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**GEOLOGICAL SURVEY OF CANADA
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Mount Pleasant Sn-W-Mo-Bi-In deposit, New Brunswick**

**M.B. McClenaghan, M.A. Parkhill, A.G. Pronk,
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2015

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Contribution to the Geological Survey of Canada's Targeted Geoscience Initiative 4 (TGI-4) Program (2010-2015)

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Till geochemical signatures of the Mount Pleasant Sn-W-Mo-Bi-In deposit, New Brunswick

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ABSTRACT

A till geochemistry study was carried out around the Mount Pleasant Sn-W-Mo-Bi-In deposit as part of the Geological Survey of Canada's (GSC) Targeted Geoscience Initiative 4 (TGI-4), a collaborative federal geoscience program with a mandate to provide industry with the next generation of geoscience knowledge and innovative techniques that will result in more effective targeting of buried mineral deposits. The <0.063 mm fraction of till clearly defines glacial dispersal at least 0.5 km down-ice of the North Zone and 1 km down-ice of the Fire Tower Zone. Indicator elements in till for this deposit include the main ore elements Sn, W, Mo, Bi and In. Pathfinder elements include Ag, As, Cd, Cu, Pd, Re, Te, Tl, and Zn. The Mount Pleasant deposit is a significant source of In and this study is one of the first to report a glacial dispersal pattern for In in till. Till overlying and just down-ice of the deposit contains between 1 and 13 ppm In, some of the highest In values ever reported for till. The study compared the efficiency of an aqua regia leach versus a lithium metaborate/tetraborate fusion followed by nitric acid digestion (total digestion) for determining metal contents in till. Results indicate that a total digestion is required to report the total concentration of Sn and W in till. On the other hand, aqua regia is suitable for determining the other indicator and pathfinder elements.

INTRODUCTION

Much of the world's Sn is produced from placer deposits, most of which are in southeast Asia. Currently, Canada has no producing Sn mines. Cassiterite (SnO₂) is the main ore mineral of Sn, although small quantities of Sn may also be recovered from stannite, cylindrite, frankeite, canfieldite, and teallite (USGS, 2014). Cassiterite is extremely resistant to both chemical and physical weathering and is hard (H=6–7), thus it readily survives glacial transport and subsequent postglacial weathering and oxidation in glacial deposits. Till geochemistry has been used successfully for Sn exploration in glaciated terrain (e.g. Szabo et al., 1975; Matilla and Peuraniemi, 1980; Rogers and Garrett, 1987; Aario and Peuraniemi, 1992). However, most published reports and case studies describe till sampling surveys or programs carried between the 1960s and the early 1990s. Till analytical methods for Sn have improved significantly in the past 30 years and consequently, the determination of the Sn content in till is now routine and inexpensive.

The Geological Survey of Canada (GSC), through its Targeted Geoscience Initiative 4 (TGI-4) Program (2010-2015), and the New Brunswick Department of Energy and Mines initiated a study of till geochemistry and mineralogy and bedrock mineralogy around two intrusion-hosted polymetallic deposits in central New Brunswick (Fig. 1): 1) Mount Pleasant Sn-W-Mo-Bi-In deposit (this study), and 2) the Sisson W-Mo deposit

(McClenaghan et al., 2013a,b,c, 2014a).

The specific objectives of the TGI-4 indicator mineral research project are (1) to determine which indicator minerals and their trace element signatures are indicative of intrusion-hosted polymetallic Sn-W deposits; and (2) to establish practical methods for their recovery from glacial sediments and procedures for their identification that can be routinely applied during Sn-W-Mo exploration in glaciated terrain. Till sampling at both study sites was not intended to outline glacial dispersal trains, but instead to characterize the till indicator mineral content at varying distances down-ice from mineralization.

The Mount Pleasant polymetallic deposit was chosen as a Sn till geochemistry and mineralogy test site because the deposit: (1) is known to contain cassiterite and wolframite, two well known indicator minerals; (2) has well known local geology; (3) outcrops and is directly overlain by till and thus was exposed to glacial erosion; (4) is road-accessible; (5) has a previously identified till geochemical dispersal train down-ice (southeast) (Szabo et al., 1975) for sampling of metal-rich till; and (6) is enriched in In and therefore, will serve as a study site for the dispersal of In in till.

The purpose of this open file is to report the geochemical data for till samples collected in 2012 at Mount Pleasant. Indicator mineral data for these samples will be published in subsequent GSC Open Files.

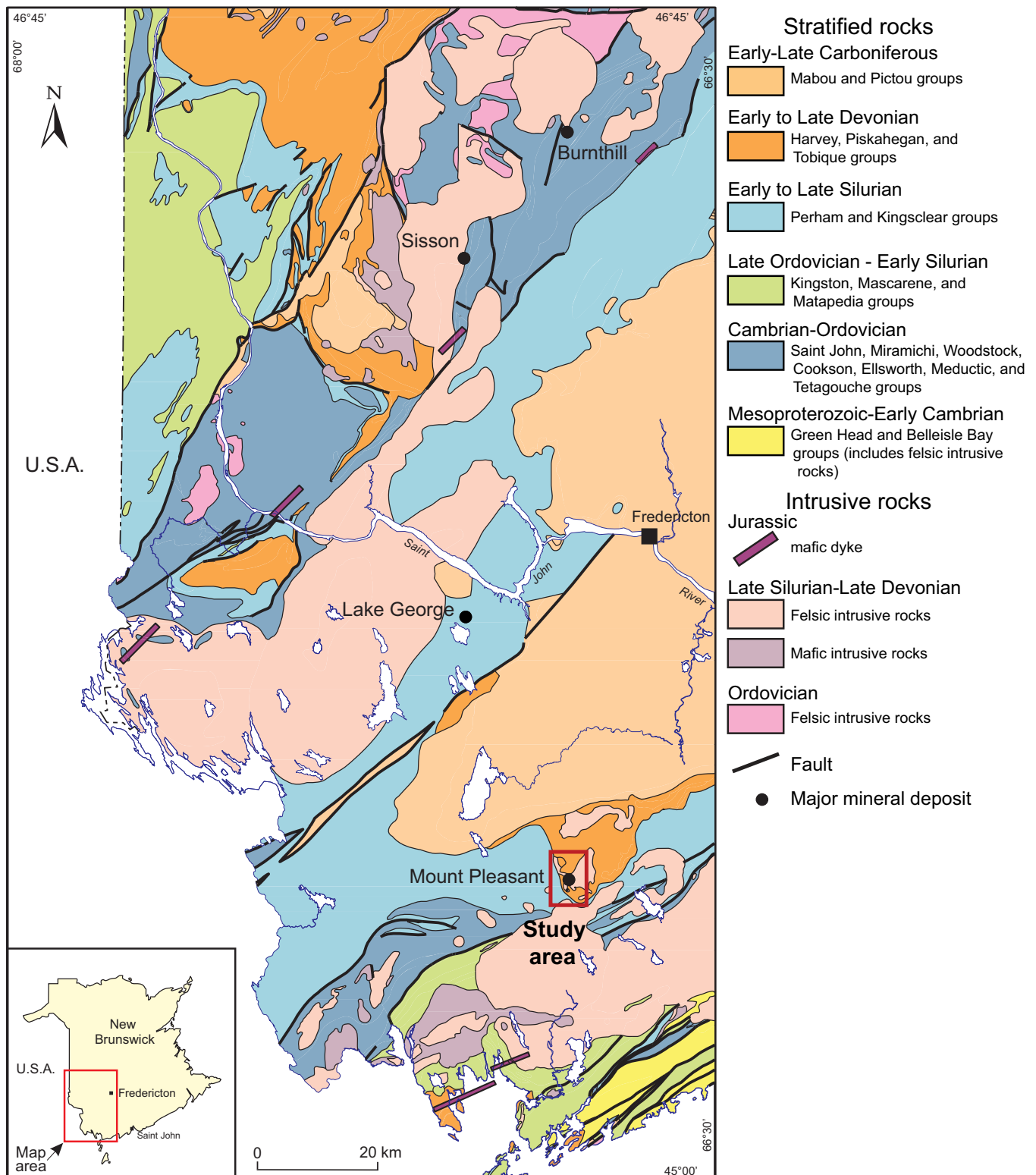


Figure 1. Bedrock geology map of west-central and southern New Brunswick showing the location of the Mount Pleasant Sn-W-Mo-Bi-In deposit and other significant intrusion-hosted deposits (modified from McCutcheon et al., 2010).

Location and access

The Mount Pleasant deposit is located in southern New Brunswick (Fig. 1) at 45°26'N and 66°49'W in the McDougall Lake map area (NTS 21 G/07). The mine

site is 60 km south of Fredericton and is easily accessed by a mine access road that extends northwest from Highway 785.

GEOLOGY

Bedrock geology

The following bedrock geology of the Mount Pleasant deposit is summarized from several sources, including Kooiman et al. (1986), Invemo and Hutchinson, (2004), Sinclair et al. (2006), and McCutcheon et al. (2010, 2103). The deposit is in the Appalachian Orogen within two subvolcanic intrusions in the Late Devonian Mount Pleasant Caldera Complex, along the north flank of the Saint George Batholith. The McDougall Brook Granitic and the Mount Pleasant Granitic suites are related to the early and late stages of caldera development, respectively. The deposit consists of Sn, W, Mo, Bi, and In mineralization that is genetically related to highly evolved granite of the Mount Pleasant Granitic Suite (Granites I,II,III), which is enriched in incompatible elements F, Li, Rb, Cs, U, Th, and Nb. Granite I and related breccia hosts W-Mo-Bi mineralization and Granite II hosts Sn-In mineralization (Figs. 2, 3). The deposit consists of three mineralized zones, from north to south: the North Zone, the Saddle Zone, and the Fire Tower Zone. Both the North and Fire Tower zones outcrop or subcrop beneath till (Fig. 3), and thus likely contributed mineralized debris to over-riding glaciers.

The North Zone consists of older W-Mo mineralization and younger Sn-In mineralization, some of which is at or near surface (Fig. 3). The Sn-In zones contain cassiterite, arsenopyrite, loellingite, sphalerite, chalcopyrite, and additional sulphide minerals listed in Table 1. The Fire Tower Zone contains predominantly large tonnage, low-grade W-Mo deposits with some small In-bearing Sn-base metal resources. The main ore minerals are wolframite and molybdenite with minor native bismuth and bismuthinite. Gangue minerals include cassiterite, arsenopyrite, loellingite, quartz, topaz, and fluorite. The Fire Tower Zone also contains small In-bearing Sn-base metal zones in irregular veins and breccias consisting mainly of cassiterite and wolframite along with the sulphide minerals listed in Table 1. Indium in the Mount Pleasant deposit occurs mainly as a solid solution between sphalerite and roquesite, but also in chalcopyrite and stannite (Petruck, 1972, 1973; Sinclair et al., 2006).

As of October 2008, the NI 43-101 resource estimate for the Fire Tower Zone consists of an indicated resource of 13.489 million tonnes at 0.33% WO₃, 0.21% MoS₂, 0.57% As, and 0.06% Bi, plus an inferred resource of 0.8417 million tonnes at 0.26% WO₃, 0.20% MoS₂, 0.21% As, and 0.04% Bi (McCutcheon et al., 2013). As of February 2012, the NI 43-101 mineral resource estimate for the North Zone is an indicated resource of 12.4 million tonnes averaging 0.38% Sn, 0.86% Zn, and 64 ppm In, and an inferred resource of

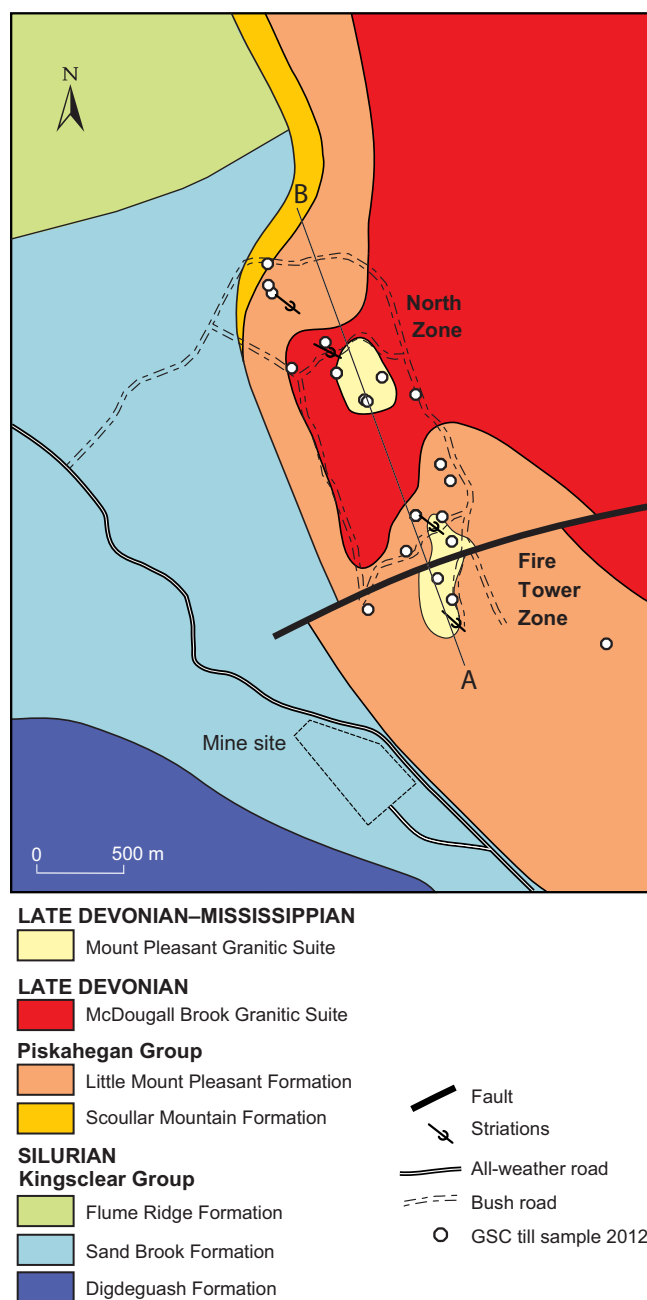


Figure 2. Local bedrock geology map of the Mount Pleasant Sn-W-Mo-Bi-In deposit area showing the location of GSC till samples (white dots) collected in 2012 up-ice (northwest), overlying, and down-ice (southeast) of the deposit (modified from McCutcheon et al., 1997, 2010).

2.8 million tonnes averaging 0.30% Sn, 1.13% Zn, and 70 ppm In (McCutcheon et al., 2013).

The area was staked in the 1950s after follow-up mineral exploration activities were conducted to investigate a Cu and Pb stream sediment anomaly on the west flank of Mount Pleasant (Parrish and Tully, 1976). Since that time, surface trenching and stripping, diamond drilling, geophysical surveys, and soil geochemical surveys have been conducted. These combined activities led to the discovery of a significant Sn-W

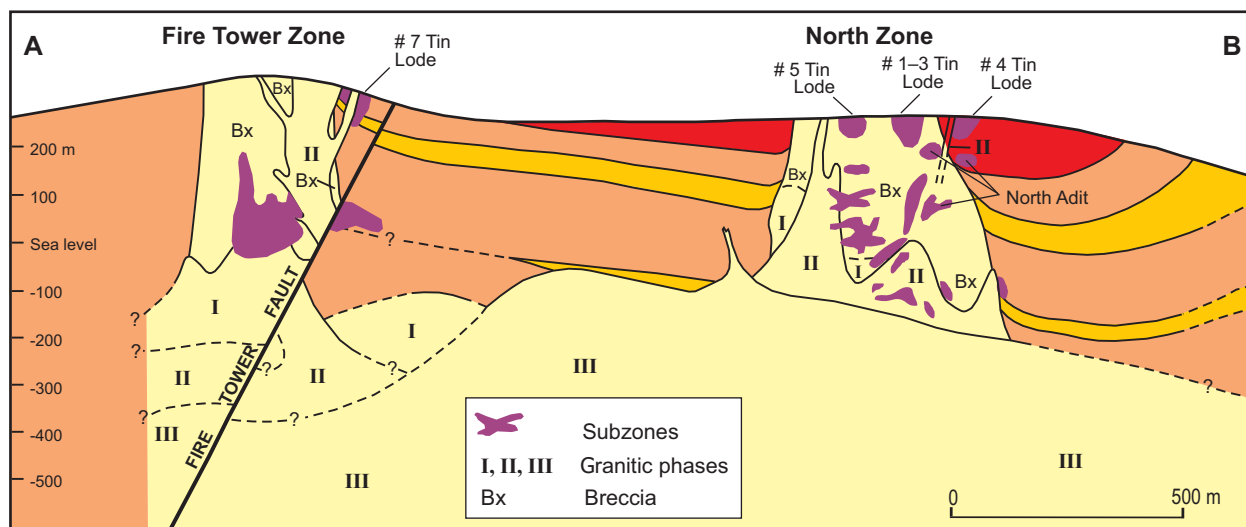


Figure 3. Cross-section A-B, shown in Figure 2, through the North Zone and Fire Tower Zone at Mount Pleasant, showing the ore subzones (purple). Note subzones at the North and Fire Tower zones subcrop. Bedrock geological units are the same as those shown in Figure 2 (modified from McCutcheon et al., 1997, 2010).

resource, followed by a mine and a mill being constructed in 1980. However, falling W prices led to the mine closing in 1985 (McCutcheon et al., 2010, 2013).

