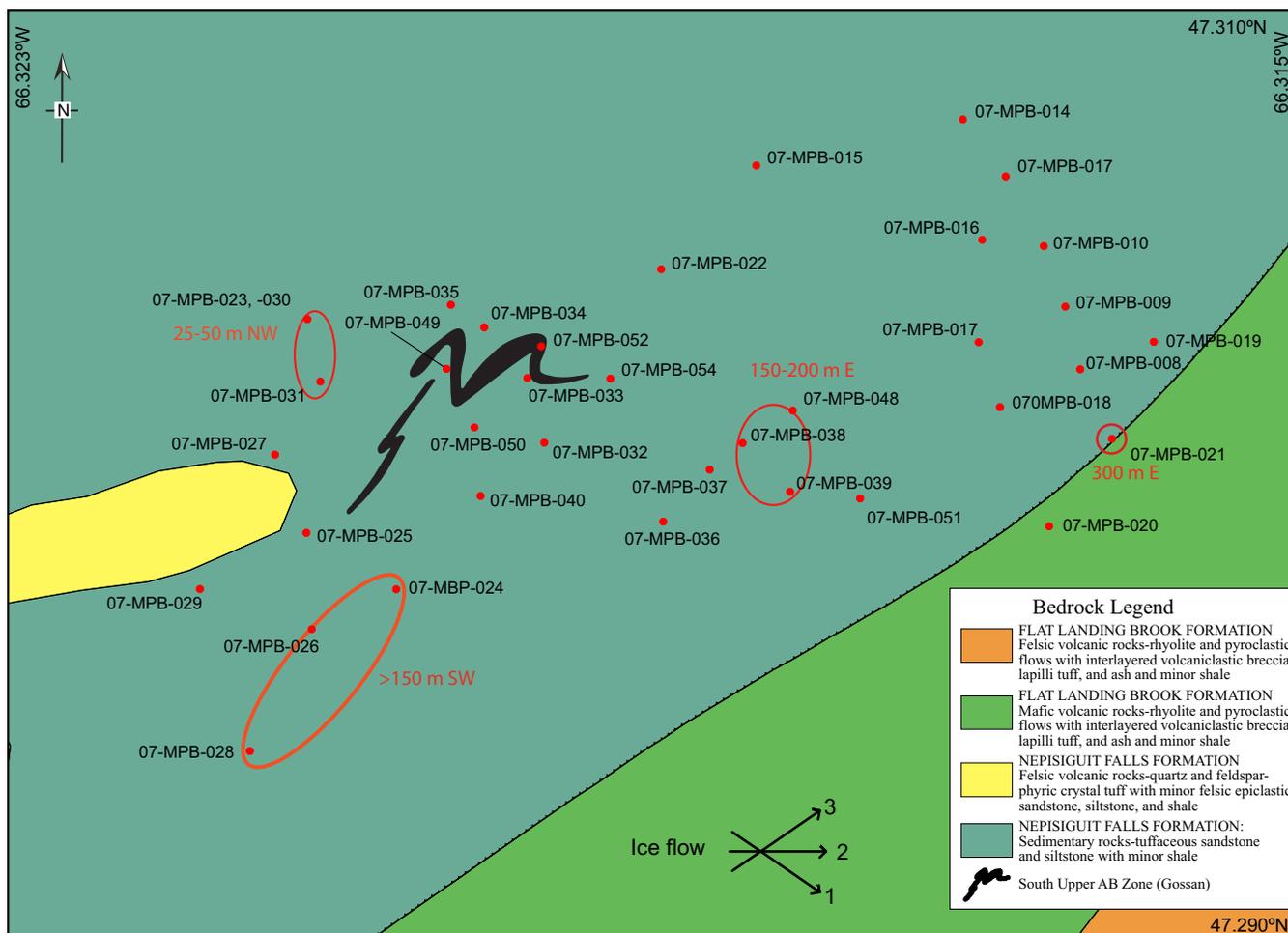


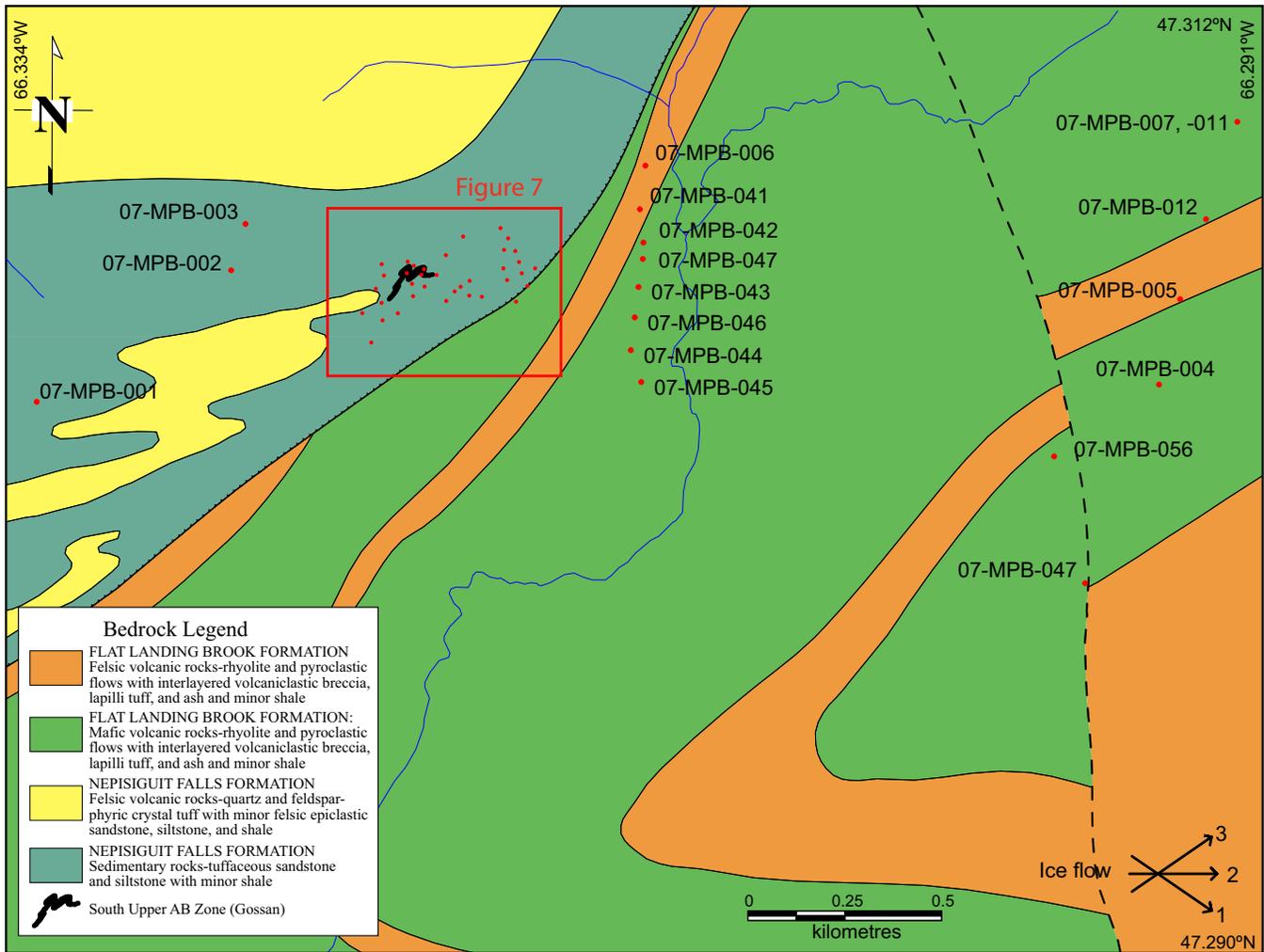
Figure 7. Locations of till samples collected in 2007 from within 500 m of the South Upper AB zone gossan. The bedrock geology is from Goodfellow et al. (2003). Red circles highlight areas where samples have with elevated concentrations of base metals.

## METHODS

### Field Sampling

Till and bedrock samples were collected in July 2007 by the GSC and NBDNR in the vicinity of the Halfmile Lake deposit. Bedrock samples were collected to document the indicator mineral and geochemical signatures of the host rocks and mineralization, for comparison with the mineralogy and geochemistry of till. A total of 55 large (25 kg) till samples were collected up-ice, in the vicinity of and at 0-10, 200, 400, and 800 m intervals down-ice (east) of the South Upper AB zone (Figs. 7, 8). Till sample distribution in 2007 was guided by till geochemical patterns reported by Parkhill and Doiron (2003). Till samples were also collected 300 and 600 m up-ice (west) of the deposit. In 2008, an additional 20 till samples were collected up to 10 km up-ice (samples 08-MPB-001 to -006, -009 to -020) and 20 km down-ice (samples 08-MPB-007, -008) to further document the distribution of specific indicator minerals found in the 2007 till samples (Fig. 9). These till samples were used to establish background concentrations of elements, as no VMS deposits are known to

exist up-ice of the Halfmile Lake deposit. Till samples were collected from holes and trenches. Hand-dug holes were used at till sample sites up-ice and far down-ice of the Halfmile Lake deposit because this method is cost effective and pits can be dug to >0.75 m depth into less oxidized till. A wheeled backhoe was used to dig trenches at sites close to the deposit where till was thicker (up to 2 m) and sample sites were more closely spaced. Till samples were also collected from cleared sections of the walls of existing exploration trenches close to the deposit. Till samples were collected from the B-C or preferably C soil horizons developed on till, as these horizons are less oxidized (Fig. 10). Detailed notes and photos were taken at each sample site. Striations were also measured where visible. Till sample location coordinates and field descriptions are included in Appendix A1 and till site photos are included in Appendix A2. In 2007, three field duplicate samples were collected 1 to 3 m from the original sites to assess field variability: sample 07-MPB-011 is a duplicate of -007, sample 07-MPB-030 is a duplicate of -023, and sample 07-MPB-053 is a duplicate of -049.



**Figure 8.** Locations of till samples collected in 2007 from within 2 km of the South Upper AB zone gossan. The area enclosed by the red rectangle box is shown in Figure 7. The bedrock geology is from Goodfellow et al. (2003).

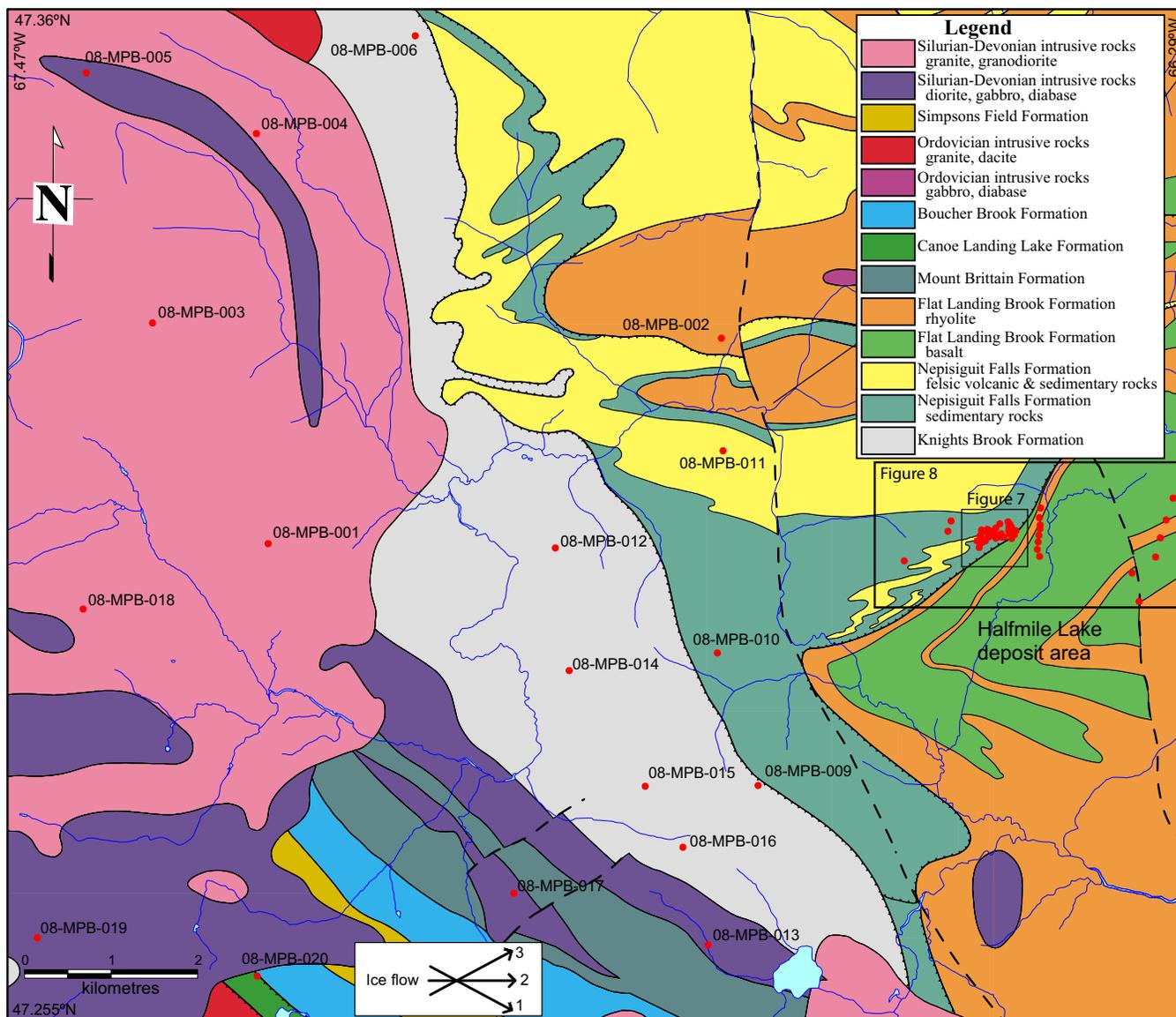
### Munsell Colour, Grain Size, Carbonate Content, and Loss on Ignition

The GSC Sedimentology Lab, Ottawa, determined till texture, carbonate content, and Munsell colour (moist) (Appendix A3). ACME Analytical Laboratories, Vancouver, determined the loss on ignition values as part of their total digestion geochemical analysis package. Till texture (percentages of clay (<0.002 mm), silt (0.002-0.063 mm), and sand (0.063-2.0 mm)) was determined using a combination of sieving and the Lecotrac LT-100 particle-size analyzer (Girard et al., 2004). Till colour was classified using the Munsell soil colour chart on moist till samples. The Leco method was used to determine inorganic carbon content using the LECO® CR412 Carbon Determinator heated to 1350°C. The determination of total carbonate content and the individual amounts of calcite and dolomite in till was made using the Chittick gasometric method (Dreimanis, 1962). This procedure is based on the volumetric evolution of carbon dioxide when carbonates react with dilute hydrochloric acid. Loss on ignition

(LOI), designed to measure the amount of moisture or impurities lost when the sample is ignited, was determined by weight difference after ignition at 1000°C.

### Pebble Lithological Analysis

Pebble lithologies were examined in the 0.8 to 35 cm fraction of selected 2007 till samples to determine the local bedrock signatures and general distances of glacial transport down-ice from the Halfmile Lake South Upper AB zone. Pebbles were grouped into 13 lithological categories that reflect the major rocks types in the area. Prior to pebble classification, approximately 15 kg of till was disaggregated and the >2 mm pebbles screened off at Overburden Drilling Management Ltd., Ottawa. This >2 mm fraction was sieved to recover the 0.8 to 35 cm fraction, which was then coned and quartered to randomly select 300 pebbles for counting. Pebble lithology data listings, including raw counts and frequency percentage, as well as photographs of the pebbles in each sample are included in Appendix B. Table 2 presents the frequency percent abundance of



**Figure 9.** Location of till samples collected in 2007 and 2008 up-ice (west), overlying, and down-ice (east) of the Halfmile Lake VMS deposit. The bedrock geology is from Goodfellow et al. (2003).

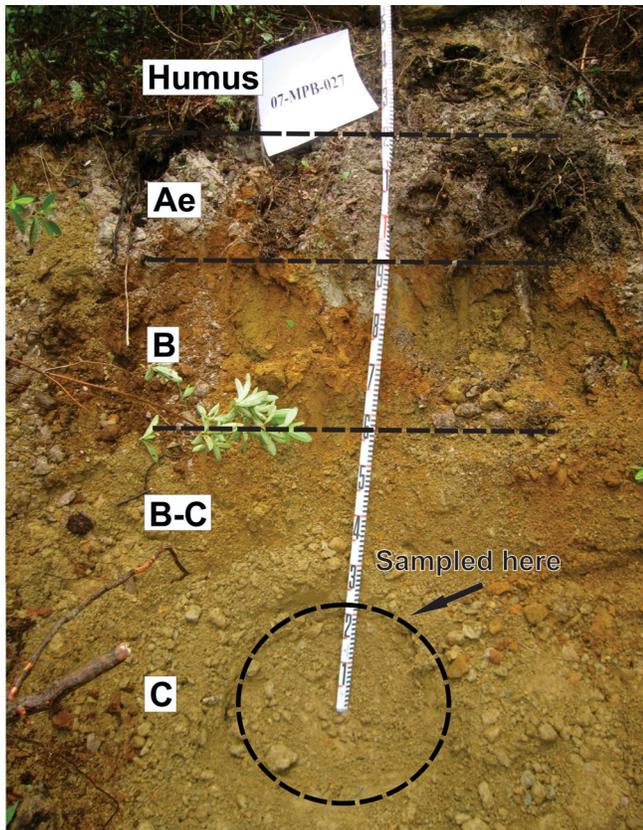
the major rock lithologies of 15 till samples selected up-ice, overlying, and down-ice of the deposit.

### Geochemical Analysis

Till samples were dry-sieved using a stainless steel 230 mesh screen to obtain the <0.063 mm (silt and clay) fraction by the GSC Sedimentology Lab, Ottawa then submitted to ACME Analytical Laboratories, Vancouver, for geochemical analyses using their 4A-4B, 1F, and 3B-MS analytical packages (Appendix C1). Samples were sieved and geochemically analyzed in a predetermined order from least metal-rich to most metal-rich to minimize cross contamination between samples. Approximately 200 g of silicic acid blank was sieved at regular intervals between samples to monitor potential cross contamination during sample preparation. These samples are numbered 07-MPB-BLK-01 to -08 within

the 2007 batch.

For the Group 4A-4B package, a 0.2 g aliquot was subjected to a total digestion using lithium metaborate/tetraborate fusion and dilute nitric digestion and analyzed by ICP-ES to determine the major oxides and several minor elements. Rare earth and refractory elements were determined by ICP-MS. A separate 0.5 g aliquot was digested using aqua regia followed by ICP-MS analysis (Group 1F). An additional 30 g aliquot was used to determine Au, Pt, and Pd by lead-collection fire-assay fusion for total sample decomposition and nitric acid digestion of the Ag doré bead followed by ICP-MS (Group 3B-MS) analysis. Geochemical data and distribution maps are included in Appendix C and D, respectively. Field duplicates are plotted on geochemical maps and included in statistical calculations.



**Figure 10.** Till section showing the location of till sample 07-MPB-27 within the soil profile. Units on the measuring tape are decametres.

### Heavy Mineral Processing and Indicator Mineral Recovery

Approximately 15 kg of each till sample was processed at Overburden Drilling Management Ltd. (ODM), Ottawa, to produce a non-ferromagnetic heavy mineral concentrate for picking of potential VMS and other indicator minerals (McClenaghan, 2012). First the <2.0 mm material was passed over a shaking table and the 0.25-2.0 mm heavy mineral fraction recovered. This fraction was then micropanned to recover gold and sulphide minerals in the <2 mm fraction. These panned minerals were examined, counted, and then returned to the sample. Gold grain counts reported in Table 3 are the result of this processing step. The 0.25-2.0 mm pre-concentrate was then further refined using heavy liquid separation in methylene iodide diluted to a specific gravity (SG) of 3.2. The ferromagnetic fraction was then removed and the non-ferromagnetic heavy mineral fraction was sieved into three size fractions: 0.25-0.5, 0.5-1.0, and 1.0-2.0 mm. These three fractions were then examined for indicator minerals. Chalcopyrite and beudantite grain counts reported in Table 3 are the result of this step. Complete listings of indicator mineral data for bedrock and till samples from this study are reported in GSC Open File 7076 (McClenaghan et al., 2012).

### Quality Assurance and Quality Control (QA/QC)

Geochemical analytical accuracy and precision were monitored using sample preparation (blind) duplicates and CANMET certified reference standards, including UM-2, UM-4 (<http://www.nrcan.gc.ca/minerals-metals/technology/certified-reference-materials/certificate-price-list/4114>), TDB-1 (<http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca.minerals-metals/files/pdf/mms-smm/tect-tech/ccrmp/cer-cer/tdb-1-eng.pdf>), and Till 4 (<http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca.minerals-metals/files/pdf/mms-smm/tect-tech/ccrmp/cer-cer/till-1-4-eng.pdf> and this for tdb-1 \*) Each standard was analyzed twice. The smaller 2008 batch of samples contained CANMET certified reference standards TDB-1, UM-2, and UM-4, each analyzed once. QA/QC data are listed in a second worksheet in Appendices C3, C4, and C5.

Blind duplicates were prepared for 3 till samples during sample preparation at the GSC Sedimentology Lab. Three duplicate field samples were collected to assess field variability between samples 07-MPB-007 and -011, 07-MPB-023 and -030, and 07-MPB-049 and -053. Field duplicate data and plots are included in Appendix C6.

### Data Plotting

Data for 2007 and 2008 till samples were treated as one data set. Geochemical values reported as less than the lower detection limit were reassigned values of one half of the detection limit for statistical calculations. Correlation coefficients were then calculated and scatter plots were generated for selected elements using Microsoft Office® Excel 2007. Concentrations of selected pathfinder elements (Cu, Pb, Zn, Au, Ag, As, Bi, Sb, Hg, Se, and Sn) were plotted using ESRI® ArcGIS 9.1 and Mapinfo Professional v7.8 using proportional dots, at a regional, local, and deposit scale (Cu and Au only) in the vicinity of the Halfmile Lake deposit (Appendix D) using natural breaks in the data as cut-off points for dot sizes. Indicator mineral grain counts were plotted using Mapinfo Professional Version 7.8 by using proportional dot maps at a regional and local scale (Appendix E).

## RESULTS

### Quality Assurance and Quality Control (QA/QC)

Reference standard and lab preparation (blind) duplicate values are presented in the second worksheet of each file in Appendices C3 to C5. The results for blind duplicates and standards (Appendix C7) show the precision and accuracy of the till geochemical data to be acceptable (<10%) for most elements, based on scatter plots and calculated %RSD. Elements with high variability may be explained by some values being close to

## Till Geochemical Signatures, Halfmile Lake Zn-Pb-Cu VMS Deposit, Bathurst Mining Camp, New Brunswick

**Table 2.** Frequency percent data for pebble lithologies counted in the 0.8 to 3.5 cm fraction of selected 2007 till samples. Brief descriptions of the lithological categories are listed below.

Sample	Sfi %	Smi %	Ofi %	Os %	OFmv %	Hf %	OFFv %	ONfv %	ONs %	ONt %	Qz %	TG %	R %	Total %
07-MPB-002	0	0	3	3	2	0	5	2	60	5	21	0	0	100
07-MPB-005	0	1	0	1	5	1	2	11	48	14	14	0	2	100
07-MPB-009	0	0	0	0	1	2	2	3	72	10	11	0	0	100
07-MPB-013	0	0	0	0	0	0	0	1	3	80	16	0	0	100
07-MPB-015	0	0	0	0	1	4	1	2	19	64	9	0	0	100
07-MPB-020	0	0	0	0	0	0	2	2	9	41	46	0	0	100
07-MPB-021	0	1	1	0	2	1	8	7	21	34	24	0	1	100
07-MPB-023	0	0	0	0	0	0	1	0	4	81	3	5	6	100
07-MPB-024	0	0	0	0	0	0	0	0	0	1	1	1	97	100
07-MPB-029	0	0	0	0	0	0	5	2	32	58	1	0	1	100
07-MPB-033	0	0	0	0	0	0	0	0	3	90	0	0	7	100
07-MPB-038	0	0	0	0	1	0	0	0	28	61	7	3	0	100
07-MPB-042	0	0	0	1	1	1	5	3	13	68	8	0	0	100
07-MPB-046	1	1	1	4	18	0	2	2	12	41	17	0	0	100
07-MPB-050	0	0	0	1	11	0	1	2	12	40	6	1	25	100

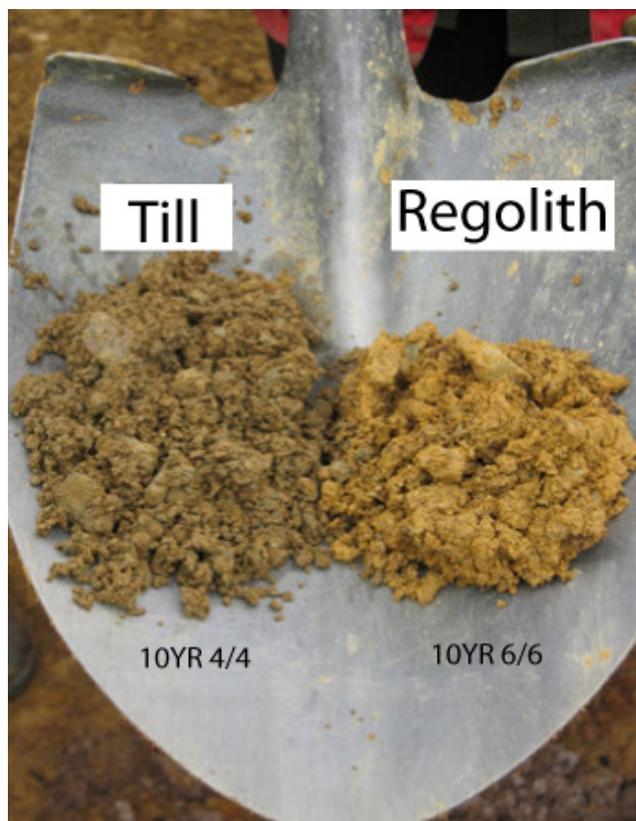
Abbreviations	Categories	Category description
Sfi	Silurian felsic intrusive	biotite granite
Smi	Silurian mafic intrusive	gabbro
Ofi	Ordovician felsic intrusive	felsic intrusive other than biotite granite
Os	Ordovician sediments	light grey sedimentary rock
OFmv	Ordovician Flat Landing Brook Fm mafic volcanic	Moody Brook andesite, other mafics
Hf	Hornfels	black, untextures, plain rock
OFFv	Ordovician Flat Landing Brook Fm felsic volcanic	rhyolite (beige in colour)
ONfv	Ordovician Nepisiguit Falls Fm felsic volcanic	quartz-feldspar porphyry
ONs	Ordovician Nepisiguit Falls Fm sedimentary rock	argillite, greywacke, chloritic mudstone
ONt	Ordovician Nepisiguit Falls Fm tuff	tuff, quartz eye tuff, epiclastic, highly altered sedimentary rock
Qz	Quartz	>80% quartz, quartzite, vein quartz, quartz majority with some Nepisiguit Falls sedimentary rock and tuff
TG	True gossan	completely altered to gossan with a darker brown colour
R	Regolith	weathered bedrock but not completely gossanized; light orange in colour

the lower detection limit (S, Te, Na), or by the nugget effect (Au, Pt, Pd).

The data and xy scatter plots for field duplicates are shown in separate worksheets in Appendix C6. Precision (i.e. relative standard deviation, %RSD) of field duplicates is acceptable (<10%) but it does indicate that there is some heterogeneity and variability between samples collected at the same sample site. Silver, Bi, Cu, As, and Te show the greatest heterogeneity, with high standard deviation and >10% RSD values (Appendix C6). Other elements with high RSD values can be explained by their concentrations being close to detection limit or due to nugget effect.

### Munsell Colour, Grain Size, Carbonate Content, and Loss on Ignition

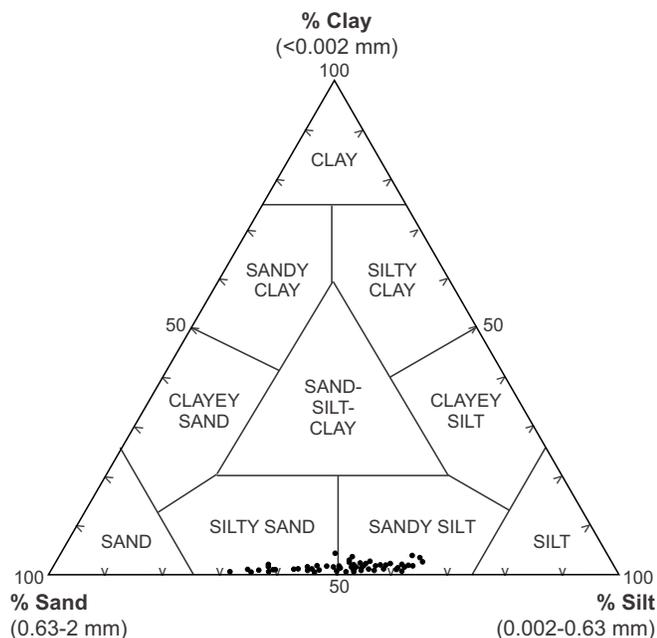
As indicated in Appendix A3, the majority (72%) of the till samples are olive brown to light olive brown (Munsell hue 2.5Y) representing samples farthest from the ore zone (Table 3). Samples within 100 m of the gossan zone are darker in colour, mostly dark yellowish brown (Munsell hue 10YR) to brown (Fig. 11). The local till sampled in this study has a sandy silt to silty sand matrix texture consisting of 35 to 68% sand, 32 to 65% silt, and 0 to 4% clay, with an average of 51% sand, 48% silt, and 1% clay (Fig. 12). The till matrix contains no inorganic carbon, as determined by the LECO® method, and on average only 0.6% carbonate deter-



**Figure 11.** Photograph of the till and regolith collected at sample site 07-MPB-021. Note that the regolith colour is more orange, i.e. more oxidized, than the till.

**Table 3.** Summary of pathfinder element contents in the <0.063 mm till fraction determined by aqua regia ICP-MS (except Au (fire assay) and Sn (borate fusion)) for the Halfmile Lake study (2007 till samples, n = 76) compared to the abundance of gold grains in the pan concentrate, and chalcopyrite and beudantite grains (normalized to 10 kg) in the 0.25-0.5 mm of the non-ferromagnetic heavy mineral fraction. Elevated indicator mineral grain abundances highlighted in pink, elevated till geochemical contents highlighted in yellow.