Quaternary geology

Till in the Mount Pleasant area was deposited by south-east- to south-southeast-flowing ice during the Caledonia Phase (Early to Middle Wisconsin) (Allard, 2011; Stea et al., 2011). Mount Pleasant is a striking topographic feature that rises approximately 220 m above the surrounding landscape and is covered by a till veneer <1 m thick. The surrounding lower lying areas are covered by a till blanket that is 1 to 5 m thick. The mountain has an elliptical shape with its long axis trending southeast. Allard (2011) mapped three coalescing southeasterly trending drumlins on Mount Pleasant. Szabo et al. (1975) reported evidence of ice flow towards the southeast (140–160°) from striations measured on Mount Pleasant and from till fabrics measured on the Mount Pleasant mine property. Bedrock striations, measured on several outcrops on the mountain and in the surrounding low-lying areas as part of this study, also trend southeast.

Szabo et al. (1975) reported the presence of two tills in the Mount Pleasant area: 1) a thin (<1.5 m thick) sandy silt till that is restricted to the Mount Pleasant area, and 2) a thicker, coarser sandy till in the Mount Pleasant and broader area. Two tills were observed while conducting till sampling as part of this study: an upper grey, sandy till and a lower reddish, silty till.

Previous surficial geochemical surveys in the Mount Pleasant area

Riddell (1967) was the first to describe the till geochemical signature of the Mount Pleasant deposit. He

analyzed more than 2500 samples of soil developed on till for Sn, Mo, Cu, Pb, and Zn using semi-quantitative colourimetric methods, unfortunately, without reporting the analyzed size fraction. Metal contents are highest in soils overlying the North and Fire Tower zones and southeast of both zones. Distribution patterns reflect glacial dispersal from the two zones as well as subsequent mechanical and/or chemical dispersal of metals down the west and east flanks of the mountain.

Szabo et al. (1975), building on the work of Riddell (1967), collected till samples, instead of soil samples, around the Mount Pleasant deposit, which defined a glacial dispersal train extending more than 16 km southeast of the deposit. Using hot nitric acid digestion, three fractions of till were analyzed: 1) <0.177 mm (-80 mesh); 2) 0.5–2.0 mm (-10+35 mesh); and 3) 0.5–2.0 mm (-10+35 mesh) heavy mineral fraction (SG >2.95) ground to <0.177 mm. The authors concluded that glacial dispersal from the deposit is best defined by the Sn (Fig. 4), As, Cu, Pb, and Zn content of the 0.5–2.0 mm heavy mineral fraction (SG >2.95). Szabo et al. (1975) also identified metal-rich till along their A-A' traverse, 1 km up-ice of the known North Zone mineralization.

Regional-scale till samples were collected across NTS map sheet 21G/07, which includes the Mount Pleasant area, by the New Brunswick Department of Energy and Mines (NBDEM) at a scale of one sample per 4 km². One of the regional till samples collected 500 m northeast of the Mount Pleasant deposit North Zone was metal-rich compared to the other till samples from the map area, containing elevated amounts of As (357 ppm), Bi (1.58 ppm), Cu (77 ppm), Cd (0.97 ppm), Mo (8.2 ppm), Pb (118 ppm), and Zn (415 ppm) in the <0.063 mm fraction (Pronk et al., 2002). This till

Till geochemical signatures of the Mount Pleasant Sn-W-Mo-Bi-In deposit, New Brunswick

Table 1. Indicator minerals for the Mount Pleasant deposit (Petruk, 1972, 1973; Parrish, 1977; Kooiman et al., 1986; Sinclair et al., 2006) and those found in bedrock polished thin sections (PTS), bedrock heavy mineral concentrates (HMC), and till heavy mineral concentrates (HMC) from this study.

Mineral	Formula	Hardness	Specific Gravity	Presence Reported by Other Authors	Identified in Bedrock PTS in this Study	Identified in Bedrock HMC in this Study	Identified in Till HMC in this Study
Tin minerals							
cassiterite	SnO ₂	6-7	6.8-7	Petruk (1972)	no	yes	yes
stannite	Cu ₂ FeSnS ₄	3.5-4	4.3-4.5	Petruk (1972)	no	no	no
k��sterite	Cu ₂ (Zn,Fe)SnS ₄	4.5	4.54-4.59	Petruk (1972)	no	no	no
ferrok��sterite	Cu ₂ (Fe,Zn)SnS ₄	4.0	4.5	Parrish (1977)	no	no	no
stannoidite	Cu ₈ Fe ₃ Sn ₂ S ₁₂	4	4.29	Petruk (1972)	no	no	no
mawsonite	Cu ₆ Fe ₂ SnS ₈	3.5-4	4.66	Petruk (1972)	no	no	no
Tungsten minerals							
scheelite	CaWO ₄	4-5	5.9-6.12	Parrish (1977)	no	no	yes
wolframite	(Fe,Mn)WO ₄	4.5	7.1-7.5	Petruk (1972)	no	no	yes
Sulphide and arsenide minerals							
molybdenite	MoS ₂	1	5.5	Petruk (1972)	no	no	yes
pyrite	FeS ₂	5-5.02	6.5	Petruk (1972)	yes	yes	yes
marcasite	FeS ₂	6.0-6.5	4.89	Petruk (1972)	no	no	no
sphalerite	(Zn,Fe)S	3.5-4	3.9-4.2	Petruk (1972)	yes	yes	no
pyrrhotite	Fe _(1-x) S (x=0-0.17)	3.5-4	4.58-4.65	Petruk (1972)	no	no	no
arsenopyrite	FeAsS	5	6.07	Petruk (1972)	no	yes	yes
loellingite	FeAs ₂	5.0	7.1-7.7	Petruk (1972)	no	no	yes
ferrimolybdate	Fe ₂ (MoO ₄) ₃ •8(H ₂ O)	2.5-3	4-4.5	Parrish (1977)	no	no	no
scorodite	Fe(AsO ₄)•2(H ₂ O)	3.5-4	3.1-3.3	Parrish (1977)	no	no	no
Bismuth minerals							
bismuthinite	Bi ₂ S ₃	2	6.8-7.2	Petruk (1972)	no	no	no
native bismuth	Bi	2-2.5	9.7-9.8	Petruk (1972)	no	no	no
arsenobismite	Bi ₂ (AsO ₄)(OH) ₃	3	5.7	Parrish (1977)	no	no	no
zairite	Bi(Fe,Al) ₃ [(OH) ₆ (PO ₄) ₂]	4.5	4.37	no	no	no	yes
Copper minerals							
chalcopyrite	CuFeS ₂	3.5	4.1-4.3	Petruk (1972)	no	yes	no
covellite	CuS	1.5-2.0	4.6-4.76	Petruk (1972)	no	no	no
tennantite	(Cu,Fe) ₁₂ As ₄ S ₁₃	3.5-4	4.6-4.7	Petruk (1972)	no	no	no
bornite	Cu ₅ FeS ₄	3.0	4.9-5.3	Petruk (1972)	no	no	no
chalcocite	Cu ₂ S	2.5-3	5.5-5.8	Parrish (1977)	no	no	no
roquesite	CuInS ₂	3.5-4	not reported	Petruk (1973)	no	no	no
digenite	Cu ₉ S ₅	2.5-3	5.6	Parrish (1977)	no	no	no
famatinite	Cu ₃ SbS ₄	3-4	4.57	Parrish (1977)	no	no	no
Lead minerals							
galena	PbS	2.5	7.2-7.6	Petruk (1972)	yes	yes	yes
wittichenite	Cu ₃ BiS ₃	2.5	6.3-6.7	Petruk (1973)	no	no	no
galenobismutite	PbBi ₂ S ₄	2.5-3	6.9-7.1	Petruk (1972)	no	no	no
aikinite	PbCuBiS ₃	2-2.5	6.1-6.8	Petruk (1972)	no	no	no
cosalite	Pb ₂ Bi ₂ S ₅	2.5-3	6.4-6.8	Petruk (1972)	no	no	no
krupkaite	PbCuBi ₃ S ₆	4	6.98	Petruk (1972)	no	no	no
beudantite	PbFe ₃ (AsO ₄)(SO ₄)(OH) ₆	4.0	4.1-4.3	no	no	no	yes
anglesite	Pb(SO ₄)	2.5-3	6.3	no	no	no	yes
plumbogummite	PbAl ₃ (PO ₄) ₂ (OH) ₅ •HO ₂	4-5	4-5	no	no	no	yes
Au and Ag minerals							
freibergite	(Ag,Cu,Fe) ₁₂ (Sb,As) ₄ S ₁₃	3.5-4	4.85-5	Petruk (1973)	no	no	no
pyrargyrite	Ag ₃ SbS ₃	2.5	5.85	Petruk (1973)	no	no	no
native silver	Ag	2.5-3	10-11	Petruk (1972)	no	no	no
gold	Au	2.5-3	16-19.3	Parrish (1977)	no	no	yes
Alteration minerals							
topaz	Al ₂ SiO ₄ (F,OH) ₂	8	3.5-3.6	Petruk (1972)	yes	yes	yes
fluorite	CaF ₂	4	3.01-3.25	Petruk (1972)	yes	yes	yes
tourmaline (black)	NaAl ₃ Al ₆ (BO ₃) ₃ (Si ₆ O ₁₈)(O,OH) ₄	7	3.01	Petruk (1972)	no	no	yes
columbite	(Fe,Mn)(Nb,Ta) ₂ O ₆	6.0	5.3-7.3	Petruk (1972)	no	no	no

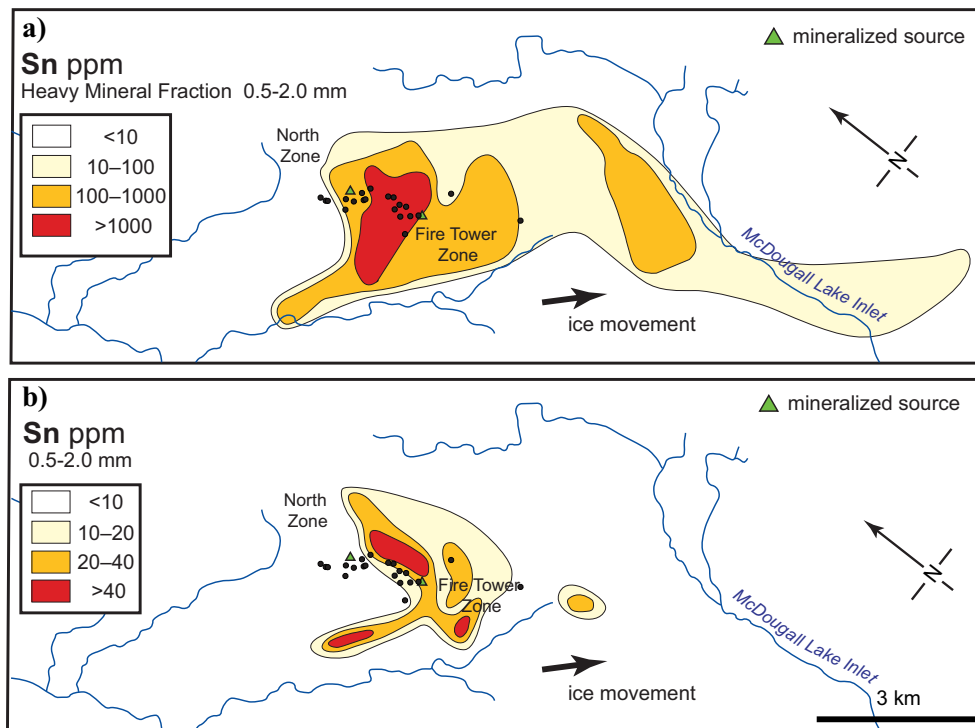


Figure 4. Distribution of Sn (ppm) in the (a) sand-size (0.5–2.0 mm) heavy mineral (SG>2.95) fraction and (b) sand-size (0.5–2.0 mm) fraction of surface till samples collected around the Mount Pleasant deposit and reported by Szabo et al. (1975). The locations of the GSC till samples collected during this study are shown as black dots. Modified from Szabo et al. (1975).

sample likely reflects the presence of the Mount Pleasant mineralization because it was collected within the dispersal train defined by Szabo et al. (1975).

Regional-scale till samples were also collected across the adjacent NTS map sheet NTS 21G/08, 25 km east of Mount Pleasant. The Sn and W content of the heavy mineral concentrate (HMC) fraction (SG >2.96) of till and the <0.177 mm fraction of B-horizon soil developed on till were determined. Several areas with anomalous Sn content in till (maximum in HMC of 4827 ppm) were reported overlying and trending southeast (down-ice) of granitic intrusions (Thomas et al., 1987). The authors concluded that the elevated Sn and W contents in till were derived from cassiterite- and scheelite-bearing greisen veins in granite. Other minerals reported in till samples with elevated Sn and W values include molybdenite, topaz, tourmaline, fluorite, and hematite.

A stream sediment survey in the late 1960s (Austria, 1970) in southwestern New Brunswick shows dispersion of Mo and Pb up to 8 km to the southeast from the Mount Pleasant (and True Hill) deposit(s). In this survey, samples were analyzed for Cu, Pb, Zn, Mn, and Mo only. Analyses were completed by atomic absorption (AA) following a nitric acid digestion, except for Mo, which was determined using the dithiol colourimetric method (after fusion with sodium nitrate, sodium chlorate, and potassium nitrate). The dispersion pattern is the net result of glacial dispersal combined with subsequent fluvial dispersion.

A more recent stream sediment and water survey was carried out in the Mount Pleasant region by the

GSC under its National Geochemical Reconnaissance (NGR) program (Friske et al., 1992). A number of elements show elevated levels compared to surrounding regions and therefore are interpreted to have been dispersed various distances downstream of Mount Pleasant, including W (by INAA) for 6 km, Mo (atomic absorption spectrometry-AAS) for 11 to 12 km, Sn (by AAS following a solvent extraction) for 7 to 8 km, and some of the rare earth elements (REE; Hf and Rb, by instrumental neutron activation analysis - INAA) for up to 17 to 18 km.

METHODS

For this study, till samples were collected up-ice, overlying, and up to 1.75 km down-ice (southeast) of the deposit (Figs. 5, 6) by the GSC and NBDEM in the summer of 2012 using GSC till sampling protocols (Spirito et al., 2011; McClenaghan et al., 2013d). One sample (12-MPB-1024) was collected away from any known mineralization, 14 km northwest of Mount Pleasant over bedrock of the Flume Ridge Formation, (Fig. 5), and therefore is considered a background sample. Sampling was focused around the two subcropping mineralized zones, the North Zone and Fire Tower Zone (Fig. 6). Till samples were collected within the glacial dispersal train documented by Szabo et al. (1975) at sites that were easily accessible by truck or foot traverse and till was sufficiently thick (>0.25 m).

Location and sample depth information for all till samples is reported in Appendix A1. Sample sites were either road cuts or hand-dug holes (Fig. 7), as is shown in the site photos included in Appendix A2. After sam-

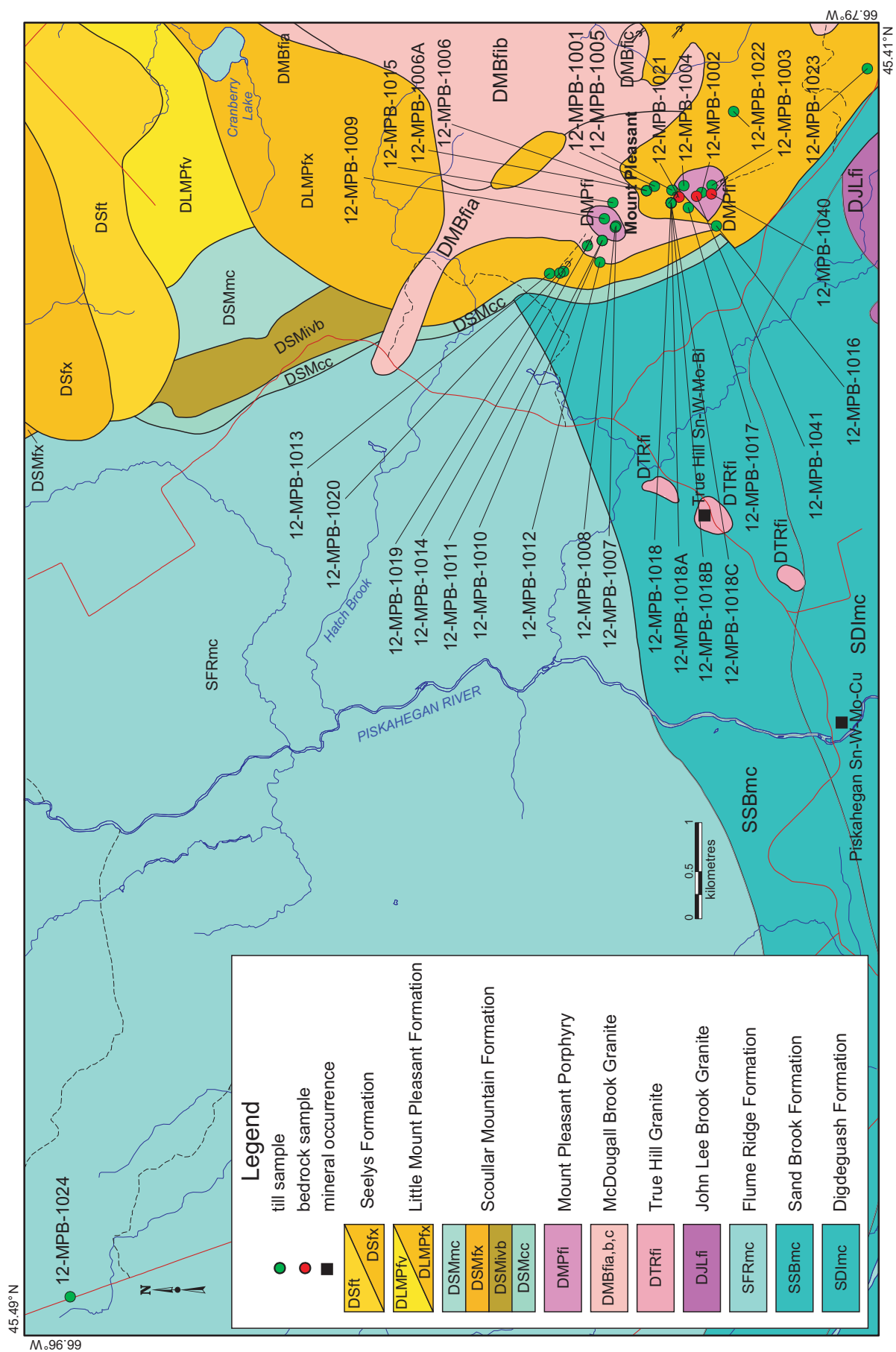


Figure 5. Location of till samples collected in the Mount Pleasant region (bedrock geology from McLeod et al., 2005).

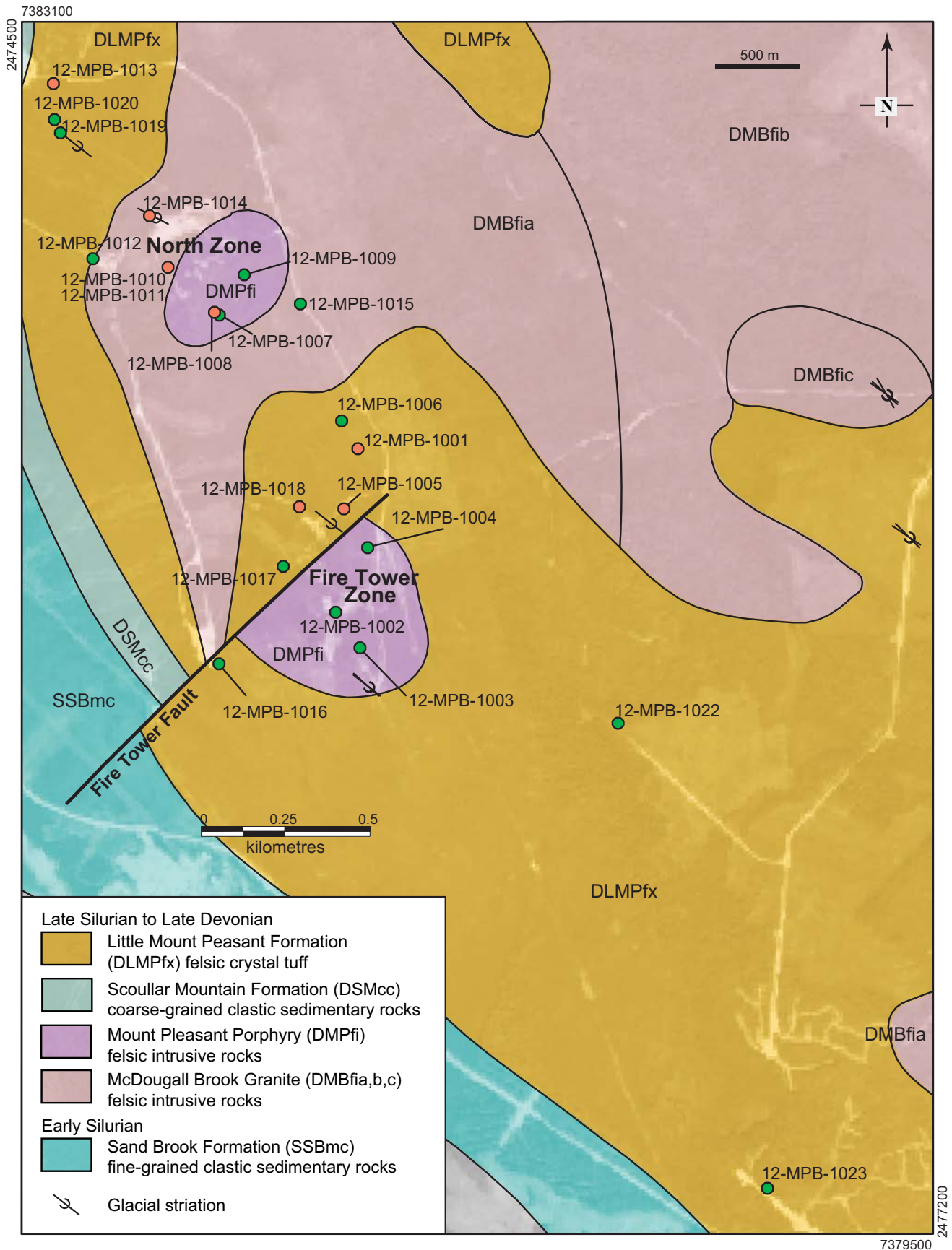


Figure 6. Location of till samples proximal to the Mount Pleasant deposit with an airphoto in the background (bedrock geology from McLeod et al., 2005).

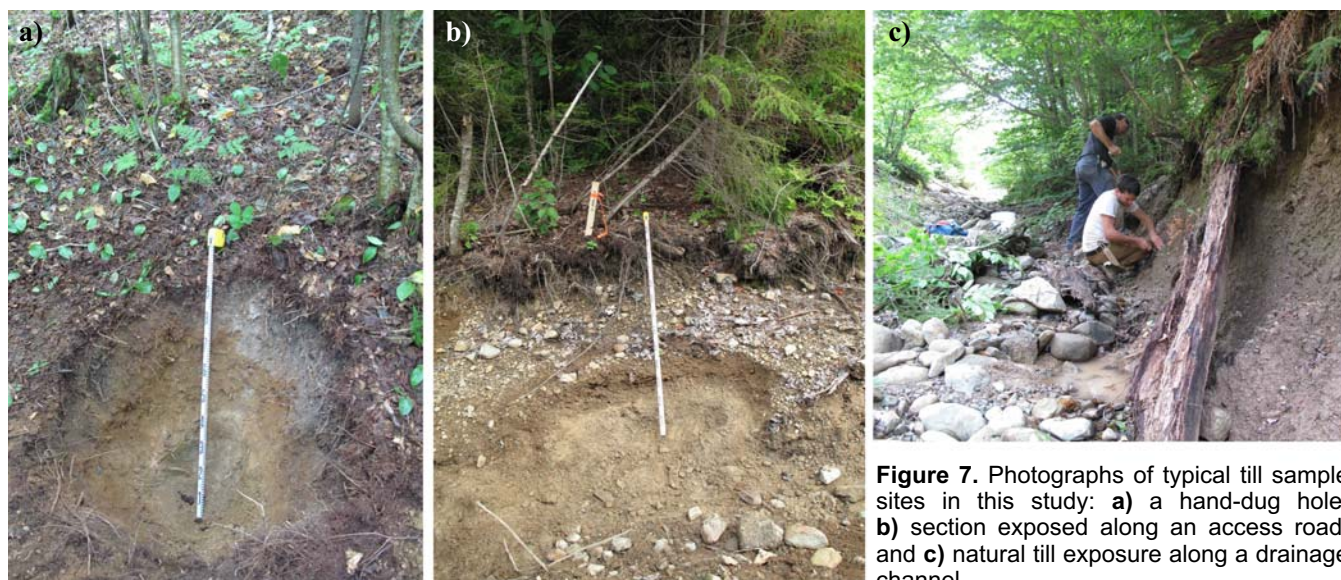


Figure 7. Photographs of typical till sample sites in this study: **a)** a hand-dug hole; **b)** section exposed along an access road; and **c)** natural till exposure along a drainage channel.

pling, all field sites were marked with a labeled wooden stake. At each site, three till samples were collected: (1) an 8 to 15 kg sample for recovery of indicator minerals; (2) a 3 kg sample for till textural determinations, geochemical analysis of the till matrix, and archiving; and (3) a 200 g sample for in-field testing using a portable XRF. The 200 g sample was placed in a sealed disposable plastic bag and was tested in the bag while moist using a portable bench top Innov-x 5000 portable XRF to provide preliminary information on the W, Sn, Cu, Mo, Bi, and As contents. This information was used daily to guide till sampling. One till site was sampled twice as a field duplicate to assess field variability: sample 12-MPB-1011 is a duplicate of sample 12-MPB-1010. The duplicate sample was collected from the same hole as the original sample.

SAMPLE PROCESSING AND ANALYSIS

The 3 kg till samples were submitted to the GSC Sedimentology Laboratory, Ottawa for (1) archiving of an ~800 g split, (2) matrix (<2 mm) grain-size analysis, (3) Munsell colour (moist) determinations; and (4) dry sieving to recover the <0.063 mm fraction, as outlined in Figure 8, using GSC procedures (Girard et al., 2004; Spirito et al., 2011; McClenaghan et al., 2013d).

Grain-size and matrix carbon analysis

The percentage of clay (<0.002 mm), silt (0.002–0.63 mm), and sand (0.63–2.0 mm) in the matrix fraction of till samples was determined using a CAMSIZER particle analyzer. Organic and inorganic carbon in till samples was determined using a LECO CR-412 Carbon Analyzer. Carbonate carbon content of the till matrix fraction was determined by acid evolution using the CM 5015 Coulometer. Munsell colour was determined on a moist sample using the SP64 X-RITE spectrophotometer. Data are listed in Appendix B1.

Matrix geochemical analysis

The <0.063 mm fraction of till was geochemically analyzed in this study for several reasons: 1) it is the most common till size fraction used for mineral exploration and government regional geochemical surveys (e.g. Pronk and Burton, 1988; Lestinen et al., 1991; Koljonen et al., 1992; McClenaghan, 1994; Edén and Björklund, 1995; Friske et al., 2001; McClenaghan et al., 2011); 2) it is readily and quickly recovered by dry sieving, especially in till samples with only minor (<2%) clay content; 3) it provides reasonable contrast between background and anomalous metal contents; 4) it is less susceptible to hydromorphic dispersion effects (Pronk, 1987); and 5) ICP-MS techniques now allow for determinations of element concentrations to very low detection limits, which permits identification of subtle anomalies in this size fraction.

The <0.063 mm fraction was submitted to ACME Laboratories, Vancouver, for analysis using a modified aqua regia leach (HCl:HNO₃ in a 1:1 ratio) followed by ICP-MS determination (ACME Group 1F04+REES package on 0.5 g) and lithium metaborate/tetraborate fusion followed by nitric acid digestion/ICP-ES, -MS (ACME Group 4A+4B GSC package on 0.2 g), which included determination of Cu, Pb, Zn, and Mo. Loss on ignition (LOI) was determined by the weight difference after ignition at 1000°C. Total carbon and total sulphur were determined by LECO. Data for all Mount Pleasant samples are reported in Appendix B2. Appendix B3 lists quality assurance and quality control data, including n-house standard, replicate, and blank samples inserted by ACME Labs.

To monitor analytical precision of the Mount Pleasant sample suite, one blind duplicate (sample 12-MPB-1011A) was prepared by the GSC Sedimentology Laboratory, Ottawa, from the till field

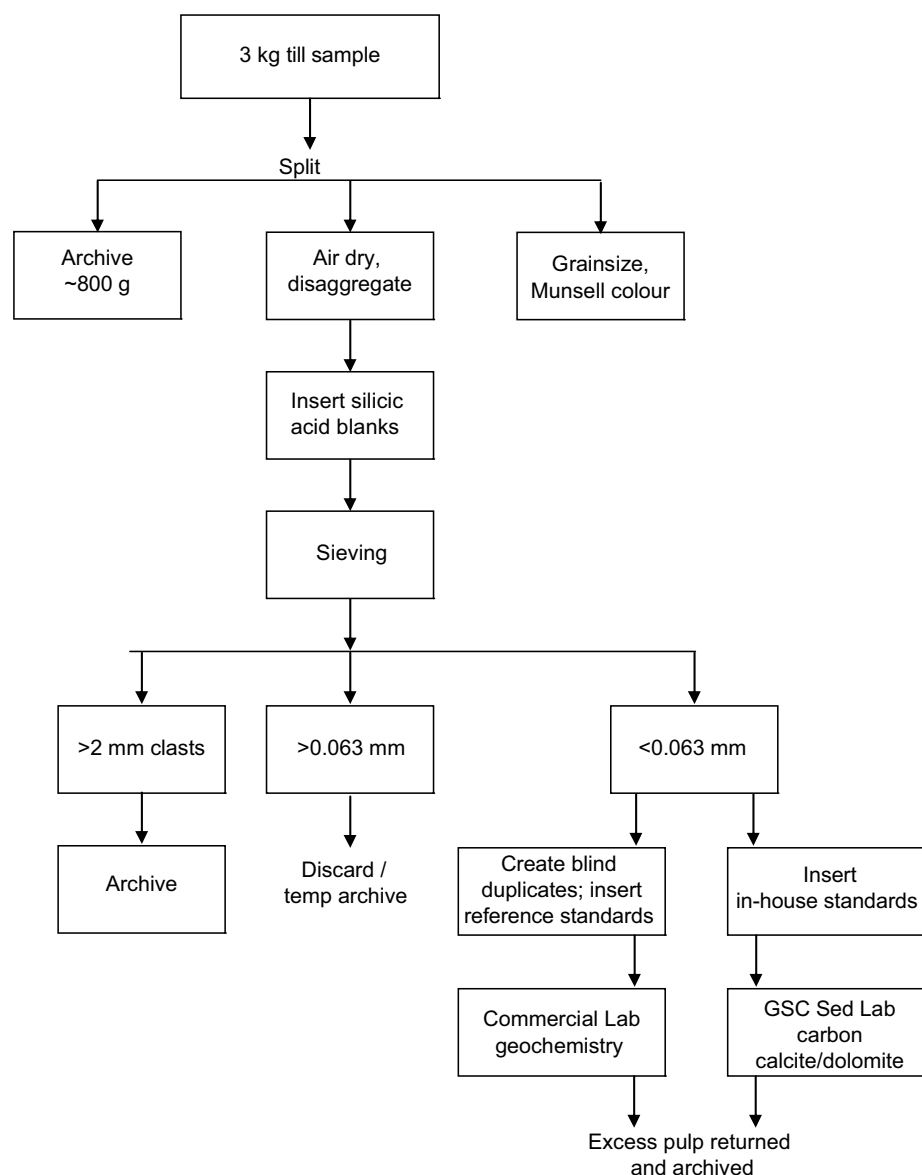


Figure 8. Flow sheet showing the sequence of steps used at the Geological Survey of Canada for sample processing, analysis, and archiving (modified from Spirito et al., 2011).

duplicate (sample 11-MPB-1011). Data for blind duplicates inserted by GSC are reported in Appendix B4.