Sample Number	Distance from Ore Zone (m)	Relative to Ore Zone	Direction from Ore Zone	No. of Gold Grains/10 kg	No. of Chalcopyrite Grains/10 kg	No. of Beudantite Grains/10 kg	Cu ppm	Pb ppm	Zn ppm	Ag ppb	Au ppb	As ppm	Bi ppm	Hg ppb	Se ppm	Sn ppm	Sb ppm
08-MPB-005	-12000	background	NW	0	0	0	17	9	40	8	<1	2	0.1	74	0.5	4	0.05
08-MPB-019	-12000	background	SW	0	0	0	26	11	66	12	2	3	0.2	27	0.3	3	0.08
08-MPB-003	-10500	background	NW	0	0	0	9	16	50	7	<1	6	0.7	44	0.6	8	0.10
08-MPB-018	-10500	background	W	0	0	0	13	9	29	7	1	3	0.3	69	0.2	4	0.08
08-MPB-004	-10000	background	NW	1	0	0	26	9	29	21	<1	2	0.2	49	0.6	3	0.05
08-MPB-020	-10000	background	SW	0	0	0	46	8	41	8	4	6	0.1	32	0.5	3	0.11
08-MPB-006	-8750	background	NW	1	0	0	29	11	67	15	<1	6	0.3	29	0.3	4	0.12
08-MPB-001	-8500	background	W	2	0	0	7	11	42	6	<1	3	0.3	57	0.5	6	0.11
08-MPB-017	-7000	background	SW	0	0	0	32	15	60	56	2	11	0.3	77	0.8	3	0.37
08-MPB-013	-6000	background	SW	0	0	0	66	13	61	35	1	17	0.3	31	0.7	3	0.24
08-MPB-016	-5500	background	SW	0	0	0	67	14	88	39	2	9	0.3	39	0.4	3	0.16
08-MPB-014	-5000	background	W	0	0	0	44	17	80	19	<1	14	0.3	15	0.4	4	0.17
08-MPB-015	-5000	background	SW	0	0	0	57	15	73	112	<1	18	0.4	64	0.7	4	0.29
08-MPB-002	-4500	background	NW	1	0	0	16	24	85	40	<1	61	0.2	24	0.4	3	0.28
08-MPB-012	-4500	background	W	0	0	0	54	33	91	157	1	30	0.4	47	0.6	4	0.14
08-MPB-009	-4000	background	SW	4	0	0	54	14	113	80	<1	18	0.4	69	0.8	4	0.27
08-MPB-010	-3500	background	W	2	0	0	50	21	76	31	<1	20	0.3	59	0.4	3	0.17
07-MPB-001	-940	background	SW	4	0	0	44	51	107	36	1	20	0.4	35	0.6	5	0.21
07-MPB-002	-410	background	W	4	0	0	38	55	127	69	2	14	0.5	44	0.5	5	0.18
07-MPB-003	-410	background	NW	1	0	0	36	51	113	63	1	16	0.5	35	0.7	4	0.30
<b>threshold</b>							<b>68</b>	<b>56</b>	<b>114</b>	<b>158</b>	<b>5</b>	<b>62</b>	<b>0.8</b>	<b>78</b>	<b>0.8</b>	<b>9</b>	<b>0.38</b>
07-MPB-029	-80	up ice	SW	1	0	3	307	105	127	88	5	61	1.2	40	0.8	3	0.43
07-MPB-027	-60	up ice	W	1	0	1	74	64	115	30	6	19	0.6	23	0.4	5	0.34
07-MPB-023	-60	up ice	W	24	28	4	1199	164	71	995	321	473	78.7	120	12.0	30	1.71
07-MPB-031	-55	up ice	W	7	14	7	1231	208	107	674	139	442	60.1	85	8.1	30	1.77
07-MPB-025	-38	up ice	SW	0	0	43	780	279	192	219	19	376	3.6	26	1.2	5	0.94
07-MPB-049	0	overlying	N	9	1	1	217	69	90	114	28	168	7.2	30	1.7	6	0.64
07-MPB-033	0	overlying	N	7	1	2	939	341	126	2227	87	553	32.9	135	5.9	16	1.61
07-MPB-052	0	overlying	N	3	0	11	152	51	95	583	23	211	4.3	66	1.3	7	0.54
07-MPB-050	25	down ice	E	4	0	68	418	824	153	1428	140	2389	32.2	76	9.2	26	4.31
07-MPB-054	25	down ice	N	9	1	21	162	128	109	630	32	266	10.1	59	1.8	8	0.78
07-MPB-034	30	down ice	N	4	39	6	429	85	71	738	166	521	22.1	60	3.9	8	1.18
07-MPB-035	30	down ice	N	0	8	0	127	52	89	492	21	164	3.6	63	0.8	5	0.40
07-MPB-024	32	down ice	S	1	0	43	892	4377	426	8078	574	8463	171.3	403	19.0	109	#####
07-MPB-040	38	down ice	E	5	0	29	139	353	113	437	23	205	2.4	68	1.2	16	0.90
07-MPB-026	60	down ice	S	0	0	43	388	2154	154	3210	49	2968	7.7	110	3.1	14	3.38
07-MPB-032	62	down ice	E	3	1	5	252	87	133	176	30	134	1.9	24	1.2	7	0.56
07-MPB-036	120	down ice	E	1	0	30	227	103	150	141	11	108	1.5	82	0.9	6	0.46
07-MPB-028	125	down ice	S	0	0	9	525	641	407	768	32	1047	3.1	78	1.7	8	1.07
07-MPB-022	130	down ice	NE	2	0	0	70	67	157	31	1	38	0.7	33	0.7	4	0.30
07-MPB-037	135	down ice	E	5	0	79	76	91	113	201	14	89	1.8	28	0.9	7	0.49
07-MPB-038	145	down ice	E	4	93	1	1254	155	142	634	204	465	148.9	42	31.1	69	3.56
07-MPB-018	160	down ice	NE	4	21	4	177	167	198	76	16	202	12.6	40	3.1	10	1.22
07-MPB-039	170	down ice	E	6	1	21	183	132	99	176	37	198	11.1	41	2.9	8	0.75
07-MPB-048	170	down ice	NE	0	5	0	292	44	83	454	8	167	23.5	61	8.2	48	1.49
07-MPB-015	180	down ice	NE	7	0	3	66	62	128	238	3	32	1.2	72	0.7	4	0.41
07-MPB-051	200	down ice	E	2	1	10	129	68	96	67	9	117	4.0	18	1.7	5	0.62
07-MPB-017	252	down ice	NE	1	0	6	79	73	177	127	2	127	1.9	51	1.5	9	0.72
07-MPB-016	265	down ice	NE	4	0	16	113	83	228	112	8	110	1.5	71	1.4	5	0.70
07-MPB-014	280	down ice	NE	0	0	4	62	178	155	206	23	54	0.9	67	1.7	7	0.80
07-MPB-013	290	down ice	NE	0	0	75	118	318	198	90	12	143	1.1	53	3.4	5	2.04
07-MPB-010	290	down ice	NE	0	10	10	98	81	265	71	<1	57	1.1	41	0.9	4	0.36
07-MPB-020	290	down ice	E	1	0	1	185	556	116	534	48	622	1.6	71	1.6	9	3.07
07-MPB-009	295	down ice	NE	0	0	4	167	155	268	90	9	76	2.5	70	2.4	11	0.76
07-MPB-008	300	down ice	NE	1	20	14	226	116	249	243	9	159	7.0	74	2.3	9	0.57
07-MPB-021	305	down ice	E	5	11	10	154	176	119	218	38	381	22.8	71	7.3	20	2.39
07-MPB-019	335	down ice	NE	3	25	10	191	404	234	188	21	221	8.9	47	2.7	12	1.16
07-MPB-043	600	down ice	E	1	0	9	62	152	122	78	4	137	1.0	34	0.9	5	0.56
07-MPB-044	600	down ice	SE	0	0	3	42	41	87	15	<1	18	0.5	10	0.5	4	0.25
07-MPB-046	600	down ice	E	1	0	3	84	45	105	43	5	24	0.6	64	0.6	4	0.22
07-MPB-047	610	down ice	NE	0	2	4	157	144	210	188	14	189	9.1	31	2.0	7	0.85
07-MPB-042	625	down ice	NE	0	2	10	111	203	227	143	11	160	2.4	52	1.4	6	0.79
07-MPB-041	630	down ice	NE	2	0	0	53	159	179	67	9	125	0.7	59	1.1	5	0.77
07-MPB-045	650	down ice	SE	1	0	0	34	35	102	11	6	16	0.4	18	0.6	4	0.24
07-MPB-006	690	down ice	NE	0	0	2	51	116	168	31	3	43	0.9	64	1.4	8	0.63
07-MPB-056	1675	down ice	SE	1	0	0	19	19	71	9	<1	9	0.4	7	0.3	3	0.14
07-MPB-057	1850	down ice	SE	3	0	0	28	24	94	12	2	10	0.4	23	0.4	3	0.12
07-MPB-004	1900	down ice	SE	0	0	0	23	22	94	10	<1	11	0.5	18	0.5	4	0.14
07-MPB-005	1925	down ice	E	1	0	0	34	25	114	18	<1	11	0.5	25	0.5	4	0.14
07-MPB-012	1990	down ice	NE	2	0	0	35	28	125	29	<1	15	0.6	39	0.6	4	0.13
07-MPB-007	2100	down ice	NE	2	7	0	96	61	144	83	2	78	2.8	22	1.0	5	0.29
08-MPB-007	20000	down ice	E	0	0	0	14	54	137	53	<1	10	0.3	46	0.6	3	0.29
08-MPB-008	26000	down ice	NE	0	0	0	13	34	102	18	<1	18	0.3	52	0.3	3	0.34



**Figure 12.** Ternary diagram of till matrix texture showing the percentage of sand, silt, and clay in the 2007 and 2008 till samples (n=76). Most of the samples plot in the silty sand to sandy silt fields.

mined by the Chittick method (Appendix A3). Loss on ignition determined by ACME Labs varies from 3.9 to 14.7% (Appendix A3) with an average LOI of 7.3%.

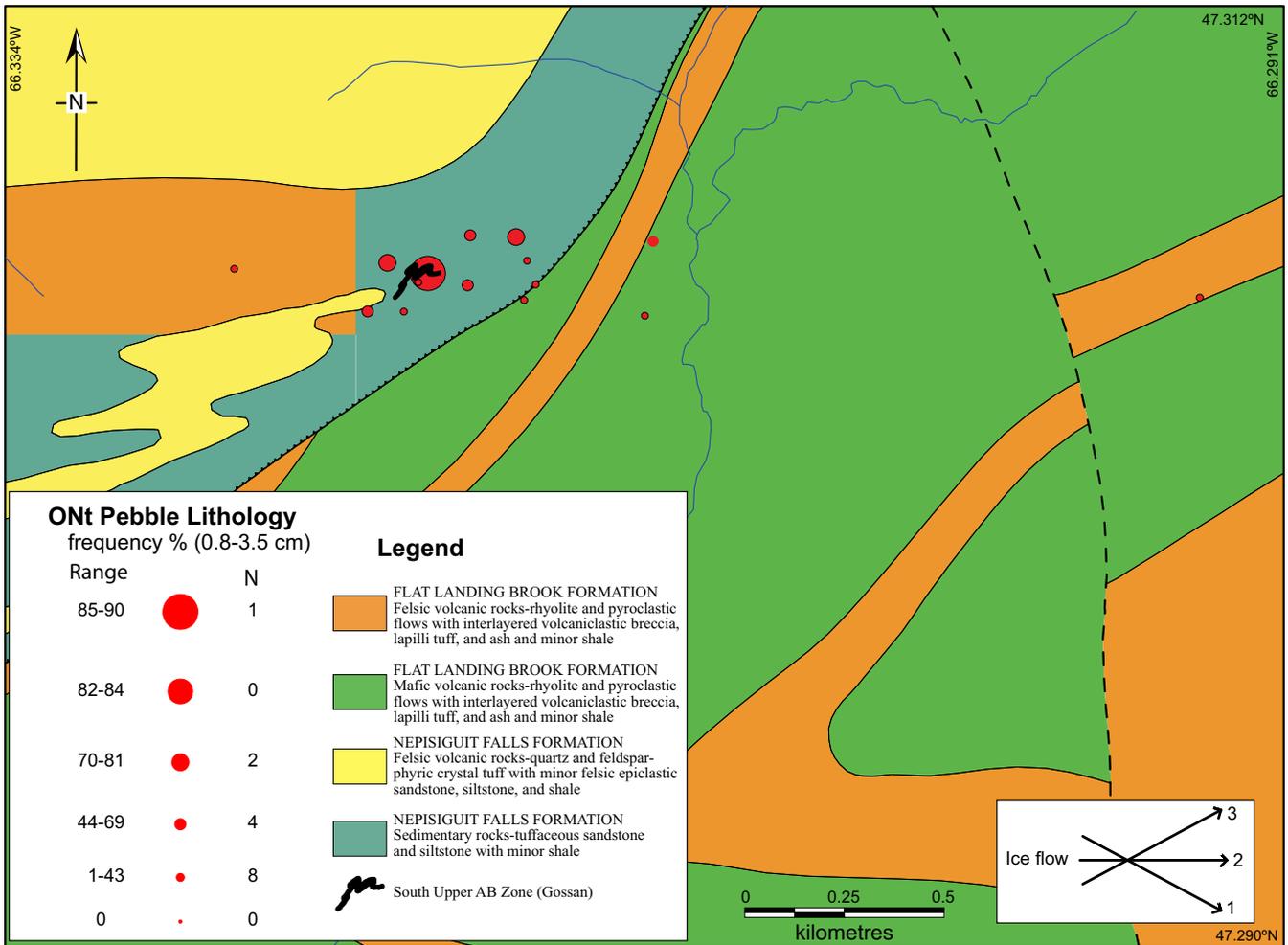
### Pebble Lithological Analyses

The frequency percent abundances of major rock lithologies in till samples across the Halfmile Lake deposit area are presented in Table 2. Appendix B contains additional data for, and photos of, the pebble fraction. Pebbles from 15 till samples were classified into 13 distinct lithologies. The categories consist of both regional and local bedrock units. More detailed descriptions of the 13 categories are listed in Table 2.

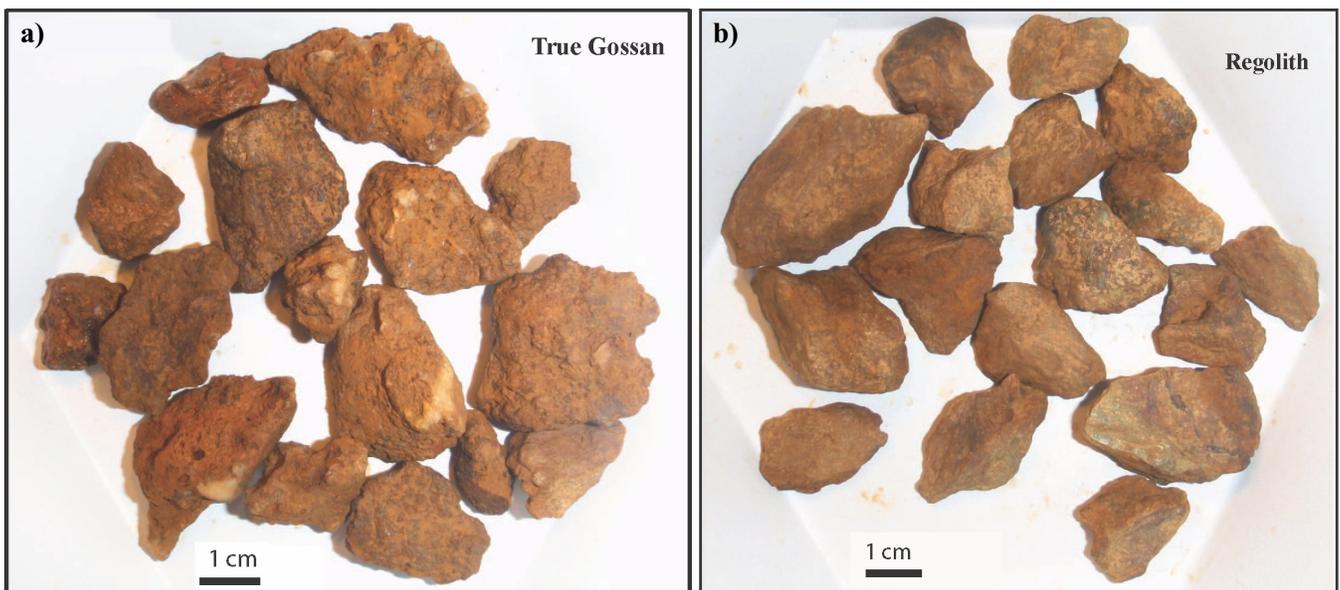
Regional bedrock lithologies distal (>500 m) to the Halfmile Lake deposit area include Silurian felsic intrusive (Sfi), Silurian mafic intrusive (Smi), Ordovician felsic intrusive (Ofi), and other Ordovician sedimentary (Os) rocks (Goodfellow et al., 2003). Pebble abundances of these four categories are low (0-4%) and thus no patterns are obvious. Hornfels pebble abundance was similarly low (0-4%), with a locally elevated abundance of 4% in till sample 07-MPB-015, collected approximately 150 m northeast of the South Upper AB zone (gossan). Almost all till samples contain a significant amount of quartz fragments. This lithological category was variable in texture and origin, and includes quartzite, quartz-rich veins, or a quartz majority with minor portions of tuff and sediment. Quartz pebble abundance varies from 0 to 46% and showed no pattern that could be linked to bedrock lithology.

Local pebble lithologies that are proximal (0-200 m) to the gossan zone include the Ordovician Flat Landing Brook Formation mafic volcanic rocks (OFmv), Ordovician Flat Landing Brook Formation felsic volcanic rocks (OFFv), Ordovician Nepisiguit Falls Formation felsic volcanic quartz-feldspar porphyry (ONfv), Ordovician Nepisiguit Falls Formation tuff and felsic volcanic rocks (ONt), and Ordovician Nepisiguit Falls Formation sedimentary rocks (ONs) (Goodfellow et al., 2003). Flat Landing Brook Formation mafic volcanic pebble abundance in till varies from 0 to 18%. Sample 07-MPB-046 contains the highest amount (18%). Felsic volcanic pebble abundances from the Flat Landing Brook and Nepisiguit Falls formations are low (0-8% and 0-11%, respectively) and do not show a distribution pattern that can be related to bedrock distribution. Nepisiguit Falls Formation sedimentary rocks represent a significant percentage of the pebbles in till (0-60%), with half the till samples containing between 10 and 30%. This unit is the underlying bedrock and thus its distribution in till indicates short (0-100 m) dispersal. The most abundant pebbles in till are from the Nepisiguit Falls Formation tuff. Out of the fifteen samples analyzed, ten of them contain >40% Nepisiguit Falls tuff pebbles and values ranged from 1 to 90%. This unit is also the local underlying bedrock at Halfmile Lake and to the west of the South Upper AB zone. Its distribution in till indicates short (0-200 m) and distinct dispersal (Fig. 13).

Gossanous pebbles were split into two categories to better understand the presence of true gossan (TG) versus regolith (R) material. True gossan pebbles are completely altered to gossan such that they are dark brown in colour, vuggy, and often contain visible quartz fragments (Fig. 14a). Regolith in this area is weathered bedrock that has not been completely altered, such that some of the original bedrock can still be identified. Where there is still evidence of the original bedrock, regolith is light orange to light grey (Fig. 14b). Pebble abundance in till of true gossan was much lower (0-5%) than that of regolith (0-97%). True gossan and regolith pebbles have been dispersed up to 50 m down-ice (east) of the South Upper AB zone (Fig. 15) and concentrations decrease to background levels (0%) up to 100 m west of the gossan zone. Till sample 07-MPB-050, collected <50 m down-ice, contains 24% regolith pebbles. Two till samples collected up-ice (west) of the known extent of South Upper AB zone (samples 07-MPB-23 and -29) and one sample collected to the south (sample 07-MPB-24) also contain gossan and regolith clasts (Fig. 15). Sample 07-MPB-24 is noteworthy because 97% of its pebbles are regolith and thus the geochemistry of this sample is expected to reflect the immediate underlying bedrock.



**Figure 13.** Local distribution of Ordovician Nepisiguit Falls Formation tuff (ONT) pebbles in the 0.8-3.5 cm fraction of till. The regional bedrock geology is from Goodfellow et al. (2003).



**Figure 14.** Colour photographs of (a) true gossan pebbles and (b) regolith pebbles.

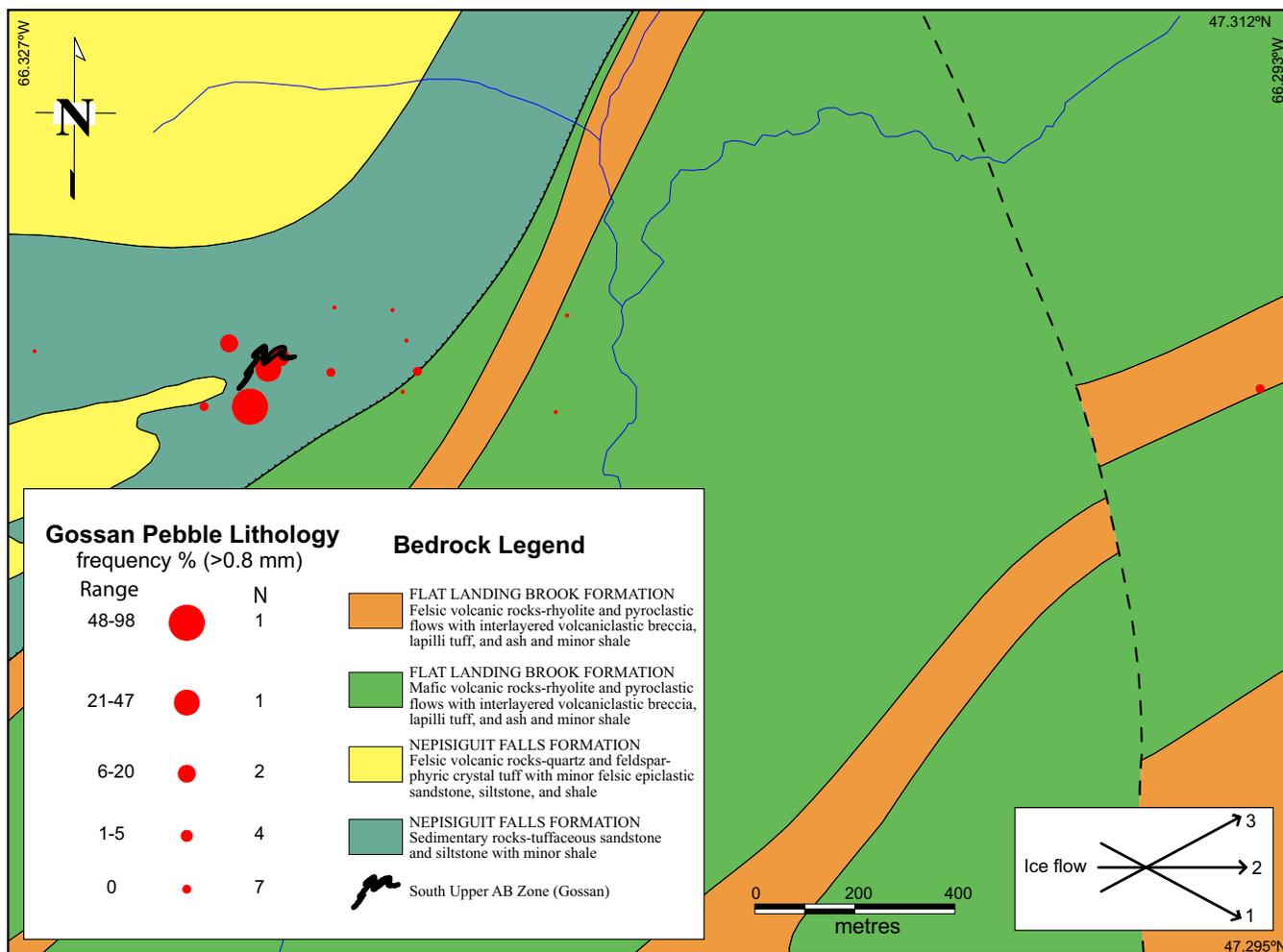


Figure 15. Local distribution of regolith (R) plus true gossan (TG) pebbles in the 0.8-0.35 cm fraction of till. The regional bedrock geology is from Goodfellow et al. (2003).

### Geochemistry of the <0.063 mm Fraction

Geochemical data for the <0.063 mm fraction of till samples collected in 2007 and 2008 are presented in Appendices C2 to C4. A summary of the geochemical data for pathfinder elements, and abundance of chalcopyrite, gold, and beudantite (Pb sulphate derived from the gossan) from the non-ferromagnetic heavy mineral fraction of the 2007 till samples is presented in Table 3. A correlation matrix for selected elements, which were determined largely by aqua regia/ICP-MS, is shown in Table 4. A correlation coefficient ( $r$ ) > 0.8 is considered to indicate a strong correlation and  $r$  values of 0.6 to 0.8 indicate a significant correlation. Local-scale geochemical distribution maps are shown in Appendix D1 (maps 1 to 11), at a deposit scale in Appendix D2 (maps 12, 13), and at a regional scale in Appendix D3 (maps 14 to 24).

The 2007-2008 till sample suite is biased towards higher geochemical values because most of the samples were collected in the vicinity (<500 m) of the Halfmile Lake deposit. Because of this skewed sample

distribution pattern, the till samples collected up-ice (samples 07-MPB-01, -02, -03) and the 2008 till samples were used to establish background values instead of using percentile values or cumulative frequency plots to establish thresholds. The up-ice samples will be referred to as the ‘background’ samples and are listed as such in Table 3. The spatial geochemical distributions of the pathfinder elements are plotted as proportionally sized dots on a bedrock geology base map at local, deposit, and regional scales and are presented in Appendix D.

### Cu, Pb, and Zn in the <0.063 mm Fraction

Cu, Pb, and Zn concentrations in the <0.063 mm fraction of till determined by aqua regia digestion are the highest base metal concentrations around the Halfmile Lake deposit (Table 3). Concentrations of Cu vary from 7 to 1254 ppm and exhibit strong ( $r > 0.8$ ) positive correlations with Ag, As, Au, Bi, Fe, and Sb, and significant positive ( $r = 0.6-0.8$ ) correlations with Pb, Se, and Sn. Copper displays a significant negative correlation with Ti (Table 4). The highest concentrations of Cu in

**Table 4.** Correlation matrix of selected log transformed elements determined by aqua regia/ICP-MS (except Au (fire assay) and Sn (borate fusion)) in the <0.063 mm till fraction (where  $r > 0.8$  the numbers are in bold red, and where  $r = 0.6-0.8$  the numbers are in bold black).

	Ag	As	Au	Bi	Cu	Fe	Hg	Pb	Sb	Se	Sn	Ti	Zn	% Clay
Ag	1.000													
As	<b>0.909</b>	1.000												
Au	<b>0.830</b>	<b>0.856</b>	1.000											
Bi	<b>0.837</b>	<b>0.866</b>	<b>0.874</b>	1.000										
Cu	<b>0.850</b>	<b>0.864</b>	<b>0.877</b>	<b>0.874</b>	1.000									
Fe	<b>0.725</b>	<b>0.712</b>	<b>0.684</b>	<b>0.766</b>	<b>0.812</b>	1.000								
Hg	<b>0.625</b>	0.467	0.505	0.465	0.437	0.456	1.000							
Pb	<b>0.806</b>	<b>0.908</b>	<b>0.772</b>	<b>0.733</b>	<b>0.737</b>	<b>0.611</b>	0.474	1.000						
Sb	<b>0.861</b>	<b>0.938</b>	<b>0.846</b>	<b>0.851</b>	<b>0.806</b>	<b>0.760</b>	0.534	<b>0.900</b>	1.000					
Se	<b>0.775</b>	<b>0.783</b>	<b>0.811</b>	<b>0.881</b>	<b>0.796</b>	<b>0.784</b>	0.582	<b>0.659</b>	<b>0.832</b>	1.000				
Sn	<b>0.736</b>	<b>0.736</b>	<b>0.760</b>	<b>0.879</b>	<b>0.719</b>	<b>0.759</b>	0.562	<b>0.676</b>	<b>0.805</b>	<b>0.860</b>	1.000			
Ti	-0.596	<b>-0.630</b>	-0.570	<b>-0.604</b>	<b>-0.601</b>	-0.501	-0.378	-0.566	<b>-0.665</b>	<b>-0.618</b>	-0.591	1.000		
Zn	0.484	<b>0.629</b>	0.370	0.417	0.478	0.431	0.218	<b>0.739</b>	<b>0.606</b>	0.328	0.342	-0.424	1.000	
% Clay	0.065	0.117	0.186	0.182	0.196	0.187	-0.101	0.178	0.088	0.089	0.156	0.082	0.116	1.000

N=76

till are found in samples 07-MPB-023 and -031, which were collected 60 m west of the South Upper AB zone, and sample 07-MPB-038, which is from 145 m down-ice (east) of the zone (Appendices D1, D2, D3: maps 1, 14). Moderate concentrations in till occur 300 m east of the gossan zone. Elevated concentrations of Cu (>100 ppm) are still detectable 600 m down-ice.

Lead concentrations vary from 8 to 4377 ppm and are strongly correlated with Ag, As, and Sb, and significantly correlated with Au, Bi, Cu, Fe, Se, Sn, and Zn (Table 4). The highest Pb concentrations are in till samples 07-MPB 024 (4377 ppm) and -026 (2154 ppm) collected southwest of the zone, and sample 07-MPB-050 (824 ppm), collected 30 m south and east of the South Upper AB zone (Appendix D1: map 2, Appendix D3: map 15; Table 3). Elevated levels of Pb (>100 ppm) are still detectable 600 m down-ice.

Zinc contents vary from 29 to 426 ppm and Zn significantly correlates with As, Pb, and Sb (Table 4). Zinc concentrations are lowest in till overlying and up to 200 m down-ice (east) of the South Upper AB zone. Concentrations of Zn in till are higher 200 to 600 m east of the South Upper AB zone (Appendix D1: map 3, Appendix D3: map 16). Elevated levels (>100 ppm) are still detectable 4 km down-ice. The highest Zn values in till are in samples 07-MPB-024 (426 ppm) and 07-MPB-028 (407 ppm) (Table 3), which are from just southwest of the South Upper AB zone.

#### ***Au and Ag in the <0.063 mm Fraction***

Gold determined by fire assay/ICP-MS and Ag determined by aqua regia/ICP-MS display high concentrations in till in close proximity (<300 m east) of the South Upper AB zone (Table 3). Concentrations of Ag range from 6 to 8078 ppb. Concentrations of Au vary from <1 to 574 ppb. The highest Au values in till are southwest of the gossan zone in sample 07-MPB-024

(574 ppb) and 30 m east in sample 07-MPB-023 (321 ppb) (Appendix D1: map 4, Appendix D3: map 17; Table 3). Gold contents are strongly correlated with Ag, As, Bi, Cu, Sb, and Se, and significantly correlated with Fe, Pb, and Sn (Table 4).

The highest Ag values in till are southwest of the known gossan zone in samples 07-MPB-024 (8078 ppb) and -026 (3210 ppb), -033 (2227 ppb), and -050 (1428 ppb) (Appendix D1: map 5, Appendix D3: map 18). Silver concentrations are similarly strongly correlated with Au, As, Bi, Cu, Pb, and Sb, and significantly correlated with Fe, Hg, Se, and Sn (Table 4). Slightly elevated values also occur west of the mineralized zone in samples 07-MPB-023 and -031.

#### ***As, Bi, and Sb in the <0.063 mm Fraction***

Arsenic (aqua regia digestion) concentrations vary from 2 to 8463 ppm (Table 3), are strongly correlated with Ag, Au, Bi, Cu, Pb, and Sb, and significantly correlated with Fe, Se, Sn, Ti, and Zn (Table 4). Concentrations are highest overlying and southwest of the South Upper AB zone in samples 07-MPB-024 (8463 ppm), and -026 (2968 ppm), -028 (1047 ppm), and -050 (2389 ppm) (Appendix D1: map 6, Appendix D3: map 19). Slightly elevated values also occur west of the mineralized zone in samples 07-MPB-023 and -031.

Bismuth concentrations range from 0.1 to 171 ppm and are strongly correlated with Ag, Au, As, Cu, Sb, Se, and Sn, and significantly correlated with Fe, Pb, and Ti (Table 4). The highest values in till are in samples 07-MPB-024 (171 ppm), which was collected southwest of the gossan zone, and 100 m down-ice (east) in sample 07-MPB-038 (149 ppm) (Appendix D1: map 7, Appendix D3: map 20). Slightly elevated values also occur west of the mineralized zone in samples 07-MPB-023 and -031 (Table 3).

The concentrations of Sb range from 0.05 to 26.46 ppm with strong positive correlations with Ag, As, Au, Bi, Cu, Pb, Se, and Sn and significant positive correlations with Fe and Zn (Table 4). The highest values occur in till 3 m south of the gossan zone in sample 07-MPB-024 (26.46 ppm) and sample 07-MPB-050 (4.31 ppm) (Appendix D1: map 8, Appendix D3: map 21; Table 3). Slightly elevated concentrations can be detected at least 500 m to the east.

### ***Fe in the <0.063 mm Fraction***

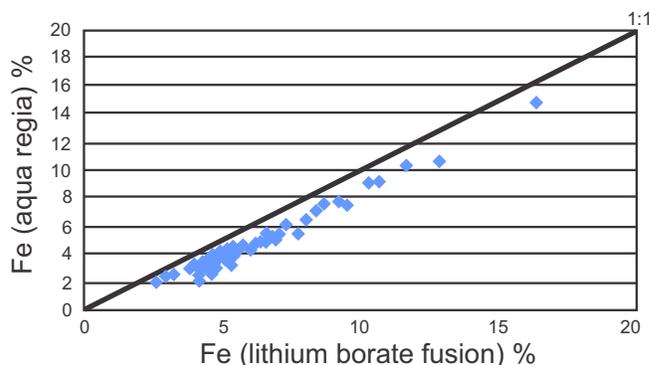
Iron concentrations determined by aqua regia digestion vary from 2 to 15% and are comparable to Fe values determined by borate fusion/ICP-MS, with an almost 1:1 relationship (Fig. 16). This pattern indicates that the Fe-bearing minerals in till in the Halfmile Lake area can be easily digested by aqua regia. Iron contents in till determined by aqua regia digestion are strongly correlated with Cu and significantly correlated with Ag, As, Au, Bi, Pb, Sb, Se, and Sn (Table 4).

### ***Hg, Se, Sn, Cd, Ga, S, and Ba in the <0.063 mm Fraction***

Mercury concentrations determined by aqua regia ICP-MS range from 7 to 403 ppm (Table 3) and are highest within 150 m of the gossan zone, in sample 07-MPB024 (403 ppb) and sample 07-MPB-033 (135 ppb) (Appendix D1: map 9, Appendix D3: map 22). Slightly elevated values also occur west of the mineralized zone in samples 07-MPB-023 and -031. Mercury displays a significant positive correlation ( $r=0.625$ ) with Ag but not with other elements (Table 4).

Concentrations of Se determined by aqua regia ICP-MS vary from 0.2 to 31.1 ppm, have strong positive correlations with Au, Bi, Sb, and Sn, significant positive correlations with Ag, As, Cu, Fe, Pb, and a negative correlation with Ti (Table 4). The highest Se values in till are in samples 07-MPB-024 (19 ppm), which was collected just southwest of the South Upper AB zone, and in sample 07-MPB-038 (31.1 ppm), which was collected 50 m east (Appendix D1: map 10, Appendix D3: map 23; Table 3). Slightly elevated values also occur west of the mineralized zone in samples 07-MPB-023 and -031.

Till samples contain 3 to 109 ppm Sn, as determined by borate fusion ICP-MS. Tin displays strong positive correlations with Bi, Sb, and Se, and significant positive correlations with Ag, As, Au, Cu, Fe, and Pb (Table 4). The highest Sn values in till were found in sample 07-MPB-024, from just southwest of the gossan zone (109 ppm), and in sample 07-MPB-038 (69 ppm), collected 50 m east (Appendix D1: map 11, Appendix D3: map 24; Table 3). Slightly elevated values also occur west of the mineralized zone in samples 07-MPB-023 and -031.



**Figure 16.** Scatter plot of iron concentrations in the <0.063 mm fraction of till as determined by aqua regia ICP-MS versus that determined by borate fusion/ICP-MS.

Cadmium values in till vary from 0.05 to 5.02 ppm, with the highest value in sample 07-MPB-024 (map 12). Till samples contain 2.3 to 14.4 ppm Ga as determined by aqua regia/ICP-MS, with the highest values in sample 07-MPB-024 just southwest of the gossan zone (map 13). Most values for S as determined by aqua regia are at or near the lower detection of 0.02%. The highest values in till (0.13 to 0.18%) are in samples 07-MPB-13, -024 and -020 (map 14). Barium values in till (aqua regia/ICP-MS) vary between 15.4 and 191, with the highest values in till samples 07-MPB-005, -017 and -024 (map 15).

### **Indicator Mineral Grain Counts**

Abundance of visible gold grains in the panned heavy mineral concentrate, and of beudantite ( $\text{PbFe}_3(\text{AsO}_4)(\text{SO}_4)(\text{OH})_6$ ) and chalcopyrite grains in the <0.25 to 0.5 mm non-ferromagnetic heavy mineral fraction of till, normalized to a 10 kg sample weight, are listed in Table 3. Till samples proximal (<80 m) to the South Upper AB Zone contain between 5 and 24 grains/10 kg of gold. Till samples farthest from the deposit commonly contain 0-4 gold grains/10 kg, as compared to counts of zero grains in samples farthest from the deposit. Significant (>10 grains/10 kg) beudantite grain counts are found within approximately 700 m of the gossan zone. Chalcopyrite is the only abundant ore mineral in till, with up 93 grains/10 kg. Chalcopyrite grain counts decrease to zero grains/10 kg at distances >400 m down-ice of the gossan zone.

## **DISCUSSION**

### **Till Matrix Colour, Texture, Carbonate Content, and Loss on Ignition**

Matrix colour for till samples collected more than 100 m up- or down-ice of the gossan zone are olive brown to light olive brown. The matrix colour becomes increasingly darker brown the closer the till sample site is to the South Upper AB zone (gossan). The till's

darker hues result from the incorporation of weathered sulphide-rich rock or regolith.

Till contains an average of 51% sand, 48% silt, and 1% clay. Shilts (1984) reported that large volumes of clay-sized material in till may have a significant influence on till geochemistry regardless of proximity to mineralization. The very low clay content and lack of correlation between clay content and element concentration (Table 4) in the Halfmile Lake area indicates that base metal patterns are not influenced by clay content. The sandy nature of the till in the area makes it an ideal sampling medium for indicator mineral methods.

There are no carbonate-bearing rocks in the immediate deposit area, thus tills do not contain any carbonate. Loss on Ignition values indicate that the majority of the till samples (92%) contain <10% volatiles, impurities, carbonate minerals, and organic material. The six till samples that have >10% LOI values are from more than 6 km up-ice (west) of the Halfmile Lake deposit. The two till samples with the highest LOI values (14%) also contain the highest concentrations of MgO and CaO. These high MgO and CaO concentrations, in the form of carbonate minerals, are likely the cause of the elevated LOI values.

### **Pebble Lithological Analysis**

Distribution patterns depicted by major pebble lithologies (OFFv, OFmv, ONfv, ONt, ONs, TG, and R) in till indicate that local lithologies make up the largest percentage of pebbles. The pebbles are generally angular to subangular, also indicating that they have not been glacially transported for any significant distance. A larger regional-scale pebble lithology study by Parkhill and Doiron (2003) described similar observations to those reported here. Their pebble data suggested that most tills reflect local variations in bedrock composition and that host-rock lithologies account for a significant (>75%) portion of the total pebble count close to their source and decrease to background levels within a few hundred metres (<250-500 m) of the source. The pebble count results in this study indicate that pebble transport distances are even shorter (0-200 m). Local distribution of the pebble lithologies shows glacial dispersal was in an east-northeast direction.

There is a degree of uncertainty in the interpretation of pebble data for the Flat Landing Brook Formation and Nepisiguit Falls Formation (OFFv, OFmv, ONfv, ONt, and ONs) because of a lack of detailed deposit-scale bedrock mapping and because of the physical similarities between the different units, which may have led to misclassification. Also, the same rock type may be present in more than one unit. For example, tuff and porphyry pebbles were categorized as Nepisiguit Falls Formation felsic volcanic rocks (ONfv) and sedimentary pebbles were categorized as Nepisiguit Falls

Formation sedimentary rocks (ONs) whereas the actual felsic volcanic bedrock unit (ONfv) does contain a minor sedimentary rock component. The high variability and lack of a dispersal pattern among the major categories also support the conclusion that there are localized units of variable geology that are not accounted for on the current local bedrock geology map.

No sulphide ore pebbles were found in the till, which is likely the result of the gossan cap protecting the underlying fresh ore from glacial erosion. True gossan and regolith pebbles are present in till samples overlying and just down-ice of the South Upper AB gossan zone, up to a maximum of 50 m down-ice. Thus, both lithologies can be useful indicators of the presence of sulphide mineralization, but at a very local scale (<50 m). Glacial dispersal distances are short, likely because gossan and regolith pebbles are not physically robust and will not survive glacial erosion and transport. Till sample 07-MPB-024 contains the highest percentage (97%) of regolith pebbles. The sample is unrepresentative of the local till as the pebble fraction shows that this sample was collected adjacent to and partly into bedrock.

### **Till Geochemistry of the <0.063 mm Fraction and Indicator Mineral Counts**

Till samples collected around and just down ice of the Halfmile Lake deposit contain significant concentrations of Cu, Pb, Zn, Ag, As, Bi, Hg, Sb, and Se (aqua regia/ICP-MS), Au (fire assay/ICP-MS), and Sn (borate fusion/ICP-MS) up to 300 m down-ice of the South Upper AB zone (gossan) (Table 3). Concentrations of these elements show dispersal at least 600 m down-ice (east) of the deposit. Based on the observed geochemical dispersal patterns, these elements are the optimal pathfinder elements for the Halfmile Lake deposit.

Overall, the local-scale geochemical maps (Appendix D1) for the pathfinder elements exhibit similar distribution patterns, with higher concentrations mirroring an east-trending (down-ice) glacial dispersal pattern, as well as higher concentrations to the northwest and southwest of the known gossan zone (enclosed in red polygons in Fig. 7). These elevated values may be due to a larger areal extent of the sub-cropping gossan and mineralization than what is currently known. There is no evidence of ice flow to the northwest or southwest in the Halfmile Lake deposit area (Parkhill and Doiron, 2003), thus these elevated metal values are not a product of different phases of ice flow. Alternatively, Parkhill and Doiron (2003) suggested the elevated metal values are the result of hydro-morphic dispersion from the South Upper AB zone. Additional till and bedrock sampling would be required

to determine the full areal extent of this area of metal-rich till and the subcropping gossan.

Other areas with elevated metal concentrations in till occur at approximately 150 and 300 m down-ice of the exposed South Upper AB mineralized zone (Fig. 7). These areas may simply reflect glacial dispersal of metal-rich debris from the deposit. Alternatively, these elevated values may reflect the existence of underlying mineralization in the same area as suggested by Parkhill and Doiron (2003).

Regional dispersal patterns (Appendix D3) of the pathfinder elements show that concentrations are low and decrease to background levels within a short distance down-ice. The element distribution patterns on the regional maps also indicate that the Halfmile Lake deposit is the only known source for the pathfinder elements noted in Table 3.

#### ***Cu, Pb, and Zn in the <0.063 mm Fraction***

Several till samples in proximity (<50 m down-ice) of the mineralization contain upwards of 1254 ppm Cu, 4377 ppm Pb, and 426 ppm Zn (Table 3). Elevated concentrations of Cu are found in till 100 m west and to at least 600 m east of the gossan zone. Chalcopyrite grains in the Cu-rich till at Halfmile Lake (Table 3) suggest that chalcopyrite is the source of the elevated Cu values.

Lead concentrations are highest in till overlying the gossan and up to 100 m to the southwest. Boyle (2003) reported the presence of beudantite in the gossan at Halfmile Lake and the mineral was recovered from metal-rich till at Halfmile Lake (Table 3), suggesting this is likely a significant source of the elevated Pb values in till down-ice of the deposit.

Zinc concentrations in till overlying the gossan zone and up to 200 m down-ice (east) ranges from background values (1 to 50 ppm) to only slightly elevated (50-200 ppm). Zinc concentrations are higher 200 to 500 m down-ice (east). The low to moderate abundances of Zn in proximal till likely reflects the low Zn concentrations in the gossan (Boyle, 2003; Parkhill and Doiron, 2003). Till samples () containing the highest Zn concentrations (samples 07-MPB-028 and -024 with 407 and 426 ppm Zn, respectively) were collected up to 100 m southwest of the gossan. These high values may reflect erosion of fresh mineralized rock that contains sphalerite.

#### ***Au and Ag in the <0.063 mm Fraction***

Silver and Au in till have similar distribution patterns. Concentrations are highest near the deposit (<60 m radius) and extend up to 150 m east (down-ice) of the deposit. Sample 07-MPB-024 contains the highest concentrations of Ag (8078 ppb) and Au (524 ppb) (Table

3). Gold occurs as inclusions in sulphide minerals at Halfmile Lake and were also seen in polished thin sections of bedrock gossan samples in this study. Elevated Au and Ag concentrations in till may reflect the presence of gold grains (electrum) and native Ag but may also reflect the presence of Au and Ag as inclusions in sulphides. Visible gold grains were recovered from pan concentrates of some till samples (Table 3), with the most gold grains (24 grains/10 kg) in Au-rich till sample 07-MPB-023 (321 ppb Au). Thus, in this sample, gold grains are likely the source of the high Au values.

#### ***As, Bi, and Sb in the <0.063 mm Fraction***

Arsenic, Bi, and Sb have similar distribution patterns in till. Values are highest near the deposit (<60 m radius) and extend up to 150 m east (down-ice) of the deposit. Other than sample 07-MPB-024, samples -038 and -050 contain the highest values of As, Bi, and Sb (Table 3). Arsenic values in till range from background values of 2 to 61 ppm to a maximum value of 8463 ppm near the deposit. Elevated values of As in till likely reflect the presence of arsenopyrite, which was seen in gossan samples in this study. Elevated values of Bi in till likely reflect its presence as a trace element in sulphides and as native Bi in the ore. Elevated values of Sb in till likely reflect its presence as a trace element in sulphides.

#### ***Fe in the <0.063 mm Fraction***

Iron in till, as determined by aqua regia digestion, is most likely derived from sulphide minerals or secondary iron-oxide minerals that can be easily digested by aqua regia. Sulphide and secondary minerals expected to be in the till at Halfmile Lake and that could contribute significant amounts of Fe include pyrite, pyrrhotite, sphalerite, arsenopyrite, chalcopyrite, and goethite and sulphate minerals (Table 1).

#### ***Hg, Se, Sn, Cd, Ga, S, and Ba in the <0.063 mm Fraction***

The distribution of Hg in till is similar to that of Ag. Elevated Hg values in till, therefore, may be derived from native silver because Hg is a common impurity in native silver (<http://www.mindat.org/min-3664.html>). More likely however, is that Hg is derived from cinnabar. In this study, cinnabar (<50 µm in size) was observed in polished thin sections of the gossan and in the pan concentrates of till samples 07-MPB-004, -011, -012, and -044.

The highest concentration of Se in till (31 ppm) is in sample 07-MPB-038, collected 150 m east (down-ice) of the South Upper AB zone gossan (Table 3). Selenium can be a common trace element in galena and also forms a solid solution with clausthalite (PbSe), which is commonly associated with low-sulphur

**Table 5.** Comparison of pathfinder elements in the <0.063 mm fraction of till for the Halfmile Lake deposit and other VMS deposits in the Bathurst Mining Camp. Pathfinder elements in this study that were not identified as pathfinders in previous studies are highlighted in red.

Location	Deposit Elements	Source of Data	Pathfinder Elements in Till
Halfmile Lake VMS deposit, Bathurst Camp, NB	Cu-Pb-Zn-Ag	this study	Cu, Pb, Zn, Ag, As, Au, Bi, Hg, Sb, Se, Sn
Halfmile Lake VMS deposit, Bathurst Camp, NB	Cu-Pb-Zn-Ag	Parkhill and Doiron (2003)	Cu, Pb, Zn, As, Sb, Sn, Au, Bi, In
Restigouche VMS deposit, Bathurst Camp, NB	Cu-Pb-Zn-Ag	Parkhill and Doiron (2003)	Cu, Pb, Zn, As, Sb, Au, In, Sn
CNE VMS deposit, Bathurst Camp, NB	Cu-Pb-Zn-Ag	Parkhill and Doiron (2003)	Cu, Pb, Zn, Au
Mount Fronsac North deposit, Bathurst Camp, NB	Cu-Pb-Zn-Ag	Campbell (2009)	Pb, Ag, Cu, In
Bog VMS deposit, Bathurst Camp, NB	Cu-Pb-Zn-Ag	Hoffman and Woods (1991)	Pb, Cu, Zn

hydrothermal deposits (<http://webmineral.com/data/Clausthalites.html>). Selenium may have concentrated in the gossan from the breakdown of galena. Boyle (2003) also suggested that Se may be present in goethite.

Both gossan and fresh mineralized samples contain cassiterite, which is likely the bedrock source for the elevated Sn values in the till. Sample 07-MPB-024 has the highest concentration (109 ppm) of Sn (Table 3) and was collected 32 m east (down-ice) of the South Upper AB zone gossan.

Barite is likely the source of the highest Ba values in till. Sphalerite is likely the source of elevated Cd and Ga contents in the till. Sulphide minerals are the source of elevated S in till.

### Comparison of Volcanogenic Massive Sulphide Till Geochemical Signatures

The till sampling around the deposit in this study was guided by the results of the earlier sampling program reported by Parkhill and Doiron (2003), which defined the geochemical signature of the dispersal train from the Halfmile Lake deposit. They reported that metal-rich till was locally derived and transported at least 500 m in an east-northeast direction from the deposit. In their study, the geochemical signature of the Halfmile Lake deposit was best defined by Pb, Cu, In, Sn, As, and Ag and to a lesser extent by Au, Zn, Bi, Se, and Sb. The results reported by Parkhill and Doiron (2003) are similar to those found in this study.

The pathfinder elements in the <0.063 mm fraction of metal-rich till collected during this study (aqua regia digestion) down-ice of the Halfmile Lake deposit (excluding regolith-dominated till sample 07-MPB-024) are compared to those of till from around other VMS deposits in the BMC (Table 5). The pathfinder element suite for this study is similar to that defined by Parkhill and Doiron (2003) for the Halfmile Lake deposit, with the exception of In, which was not analyzed in this study, and with the addition of Hg and Se. The suite identified in this till study is similar to those of other VMS deposits in the BMC (Hoffman and Woods, 1991; Campbell, 2009).

### CONCLUSIONS

Till in the Halfmile Lake deposit study area is thin (<2 m), light olive brown to dark brown in colour, silty sand to sandy silt in texture, and contains no carbonate minerals. Ice flowed across the area to the east-northeast. This study identified that glacial dispersal from the Halfmile Lake deposit is best defined by high concentrations of Cu, Pb, Zn, Ag, As, Au, Bi, Hg, Sb, Se (aqua regia), Au (fire assay), and Sn (borate fusion) in the <0.063 mm fraction of till. Results from the Halfmile Lake VMS deposit indicate that elevated geochemical concentrations in till are locally derived and transported at least 600 m in an east-northeasterly direction. Elevated concentrations of Cu, Pb, Zn, Ag, As, Au, Bi, Hg, Sb, Se, and Sn are consistent with the mineralogy of the Halfmile Lake deposit and confirm that till geochemistry is a useful tool for detecting VMS mineralization in the glaciated terrain of the BMC.

Through examination of the till at varying distances down-ice from the Halfmile Lake deposit this study showed that the highest geochemical abundances of base metals are in the first 50 to 150 m down-ice (east) of the deposit. Based on the patterns reported here, it is likely that additional unmapped subcropping gossan zones could be found immediately northwest and south of the Upper AB zone. The geochemical data from this report provides a baseline of the metal content of till samples collected around the Halfmile Lake deposit and, as such, provides the context in which to interpret the indicator mineral data for these samples.

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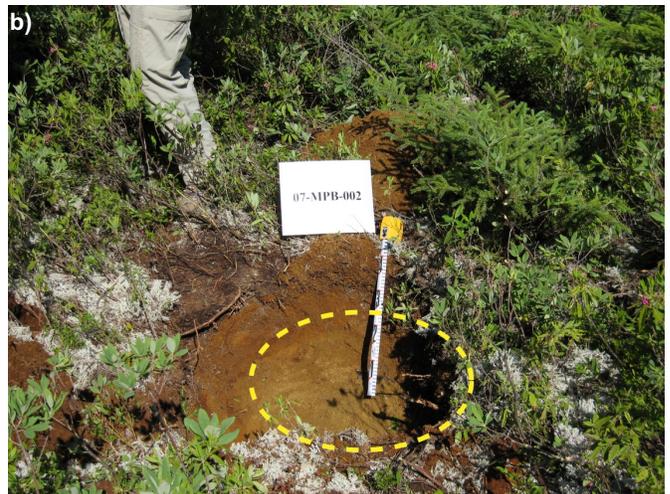
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APPENDIX A2. Field photos of 2007 and 2008 till sample sites.



Sample site 07-MPB-001. a) Overview of till sample site 07-MPB-001 in a logged clearing. b) Close-up of till section.



Sample site 07-MPB-002. a) Close-up of till sample site 07-MPB-002. b) Overview of till sample site before sampling. c) Bedrock float of local lithology found next to site.

**APPENDIX A2 continued.**



**Sample site 07-MPB-003. a)** Overview of till sample site 07-MPB-003. **b)** Till section after sampling. **c)** Close-up of till sample site.

APPENDIX A2 continued.



Sample site 07-MPB-004. a) Overview of till sample site 07-MPB-004. b) Close-up of the till at the sample site.



Sample site 07-MPB-005. a) Close-up of till sample site 07-MPB-005. b) Overview of sample site after sampling. c) Overview of sample site.

**APPENDIX A2 continued.**



**Sample site 07-MPB-006. a)** Overview of till sample site 07-MPB-006 in a shallow backhoe trench. **b)** Sample site prepared for sampling.



**Sample site 07-MPB-007. a)** Float boulder at till sample site 07-MPB-007. **b)** Close-up of sample site. **c)** Overview of till sample site.

APPENDIX A2 continued.

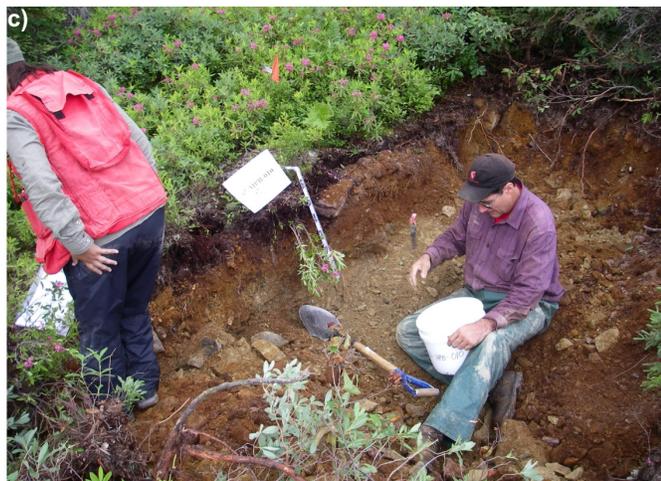


**Sample site 07-MPB-008.** a) Boulder-rich till sample site 07-MPB-008. b) Close-up of compact sandy till collected from surrounding boulders. c) Overview of till sample site.

**APPENDIX A2 continued.**



**Sample site 07-MPB-009. a)** Overview of till sample site 07-MPB-009. **b)** Close-up of till sample site.



**Sample site 07-MPB-010. a)** Close-up of till sample site. **b)** Sample area. **c)** Overview of till sample site 07-MPB-010.

APPENDIX A2 continued.



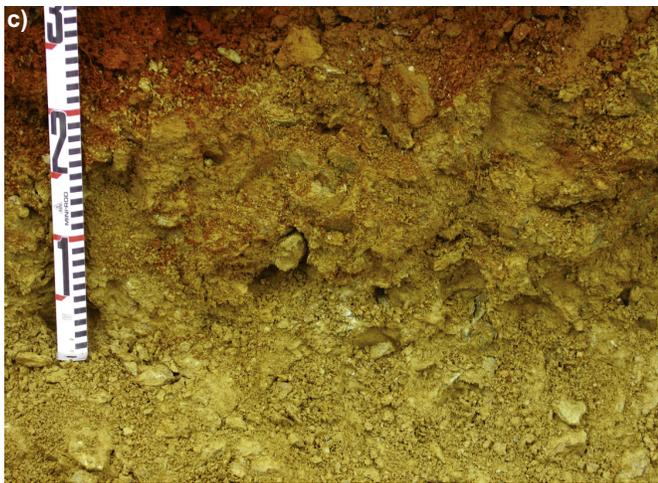
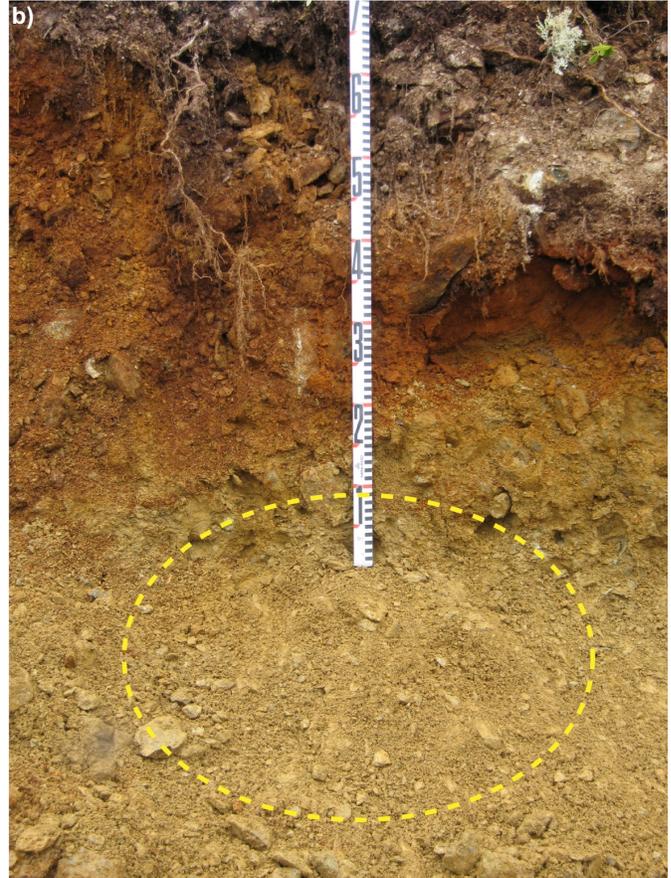
Sample site 07-MPB-011. a) Overview of till sample site 07-MPB-011. b) Close-up of sample site before sampling.

**APPENDIX A2 continued.**



**Sample site 07-MPB-012. a) Close-up of sandy till at sample site 07-MPB-012. b) Overview of sample site in the forest. c) Till section after sampling. d) Overview of till sample site.**

APPENDIX A2 continued.



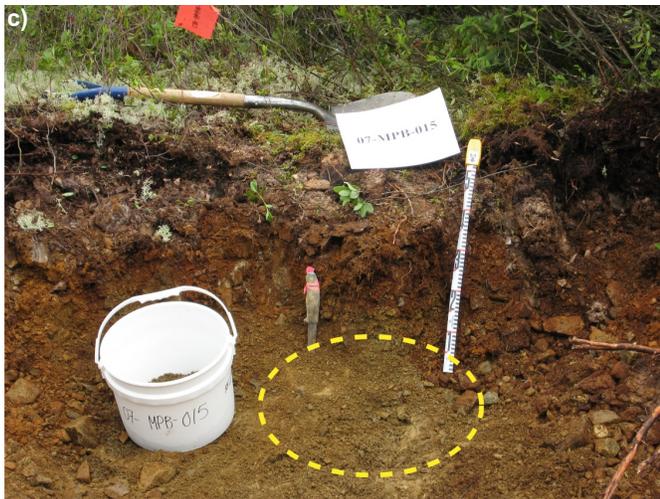
**Sample site 07-MPB-013.** a) Overview of till sample site 07-MPB-013. b) Close-up of sample area. c) Close-up of sandy till collected.

**APPENDIX A2 continued.**



**Sample site 07-MPB-014. a) Overview of till sample site 07-MPB-014 in a shallow backhoe trench. b) Close-up of sample site with boulder-rich upper horizon.**

APPENDIX A2 continued.



**Sample site 07-MPB-015.** a) Close-up of sandy till at sample site 07-MPB-015. b) Overview of sample site in forest clearing. c) Overview of sample site.

**APPENDIX A2 continued.**



**Sample site 07-MPB-016. a)** Overview of till at sample site 07-MPB-016. **b)** Boulder-rich sample site in a shallow backhoe trench. **c)** Overview of sample area.



**Sample site 07-MPB-017. a)** Overview of till at sample site 07-MPB-017. **b)** Close-up of sample site overlying angular bedrock.

APPENDIX A2 continued.



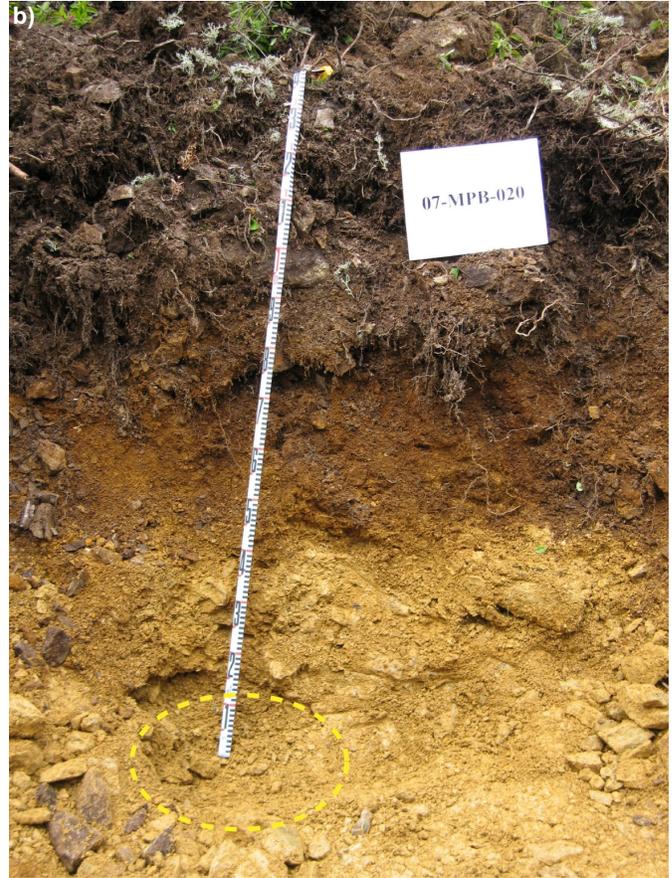
**Sample site 07-MPB-018.** a) Overview of till sample site 07-MPB-018. b) Boulder-rich till section prepared for sampling. c) Close-up of sandy till collected.

**APPENDIX A2 continued.**



**Sample site 07-MPB-019. a) Shallow till section at sample site 07-MPB-019. b) Boulder-rich shallow sample site before sampling. c) Overview of sample site in a backhoe trench.**

APPENDIX A2 continued.



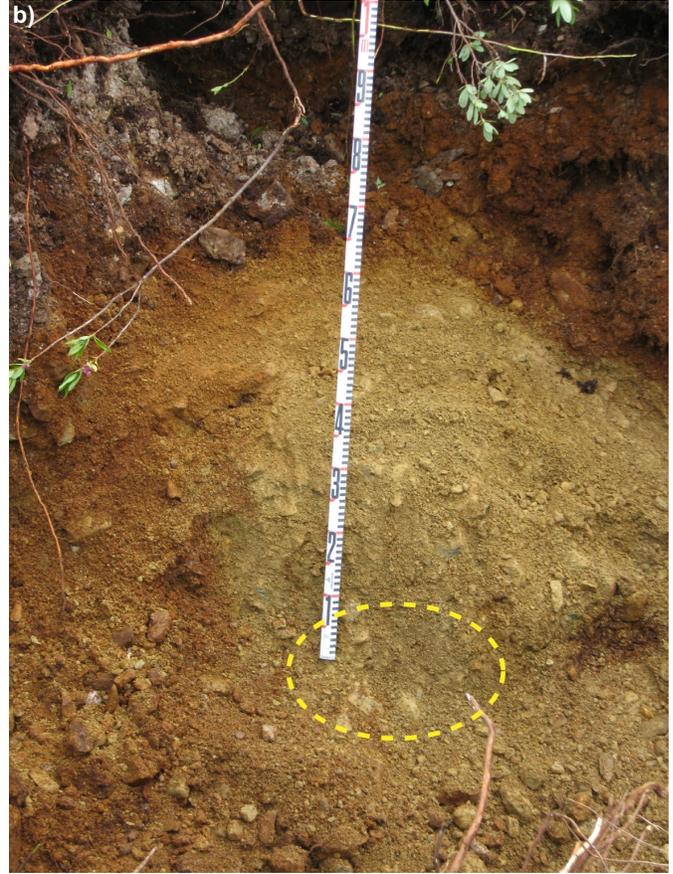
**Sample site 07-MPB-020.** a) Close-up of sandy till sample 07-MPB-020. b) Till section showing sampling area. c) Overview of sample site.

**APPENDIX A2 continued.**



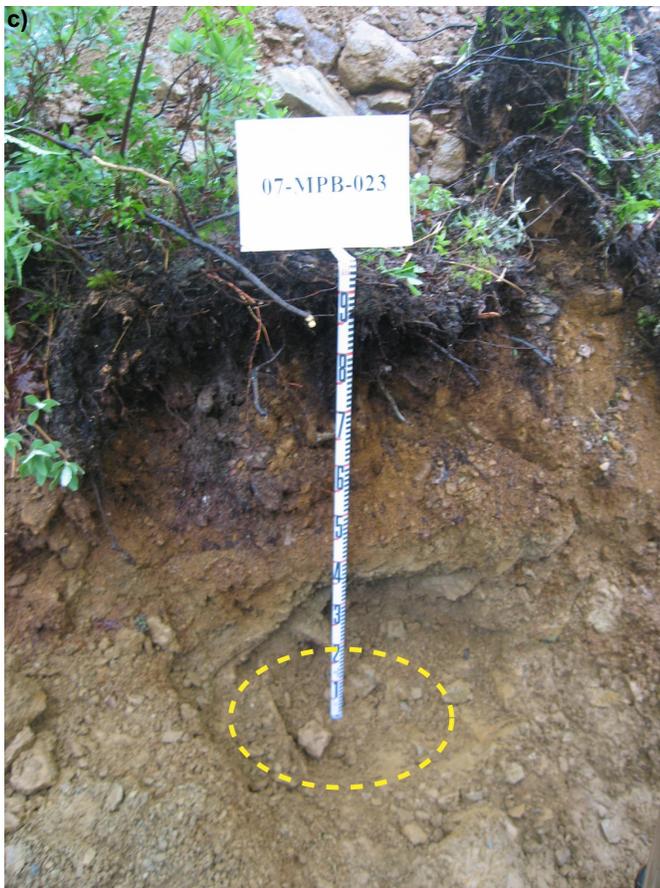
**Sample site 07-MPB-021. a)** Close-up of till (left) and regolith (right) at sample site 07-MPB-021. **b)** Till and regolith side-by-side colour comparison showing the more oxidized regolith on the right. **c)** Overview of till sample site. **d)** Till section showing grey till over top of orange regolith.

APPENDIX A2 continued.



**Sample site 07-MPB-022. a)** Close-up of till section 07-MPB-022. **b)** Sample site cleared before sampling. **c)** Overview of till sample site in a backhoe trench.

**APPENDIX A2 continued.**



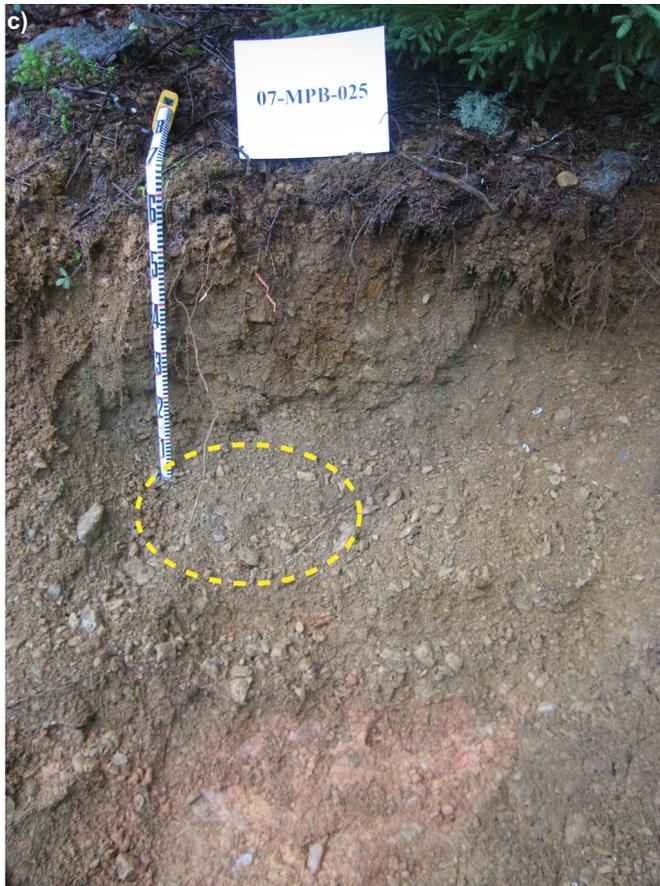
**Sample site 07-MPB-023. a) Close-up of sandy and cobble-rich till at sample site 07-MPB-023. b) Overview of sample site on a rainy day. c) Till section after sampling.**

APPENDIX A2 continued.



**Sample site 07-MPB-024.** a) Overview of till sample site 07-MPB-024 in a backhoe trench. b) Till section at sample area. c) Close-up of sandy pebble-rich till (scale is in decimetres).

**APPENDIX A2 continued.**



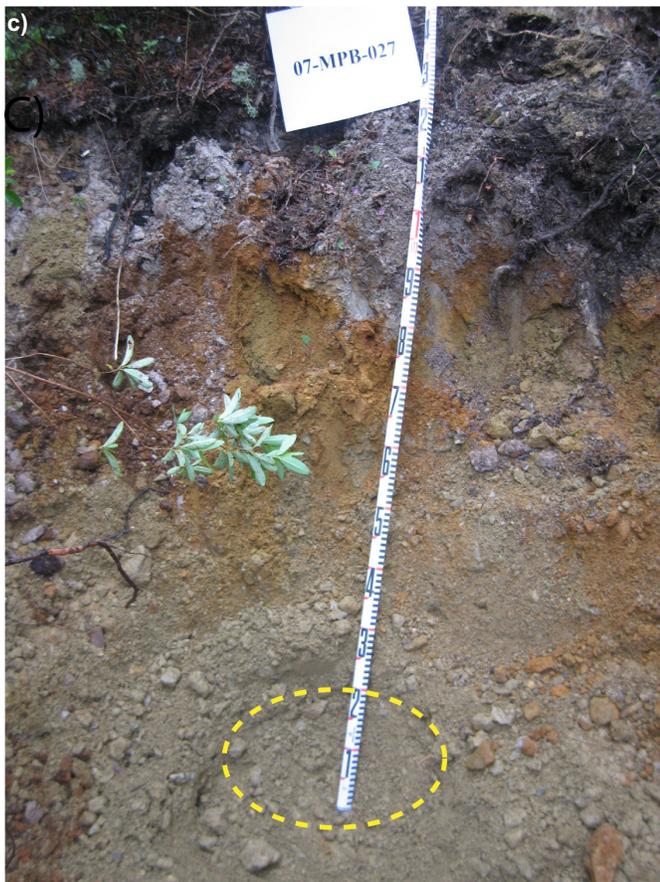
**Sample site 07-MPB-025. a)** Close-up of sandy regolith below grey till at sample site 07-MPB-025. **b)** Overview of till sample site. **c)** Till section of sample area. **d)** Comparison of different levels of weathering among regolith (red), highly oxidized till (light orange), and moderately oxidized till (light grey).