CANMET certified reference standard TILL-4 was inserted into the batch (samples 12-MPB-1009A, 12-MPB-1026A) prior to geochemical analysis to monitor analytical accuracy. The certificate of analysis for this reference material is available at <http://www.nrcan.gc.ca/minerals-metals/technology/certified-reference-materials/certificate-price-list/4261>. Reference standard TILL-4 was originally collected from a trench dug in till near the Sisson W-Mo deposit (Lynch, 1996). Data for standards inserted by the GSC are reported in Appendix B5.

Three silicic acid (silica sand) blanks (samples 12-MPB-1000, 12-MPB-1012A, and 12-MPB-1032) from pail number C49643 were sieved and analyzed as part

of the Mount Pleasant portion of the sample batch to monitor cross contamination between metal-rich samples during sieving and instrumental memory effect during analytical procedures. Data for the three blank samples are reported in Appendixes B3.

Data plotting

The data for the first sample of each duplicate field pair were used in calculation of statistics and for plotting distribution maps. Prior to calculation of statistics and plotting distribution maps, all geochemical values reported as less than the lower detection limit were reassigned values of one half of the lower detection limit. Correlation coefficients and scatter plots were calculated for the till sample data using the Macintosh program Aabel (version 2.4). The concentration of

selected elements was plotted as proportional dots using MapInfo Professional (version 7.8). The thresholds of the dot sizes were determined using natural breaks in the till sample data.

RESULTS

Quality assurance/quality control

One blind duplicate (sample 12-MPB-1011A) was inserted into the 2012 ACME Labs analytical batch to assess analytical precision; results are reported in Appendix B4, along with separate worksheets containing tables summarizing the analytical precision (expressed as the relative standard deviation (%RSD)) for elements determined by aqua regia, borate fusion, LECO, and LOI. These data listings and calculated RSD values are reported by the GSC Sedimentology Laboratory Information Management System, which defines analytical precision as the relative standard deviation (5) at the 95% confidence level, calculated using the method defined by Garrett (1969) but without a log normal transformation of the analytical values. Precision lower than $\pm 20\%$ is considered adequate for most elements. For elements whose values are at or near the lower detection limit, RSD values are higher (e.g. RSD 49% for Re, detection limit 0.5 ppb).

Accuracy of the ACME Labs analytical data was monitored using the certified reference standard TILL-4; these data are listed in separate worksheets in Appendix B5 along with its reported recommended values. Data for each analytical method (borate fusion, aqua regia, LECO, LOI) as well as X-Y scatter plots of all elements determined by each method are reported in separate worksheets. Based on these reported results, the analytical accuracy was judged to be satisfactory.

Cross contamination among metal-rich samples was monitored using three silicic acid blanks (qtz-J29623). Data from the blanks are reported in separate worksheets in Appendix B5 and with the routine samples in Appendix B1 and B2. The silica blank returned average values of $\sim 87.35\%$ SiO_2 and $\sim 12.7\%$ LOI, which is consistent with previously reported values for this material (e.g. McClenaghan et al., 2013c,d). Borate fusion/ICP-ES Pb values reported for silicic acid blanks 12-MPB-1012A and 12-MPB-1032 were elevated above the expected value of <1 ppm. Sample 12-MPB-1012A was reported to contain 23 ppm Pb, and sample 12-MPB-1032 was reported to contain 11 ppm Pb (Appendix B2). Furthermore, silica blank 12-MPB-1032 returned 28 ppm Ni following the same analysis (Appendix B2). Given those spurious Pb and Ni values, twelve samples from the original analytical batch were resubmitted for borate fusion/ ICP-MS. The samples submitted for re-analysis were selected based on their processing order in the original sample batch, i.e., the samples were analyzed just before or just after the sil-

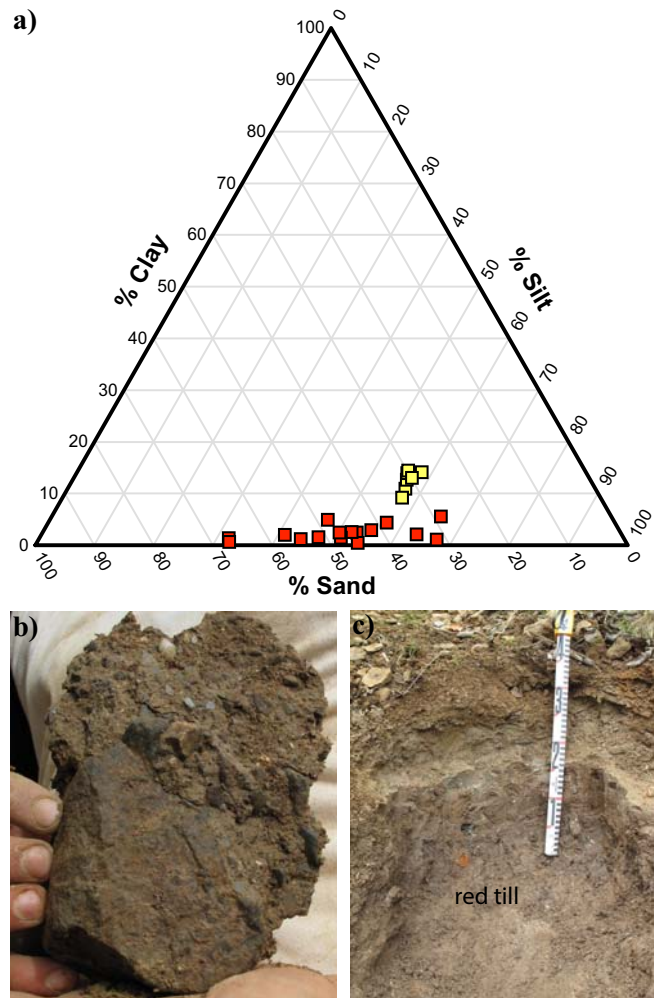


Figure 9. a) Ternary plot of the percentage of clay, silt, and sand in the till matrix ($n=24$). Yellow symbols ($n=7$) indicate till samples with $>10\%$ clay, red symbols ($N=17$) indicate till samples with $<10\%$ clay; b) colour photo of the oxidized silty sand till matrix at site 12-MPB-1012; c) colour photo of reddish clayey sand till matrix at site 12-MPB-1014.

ica blanks that had spurious values. The results of the re-analysis are reported in Appendix B6, and are compared to the initial analytical data in Appendix B7. Only the results from the re-analysis were used in the data compilation of the silica blank and the standard TILL-4 that are presented in Appendix B5. The new Pb values were substituted into the data listing reported in Appendix B2 and used for plotting the Pb map in Appendix C. The new Pb and Ni values indicate that the initial values were too high because of analytical errors (probably instrumental memory effect) and not due to contamination of the sample blanks during sample preparation. No contamination of the blank material during sample preparation was detected in this study.

Till grain-size, colour, and carbon content

On average, the till matrix contains 42% sand, 53% silt, and 5% clay (Fig. 9). The sand content in till around the

deposit ranges from 30% in sample 12-MPB-1014, which was collected on the north side of the North Zone, to 67% in sample 12-MPB-1016, collected 500 m west of the Fire Tower Zone (Fig. 6). Background sample 12-MPB-1024 (Fig. 5), is also sand-rich (66% sand). Eight samples (12-MPB-1001, -1005, -1008, -1010, -1011, -1013, -1014, and -1018) have clay contents of >9%; these samples are shown as yellow squares on the ternary plot in Figure 9. Their locations are indicated with red dots in Figure 6.

The organic carbon content of the till samples is low; most values are <1.0% with the exception of sample 12-MPB-1003, which has an organic C value of 5.5%. This sample is highly oxidized (Appendix A2, site photo 12-MPB-1003) and has an LOI value of 16.1%, indicating that it contains a significant amount of organic material compared to the other till samples.

Till geochemistry

Tin and tungsten in the <0.063 mm fraction of till

Tin content in till was determined by two analytical methods: total concentration by lithium meta/tetraborate fusion/ICP-MS and partial concentration by aqua regia/ICP-MS. Values for both methods are reported in Appendix B2 and are compared in a scatter plot in Figure 10. Total versus partial Sn concentrations display a strong positive correlation of 0.88. Aqua regia values are 3 to 35% of the total Sn determined by borate fusion. Because of lower Sn recovery by aqua regia, only the total values determined by borate fusion/ICP-MS are further described and used in plots in this report.

Tin values in till in the Mount Pleasant area range from 2 to 349 ppm (Appendix B2). Table 2 lists the Sn values for till samples, sorted by location relative to the North and Fire Tower mineralized zones and their cumulative southeast-trending glacial dispersal train, and the threshold between background values in till and metal-rich till samples collected overlying and down-ice. Background content in till up-ice was defined using sample 12-MPB-1024 (2 ppm). The highest Sn contents are in till samplers 12-MPB-1002 (263 ppm) and 12-MPB-1004 (349 ppm), overlying the Fire Tower Zone (Appendix C, map 1). Elevated values of between 8 and 166 ppm Sn occur northwest of the North Zone (samples 12-MPB-1019 and -1020), immediately overlying and down-ice (southeast) of the North Zone, and southeast of the Fire Tower Zone (samples 12-MPB-1022 and -1023). Tin values display a strong ($r>0.8$) positive correlation with In and moderate ($r=0.6$ – 0.8) correlations with W, Mo, Pb, As, Bi, and Te (Table 3).

Tungsten content in till was also determined by two analytical methods: total concentration by borate

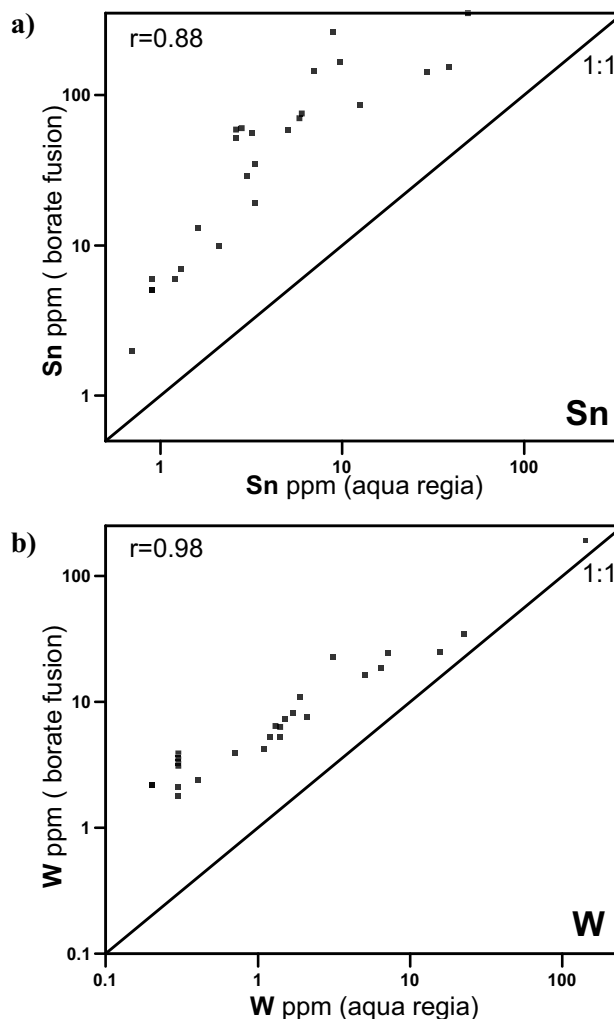


Figure 10. Scatter plot of partial (aqua regia/ICP-MS) versus total (borate fusion/ ICP-MS) data for (a) Sn and (b) W in the <0.063 mm fraction of till samples ($n=25$) collected around the Mount Pleasant deposit.

fusion/ICP-MS and partial concentration by aqua regia/ICP-MS. Values for both methods are reported in Appendix B2 and are compared in a scatter plot in Figure 10. Similar to Sn, aqua regia digestion recovers less W (8–65% of the total) than the borate fusion. The upper detection limit of W by ICP-MS analysis following the aqua regia leach is 100 ppm, which is too low and not precise enough to evaluate the distribution of W in till at Mount Pleasant. Thus, only the total W content determined by borate fusion/ICP-MS are further described and plotted in this report.

Tungsten values in till in the Mount Pleasant area range from 1.8 ppm in background sample 12-MPB-1024 to 22.6–34.6 ppm W in the three till samples (12-MPB-1002, -1003, -1004) collected overlying the Fire Tower Zone (Appendix C, map 2). Slightly elevated W values of 18 to 25 ppm were detected in till samples 12-MPB-1006 and 12-MPB-1001, collected 0.5 km south-east of the North Zone. Tungsten displays strong

($r > 0.8$) positive correlations with Bi, and moderate ($r = 0.6$ – 0.8) correlations with Sn, Mo, As, Te, and In (Table 3).

Molybdenum, copper, and bismuth in the <0.063 mm fraction of till

Molybdenum values in till at Mount Pleasant range from 0.7 ppm (background sample 12-MPB-1024) to 386 ppm (Appendix B2). The highest values (305 and 386 ppm, samples 12-MPB-002 and -004, respectively) occur in till overlying the Fire Tower Zone (Appendix C, map 3). One elevated value of 45 ppm occurs in till sample 12-MPB-1015, collected 300 m southeast of the North Zone. Molybdenum displays strong ($r > 0.8$) positive correlations with Bi, Pb, and In, and moderate ($r = 0.6$ – 0.8) correlations with Sn, W, As, Tl, and Te (Table 3).

Copper concentrations in till around Mount Pleasant range between a background value of 25 ppm and a high value of 479 ppm (Appendix C, map 4). The highest values are in till that overlies the Fire Tower Zone. Copper displays a moderate ($r = 0.6$ – 0.8) correlation with In (Table 3).

Bismuth concentrations in till at Mount Pleasant range between a background value of 0.54 ppm and a high value of 208 ppm (Appendix B2). The highest values (192–208 ppm) are in till directly overlying the Fire Tower Zone (Appendix C, map 5). Slightly elevated Bi values of between 30 and 77 ppm trend southeast from the North Zone. Bismuth displays strong ($r > 0.8$) positive correlations with W, Mo, Te, and In, and moderate ($r = 0.6$ – 0.8) correlations with Sn, Pb, Ag, As, and Tl (Table 3).