APPENDIX A2 continued.



**Sample site 07-MPB-026.** a) Close-up of till sample 07-MPB-026 that has been collected in a pail. b) Till section showing sampling area. c) Overview of sample site.

**APPENDIX A2 continued.**



**Sample site 07-MPB-027. a)** Close-up of sandy fresh till at sample site 07-MPB-027 (scale is in decimetres). **b)** Overview of sample site. **c)** Close-up of till section.

APPENDIX A2 continued.



**Sample site 07-MPB-028.** a) Close-up of sandy moderately oxidized till at sample site 07-MPB-028 (scale is in decimetres). b) Large boulder removed from the above sample pit. c) Overview of till sample site.

**APPENDIX A2 continued.**



**Sample site 07-MPB-029. a)** Close-up of sandy boulder-rich till at sample site 07-MPB-029 (scale is in decimetres). **b)** Till section before sampling. **c)** Location of sampling area. **d)** Overview of till sample site in a backhoe trench with surrounding boulders.

APPENDIX A2 continued.



**Sample site 07-MPB-030.** a) Close-up of sandy boulder-rich till at sample site 07-MPB-030 (scale is in decimetres). b) Till section at sample site. c) Overview of sample site cleared with a backhoe. Note: Duplicate sample 07-MPB-023.

**APPENDIX A2 continued.**



**Sample site 07-MPB-031. a)** Close-up of sandy till surrounded by angular boulders at sample site 07-MPB-031 (scale is in decimetres). **b)** Till section at sample site. **c)** Overview of till sample site in a backhoe trench.

APPENDIX A2 continued.



**Sample site 07-MPB-032.** a) Overview of till sample site 07-MPB-032. b) Close-up of moderately oxidized till (scale is in decimetres). c) Broad overview of sample site in a backhoe trench. d) Close-up of moderately oxidized till below less oxidized till.

**APPENDIX A2 continued.**



**Sample site 07-MPB-032. a)** Overview of till sample site 07-MPB-032. **b)** Close-up of moderately oxidized till (scale is in decimetres). **c)** Broad overview of sample site in a backhoe trench. **d)** Close-up of moderately oxidized till below less oxidized till.

APPENDIX A2 continued.



Sample site 07-MPB-033. a) Close-up of compact till between angular boulders at sample site 07-MPB-033. b) Overview of sample site. c) Close-up of till section.



Sample site 07-MPB-034. a) Till section 07-MPB-034 in a backhoe trench surrounded by large boulders. b) Overview of sample site in dense forest.

**APPENDIX A2 continued.**



**Sample site 07-MPB-035. a)** Close-up of sandy, boulder-rich till at sample site 07-MPB-035. **b)** Close-up of fresh till overlying orange regolith. **c)** Overview of sample site.



**Sample site 07-MPB-036. a)** Overview of till sample site 07-MPB-036. **b)** Close-up of sample site.

APPENDIX A2 continued.



Sample site 07-MPB-037. a) Close-up of till sample site 07-MPB-037 before sampling. b) Overview of sample site in a backhoe trench.

**APPENDIX A2 continued.**



**Sample site 07-MPB-038. a) Overview of sample site 07-MPB-038. b) Till section. c) Overview of sample site.**

APPENDIX A2 continued.

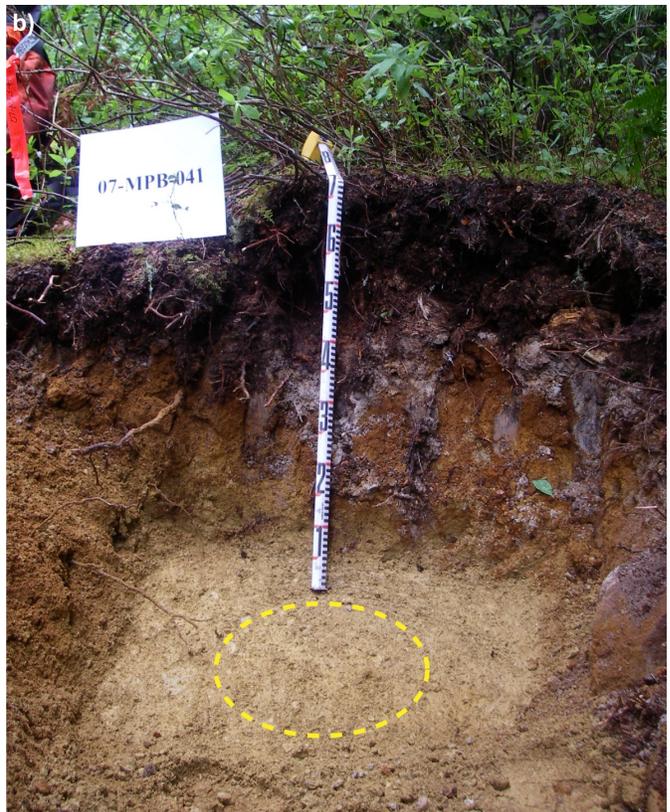


Sample site 07-MPB-039. a) Overview of sample site 07-MPB-039. b) Till collection site. c) Close-up of till section.

**APPENDIX A2 continued.**



**Sample site 07-MPB-040. a) Close-up of shallow till sample site 07-MPB-040. b) Overview of sample site.**



**Sample site 07-MPB-041. a) Till section after collecting sample at site 07-MPB-041. b) Till section in a backhoe trench before collecting sample.**

APPENDIX A2 continued.



Sample site 07-MPB-042. a) Till section in a backhoe trench at sample site 07-MPB-042. b) Overview of sample site.



Sample site 07-MPB-043. a) Overview of till sample site 07-MPB-043. b) Close-up of shallow till section.



Sample site 07-MPB-044. a) Overview of till sample site 07-MPB-044 being cleared for sampling. b) Close-up of till section.

**Till Geochemical Signatures, Halfmile Lake Zn-Pb-Cu VMS Deposit, Bathurst Mining Camp, New Brunswick**



**Sample site 07-MPB-045. a) Overview of till sample site 07-MPB-045, which contained large boulders. b) Overview of till site, which was dug by a backhoe. c) Close-up of till section.**

APPENDIX A2 continued.



**Sample site 07-MPB-046.** a) Overview of till sample site 07-MPB-046. b) Close-up of sampling area. c) Till section before sampling.

**APPENDIX A2 continued.**



**Sample site 07-MPB-047. a)** Overview of till sample site 07-MPB-047. **b)** Close-up of till section in a backhoe trench. **c)** Overview of till section prepared for sampling.

APPENDIX A2 continued.



Sample site 07-MPB-048. a) Close-up of sample hole at site 07-MPB-048. b) Overview of the sample site.



Sample site 07-MPB-049. a) Close-up of sample site 07-MPB-049 after sampling. b) Sample site overview. c) Sample site overview. Note: A duplicate sample (07-MPB-053) was also collected.

**APPENDIX A2 continued.**



**Sample site 07-MPB-050. a) Close-up of sandy till from sample site 07-MPB-050. b) Overview of sample site. c) Overview of sample site. d) Close-up of till sampling area.**

APPENDIX A2 continued.



Sample site 07-MPB-051. a) Close-up of till section at site 07-MPB-051. b) Sample site overview.



Sample site 07-MPB-052. a) Overview of sample site 07-MPB-052. b) Closer view of sample site.

**APPENDIX A2 continued.**



**Sample site 07-MPB-054. a) Overview of sample site 07-MPB-054. b) Close-up of till section. c) Overview of sample site surrounded by fallen trees.**

APPENDIX A2 continued.



**Sample site 07-MPB-056** a) Overview of till sample site 07-MPB-056 in a wooded area. b) Close-up of sample hole.

**APPENDIX A2 continued.**



**Sample site 07-MPB-057. a) Overview of sample site 07-MPB-057 and crew. b) Till section. c) Close-up of till that has sampled in hole. d) Close-up of till sample site.**

APPENDIX A2 continued.



Sample site 08-MPB-001 a) Blocks of local bedrock on surface in area of site 08-MPB-001. b) Till sample site 08-MPB-001.



Sample site 08-MPB-003 a) Overview of site 08-MPB-003. b) Till sample site 08-MPB-003.



Sample site 08-MPB-004 a) Overview of site 08-MPB-004. b) Till sample site 08-MPB-004.

**APPENDIX A2 continued.**



**Sample site 08-MPB-005 a) Overview of site 08-MPB-005. b) Till sample site 08-MPB-005.**



**Sample site 08-MPB-006 a) Overview of site 08-MPB-006. b) Till sample site 08-MPB-006. c) Close-up of till samples.**

APPENDIX A2 continued.



Sample site 08-MPB-007 a) Overview of site 08-MPB-007. b) Till sample site 08-MPB-007.



Sample site 08-MPB-008 a) Overview of area of site 08-MPB-008. b) Till sample site 08-MPB-008.



Sample site 08-MPB-009 a) Overview of that area at site 08-MPB-009. b) Till sample site 08-MPB-009.

**APPENDIX A2 continued.**



**Sample site 08-MPB-010 a) Blocks of site 08-MPB-010. b) Till sample site 08-MPB-010.**



**Sample site 08-MPB-011 a) Overview of site 08-MPB-011. b) Close-up of till sampled.**

APPENDIX A2 continued.



**Sample site 08-MPB-012 a) Overview of site 08-MPB-012. b) Overview of site 08-MPB-012. c) Till sample site 08-MPB-012.**

**APPENDIX A2 continued.**



**Sample site 08-MPB-013 a) Overview of site 08-MPB-013. b) Till sample site 08-MPB-013. c) Close-up of material sampled.**

APPENDIX A2 continued.



**Sample site 08-MPB-014** a) Overview of site 08-MPB-014.  
b) Section sampled at site 08-MPB-014.

**APPENDIX A2 continued.**



**Sample site 08-MPB-015 a) Overview of site 08-MPB-015. b) Till section sampled at site 08-MPB-015.**



**Sample site 08-MPB-016 a) Overview of site 08-MPB-016. b) Overview of site 08-MPB-016. c) Till section sampled at site 08-MPB-016.**

APPENDIX A2 continued.



Sample site 08-MPB-017 a) Overview of the area of site 08-MPB-017. b) Close-up of till sample site 08-MPB-017.



Sample site 08-MPB-013 a) Overview of the area around site 08-MPB-018. b) Till sample site 08-MPB-018. c) Local bed-rock clasts in till.

**APPENDIX A2 continued.**

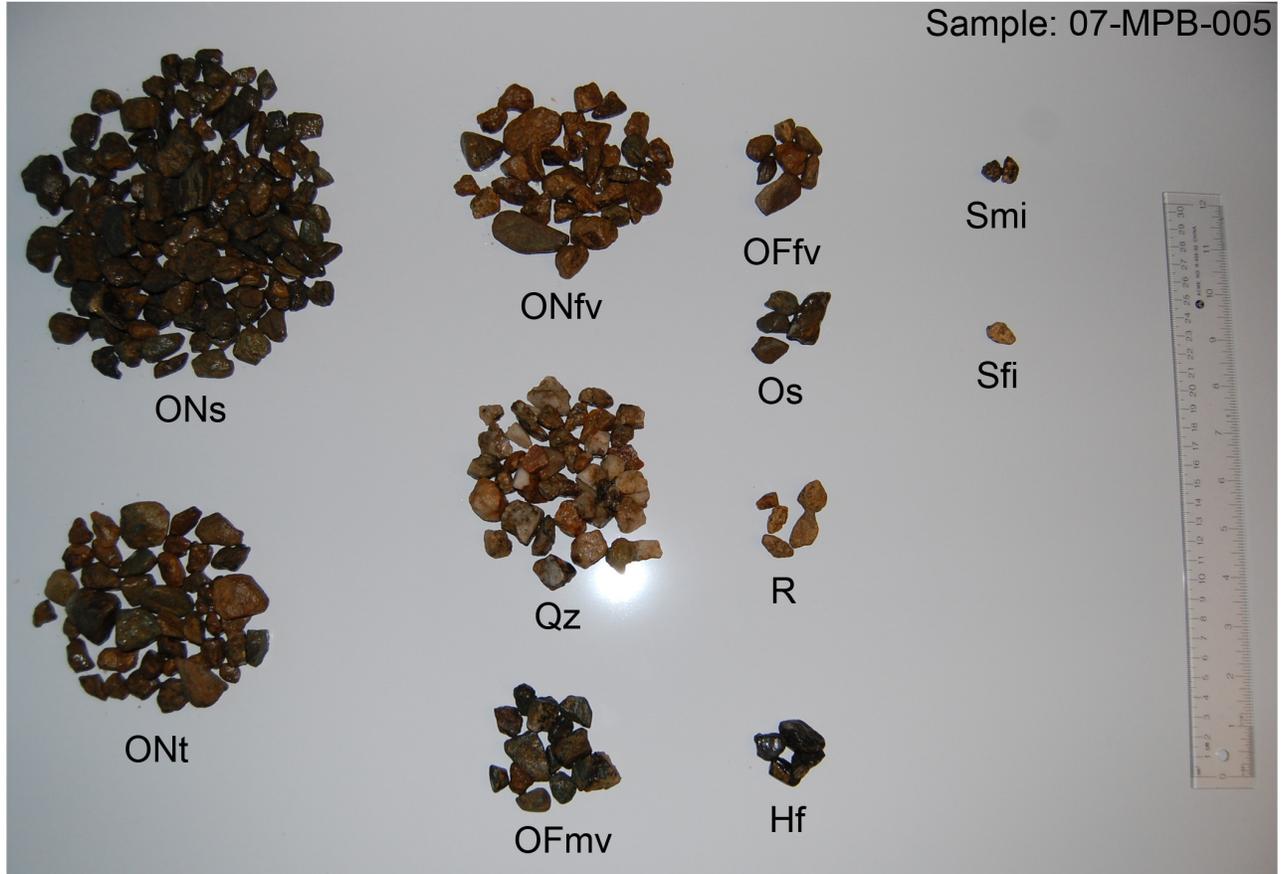


**Sample site 08-MPB-019 a) Overview of the area at site 08-MPB-019. b) Till sample site 08-MPB-019.**

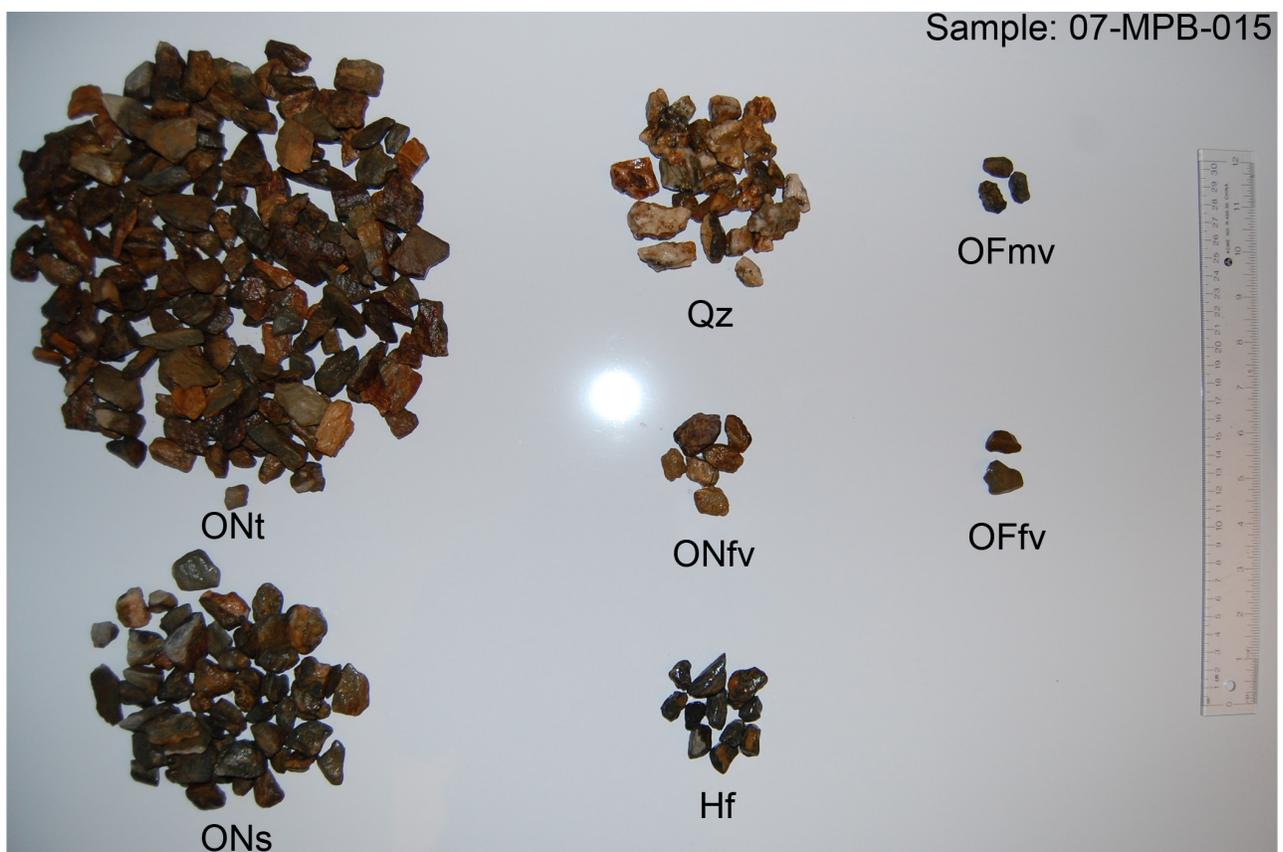
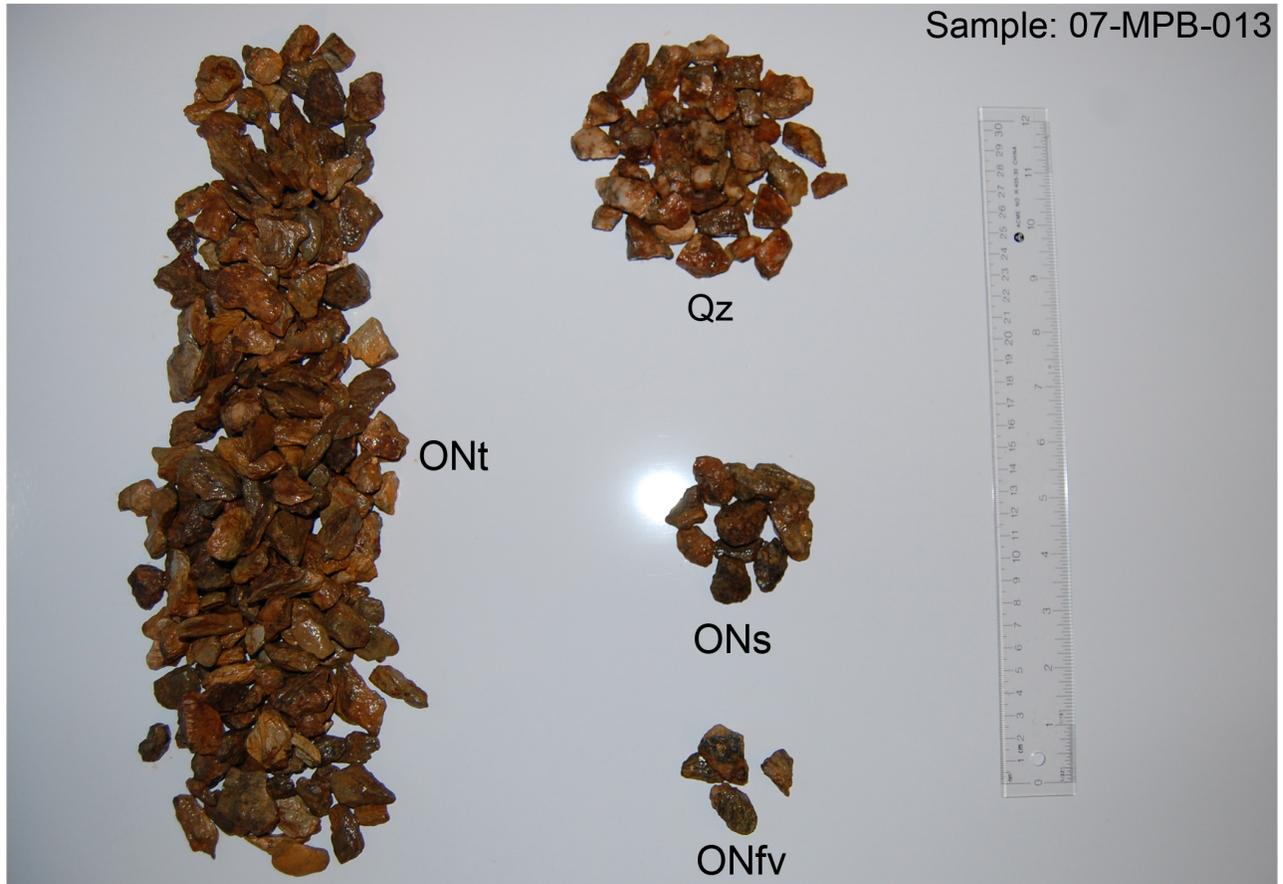


**Sample site 08-MPB-020 a) Overview of the area at site 08-MPB-020. b) Till sample site 08-MPB-020.**

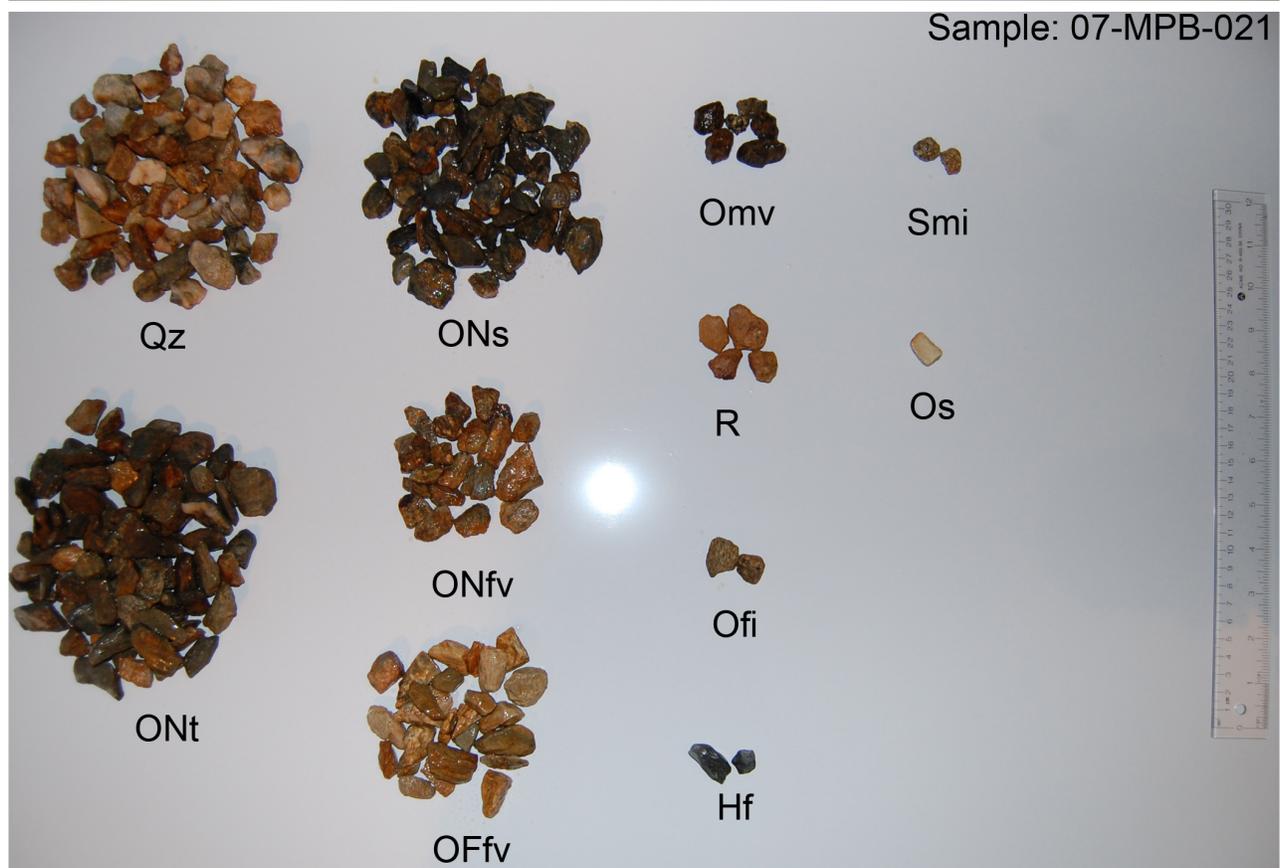
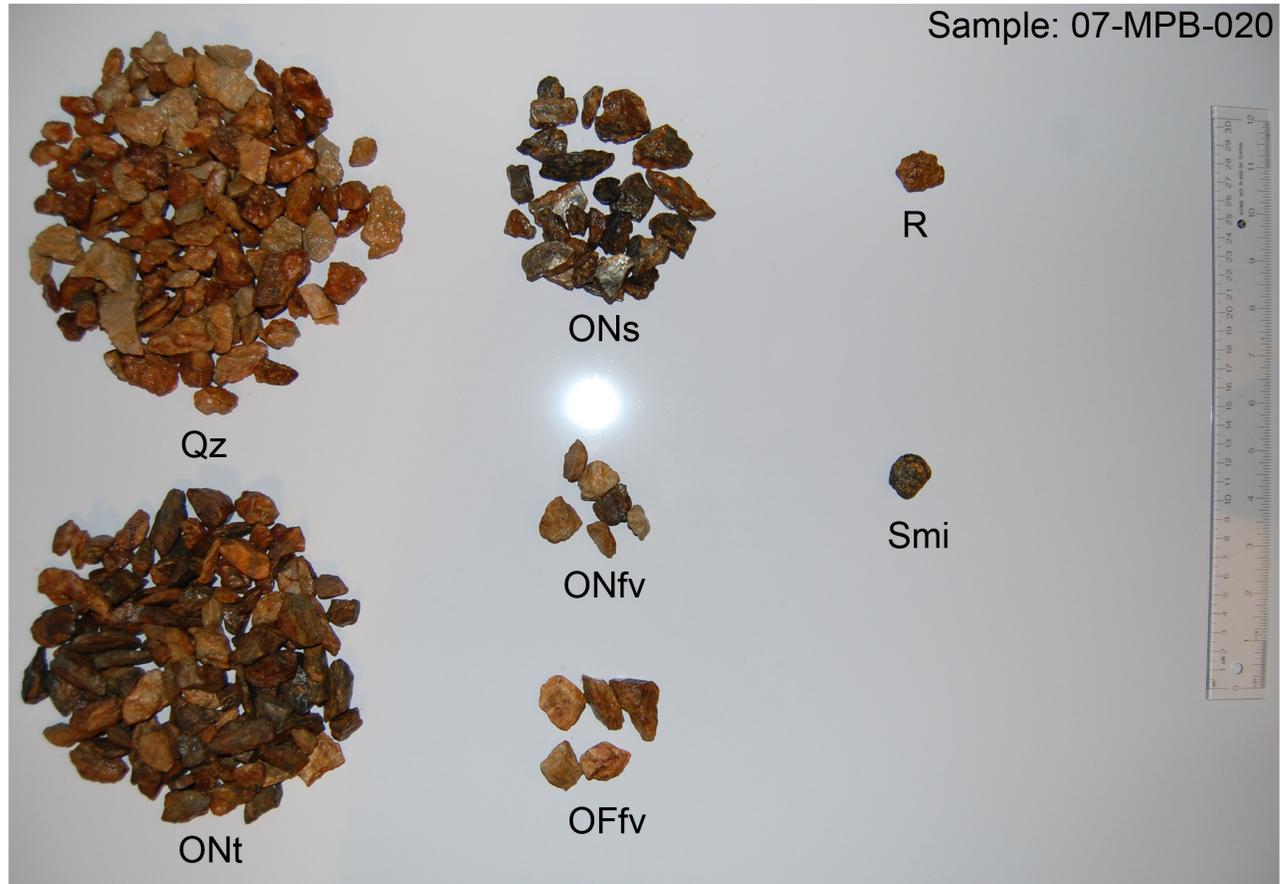
APPENDIX B2. Photos of pebble counts grouped by category.



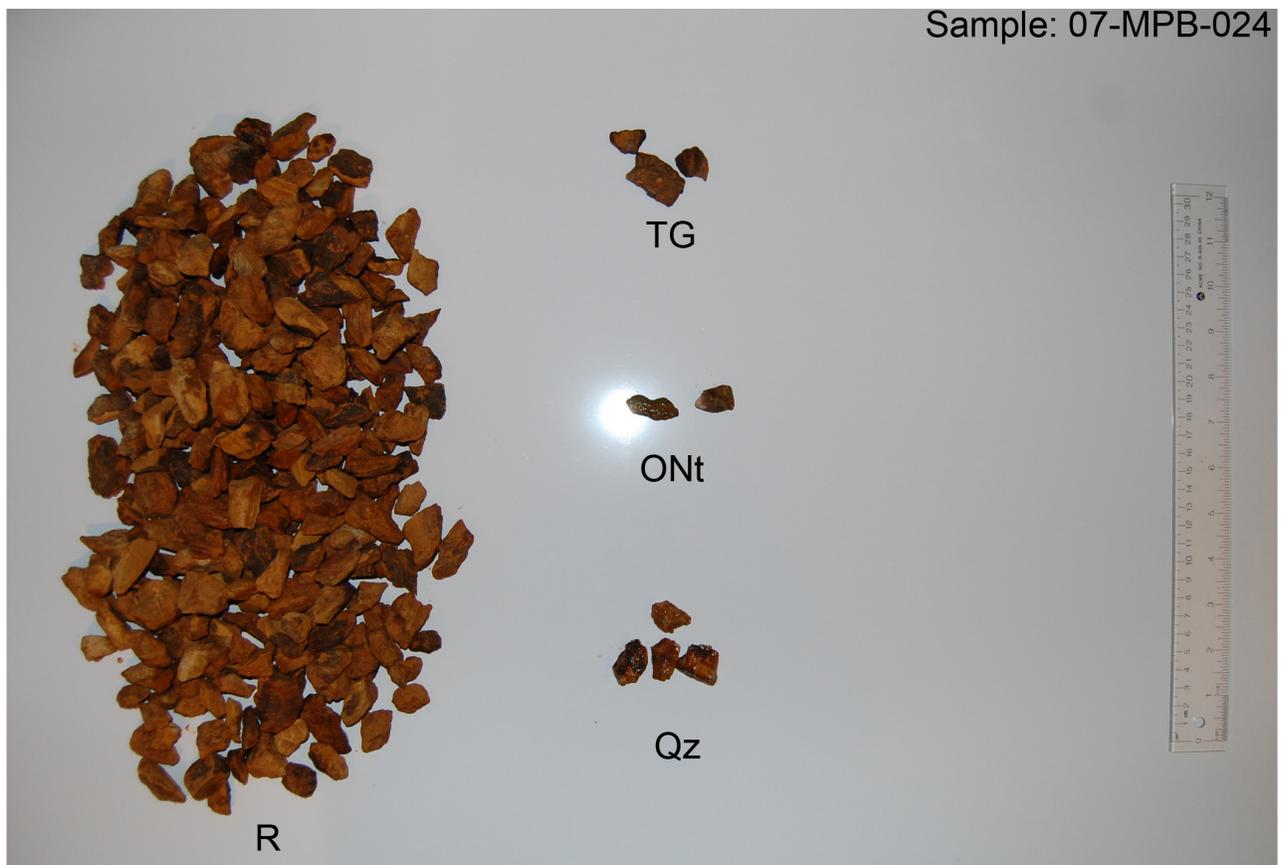
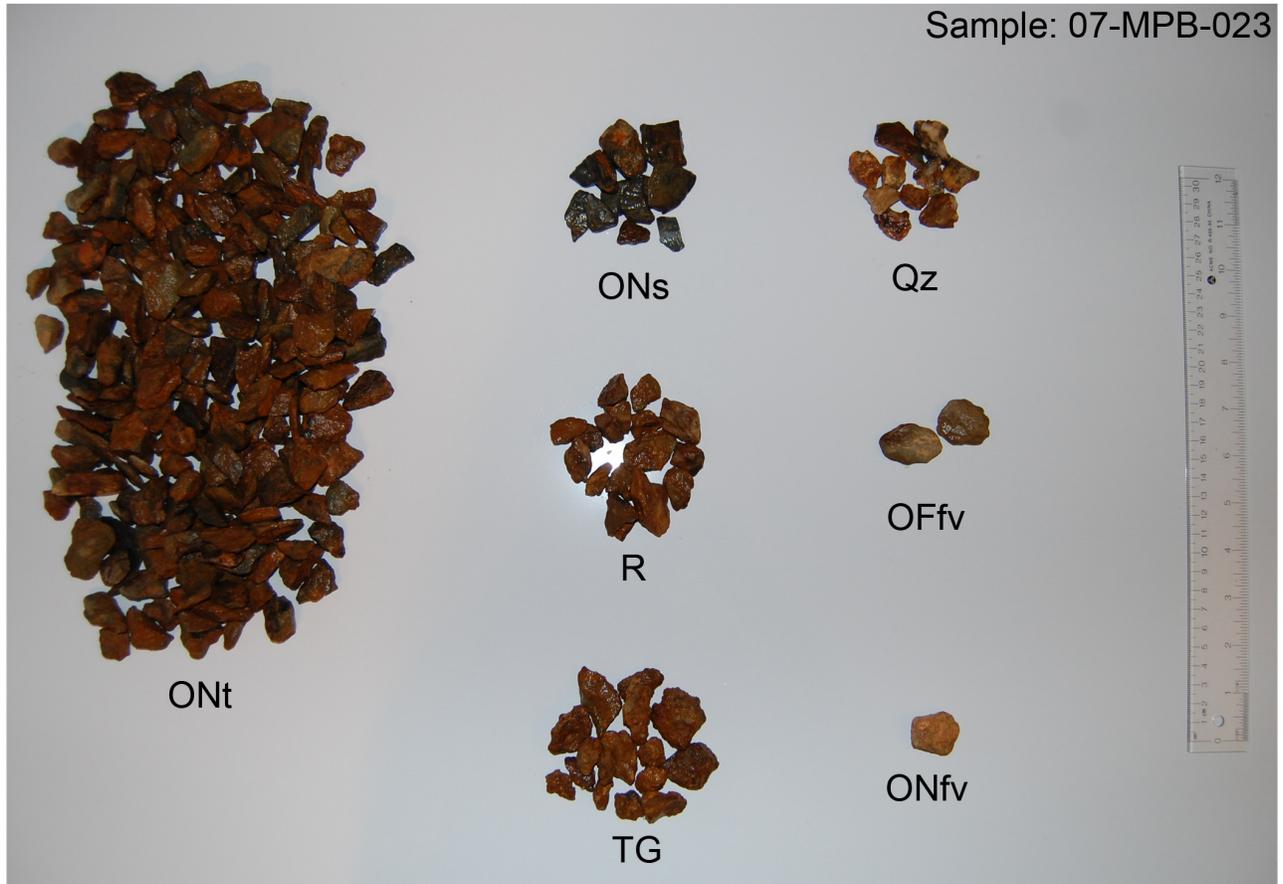
APPENDIX B2 continued.



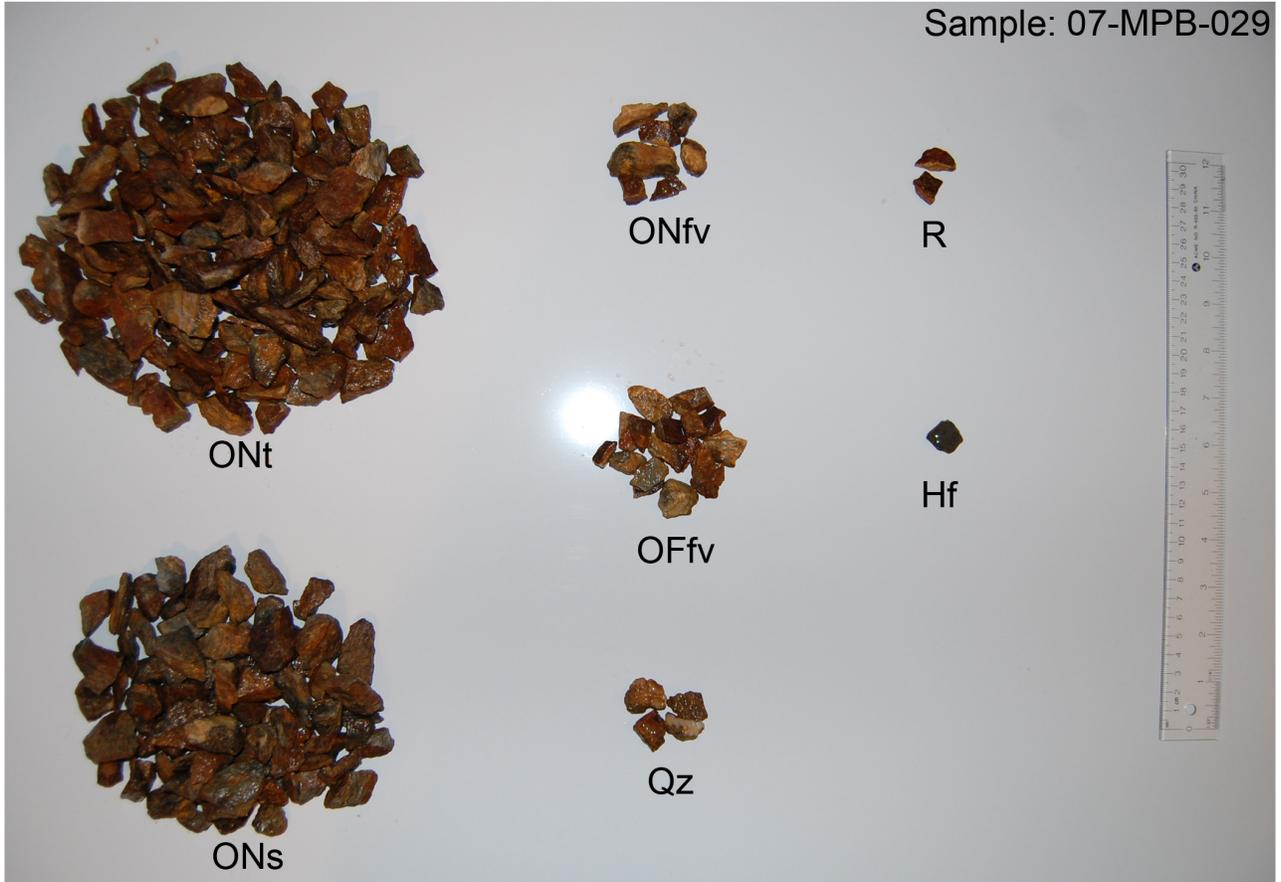
APPENDIX B2 continued.



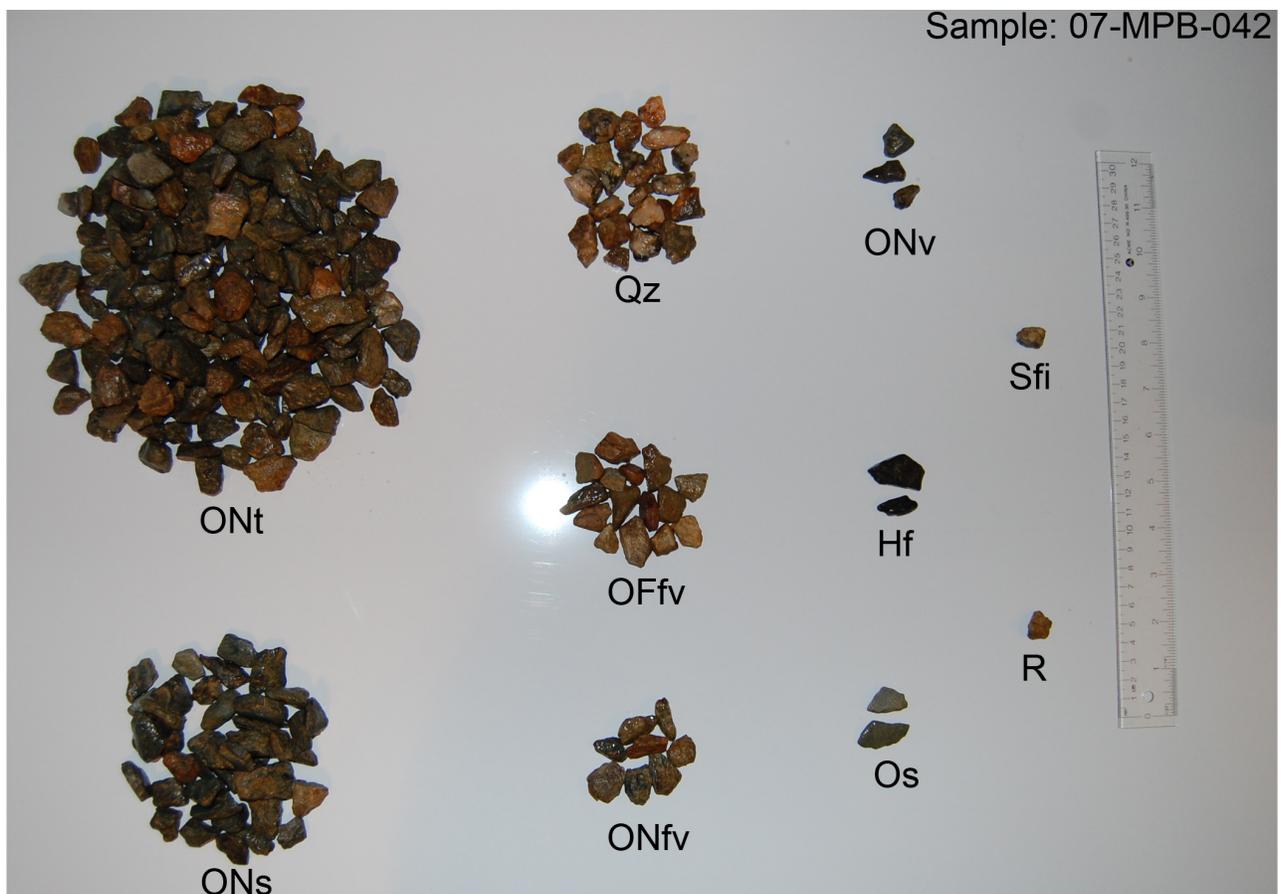
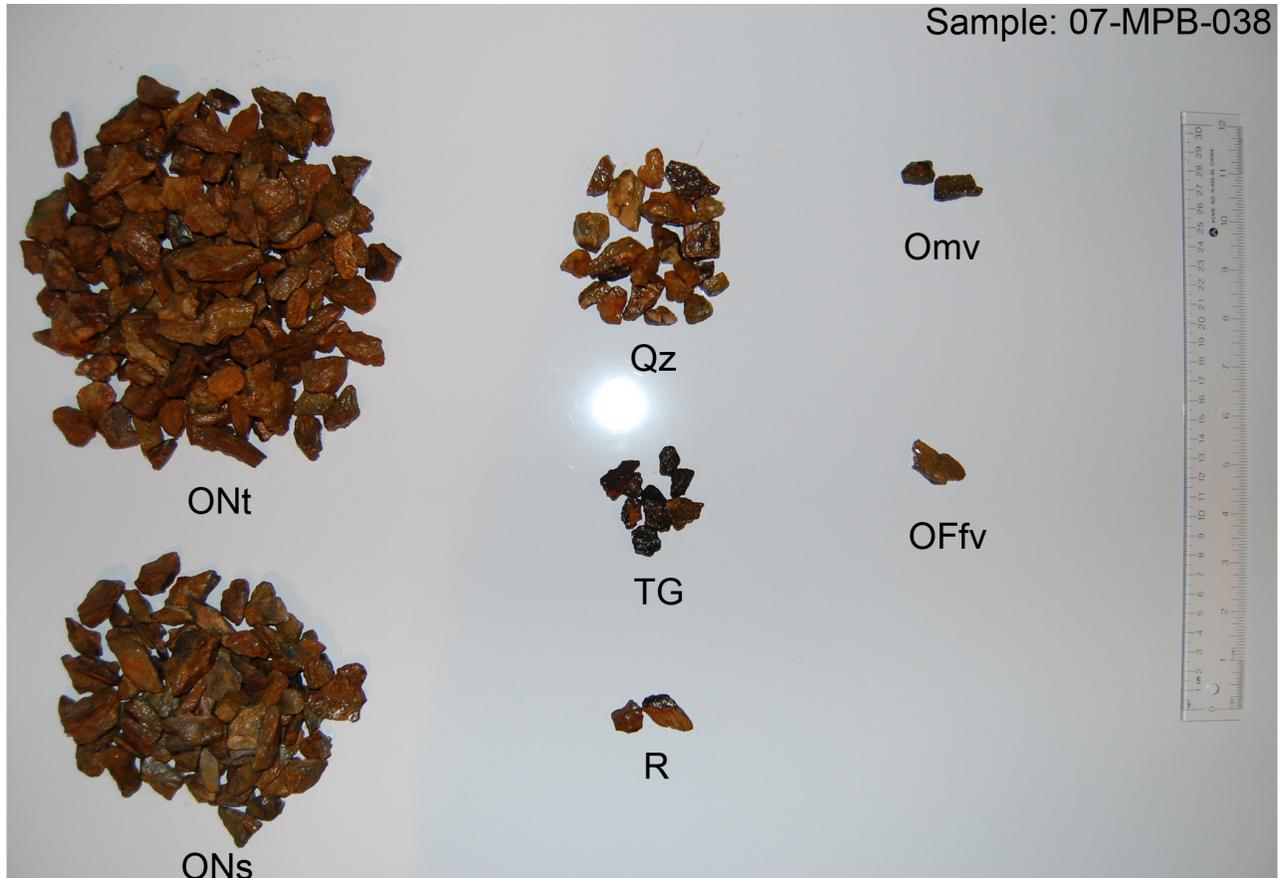
APPENDIX B2 continued.



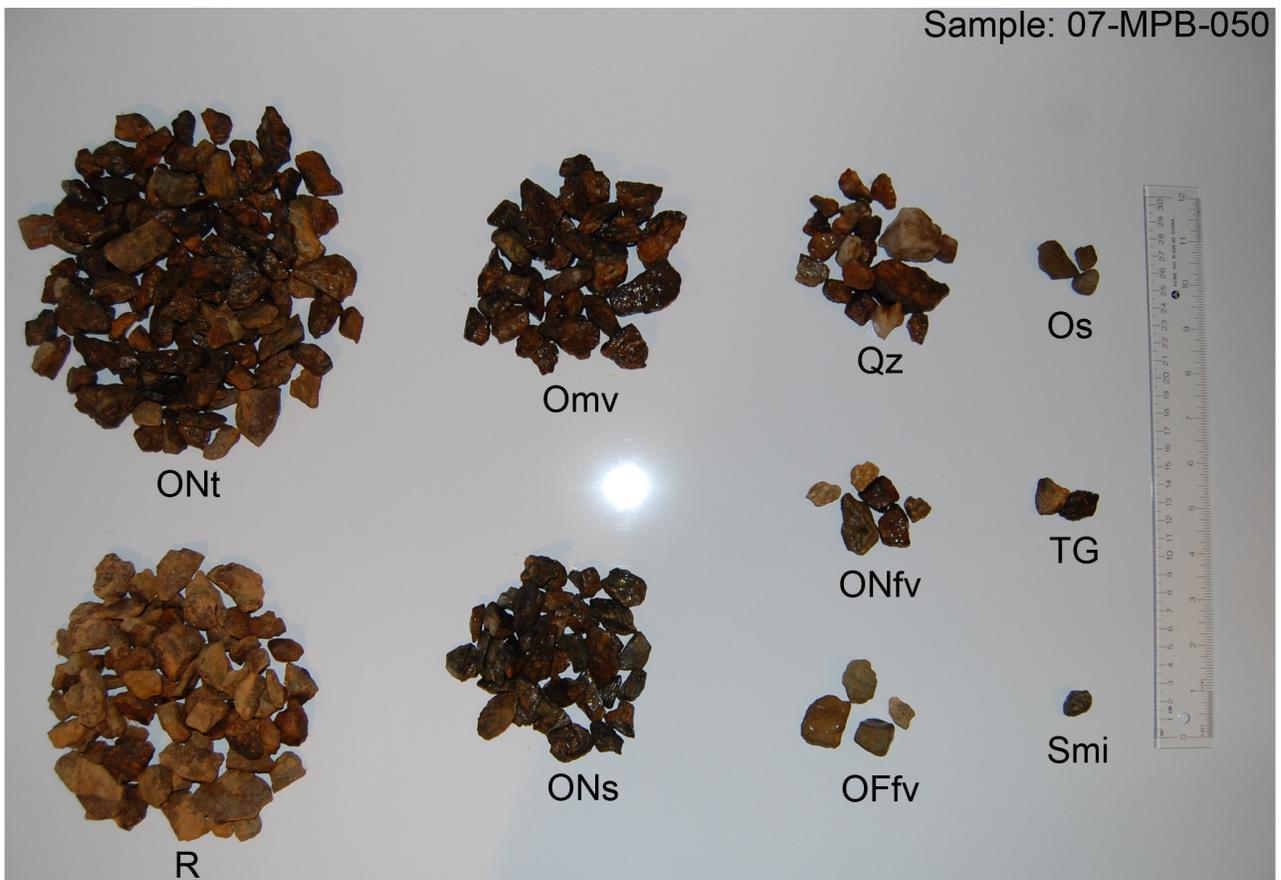
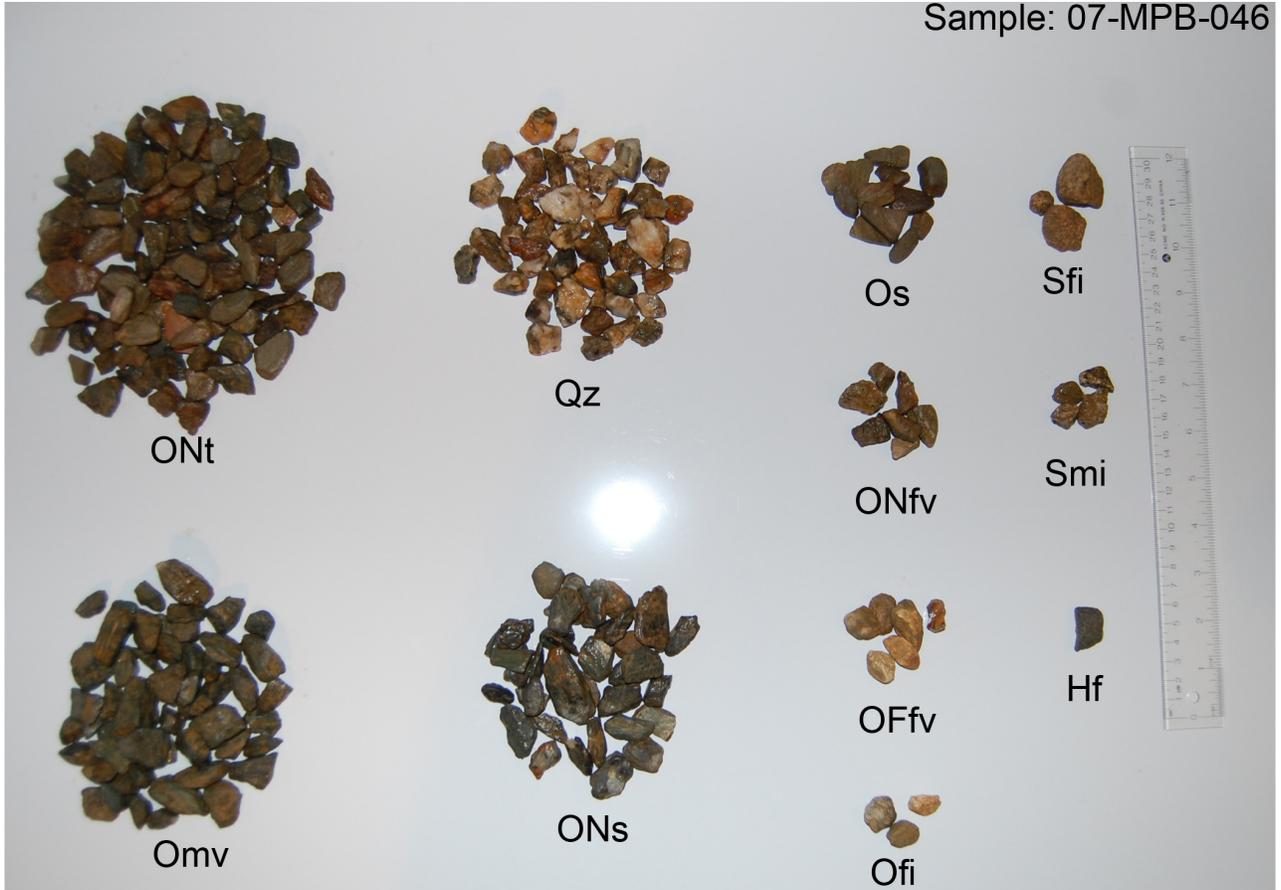
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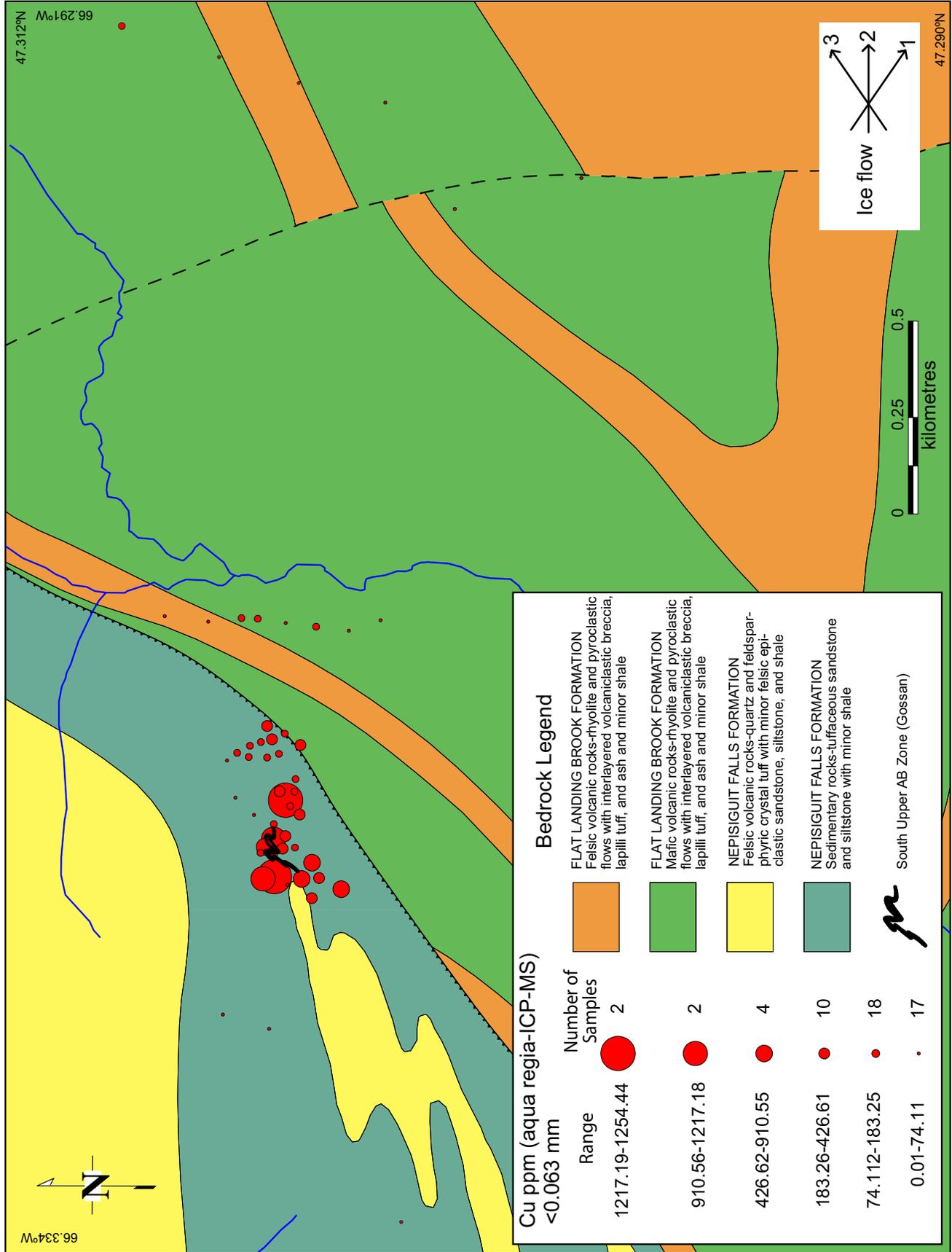
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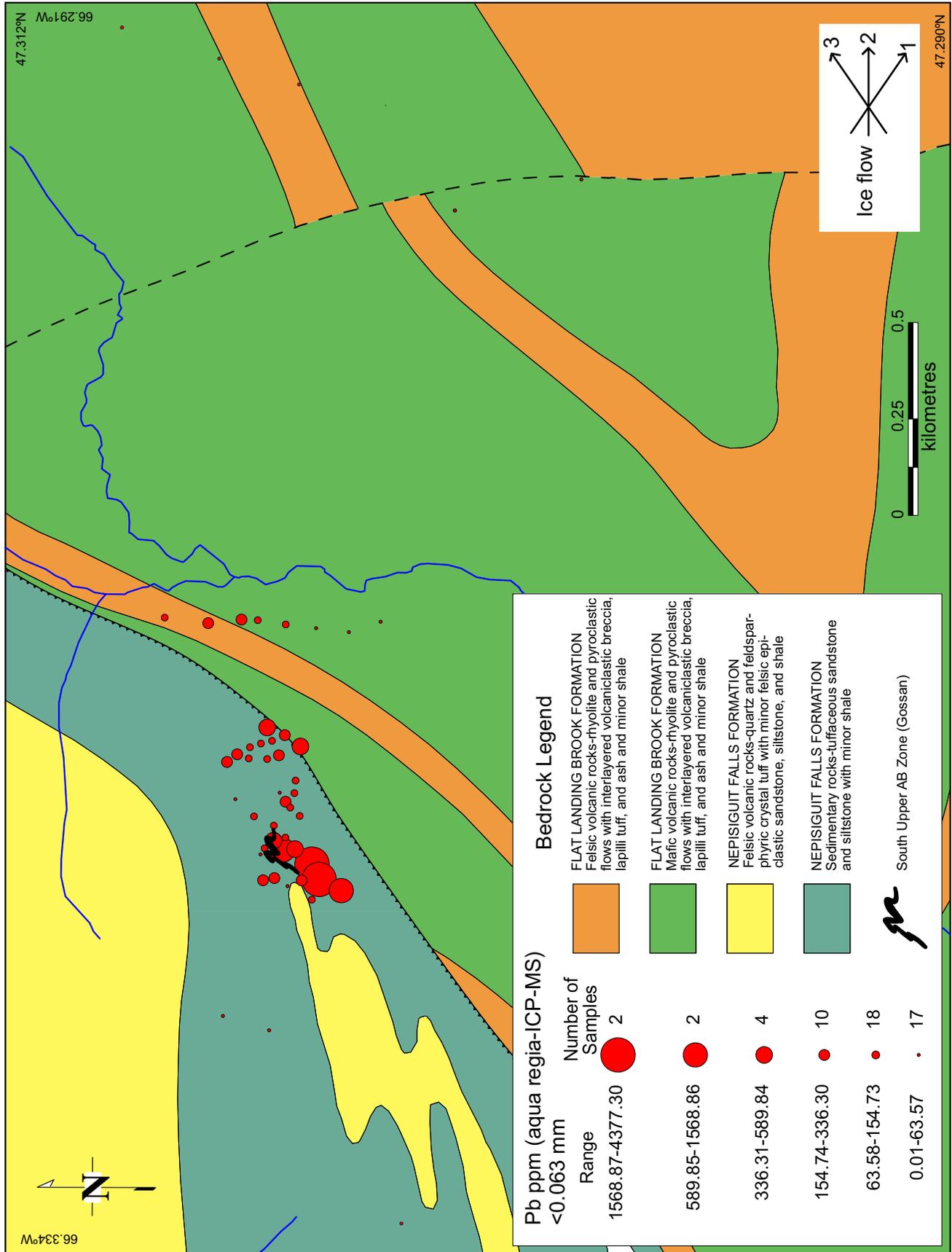
APPENDIX B2 continued.



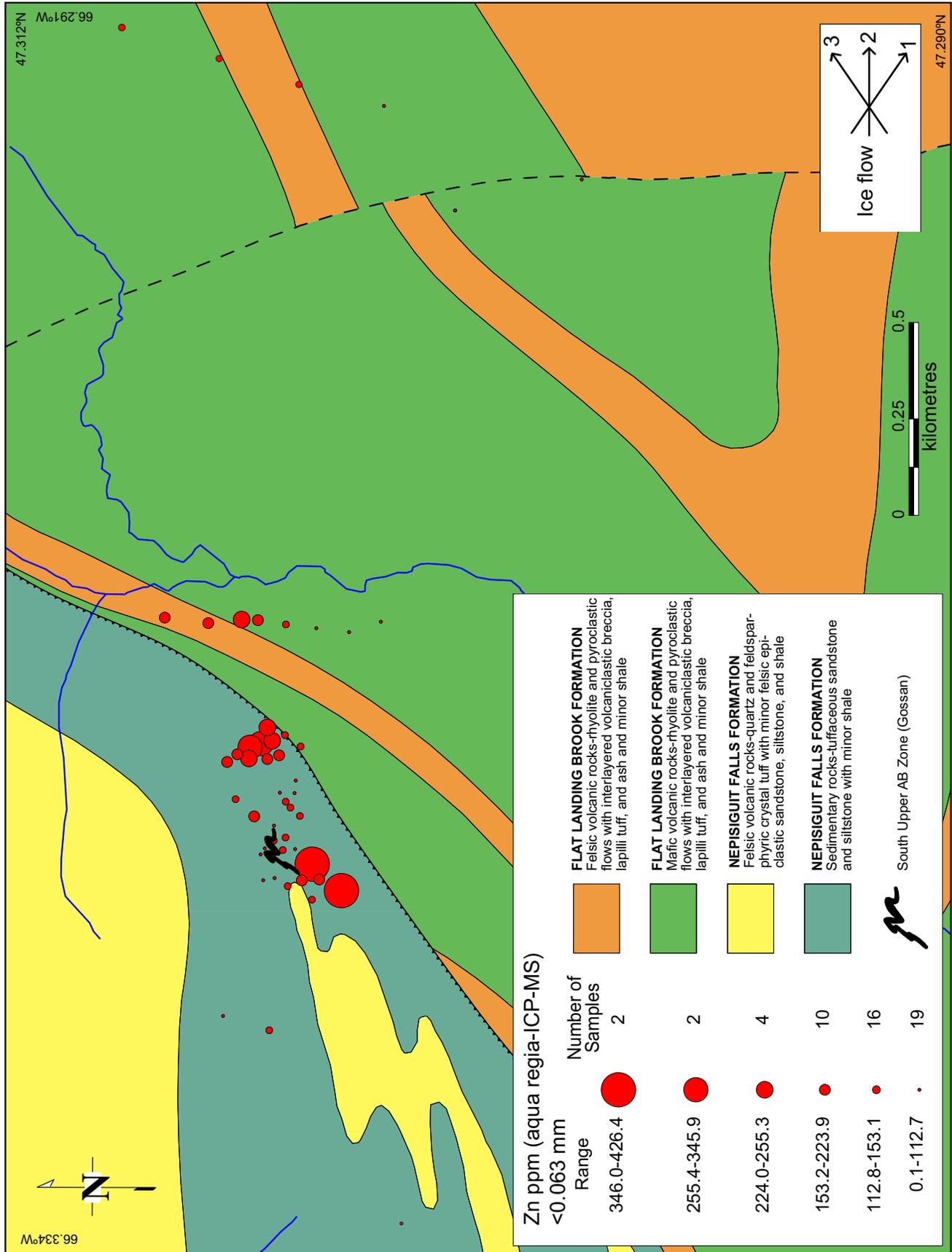
APPENDIX D1. Local-scale maps of the 2007 till samples plotted on regional bedrock geology from Goodfellow et al. (2003). Map 1: Copper.



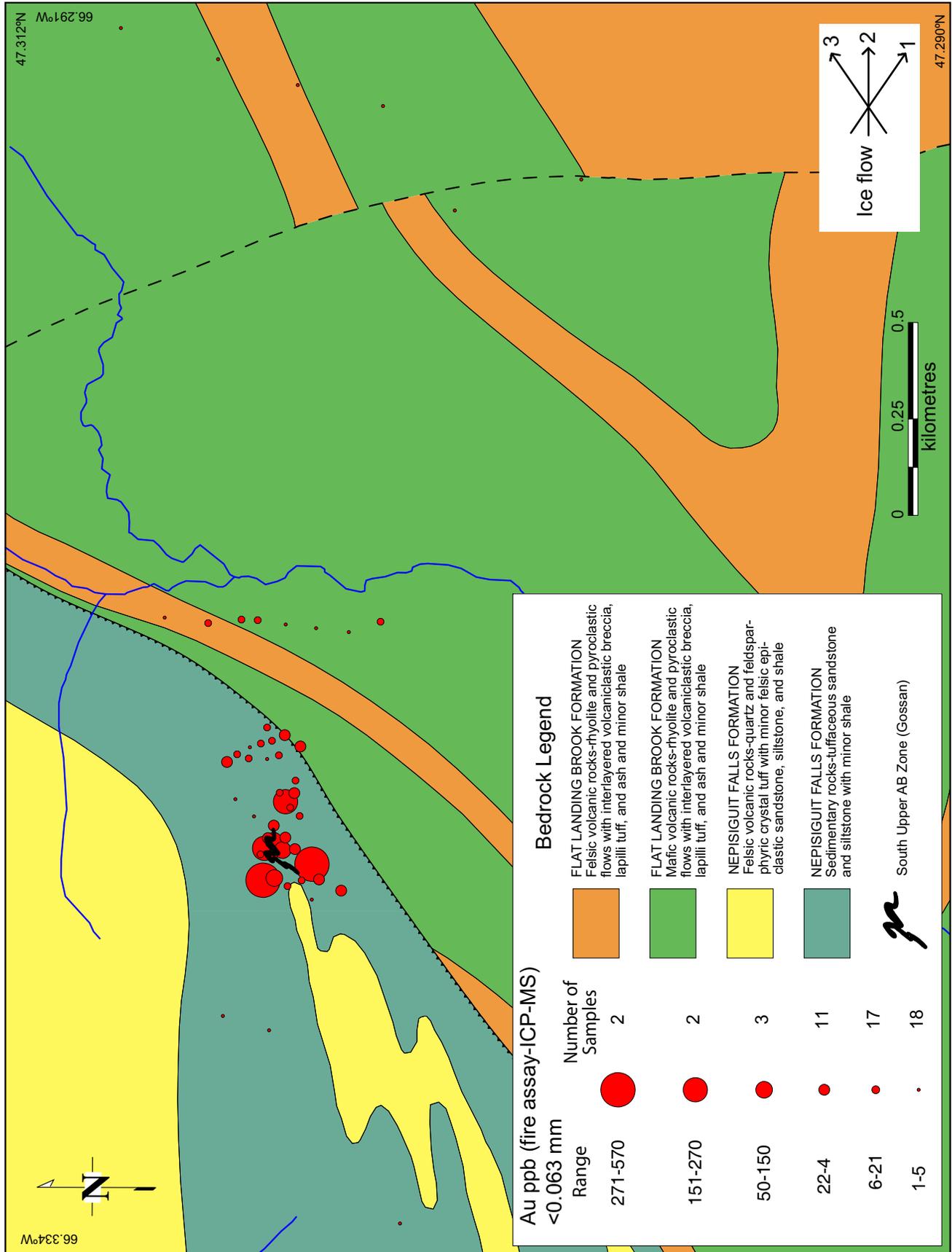
APPENDIX D1 continued. Map 2: Local-scale map of lead distribution.