Arsenic, lead, zinc, cadmium, indium, and thallium in the <0.063 mm fraction of till

Arsenic content in till ranges from a background value of 13 ppm in sample 12-MPB-1024 to a high value of 2392 ppm (Appendix B2). The highest values in till (1347 and 2392 ppm) overlie the Fire Tower Zone (Appendix C, map 6) in samples 12-MPB-1003 and -1004. Elevated As values between 199 and 541 ppm trend southeast and northwest of the North Zone. Arsenic displays moderate ($r = 0.6$ – 0.8) correlations with Sn, W, Mo, In, and Bi (Table 3).

Lead concentrations in till range from a background value of 15 ppm to the highest values of 1799 and 2479 ppm (samples 12-MPB-1002, -1004, respectively) that overlie the Fire Tower Zone. Elevated Pb values were found in till 500 m south of the North Zone (273–327 ppm), 500 m northwest of the North Zone in samples 12-MPB-1019 and -1020 (254–292 ppm), and 1 km southeast of the Fire Tower zone in sample 12-MPB-1022 (359 ppm) (Appendix C, map 7). Lead displays a

strong ($r > 0.8$) positive correlation with Mo and In, and moderate ($r = 0.6$ – 0.8) correlations with Sn, Ag, Bi, Tl, and Te (Table 3).

Zinc content in till ranges from a background value of 53 ppm to a high value of 2989 ppm (Appendix B2). The highest values in till overlie the North Zone (986–2213 ppm) and 0.5 km northwest of the North Zone in till samples 12-MPB-1013, -1019, and -1020 (1150–2989 ppm) (Appendix C, map 8). Zinc displays a significant ($r > 0.8$) positive correlation with Cd (Table 3).

Cadmium contents in till range from background values of 0.05 to 2.94 ppm (Appendix B2). The highest concentrations of Cd (1.94–2.94 ppm) are in till samples overlying the North Zone (Appendix C, map 9). Elevated values (1.05–1.63 ppm) overlie the Fire Tower Zone. Cadmium displays significant ($r > 0.8$) positive correlation with Zn (Table 3).

The background In content in till sample 12-MPB-1024 is 0.03 ppm. The highest In value in till in this study is an exceptional 13.08 ppm in sample 12-MPB-004, which overlies the Fire Tower Zone. Elevated In values between 1.1 and 4.72 ppm overlie the Fire Tower Zone, and trend southeast from the North Zone. Elevated values also occur in samples 12-MPB-1019 (2.21 ppm) and 12-MPB-1020 (2.78 ppm), collected 500 m northwest of the North Zone (Appendix C, map 10). Indium displays significant ($r > 0.8$) positive correlations with Sn, Mo, Pb, and Bi and moderate ($r = 0.6$ – 0.8) correlations with W, Cu, As, and Te (Table 3).

Thallium content in till at Mount Pleasant varies from a background content of 0.13 ppm to a high value of 1.58 ppm. The highest Tl values are found in till overlying the North and Fire Tower zones, as well as till southeast of these two zones (Appendix C, map 11). Thallium displays moderate ($r = 0.6$ – 0.8) correlations with Mo, Pb, and Bi (Table 3).

Silver, gold, tellurium, and rhenium in the <0.063 mm fraction of till

Silver contents in till range from a background value of 54 ppb to a highest value of 1666 ppb. Till with the highest Ag contents overlies the North and Fire Tower zones (229–1666 ppb), just (southeast) of the North Zone, and in 500 m northwest of the North Zone in sample 12-MPB-1019 (877 ppb) (Appendix C, map 12). Silver displays moderate ($r = 0.6$ – 0.8) correlations with Pb, Bi, and Au (Table 3).

Most Au contents in till are <10 ppb. The highest values (10.8 and 19.7 ppb) are in till samples 12-MPB-1003 and -1004 that overlie the Fire Tower Zone, sample 12-MPB-1016 (11.3 ppb) just southwest of the Fire Tower Zone, and sample 12-MPB-1020 (17.0 ppb),

Table 2. Concentrations of Sn, W, Mo, Cu, Pb, Zn, Ag, As, Cd, Bi, In, and Te in the <0.063 mm fraction of surface till samples within or near the glacial dispersal train southeast of the Mount Pleasant deposit, listed by location relative to the North Zone or Fire Tower Zone: up-ice, overlying, and down-ice. Tin and W were determined by borate fusion/ICP-MS and all other elements were determined by aqua regia/ICP-MS. Includes cassiterite and wolframite grain counts normalized to 10 kg bulk sediment (<2 mm) weight (data from McClenaghan et al., 2014b).

Sample Number	Vertical Position	Location Relative to Mineralized Bedrock Zone (km)	Distance from Fire Tower Zone (km)	Cassiterite 0.25–0.5 mm / 10 kg	Wolframite 0.25–0.5 mm / 10 kg	Sn (ppm)	W (ppm)	Mo (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ag (ppb)	Mn (%)	Fe (%)	As (ppm)	Au (ppb)	Cd (ppm)	Sb (ppm)	Bi (ppm)	Tl (ppm)	Te (ppm)	In (ppm)	Re (ppb)
12-MPB-1024		background	-13 NW	0	0	2	1.8	0.7	25	15	53	54	278	2.6	13	1.9	0.05	0.4	1	0.13	0.04	0.03	<1
12-MPB-1013		up-ice	-0.6 NW	2	0	5	2.2	1.1	38	27	2989	21	610	3.5	166	1.0	1.63	0.7	1	0.19	<0.02	0.12	<1
12-MPB-1020		up-ice	-0.5 NW	630	3	166	3.1	8.7	110	292	1149	228	446	2.1	384	17.0	0.70	0.6	10	0.33	0.03	2.78	<1
12-MPB-1019		up-ice	-0.45 NW	7	0	59	3.9	8.2	144	254	1241	877	298	2.0	302	3.0	1.12	0.4	12	0.31	0.03	2.21	<1
12-MPB-1014		up-ice	-0.2 NW	2	0	5	2.2	10.5	125	17	2214	17	741	3.2	145	<0.2	2.89	0.8	2	0.14	0.06	0.34	<1
12-MPB-1012		up-ice	-0.2 W	89	14	52	5.2	13.3	123	59	1487	36	474	2.5	541	6.0	2.24	0.8	9	0.12	0.05	2.23	2
12-MPB-1007		overlying	0.0	8	2	85	6.4	8.6	103	327	986	124	466	2.5	426	3.1	1.58	1.3	14	0.22	0.12	4.67	<1
12-MPB-1008		overlying	0.0	6	0	10	2.1	14.8	165	168	2060	42	575	3.2	312	1.9	2.63	1.3	4	0.31	0.07	1.05	<1
12-MPB-1009		overlying	0.0	10	0	70	11.0	14.3	44	273	563	640	420	2.1	198	8.8	0.72	0.3	46	1.58	0.28	1.53	2
12-MPB-1010		overlying	0.0	37	8	59	7.6	3.9	82	41	397	47	456	2.5	195	1.4	1.94	0.7	8	0.10	0.07	1.34	<1
12-MPB-1015		down-ice	0.3 SE	44	11	143	8.2	44.8	115	214	671	94	786	3.2	520	4.0	0.65	1.1	69	0.49	0.34	2.66	<1
12-MPB-1006	upper till	down-ice	0.5 SE	53	35	142	24.6	18.4	165	270	462	503	350	2.9	937	1.9	0.54	1.8	41	0.44	0.18	4.14	<1
12-MPB-1006A	lower till	down-ice	0.5 SE	NA	NA	154	16.3	20.9	359	572	1069	203	580	2.7	811	3.6	1.42	2.1	40	0.38	0.21	5.76	<1
12-MPB-1001		down-ice	0.6 SE	63	32	75	18.7	16.2	167	179	455	66	573	3.4	477	6.4	0.32	1.5	43	0.57	0.36	2.25	<1
12-MPB-1018		up-ice	-0.1 N	1	0	6	3.6	1.2	41	40	882	28	837	3.3	44	0.8	2.94	0.6	2	0.14	<0.02	0.10	1
12-MPB-1002		overlying	0.0	5	2	263	34.6	386.3	82	1799	440	165	233	2.6	800	3.3	0.47	0.8	192	0.56	0.65	4.72	4
12-MPB-1003		overlying	0.0	2	0	7	24.9	4.9	40	45	138	514	461	3.6	2392	10.8	0.37	0.5	77	0.21	0.27	0.49	<1
12-MPB-1004		overlying	0.0	12	32	349	22.6	305.2	227	2479	562	1666	372	3.2	1347	19.7	0.89	2.1	208	0.59	2.58	13.08	4
12-MPB-1005		overlying	0.0	9	9	35	3.3	2.7	164	200	999	160	594	2.8	93	1.8	1.05	0.6	4	0.20	0.09	0.72	<1
12-MPB-1017		overlying	0.0	0	0	6	2.4	13.9	151	219	887	607	404	3.1	125	8.1	0.96	0.4	12	0.30	0.09	1.40	<1
12-MPB-1016		down-ice	0.3 SW	0	0	29	5.2	11.2	374	203	1156	596	696	2.9	197	11.3	1.28	0.6	29	0.22	0.26	1.60	<1
12-MPB-1022		down-ice	0.7 SSE	0	0	19	3.9	23.7	479	359	851	571	709	2.7	374	4.8	1.16	0.3	12	0.56	0.05	1.08	<1
12-MPB-1023		down-ice	2.2 SE	0	0	13	4.2	3.3	76	64	166	496	465	2.7	99	1.8	0.25	0.4	6	0.24	0.07	0.59	<1

NA = not analyzed

Table 3. Correlation matrix of selected log transformed elements determined by aqua regia/ICP-MS or borate fusion/ICP-MS (Sn, W) in the <0.063 mm fraction of till samples from the Mount Pleasant deposit (N=24). Moderate correlations ($r > 0.6$ or < -0.6) are in bold and strong correlations ($r > 0.8$) are in bold red.

	Sn	W	Mo	Cu	Pb	Zn	Cd	Ag	As	Au	Bi	Tl	Te	In
Sn	1.00													
W	0.66	1.00												
Mo	0.72	0.62	1.00											
Cu	0.39	0.06	0.53	1.00										
Pb	0.78	0.54	0.83	0.54	1.00									
Zn	0.09	-0.34	0.13	0.42	0.12	1.00								
Cd	0.04	-0.23	0.08	0.33	0.01	0.86	1.00							
Ag	0.39	0.40	0.42	0.38	0.64	-0.26	-0.28	1.00						
As	0.63	0.73	0.69	0.36	0.56	0.13	0.15	0.38	1.00					
Au	0.45	0.39	0.31	0.18	0.57	-0.24	-0.30	0.63	0.39	1.00				
Bi	0.75	0.87	0.82	0.35	0.77	-0.16	-0.12	0.62	0.78	0.58	1.00			
Tl	0.53	0.49	0.63	0.26	0.72	-0.01	-0.20	0.57	0.42	0.45	0.65	1.00		
Te	0.60	0.77	0.78	0.32	0.66	-0.29	-0.26	0.51	0.59	0.41	0.85	0.57	1.00	
In	0.89	0.60	0.82	0.61	0.83	0.22	0.19	0.52	0.75	0.47	0.81	0.53	0.66	1.00

500 m northwest of the North Zone. Gold displays moderate ($r=0.6-0.8$) correlations with Ag (Table 3).

Till in the Mount Pleasant area contains between <0.02 (background) and 2.58 ppm Te (Appendix B2). The highest value (2.58 ppm Te) is overlying the Fire Tower Zone (Appendix C, map 13). Elevated values between 0.13 and 0.65 ppm Te occur in till overlying the Fire Tower Zone and southeast of the North Zone. Tellurium displays a strong ($r>0.8$) positive correlation with Bi, and moderate ($r=0.6-0.8$) correlations with Sn, W, Mo, Pb, and In (Table 3).

Most Re values for till samples in this study are <1 ppm (Appendix B2) and therefore are not plotted on a map. Four samples contain between 2 and 4 ppm Re; samples 12-MPB-1002 and -1004 overlying the Fire Tower Zone, and samples 12-MPB-1012 and -1009 overlying the North Zone.

DISCUSSION

Glacial dispersal patterns

Szabo et al. (1975) documented glacial dispersal from the Mount Pleasant deposit up to 16 km down-ice (southeast) using the content of Sn, Cu, Pb, and Zn in the till matrix. Their highest metal values in till were found within the first 3 km of the dispersal train. In this study, new till samples were collected a maximum of 2 km down-ice (southeast), well within the most metal-rich part of dispersal train defined by Szabo et al. Metal contents in till samples in the current study are highest overlying the Fire Tower Zone.

Indicator and pathfinder elements

The term ‘indicator element’ is used here to refer to an element that is an economically valuable component of the ore being sought and may be used to detect an orebody (Rose et al., 1979). The results reported here indicate that the indicator elements for the Mount Pleasant deposit are Sn, W, Mo, Bi, and In.

The term ‘pathfinder element’ is used here to refer to non-ore elements associated with the orebody that may be used to detect the orebody (Rose et al., 1979). Pathfinder elements in till overlying and down-ice of the Mount Pleasant deposit include Ag, As, Cd, Cu, Pb, Re, Te, Tl, and Zn. This list of elements is more extensive than Sn, Mo, Cu, Pb, and Zn that Riddell (1966) and Szabo et al. (1975) identified as key indicator/pathfinder elements in their till geochemical study of the deposit.

The Mount Pleasant indicator/pathfinder element suite identified in this study is also more extensive than that identified in other published studies around Sn-W mineralization, which have variably included Sn, W, Mo, Cu, Pb, and Zn (e.g. Matilla and Peuraniemi, 1980; Toverud, 1982; Peuraniemi et al., 1984; Thomas

et al., 1987; Lamothe, 1990; Rogers et al., 1990;). The extensive suite of indicator/pathfinder elements identified at Mount Pleasant reflects, in part, the polymetallic nature of the deposit as well as the ability of modern ICP-MS techniques to determine a broader suite of elements at lower detection limits.

An analytical technique that reports the total content of W and Sn is necessary for till analysis as aqua regia does not fully digest Sn- and W-bearing oxides. In this study, lithium tetra/metaborate fusion followed by a nitric digestion/ICP-MS was used to determine the total Sn and W content of till samples. The other pathfinder and indicator elements listed above were determined by aqua regia digestion, as they are derived from sulphide minerals (Table 1) that are easily digested by aqua regia.

Source of high metal contents in till

As described above, the Fire Tower Zone is a significant resource of WO_3 , MoS_2 , As, and Bi and the North Zone is a significant resource of Sn, Zn, and In (McCutcheon et al., 2013). Thus, it is not unexpected for glacial debris eroded from the deposit to contain significant contents (100s ppm) of Sn, W, Mo, As, Bi, Zn, and In (Table 2). The high W values in till likely reflect the presence of wolframite and minor scheelite, and the high Sn values in till reflect cassiterite and stannite, as well as other Sn-sulphide minerals (Table 1).

Till overlying and just down-ice of the deposit contains between 1 and 13 ppm In; these values are some of the highest In values ever reported for till. By comparison, recently published till geochemical studies have reported In contents in till around VMS or intrusion-hosted W deposits of between <0.02 and 0.41 ppm (Hicken et al., 2012; McClenaghan et al., 2013c, 2014c). Elevated In concentrations in till at Mount Pleasant are likely derived mainly from sphalerite and roquesite, and to a lesser extent from chalcopyrite and stannite in the deposit (Sinclair et al., 2006).