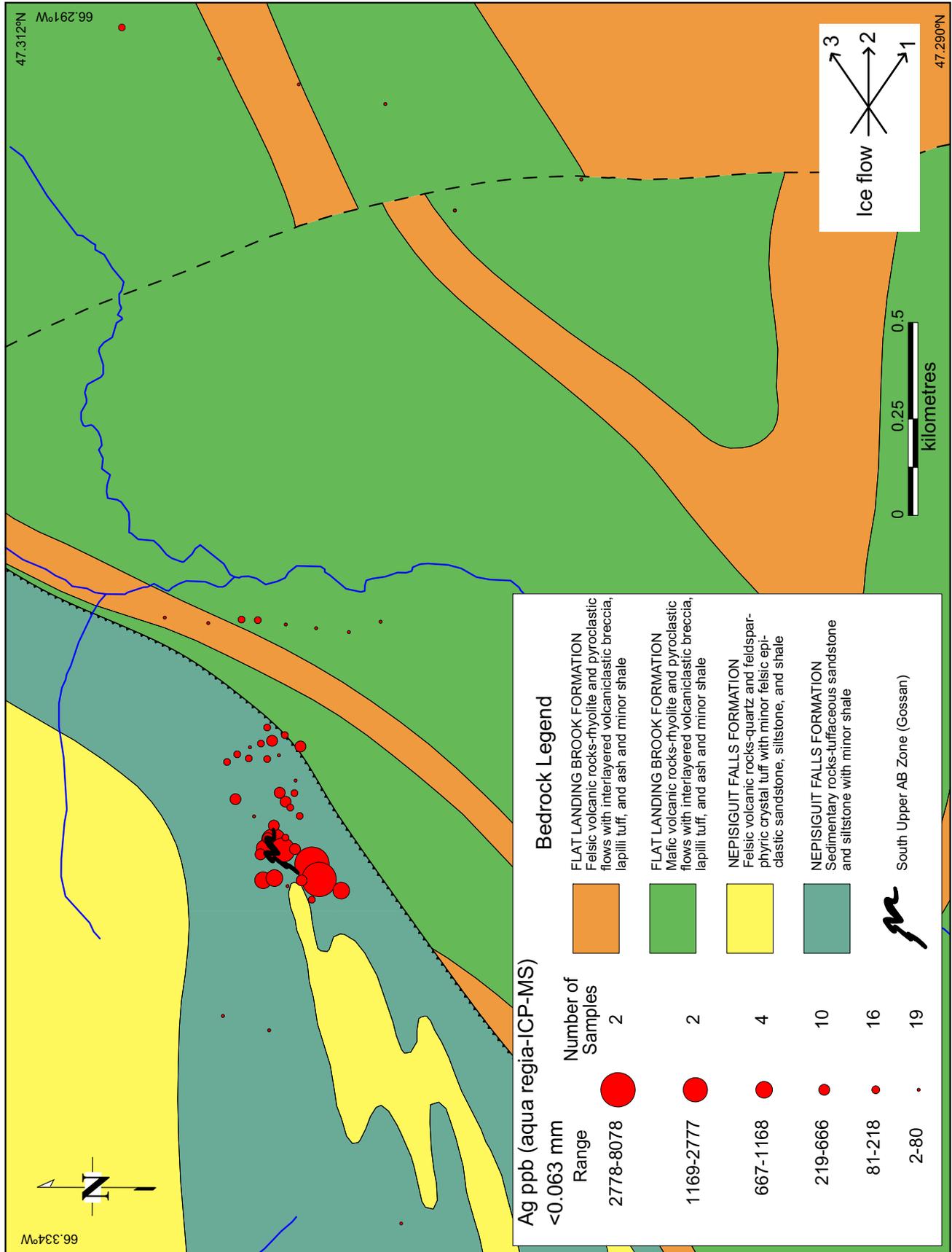
APPENDIX D1 continued. Map 3: Local-scale map of zinc distribution.



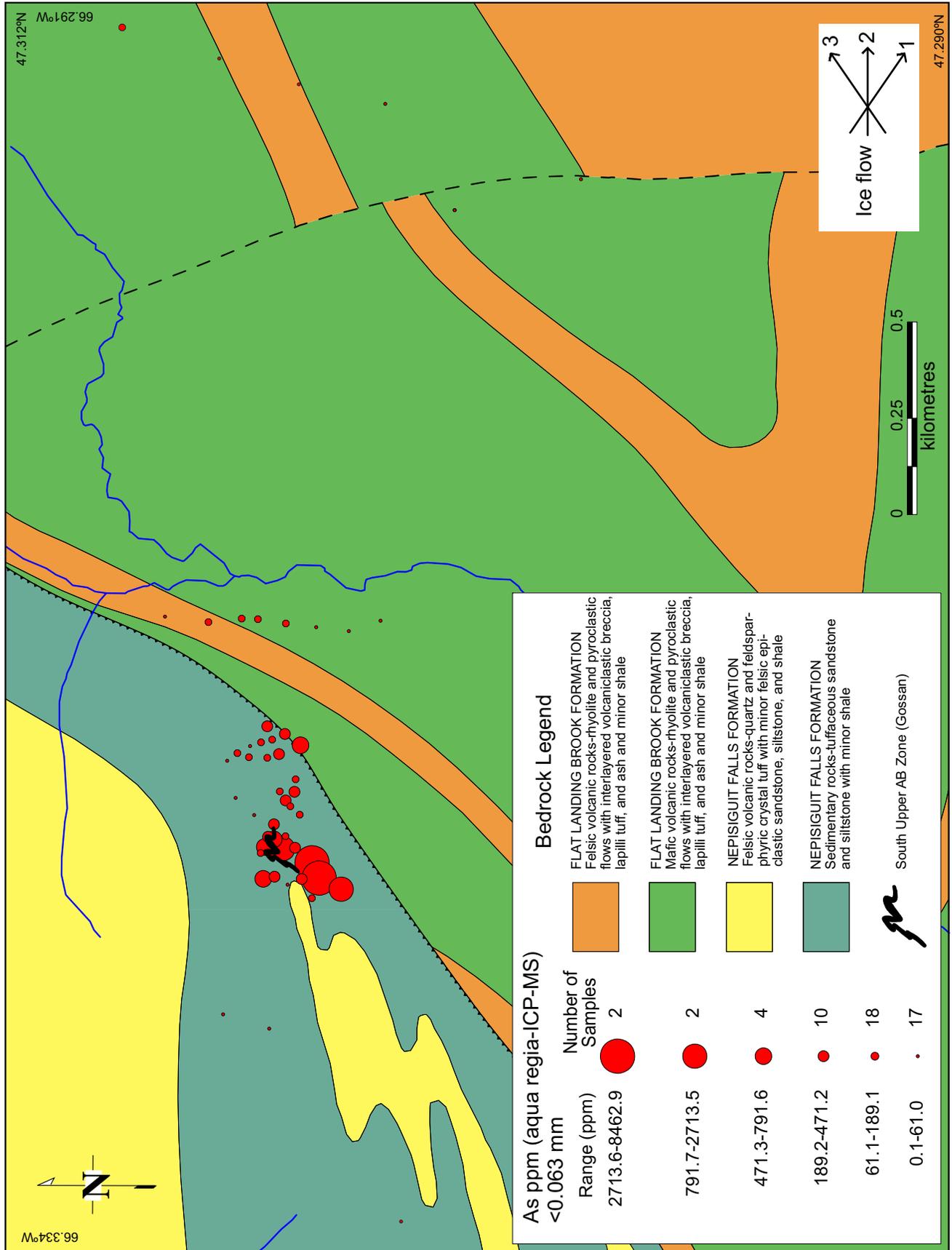
APPENDIX D1 continued. Map 4: Local-scale map of gold distribution.



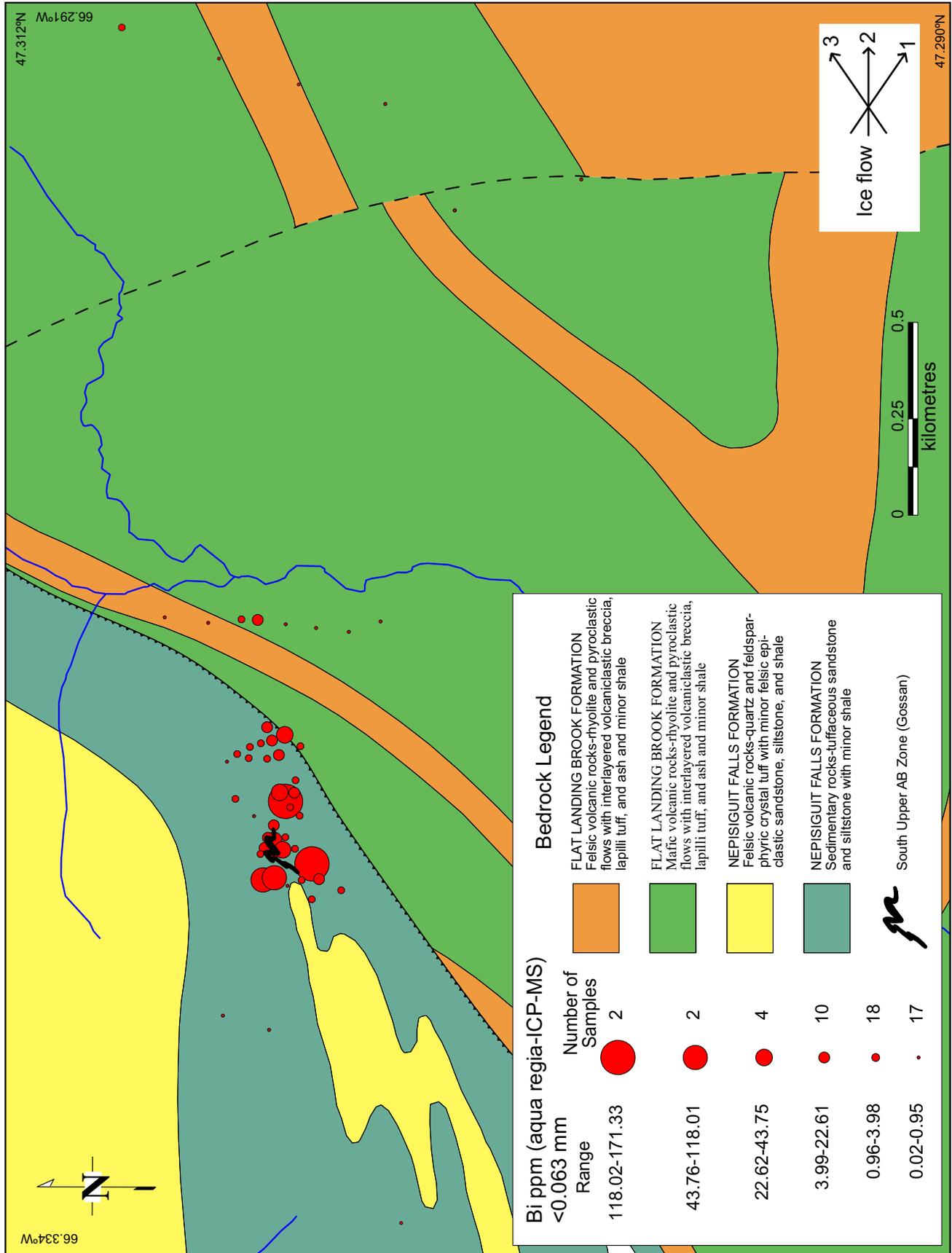
APPENDIX D1 continued. Map 5: Local-scale map of silver distribution.



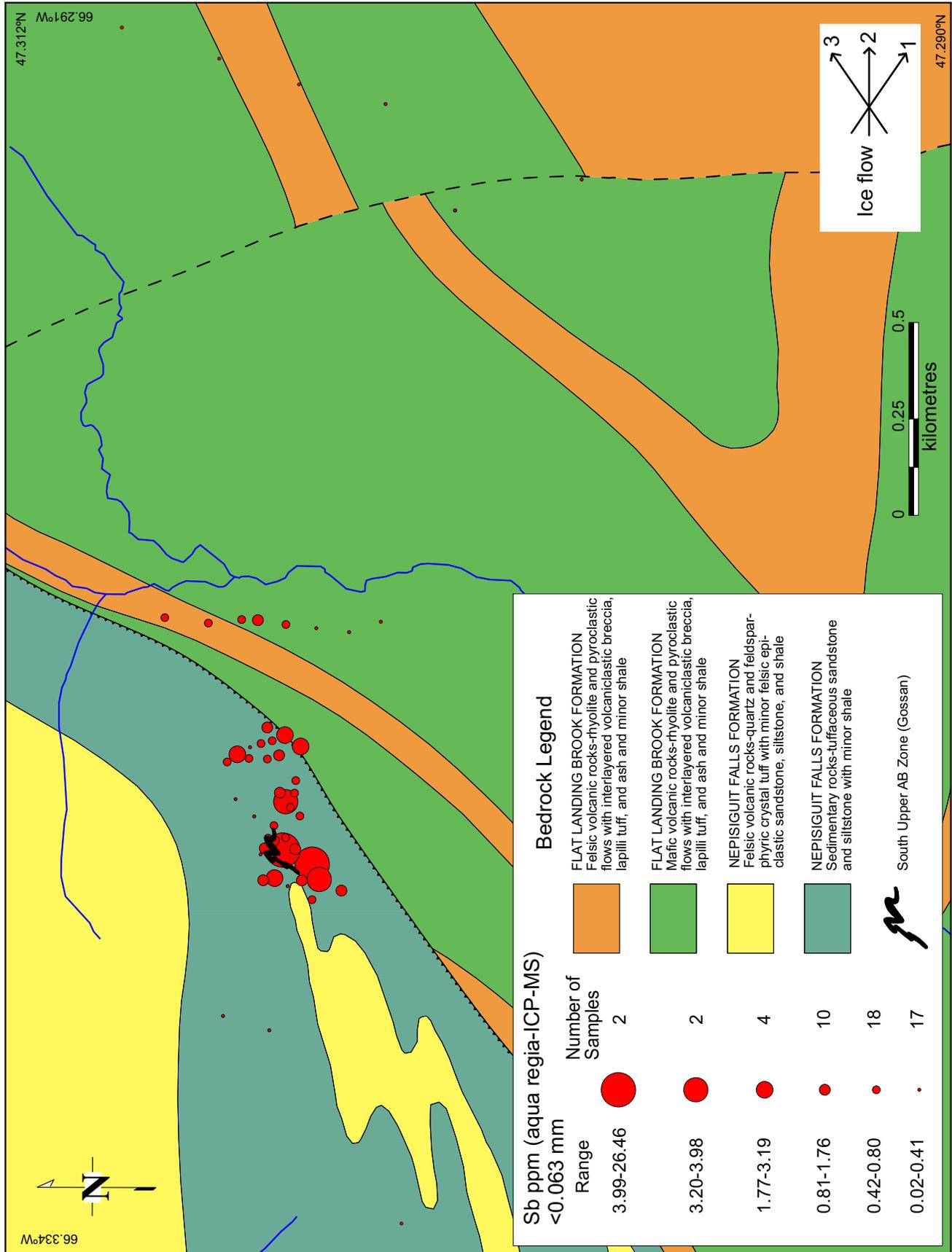
APPENDIX D1 continued. Map 6: Local-scale map of arsenic distribution.



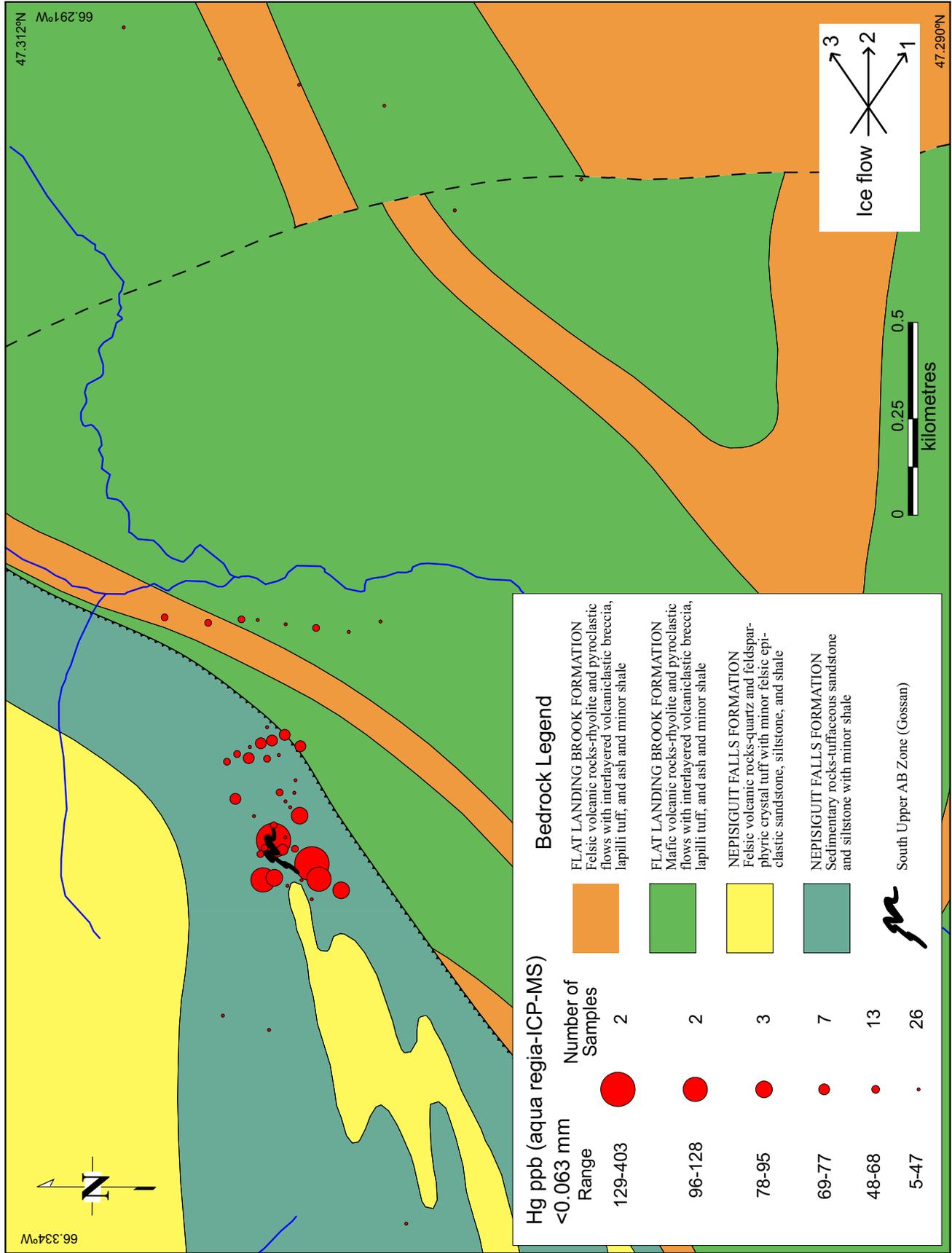
APPENDIX D1 continued. Map 7: Local-scale map of bismuth distribution.



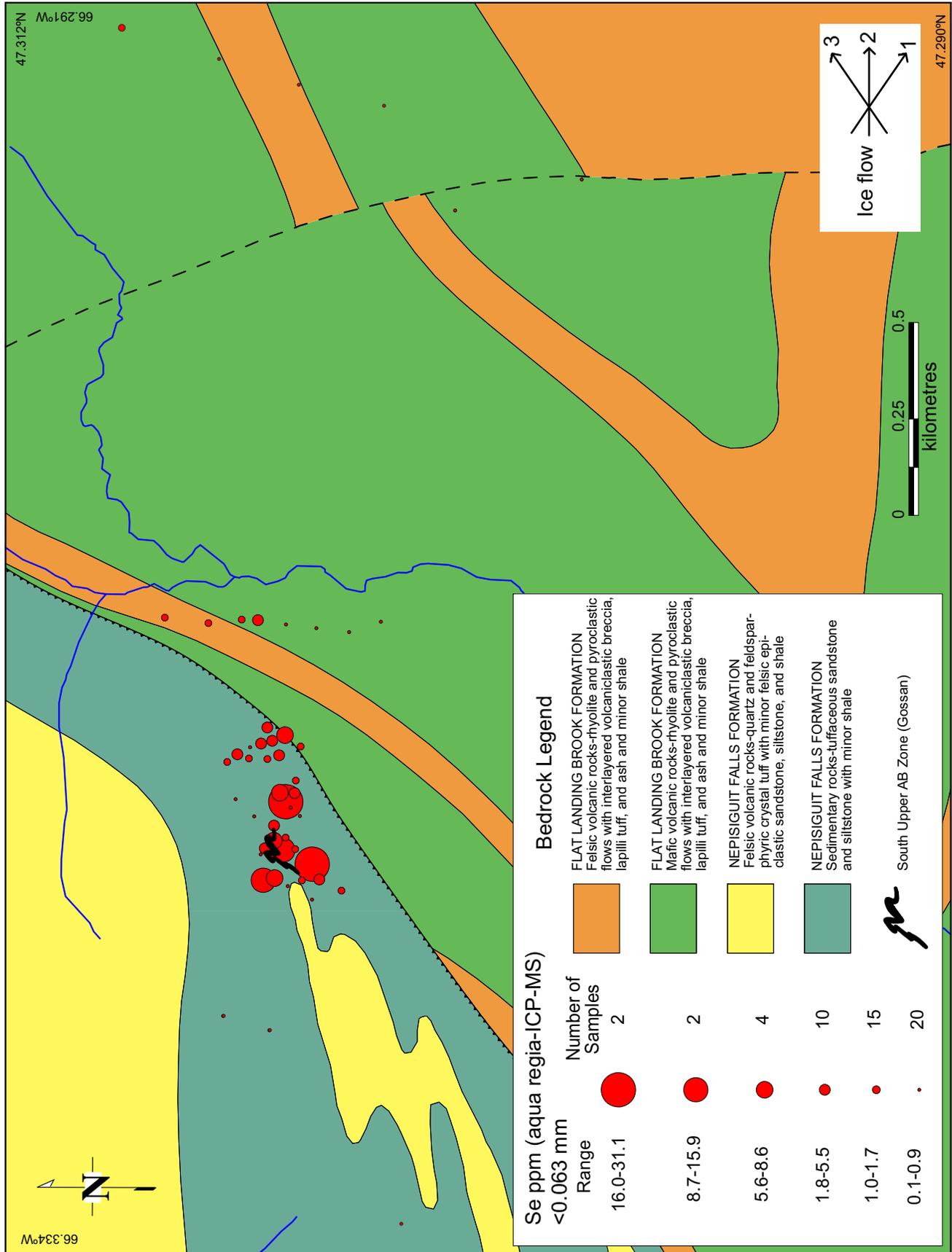
APPENDIX D1 continued. Map 8: Local-scale map of antimony distribution.



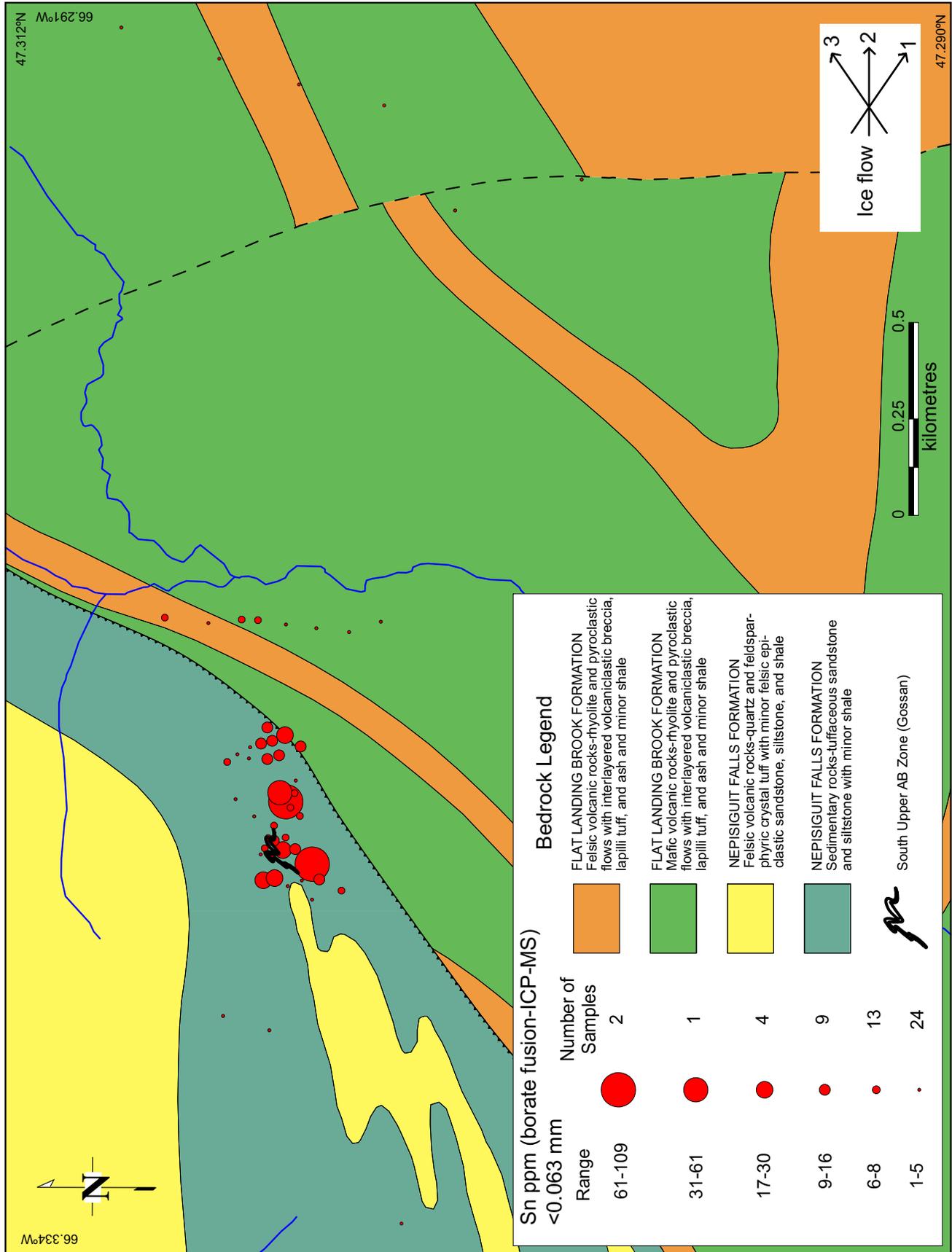
APPENDIX D1 continued. Map 9: Local-scale map of mercury distribution.



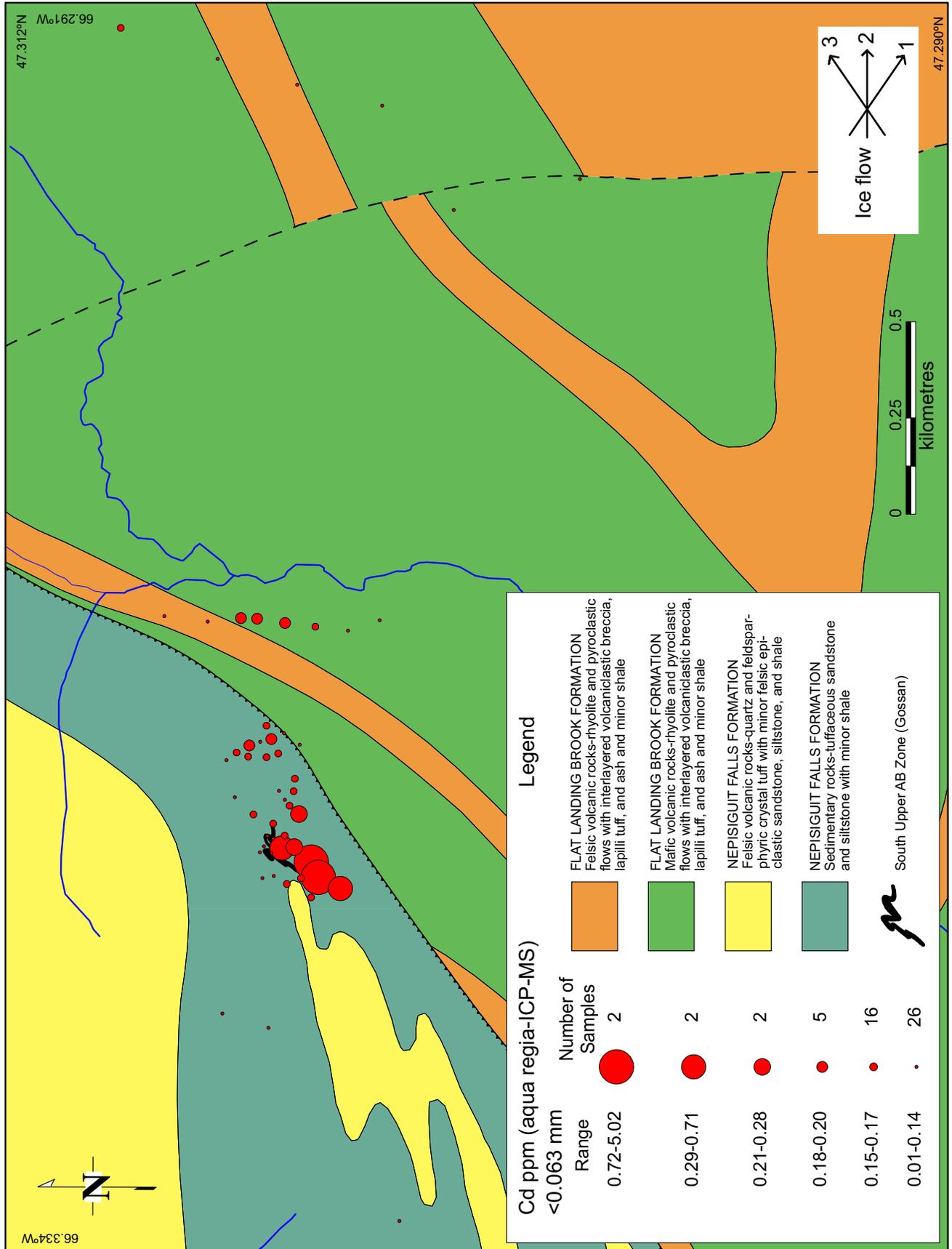
APPENDIX D1 continued. Map 10: Local-scale map of selenium distribution.



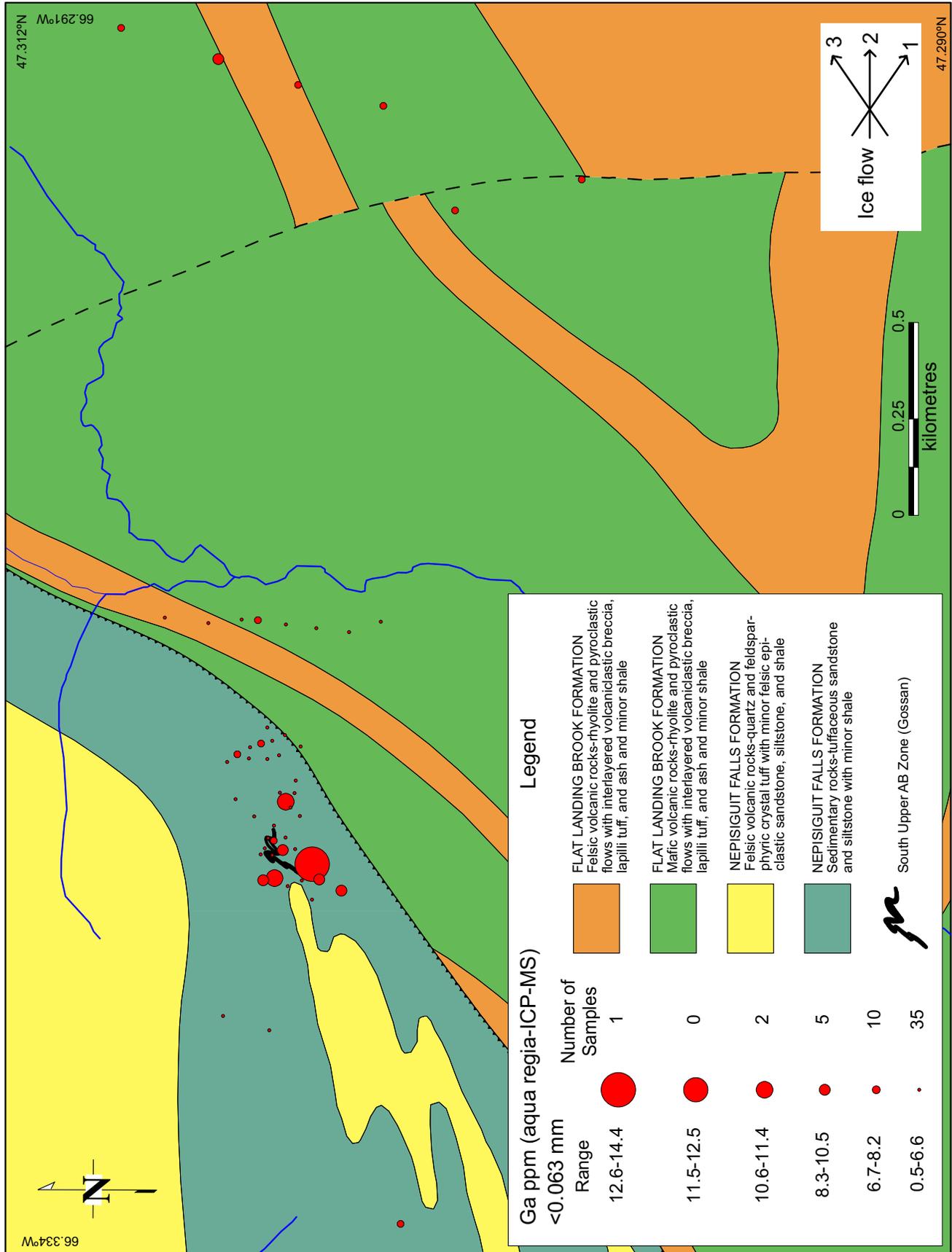
APPENDIX D1 continued. Map 11: Local-scale map of tin distribution.