Elevated Bi content in till (10s to 100s ppm) is likely derived from native bismuth (Bi) and Bi-bearing minerals, such as bismuthinite (Bi_2S_3) as well as other Pb-Bi sulphide minerals that occur in the deposit (Table 1). Arsenopyrite, loellingite, and other As-bearing sulphide minerals also occur in the deposit (Table 1), and are the most likely source of the high As values (100s to 1000s ppm) in till. Sphalerite is a minor mineral in the deposit, and is likely the source of elevated Zn (100s ppm) and Cd (>1 ppm). Silver-bearing minerals in the deposit include native silver, freibergite, and pyrargyrite (Kooiman et al., 1986; Sinclair et al., 2006). These minerals may be the source of elevated Ag (100s to 1000s ppb) in till overlying the deposit. Galena and other Pb-sulphide minerals (Table 1) are

the likely source of the high Pb contents (100s to 1000s ppm) in the till. Elevated values of Te (>0.10 ppm) in till over the deposit are likely related to Te-bearing minerals in the mineralization. There are no reported telluride minerals in the Mount Pleasant deposit; however, the positive correlation of Te with Pb (Table 3) suggests that galena may be the source of some of the Te. Tellurium also displays strong positive correlations with Mo and Bi, suggesting that Te may also be derived from Mo and Bi sulphides. Copper is present in several Sn sulphide minerals as well as in several Cu sulphide minerals (Table 1) and these are the likely sources of elevated Cu contents (100s ppm) in the local till. Detectable Re contents in till likely reflect its presence in molybdenite (Giles and Schilling, 1972; Millensifer et al., 2014) in the deposit, as no other potentially Re-bearing minerals are present in the deposit

Till size fractions

Previous till geochemical studies conducted around Sn mineralization analyzed a broad range of till size fractions to geochemically detect or model glacial dispersal of Sn, including the <1.0 mm heavy mineral fraction (e.g. Mattila and Peuraniemi, 1980; Toverud, 1982; Peuraniemi et al., 1984), the <0.177 mm fraction (sand+silt+clay) (e.g. Szabo et al. 1975), the <0.002 mm fraction (clay) (Lamothe, 1990), or the <0.063 mm (silt+clay) fraction. These different size or density fractions were used in these older (>20 years) till studies in attempts to evaluate which fraction might provide acceptable contrast between background and anomalous concentrations in till down-ice of Sn mineralization.

The <0.063 mm fraction of till was geochemically analyzed in this study because it is most cost effective to use, is widely used by industry, and modern ICP-MS techniques now allow for determinations of element concentrations to very low detection limits in this size fraction. This study demonstrated that the <0.063 mm fraction does provide adequate contrast between background and elevated concentrations of Sn and related indicator and pathfinder elements around Sn mineralization.

Comparisons to other studies

Table 4 summarizes geochemical values for Sn, W, and other selected elements for samples from this study and other published till geochemical studies around Sn deposits or Sn mineralization in granite. Of note is that the previous till geochemical studies, with the exception of the Sisson deposit study, were carried out quite a long time ago, between 1966 and 1992. Tin values reported in the other studies cannot be directly compared to results reported here as the other studies used different analytical methods on different size and/or

Table 4. Comparison of the highest geochemical contents for indicator and pathfinder elements in various size and density fractions of till at the Mount Pleasant deposit and other Sn mineralization worldwide. All elements reported in this study were determined by aqua regia/ICP-MS except for Sn and W, which were determined by borate

Location	Data Source	Fraction	Sn (ppm)	W (ppm)	Mo (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ag (ppb)	As (ppm)	Cd (ppm)	Bi (ppm)	Tl (ppm)	Te (ppm)	In (ppm)	Re (ppb)
Mount Pleasant Sn-W-Mo-Bi-In deposit, Canada	this study	<0.063 mm	349	35	386	227	2479	2989	1666	2392	2.9	208	1.6	2.58	13.08	4
Sisson W-Mo deposit, Canada	McClenaghan et al., 2014c	<0.063 mm	28	816	63	978	213	239	520	745	0.9	54	1.1	0.89	0.41	5
Mount Pleasant deposit, Canada	Szabo, 1975	<0.177 mm	25	NR	NR	580	600	1900	NR	150	NR	NR	NR	NR	NR	NR
Mount Pleasant Sn deposit, Canada	Riddell, 1967	not reported	>250	NR	400	>200	>100	>500	NR	NR	NR	NR	NR	NR	NR	NR
eastern Nova Scotia, Canada	Turner & Stea, 1990	0.063–0.3 mm HMC	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
East Kemptville Sn deposit, Canada	Rogers et al., 1990	not reported	>1500	>1200	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
East Kemptville Sn deposit, Canada	Rogers & Garrett, 1987	<2.0 mm	>400	>100	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Central New Brunswick Sn-bearing granite, Canada	Lamothe, 1990	<0.002 mm	93	1600	57	969	3800	815	NR	2000	1.7	NR	NR	NR	NR	NR
eastern Nova Scotia, Canada	Stea, 1982	0.063–0.3 mm HMC	30	>2000	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Hämeenlinna, Finland	Peuraniemi & Gehör, 2000	<0.5 mm SG	1310	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Hieronmaki, Finland	Peuraniemi, 1992	<0.06 mm	14	370	NR	354	NR	381	NR	NR	NR	NR	NR	NR	NR	NR
southeastern Finland	Peuraniemi, 1985	<1.0 mm HMC	5530	NR	NR	13	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
southeastern Finland	Peuraniemi & Heinänen, 1985	<1.0 mm HMC	5530	NR	NR	13	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
southeastern Finland	Peuraniemi et al., 1984	<1.0 mm HMC	>91	NR	NR	>210	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
southern Finland	Aario & Peuraniemi, 1992	HMC	520	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
various, Finland	Peuraniemi, 1990	<1.0 mm HMC	760	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
various, Finland	Matilla & Peuraniemi, 1980	<1.0 mm HMC	1730	230	200	NR	NR	690	NR	NR	NR	NR	NR	NR	NR	NR
Jakvissle, Sweden	Toverud, 1987	<1.0 mm HMC	4822	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
upper central Sweden	Toverud, 1982	<0.5 mm SG	8926	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

NR = not reported

HMC = heavy mineral concentrate

density fractions of till and were carried out around much lower grade Sn mineralization. In the older studies, Sn values reported for till HMC (SG>2.96) are the highest as the process of concentrating heavy minerals in till concentrates cassiterite (SG=6.6–7) and potentially other heavy Sn-bearing minerals (see Table 1 for examples) associated with the Sn mineralization.

CONCLUSIONS

This till geochemical study around the Mount Pleasant Sn-W-Mo-Bi-In deposit, which also incorporates the earlier work of Riddell (1966) and Szabo et al. (1975), is the most recent detailed till geochemical study around a major Sn deposit in glaciated terrain. The <0.063 mm fraction of till was found to clearly reflect the glacial dispersal at least 0.5 km down-ice of the North Zone and 1 km down-ice of both the North and Fire Tower zones. The use of this size fraction of till is cost effective to prepare and geochemically analyze. Therefore the <0.063 mm size fraction of till is recommended for regional and local Sn exploration programs. The Sn, W, Mo, Bi, and In contents of the samples reported in Table 2 offer a guide to metal contents that might be expected in till proximal to a Sn-mineralized source.

Indicator elements in till for the Mount Pleasant deposit include the main ore elements Sn, W, Mo, Bi, and In. Pathfinder elements in till include Ag, As, Cd, Cu, Pb, Re, Te, Tl, and Zn. These elements reflect the presence of Sn mineralization as well as the polymetallic nature of the deposit. The deposit contains a significant resource of In and this is reflected in the high In contents (up to 13 ppm) in till down-ice. A total digestion method is required to report the total concentrations of Sn and W in till. The total method that was used in this study, lithium tetra/metaborate fusion followed by nitric digestion/ICP-MS, or instrumental neutron activation analysis (INAA), are two common methods that could be used to determine the total Sn and W content of till. Aqua regia/ICP-MS is a suitable method for determining the other pathfinder and indicator elements identified.

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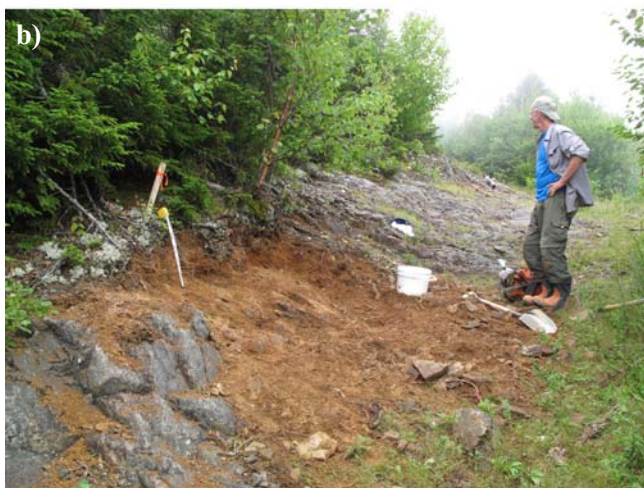
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Appendix A2. Field site photographs of till sample sites



Sample site 12-MPB-1001.



Sample site 12-MPB-1002.



Sample site 12-MPB-1003.



Appendix A2 continued.



Sample site 12-MPB-1004.



Sample site 12-MPB-1005.



Sample site 12-MPB-1006.

Appendix A2 continued.



Sample site 12-MPB-1007.



Sample site 12-MPB-1008.



Sample site 12-MPB-1009.



Appendix A2 continued.



Sample site 12-MPB-1010 and -1011.



Sample site 12-MPB-1013.



Sample site 12-MPB-1012.



Sample site 12-MPB-1014.



Appendix A2 continued.



Sample site 12-MPB-1015.



Sample site 12-MPB-1016.



Sample site 12-MPB-1017.

Appendix A2 continued.



Sample site 12-MPB-1018.



Sample site 12-MPB-1019.

Appendix A2 continued.



Sample site 12-MPB-1020.



Sample site 12-MPB-1022.



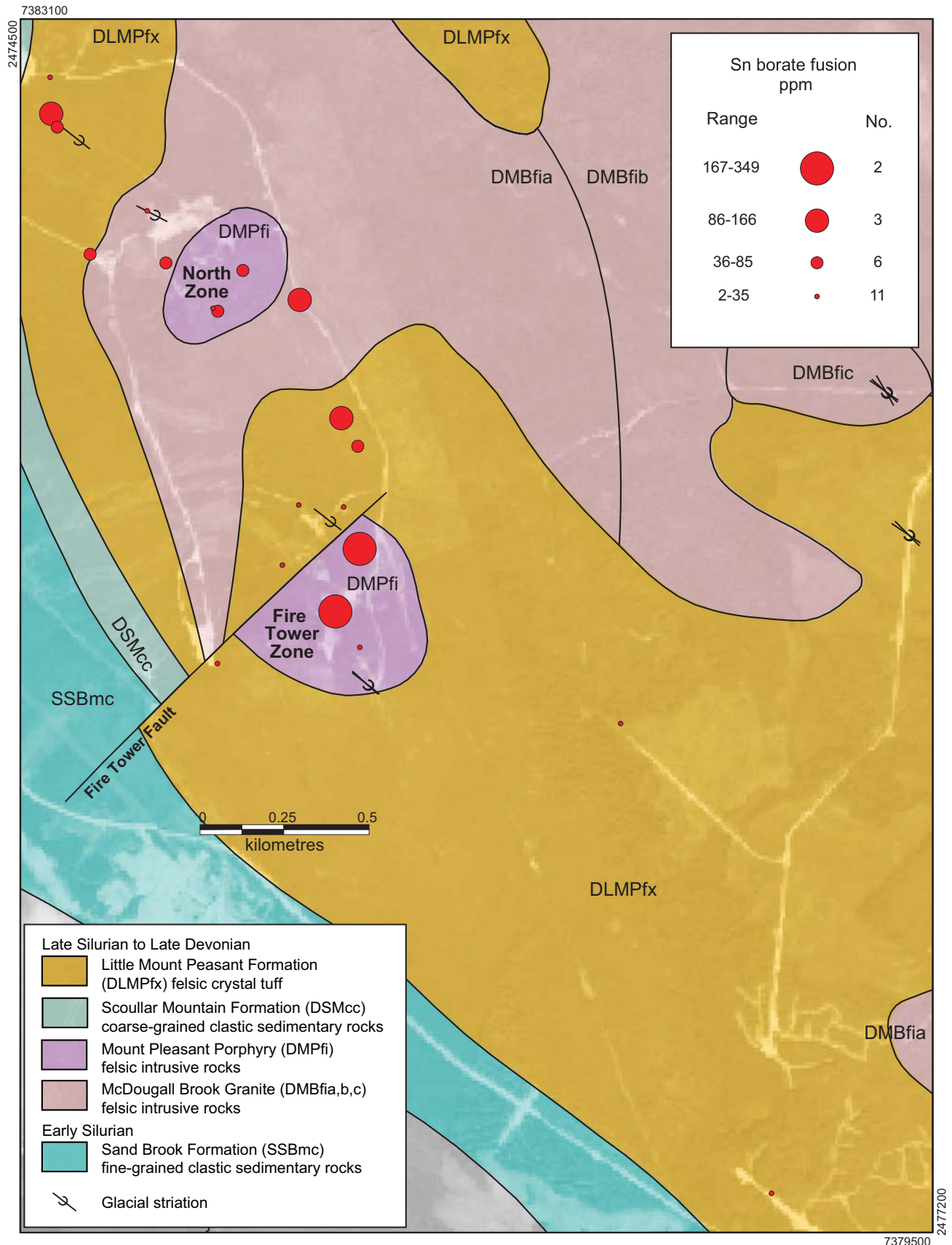
Sample site 12-MPB-1023.

Appendix A2 continued.



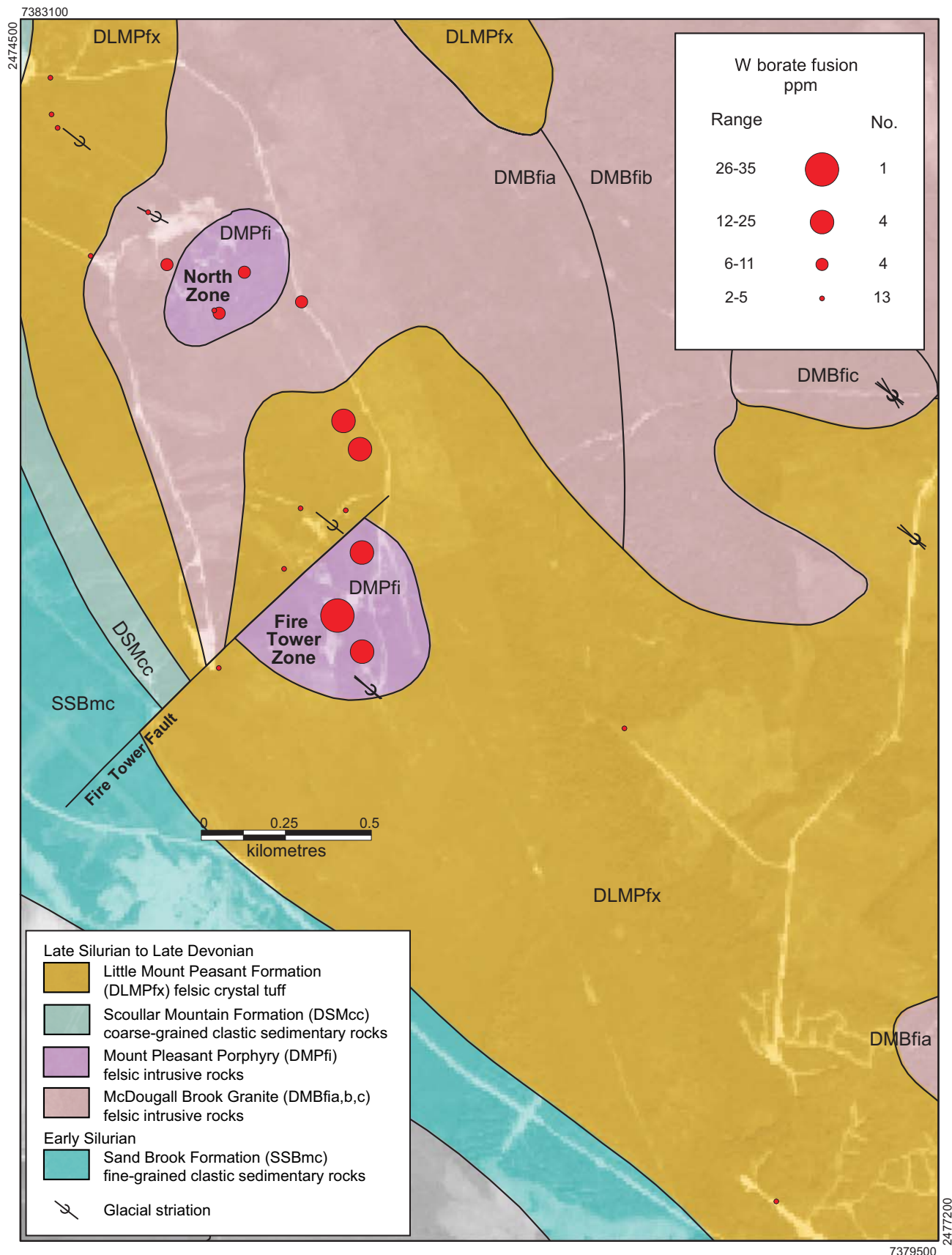
Sample site 12-MPB-1024.