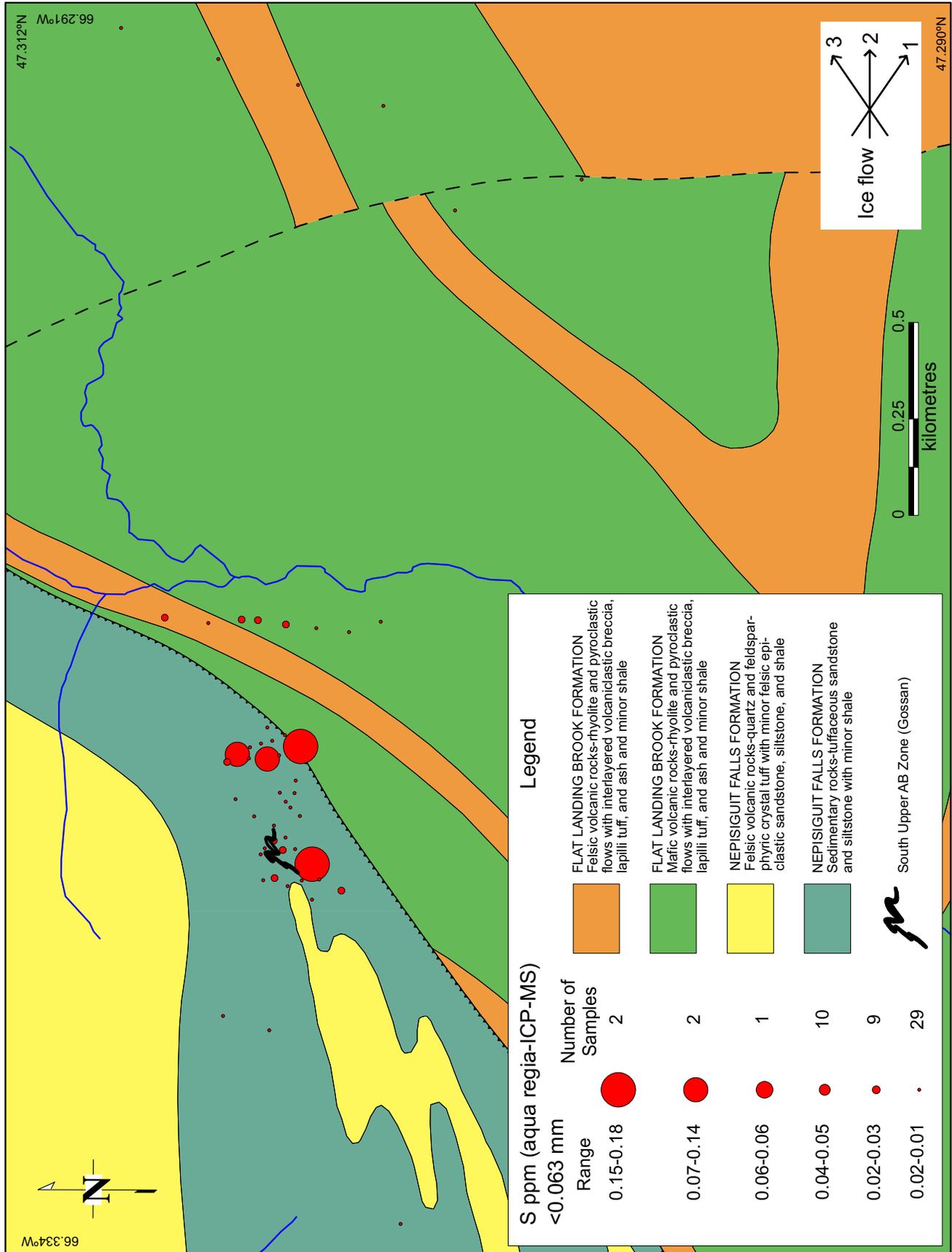
APPENDIX D1 continued. Map 12: Local-scale map of cadmium distribution.



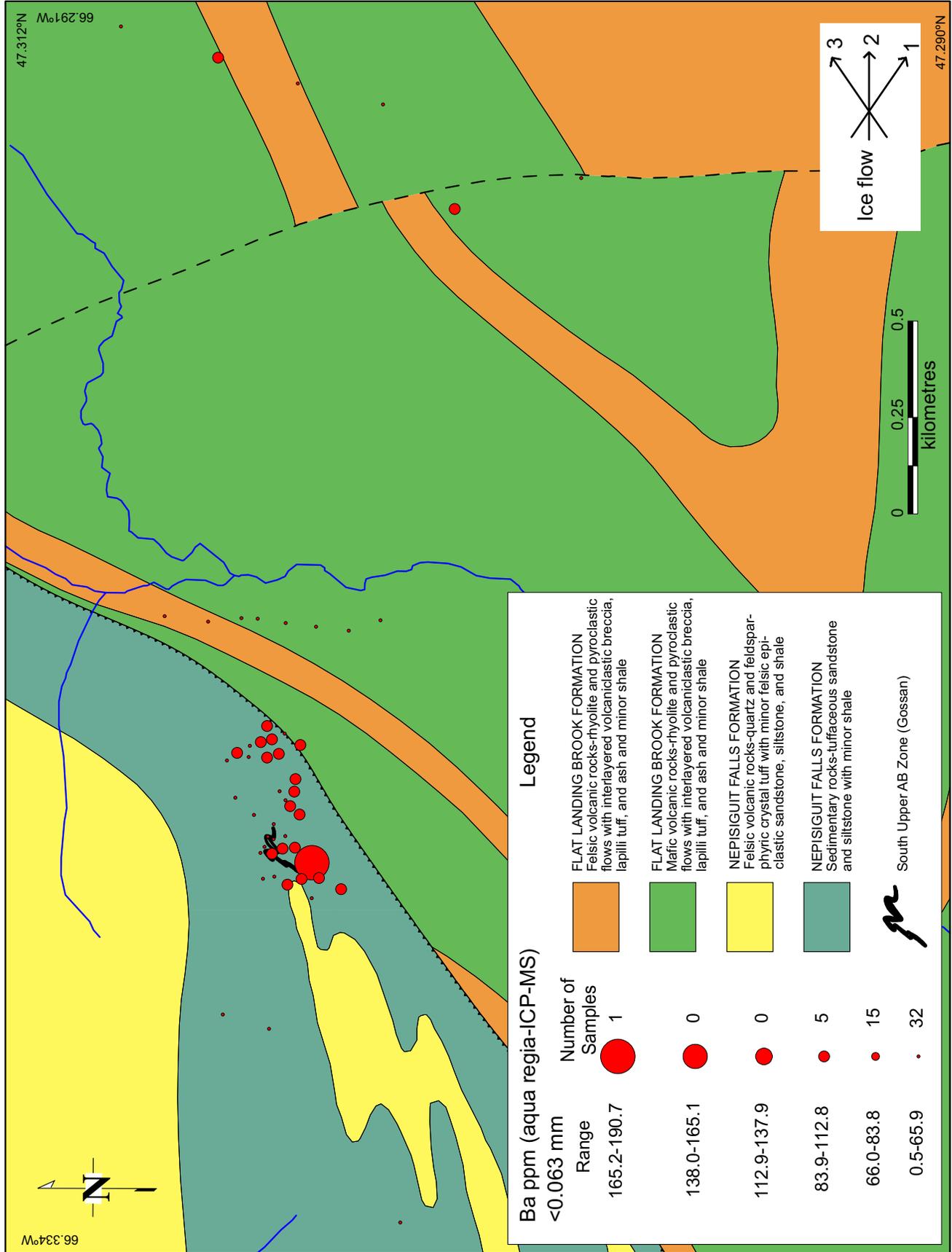
APPENDIX D1 continued. Map 13: Local-scale map of gallium distribution.



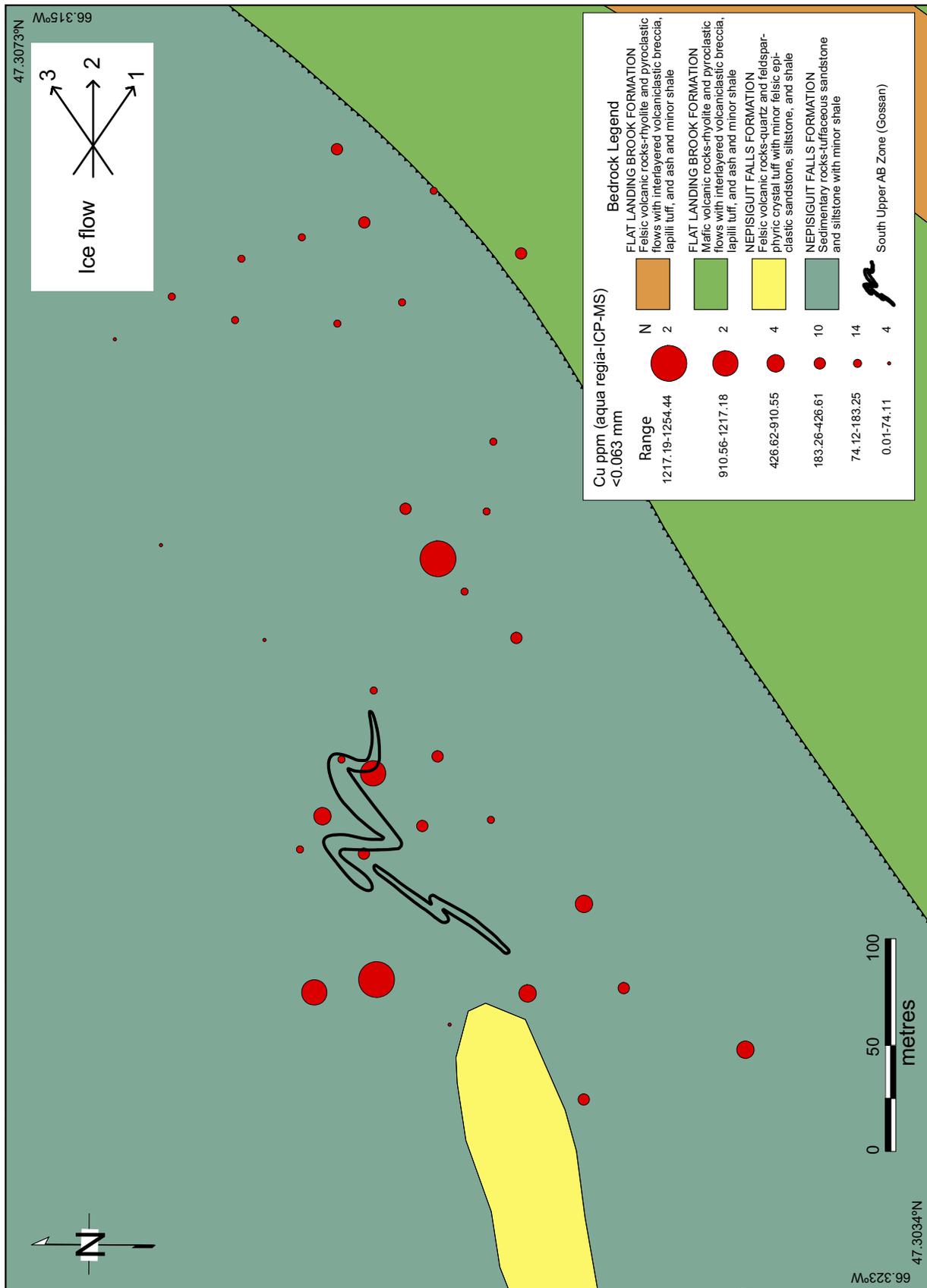
APPENDIX D1 continued. Map 14: Local-scale map of sulphur distribution.



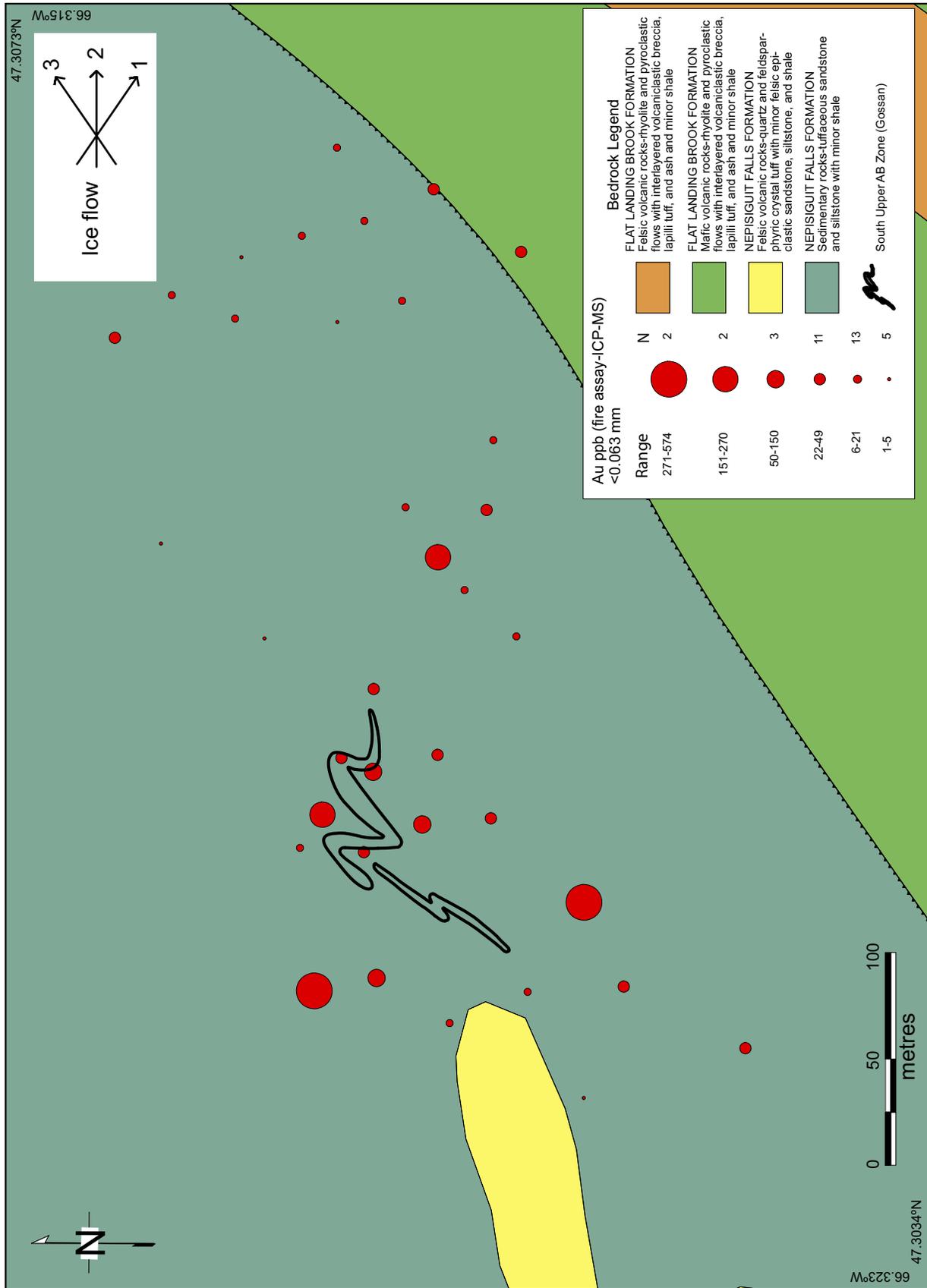
APPENDIX D1 continued. Map 15: Local-scale map of barium distribution.



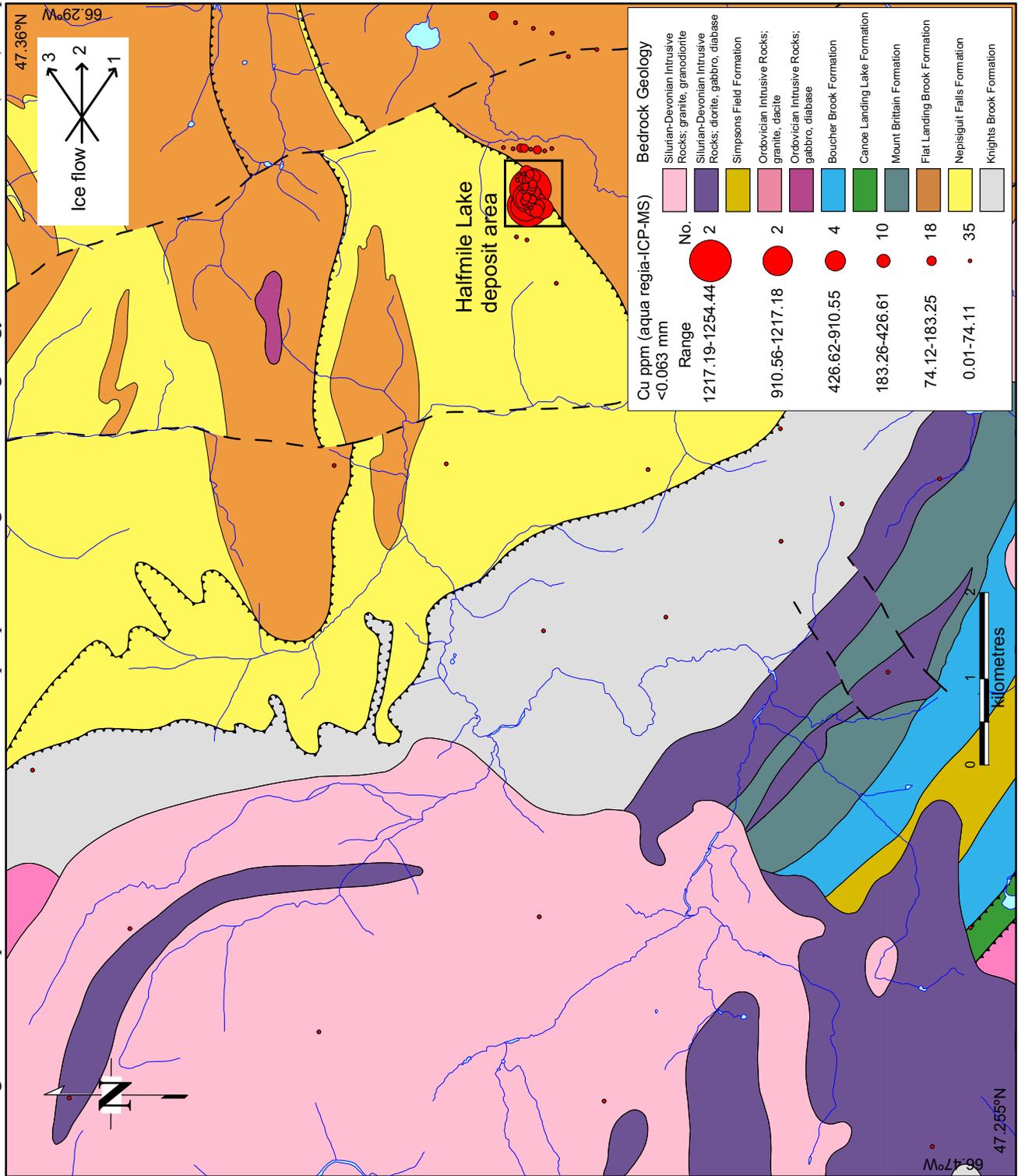
APPENDIX D2. Deposit-scale maps for the 2007 till samples plotted on regional bedrock geology from Goodfellow et al. (2003). Map 16: copper.



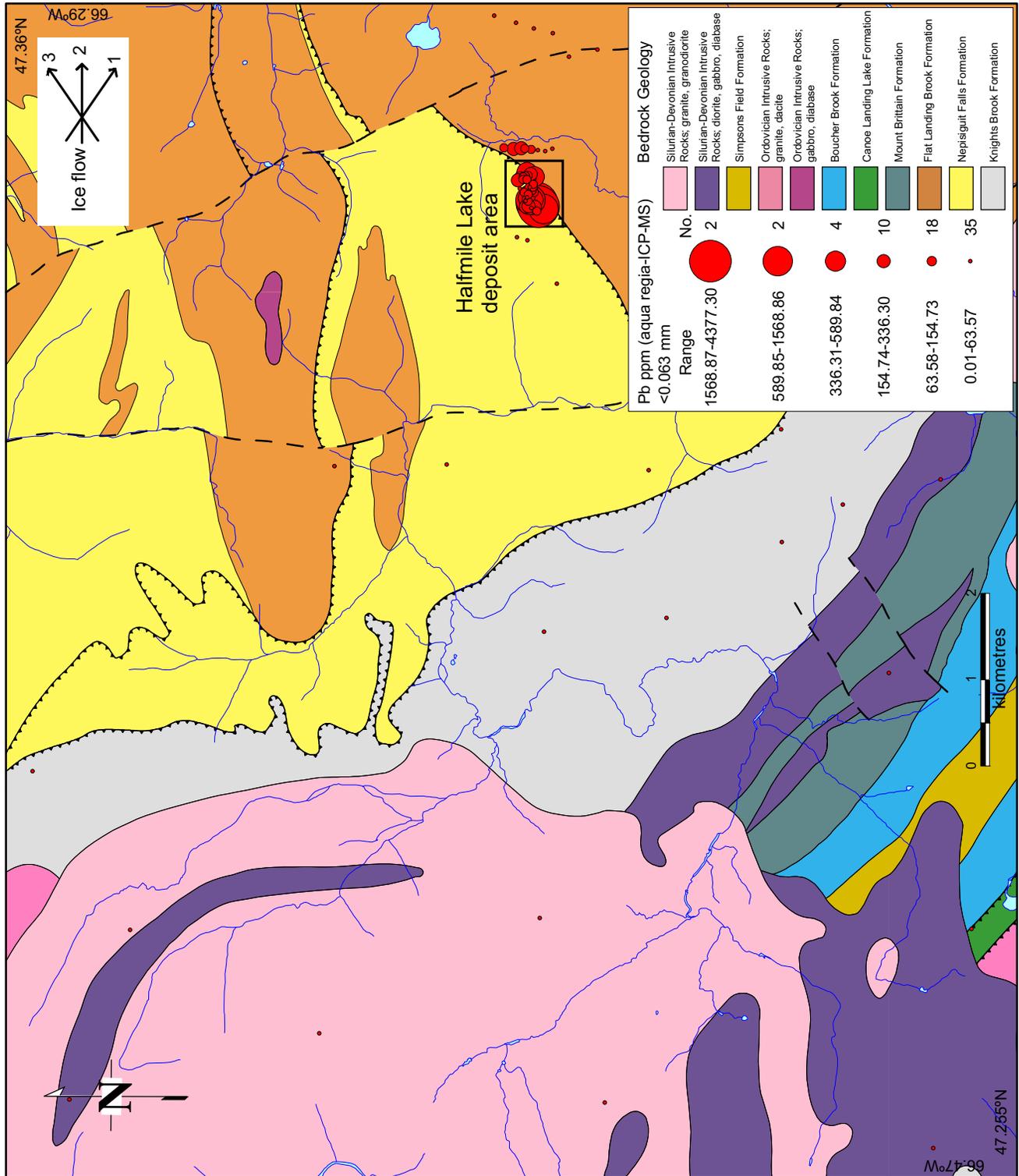
APPENDIX D2 continued. Map 17: Deposit-scale map of gold distribution.



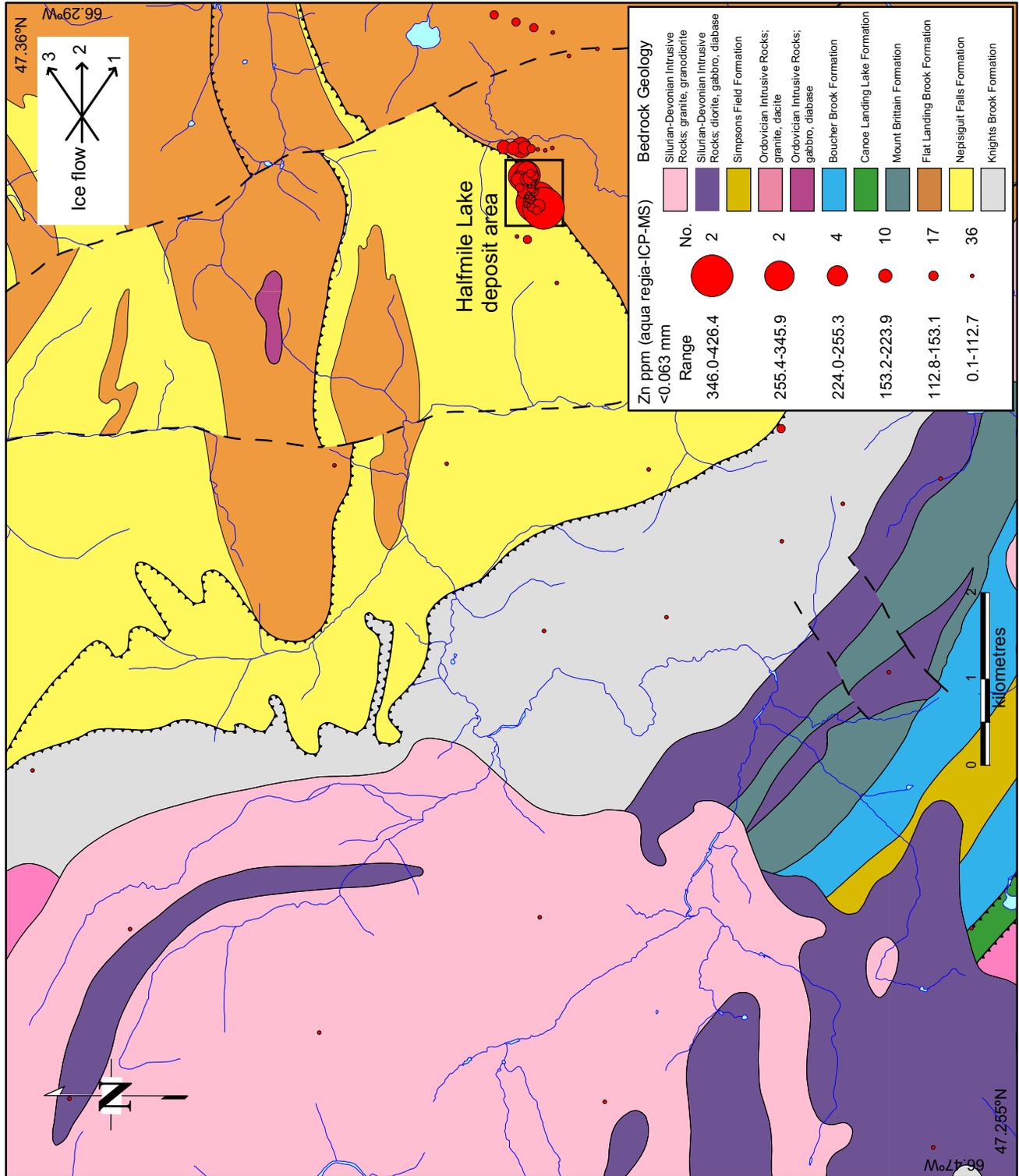
APPENDIX D3. Regional-scale maps of the 2007 and 2008 till samples plotted on regional bedrock geology from Goodfellow et al. (2003). Map 18. copper.



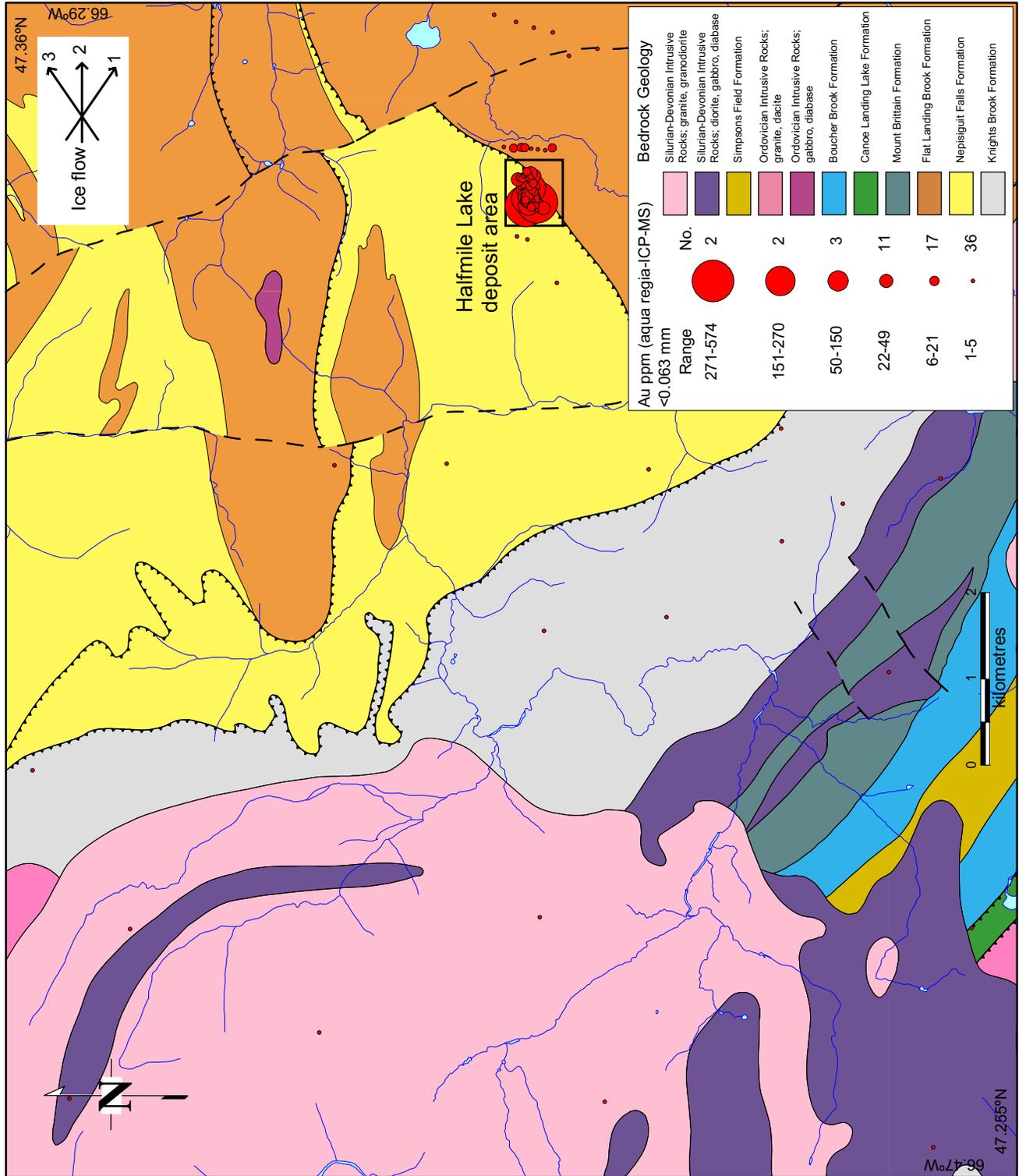
APPENDIX D3 continued. Map 19: Regional-scale map of lead distribution.



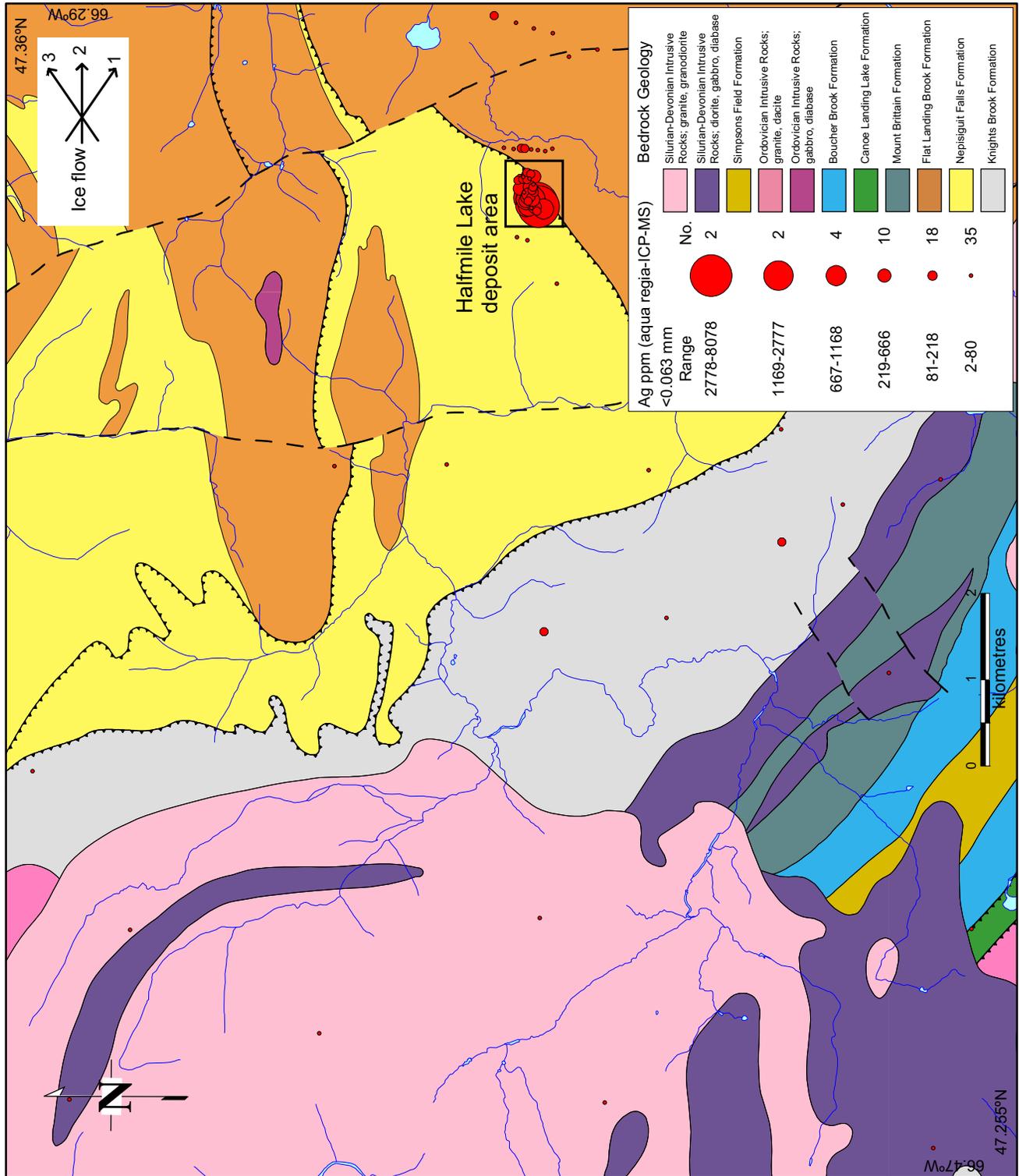
APPENDIX D3 continued. Map 20: Regional-scale map of zinc distribution.



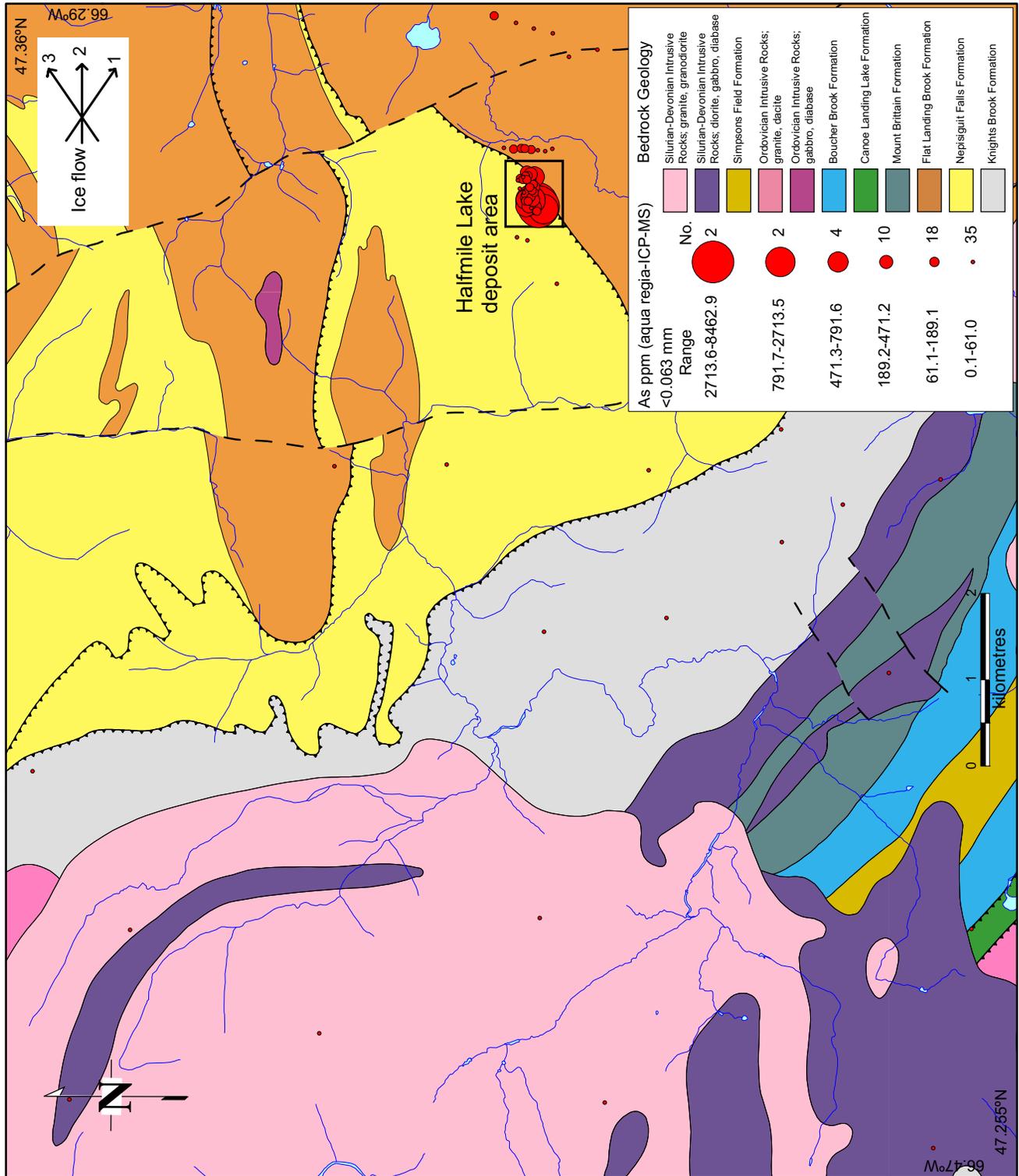
APPENDIX D3 continued. Map 21: Regional-scale map of gold distribution.



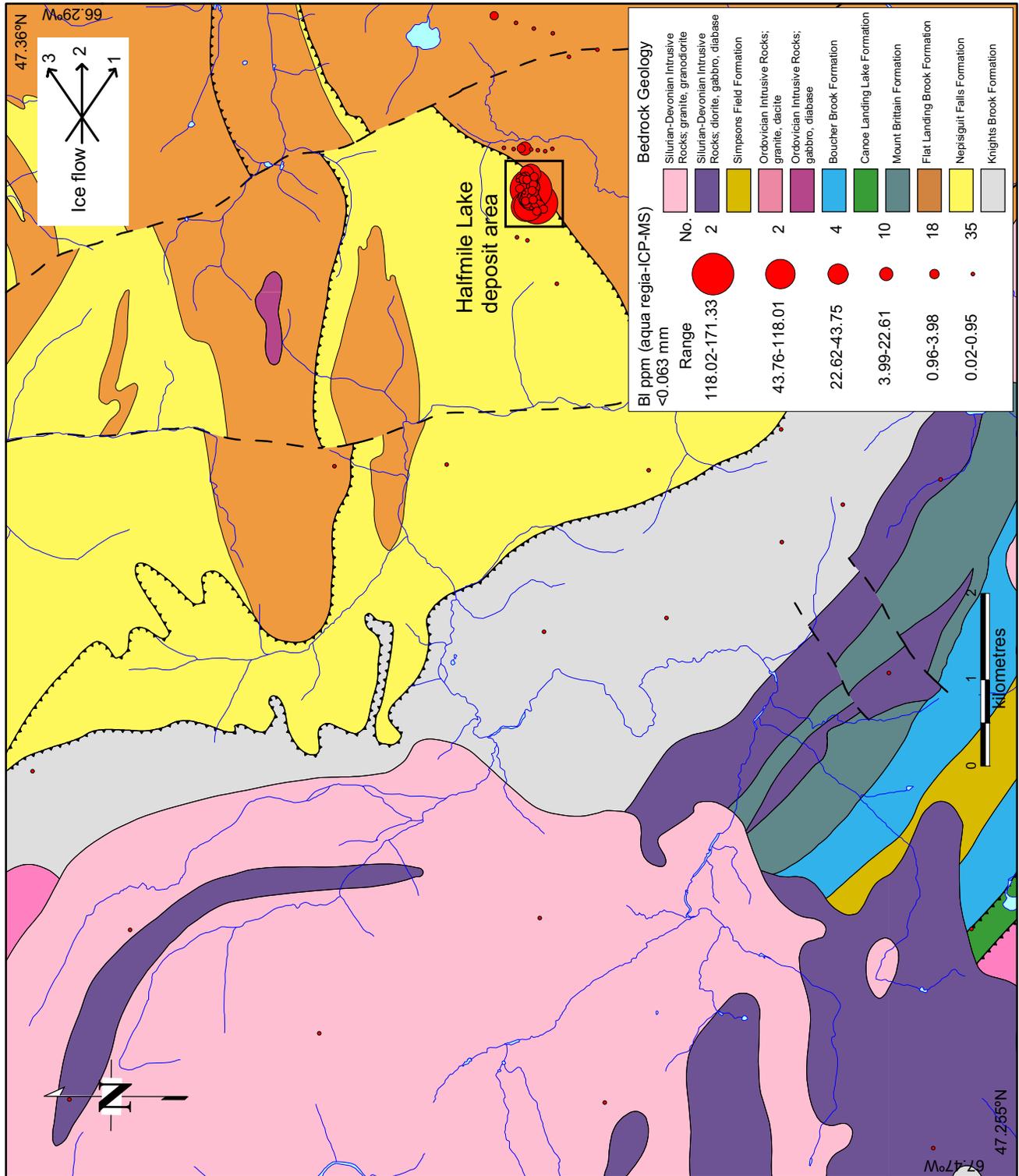
APPENDIX D3 continued. Map 22: Regional-scale map of silver distribution.



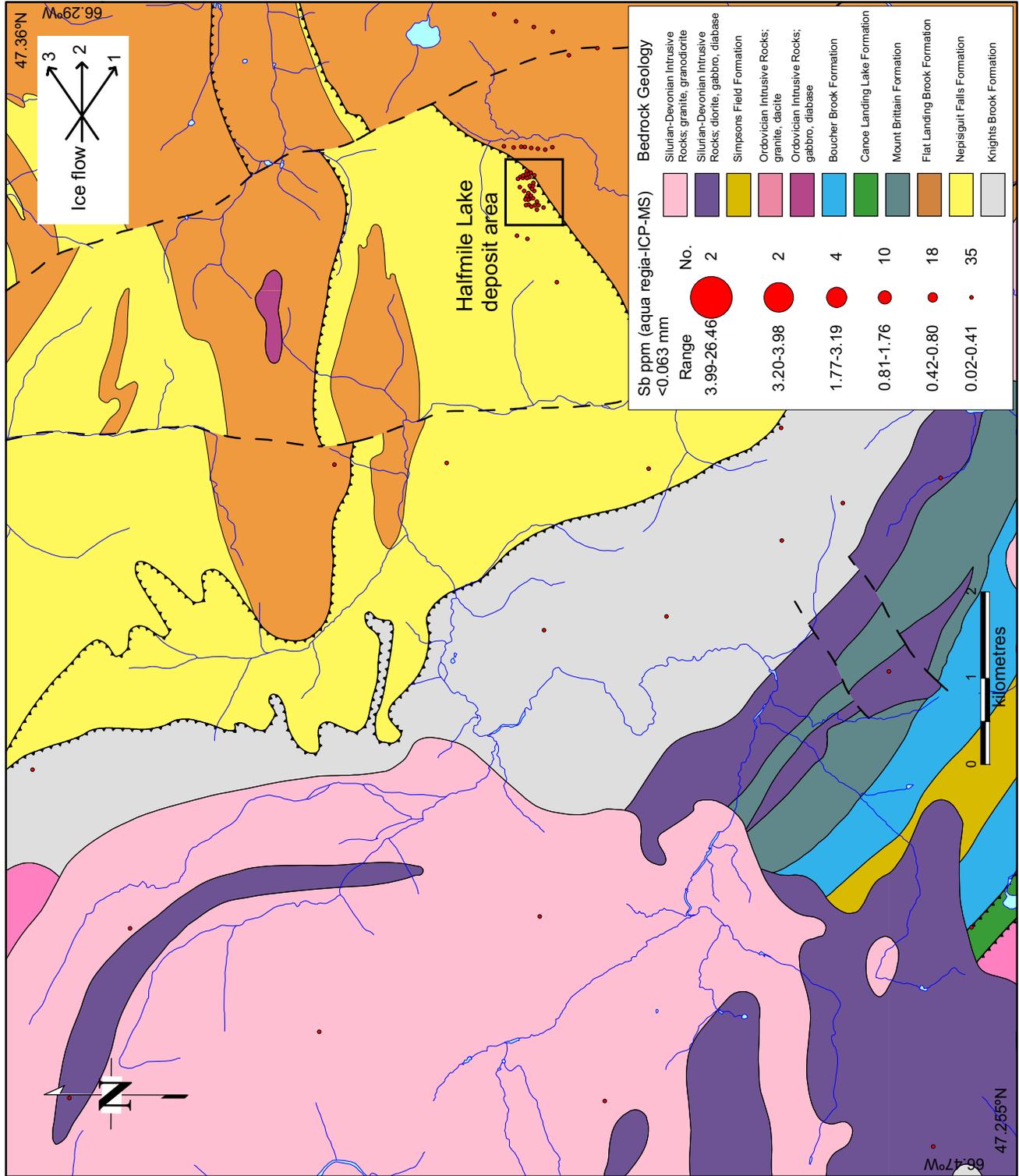
APPENDIX D3 continued. Map 23: Regional-scale map of arsenic distribution.



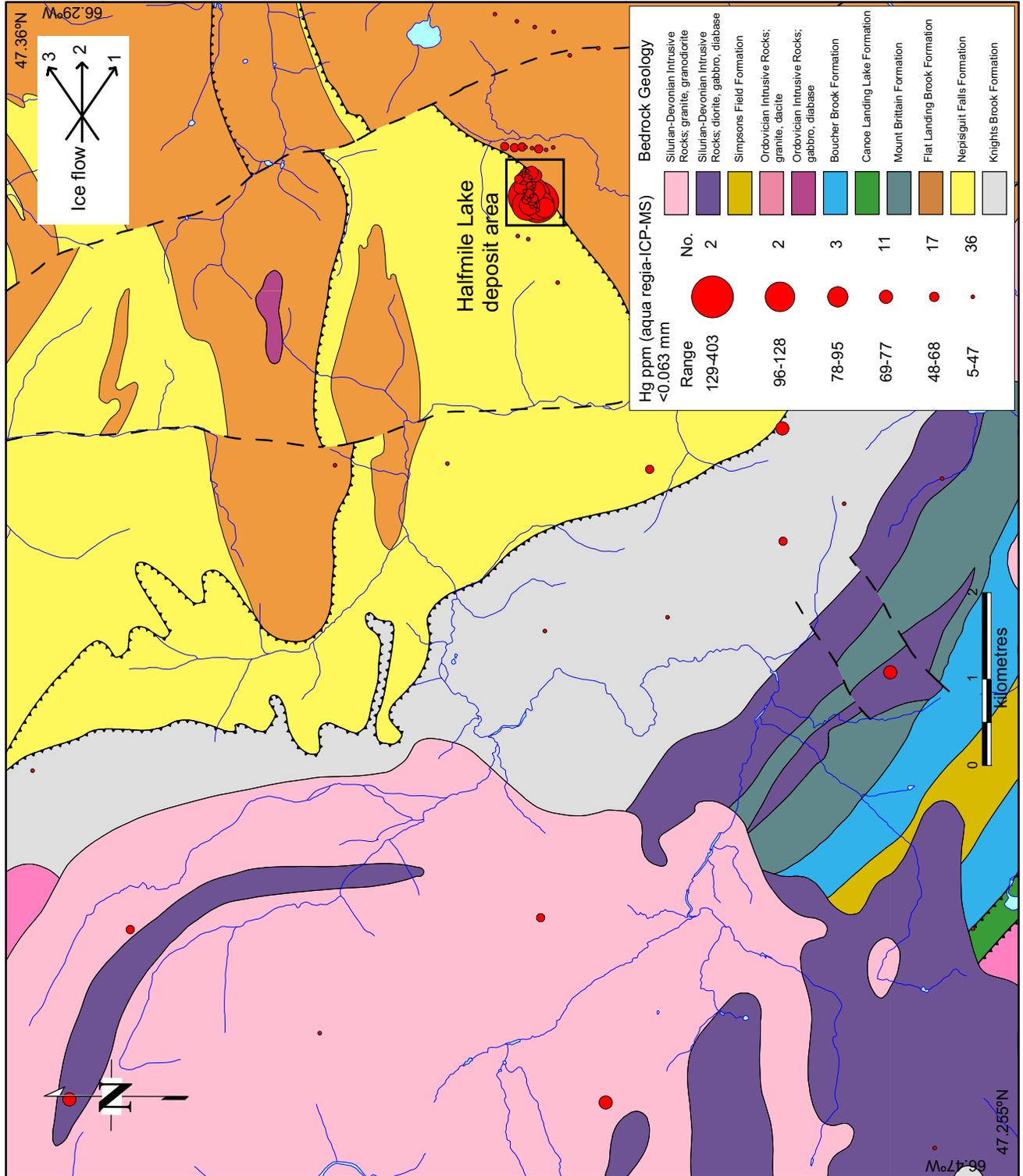
APPENDIX D3 continued. Map 24: Regional-scale map of bismuth distribution.



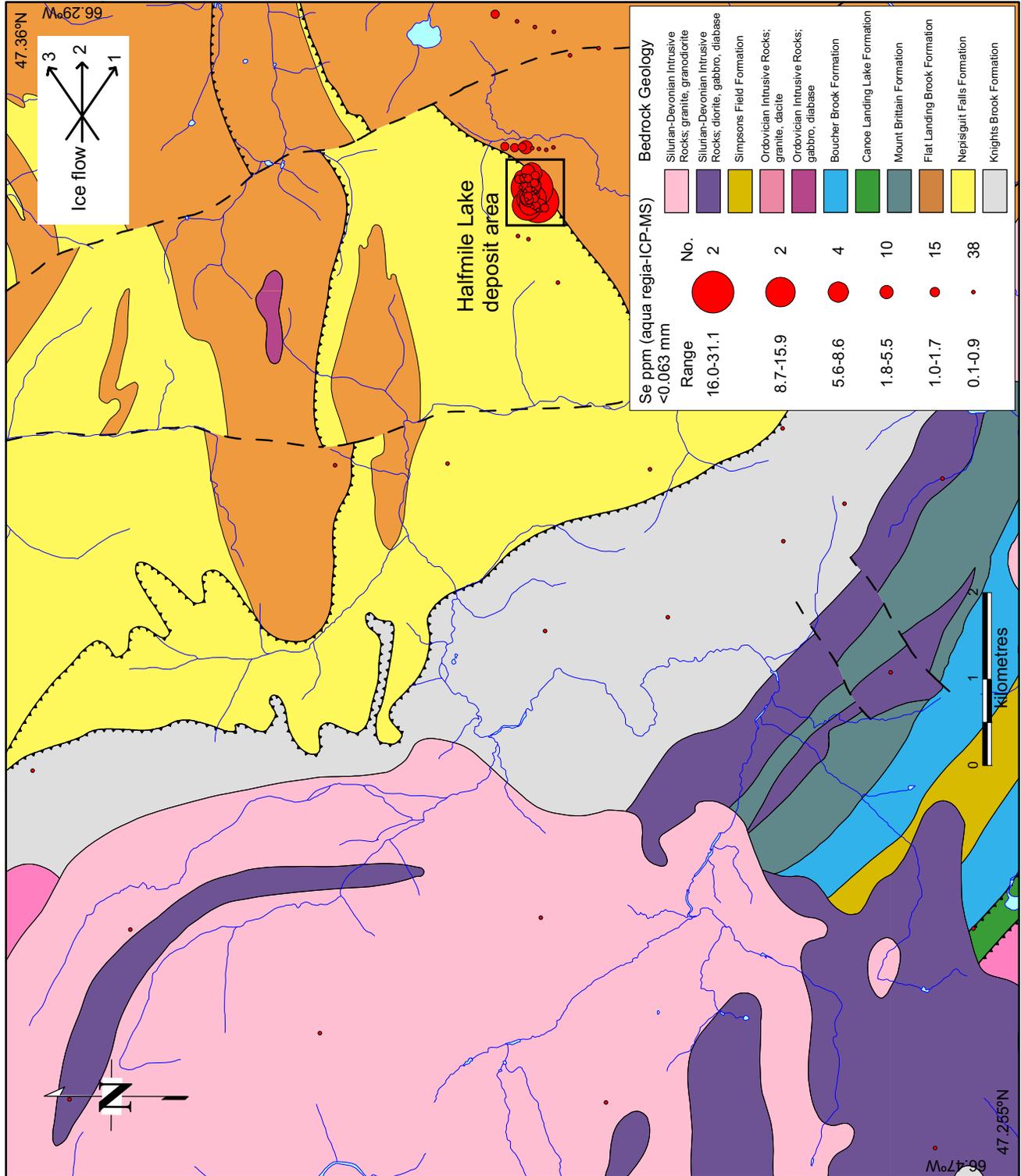
APPENDIX D3 continued. Map 25: Regional-scale map of antimony distribution.



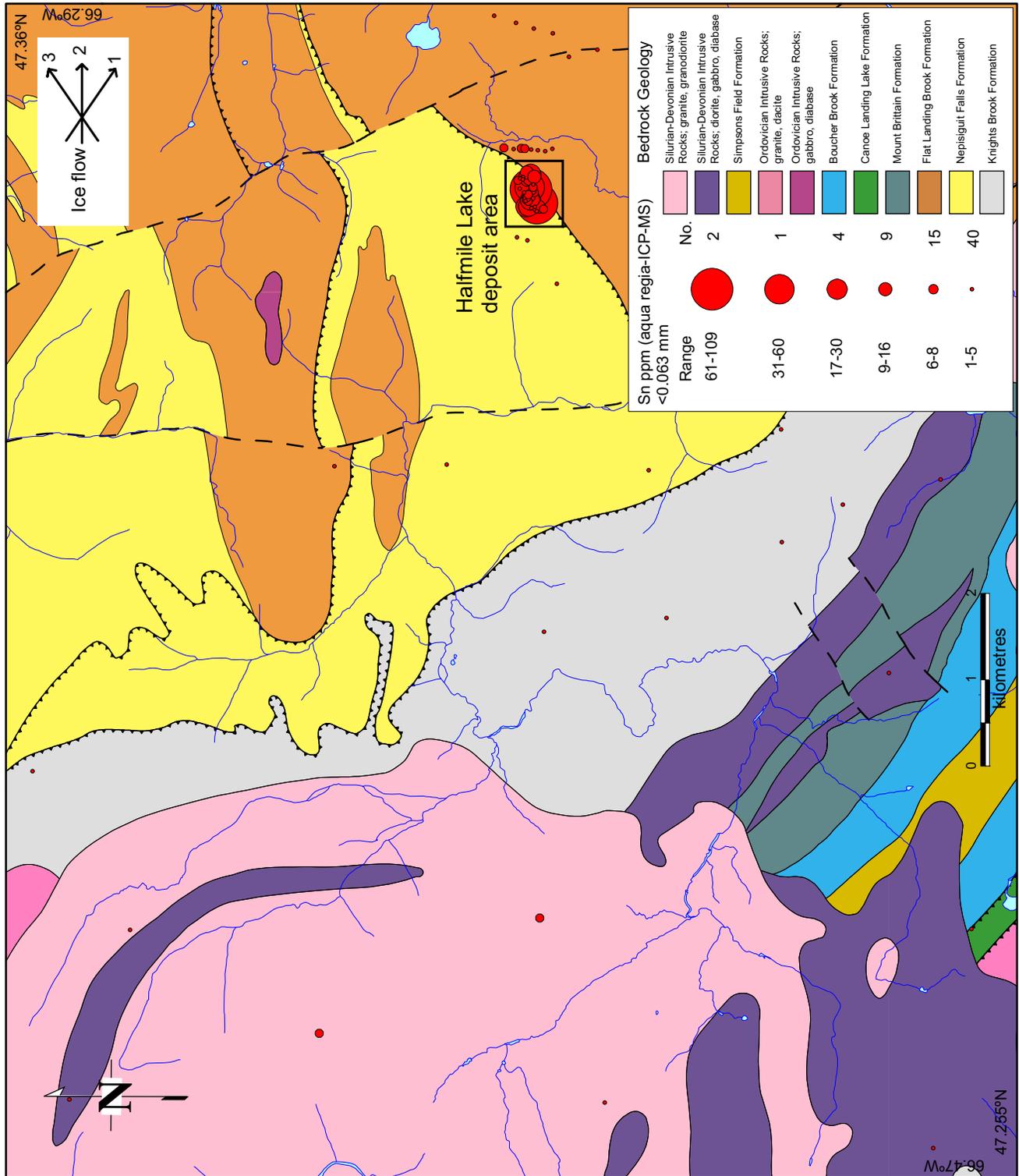
APPENDIX D3 continued. Map 26: Regional-scale map of mercury distribution.



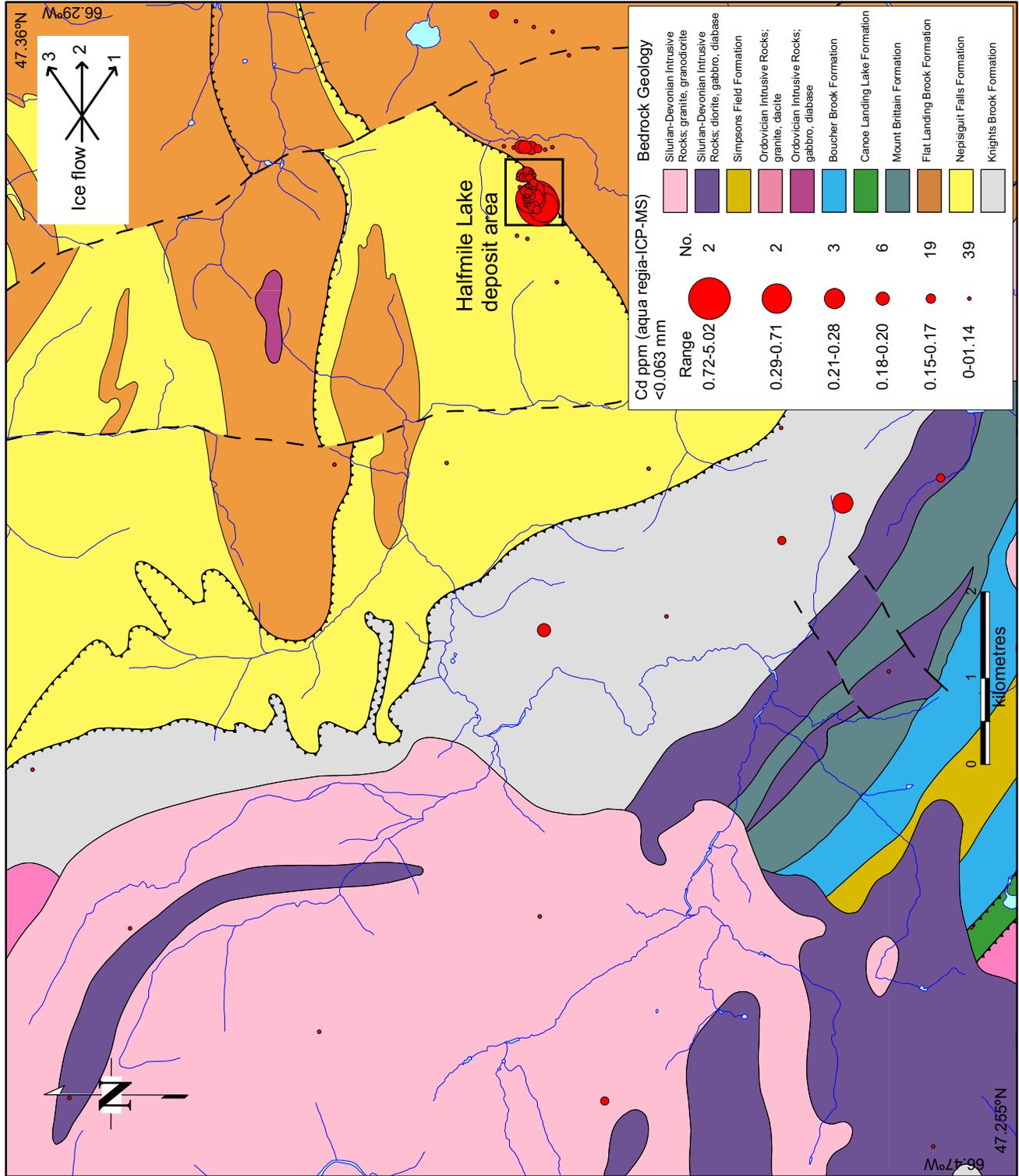
APPENDIX D3 continued. Map 27: Regional-scale map of selenium distribution.



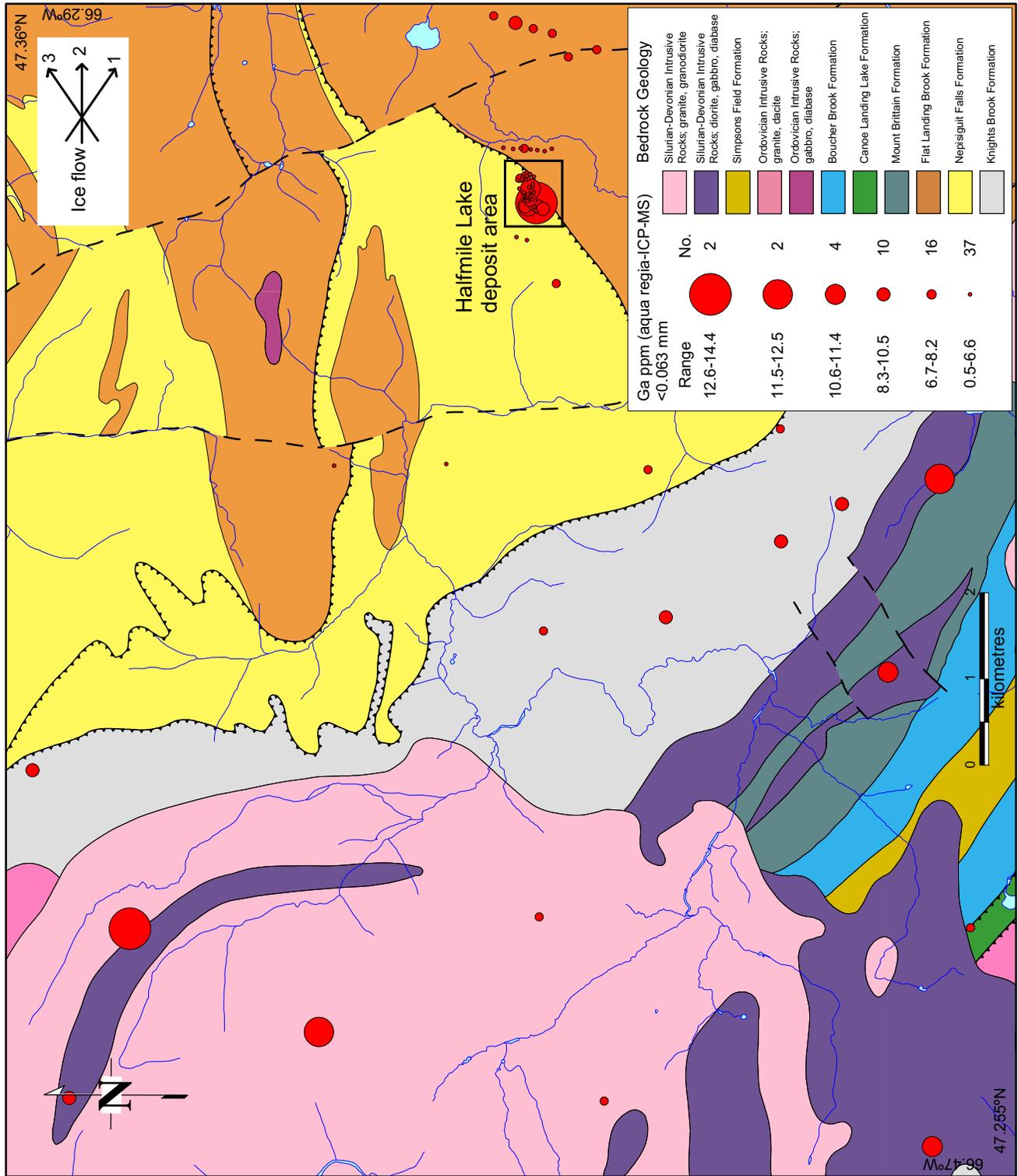
APPENDIX D3 continued. Map 28: Regional-scale map of tin distribution.



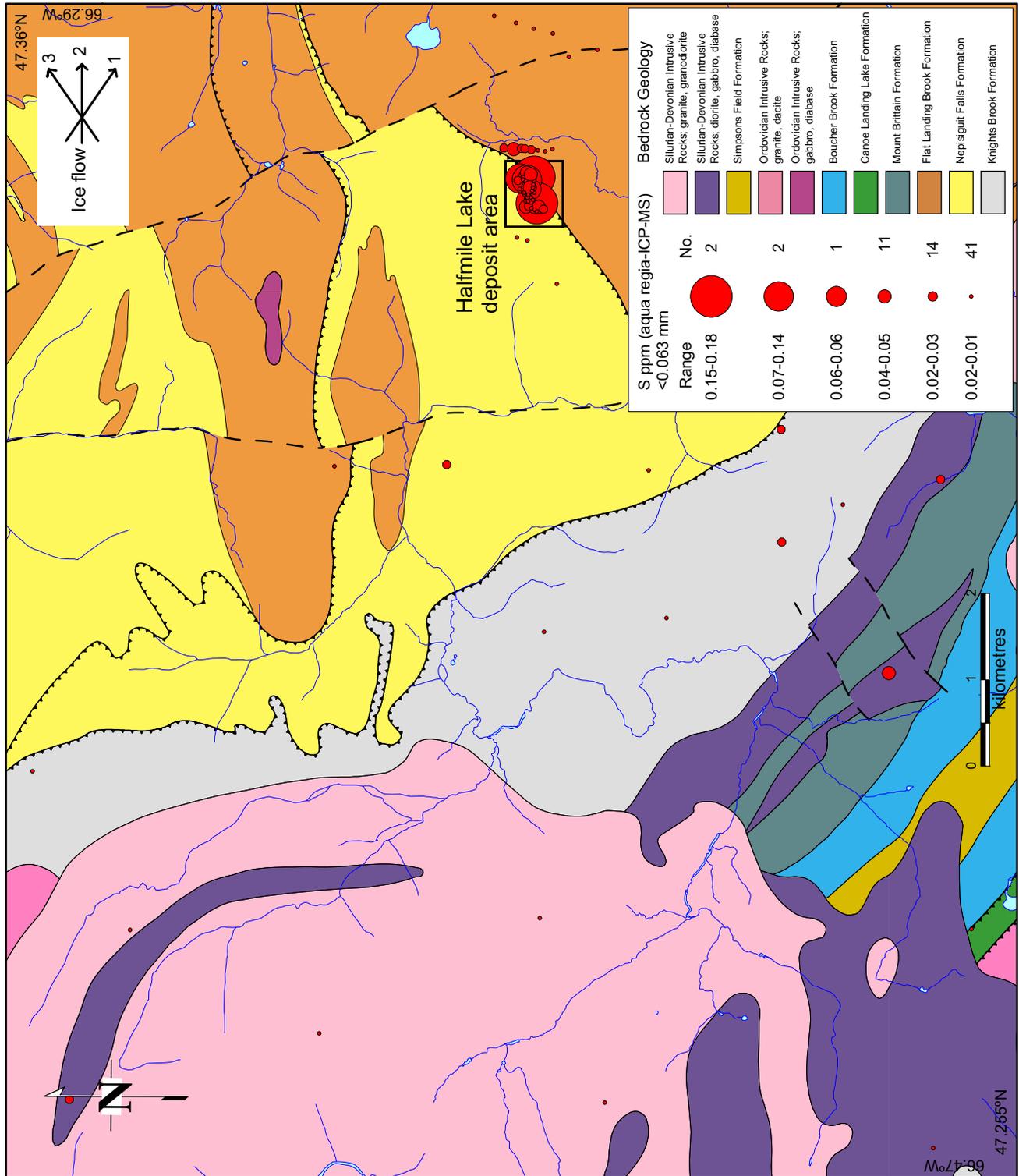
APPENDIX D3 continued. Map 29: Regional-scale map of cadmium distribution.



APPENDIX D3 continued. Map 30: Regional-scale map of gallium distribution.



APPENDIX D3 continued. Map 31: Regional-scale map of sulphur distribution.



APPENDIX D3 continued. Map 32: Regional-scale map of barium distribution.