APPENDIX C. Proportional dot maps of trace element geochemistry



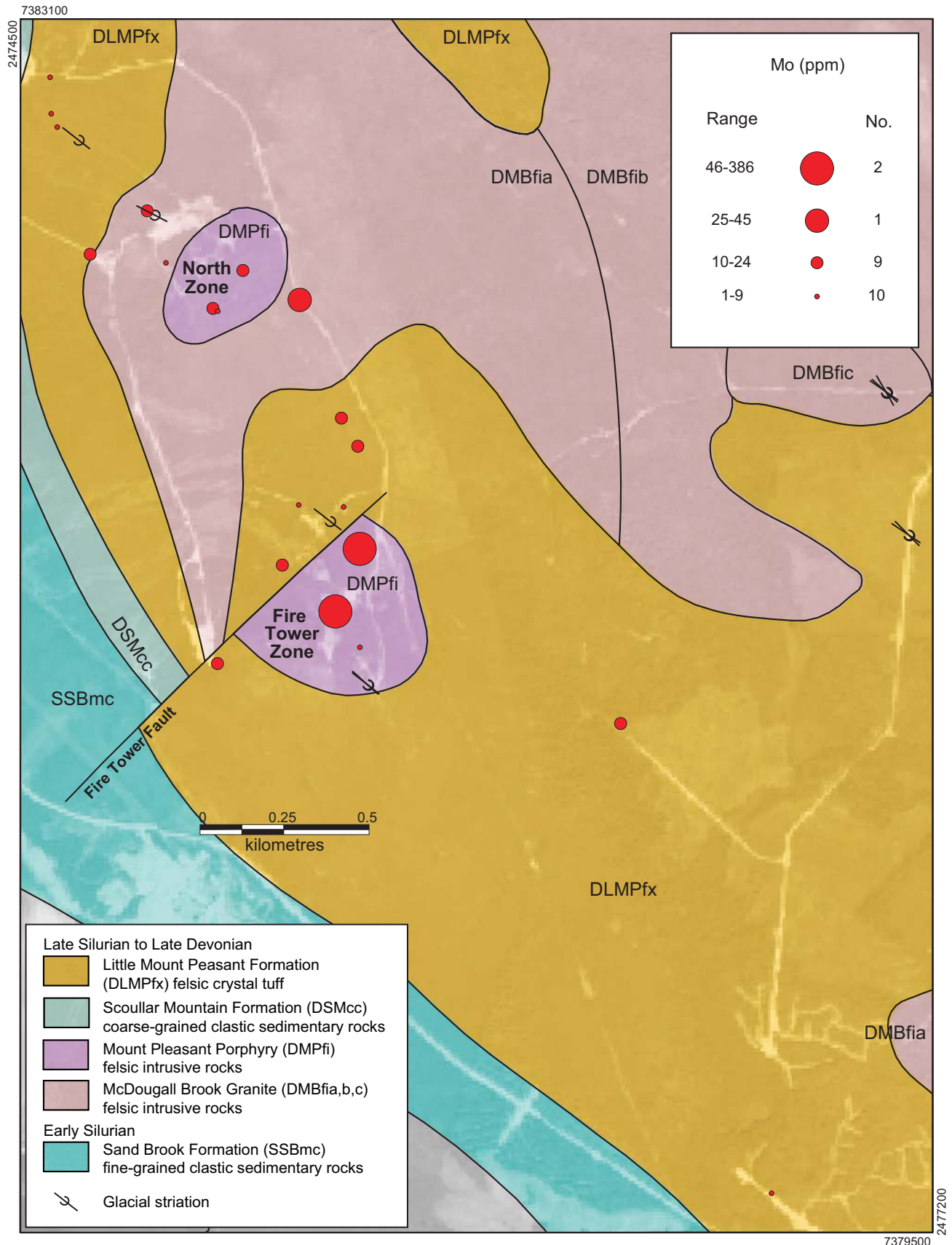
Map 1. Proportional dot map showing the tin (Sn) concentration in the <0.063 mm fraction of till samples. Bedrock geology modified from McLeod et al. (2005).

Appendix C continued.



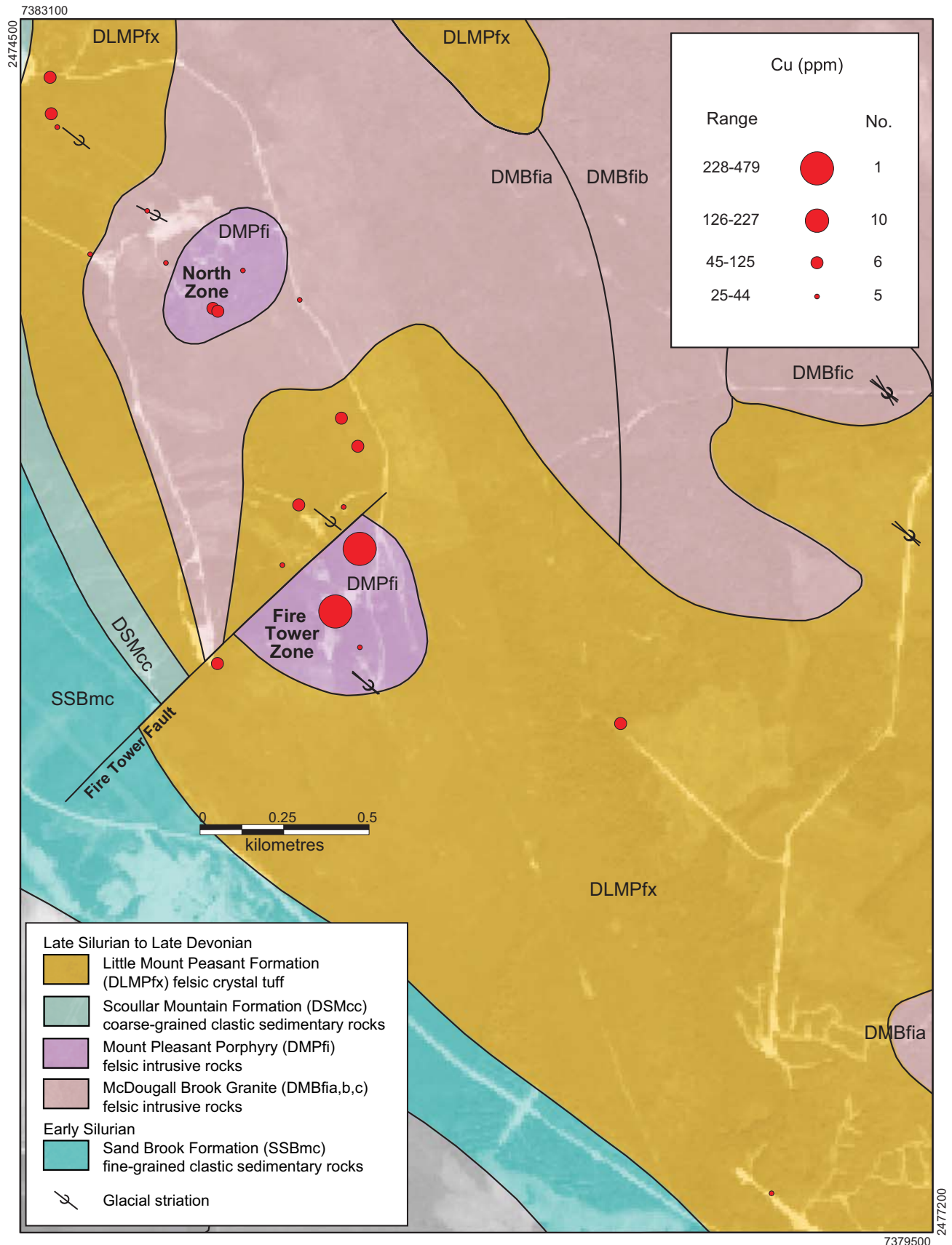
Map 2. Proportional dot map showing the tungsten (W) concentration in the <0.063 mm fraction of till samples. Bedrock geology modified from McLeod et al. (2005).

Appendix C continued.



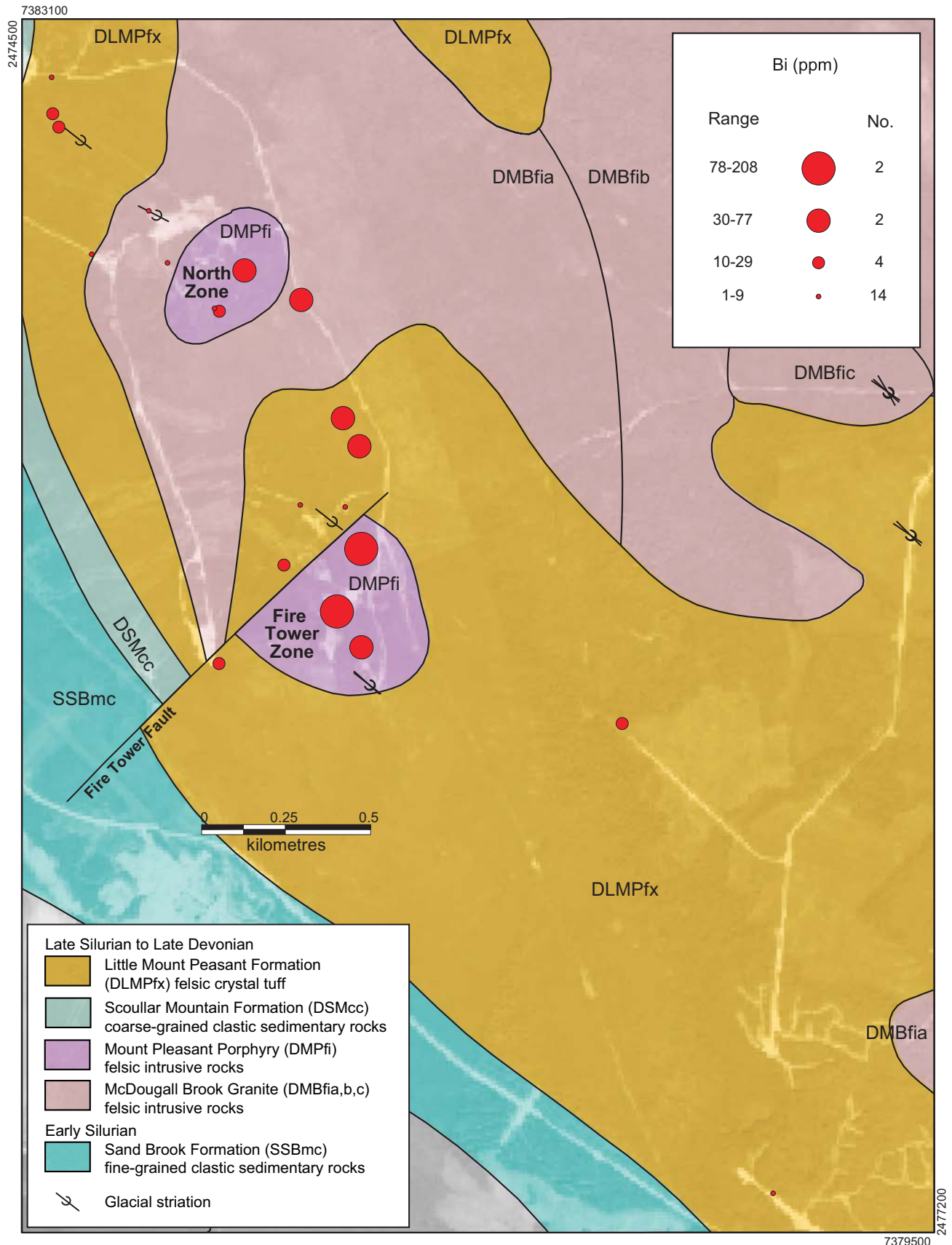
Map 3. Proportional dot map showing the molybdenum (Mo) concentration in the <0.063 mm fraction of till samples. Bedrock geology modified from McLeod et al. (2005).

Appendix C continued.



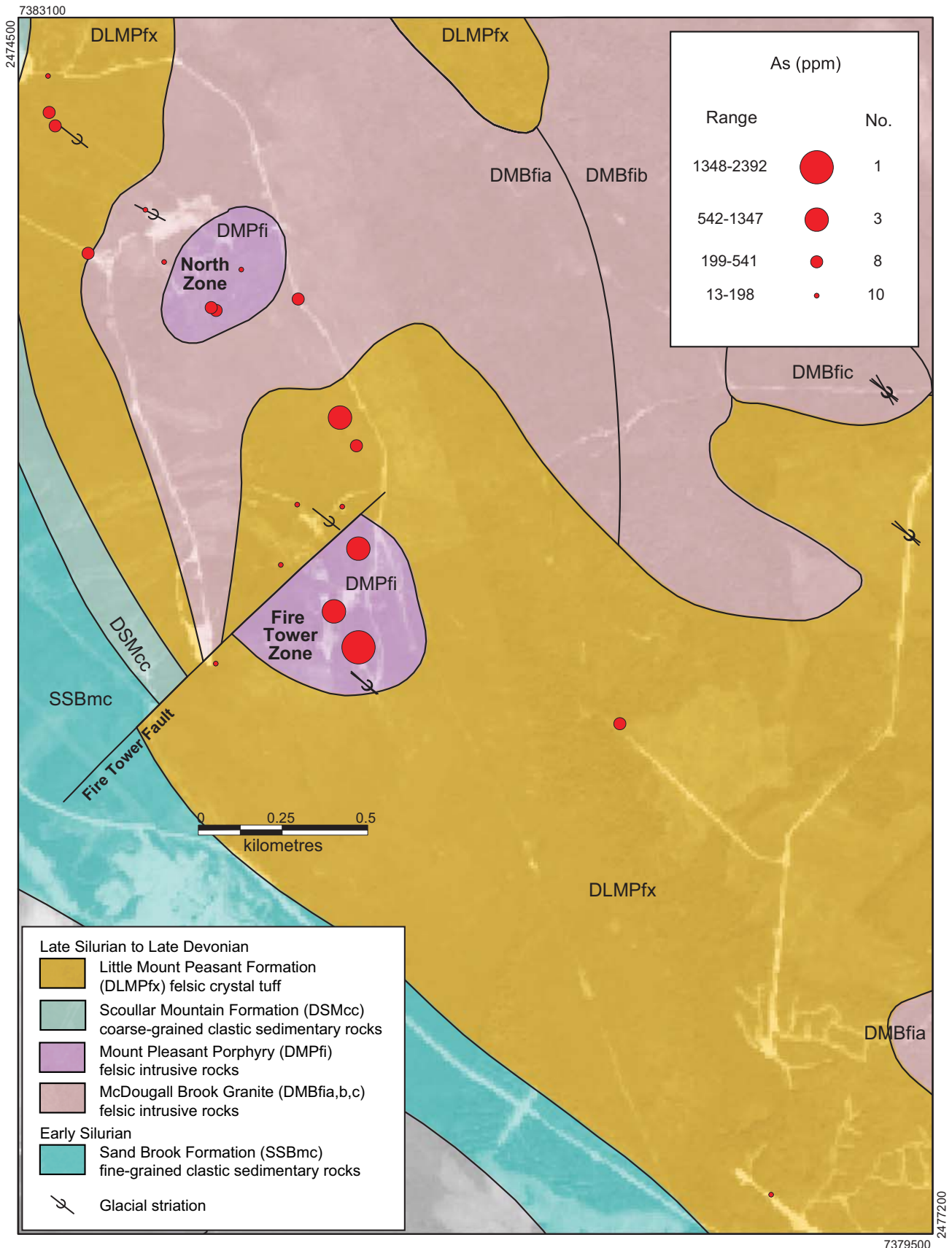
Map 4. Proportional dot map showing the copper (Cu) concentration in the <0.063 mm fraction of till samples. Bedrock geology modified from McLeod et al. (2005).

Appendix C continued.



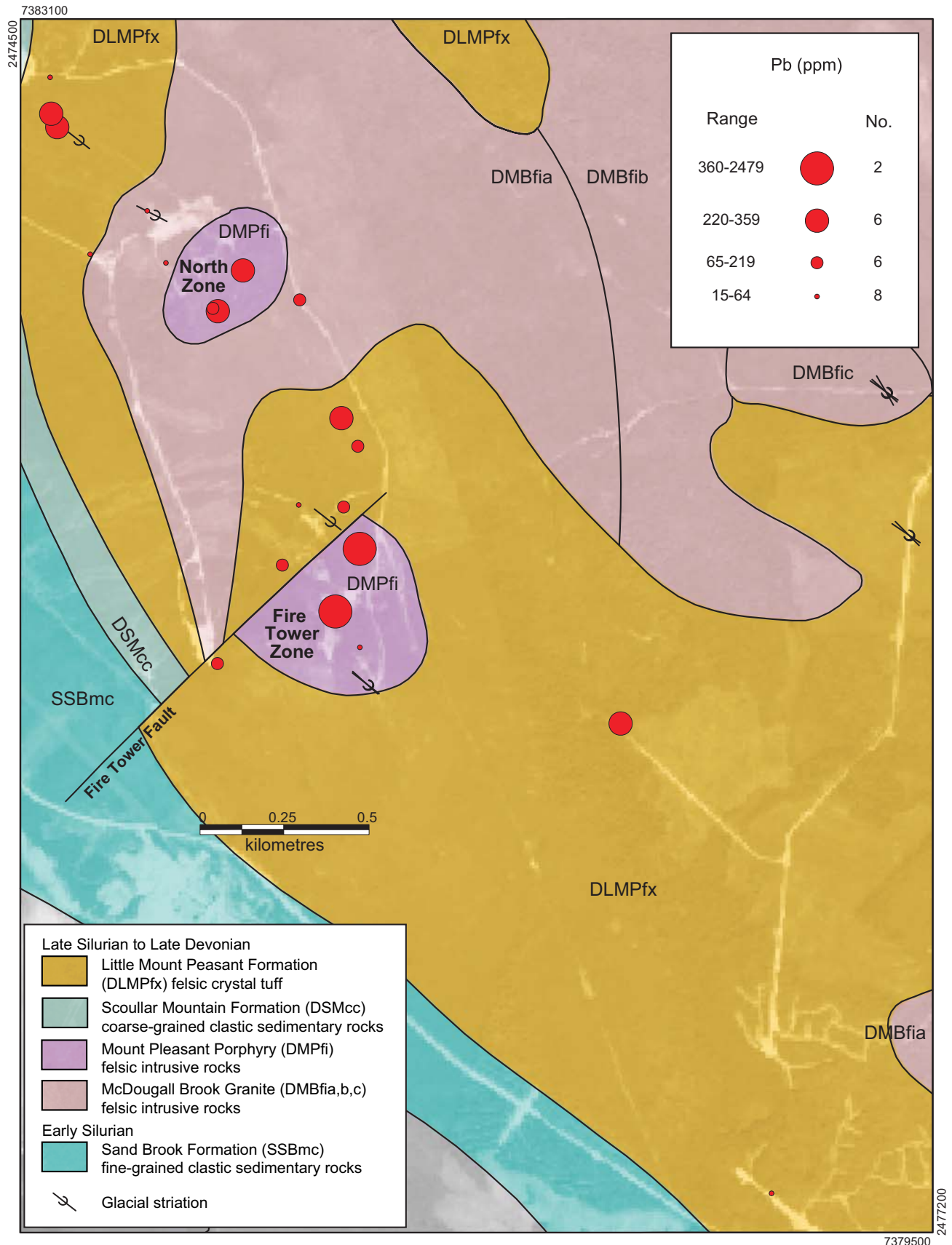
Map 5. Proportional dot map showing the bismuth (Bi) concentration in the <0.063 mm fraction of till samples. Bedrock geology modified from McLeod et al. (2005).

Appendix C continued.



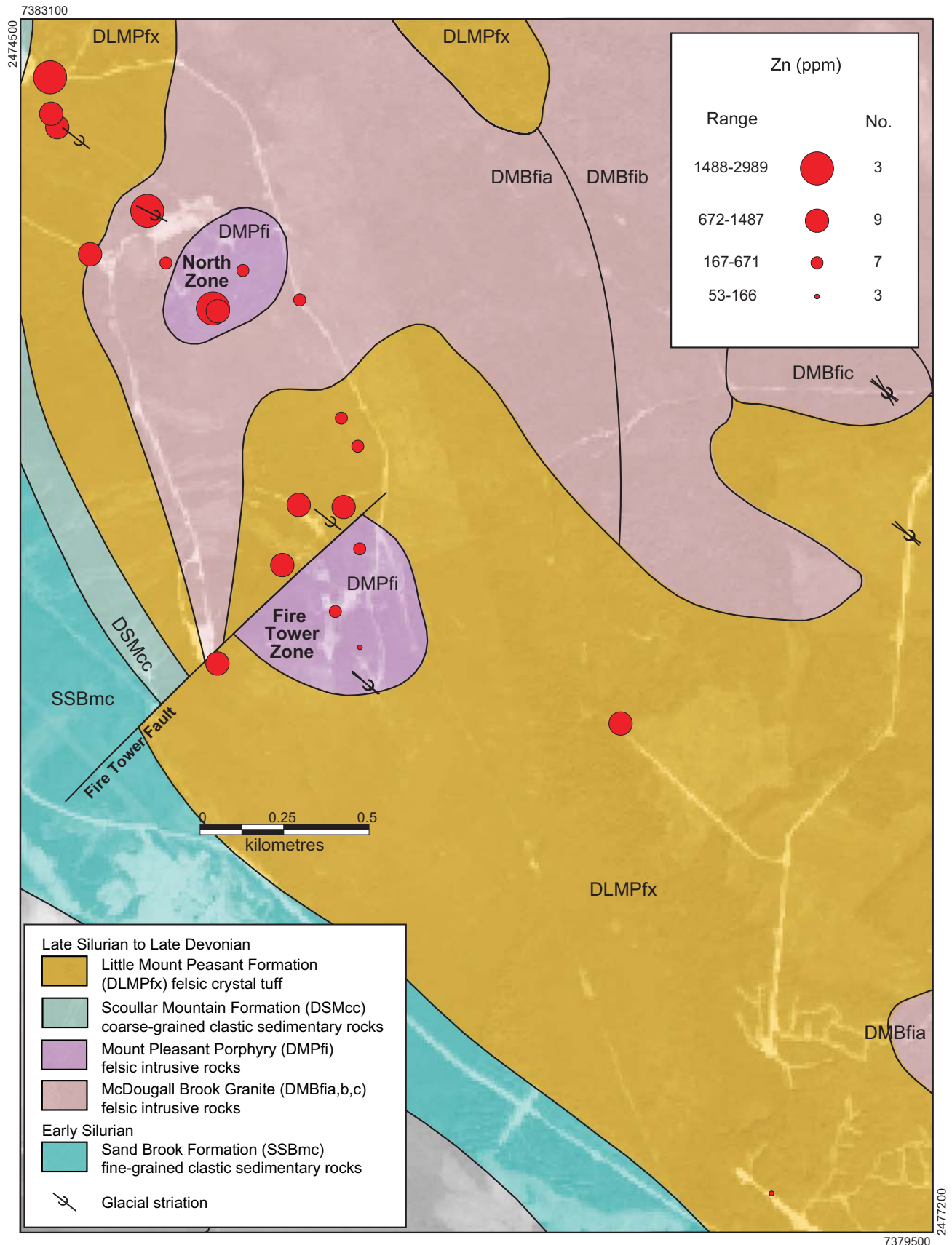
Map 6. Proportional dot map showing the arsenic (As) concentration in the <0.063 mm fraction of till samples. Bedrock geology modified from McLeod et al. (2005).

Appendix C continued.



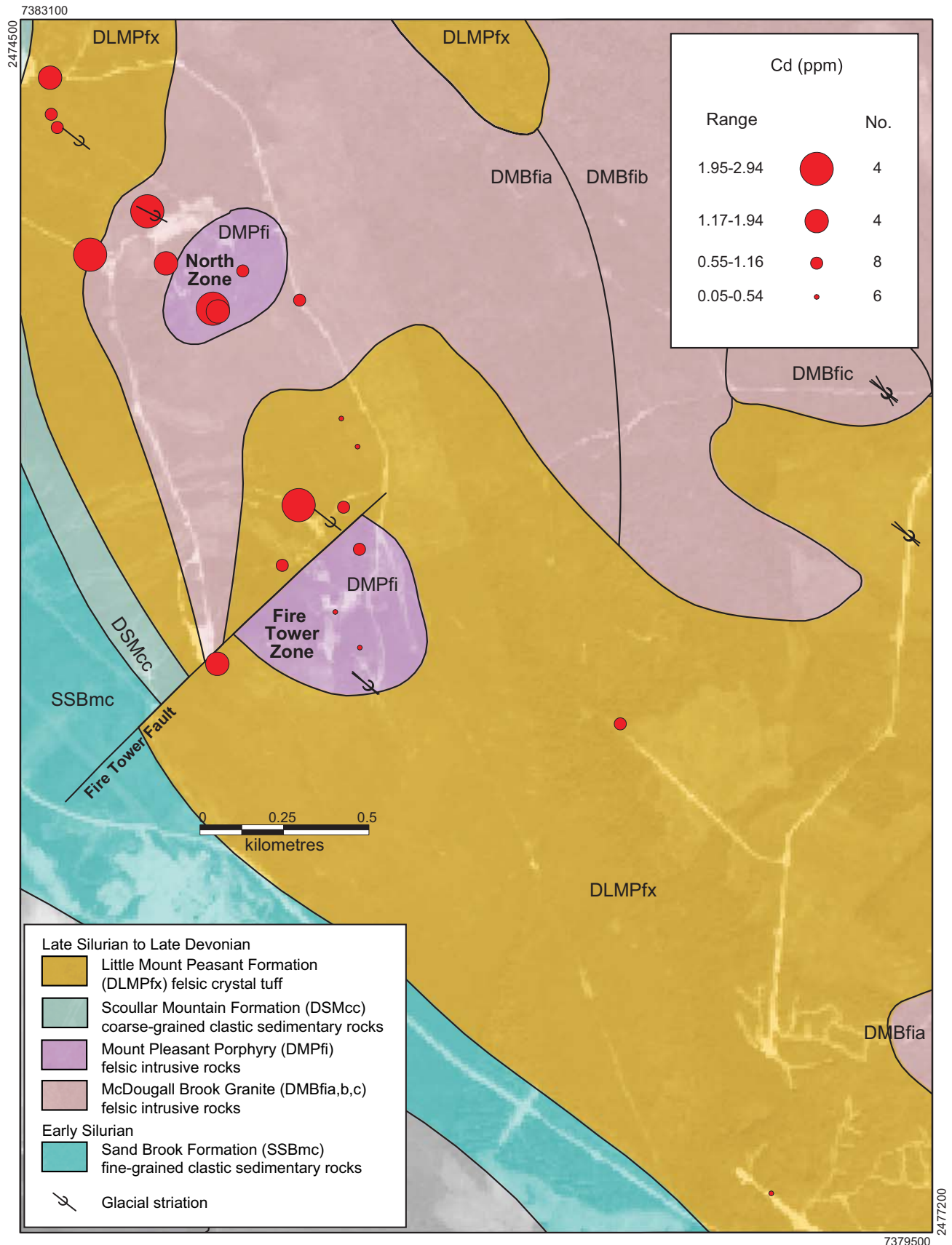
Map 7. Proportional dot map showing the lead (Pb) concentration in the <0.063 mm fraction of till samples. Bedrock geology modified from McLeod et al. (2005).

Appendix C continued.



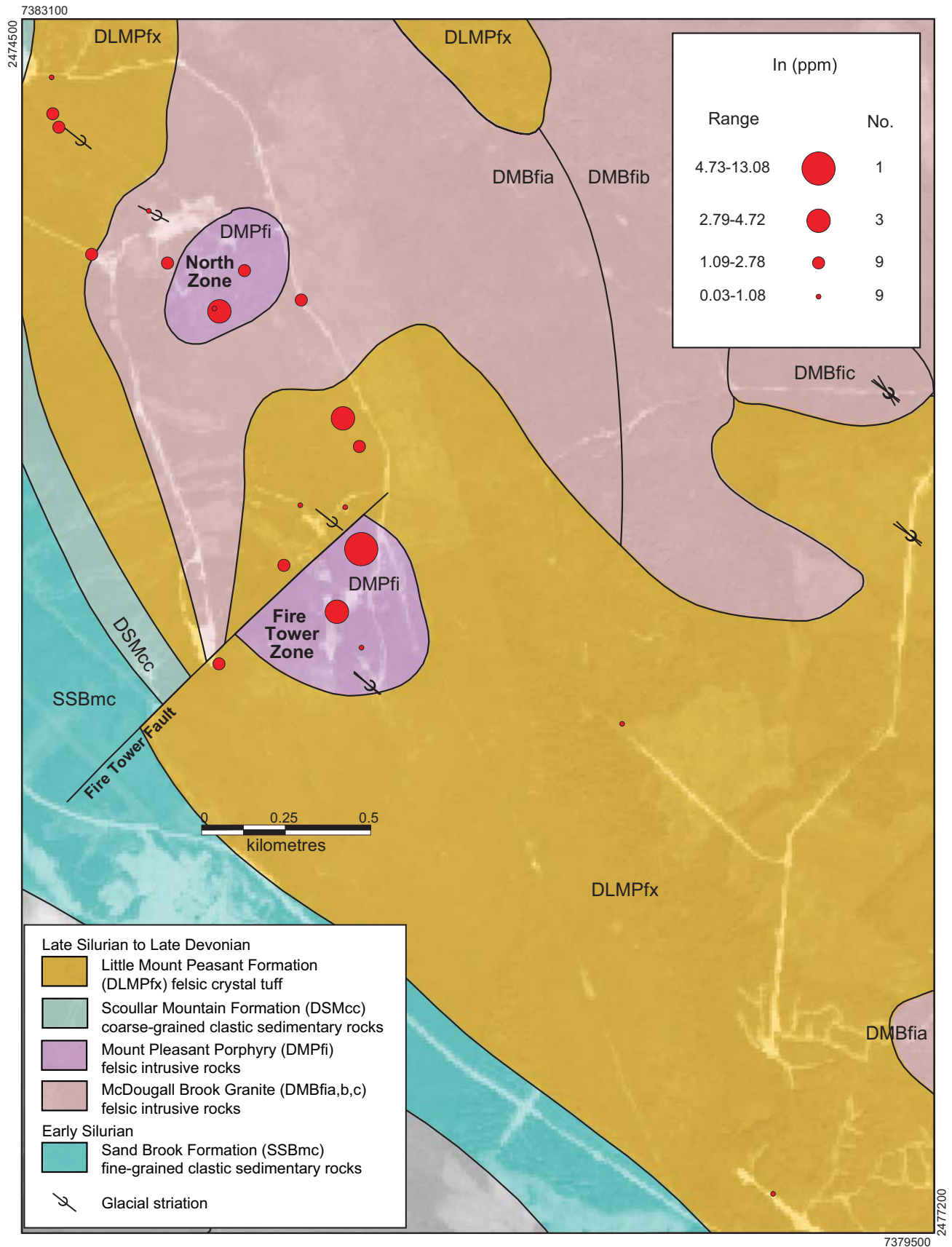
Map 8. Proportional dot map showing the zinc (Zn) concentration in the <0.063 mm fraction of till samples. Bedrock geology modified from McLeod et al. (2005).

Appendix C continued.



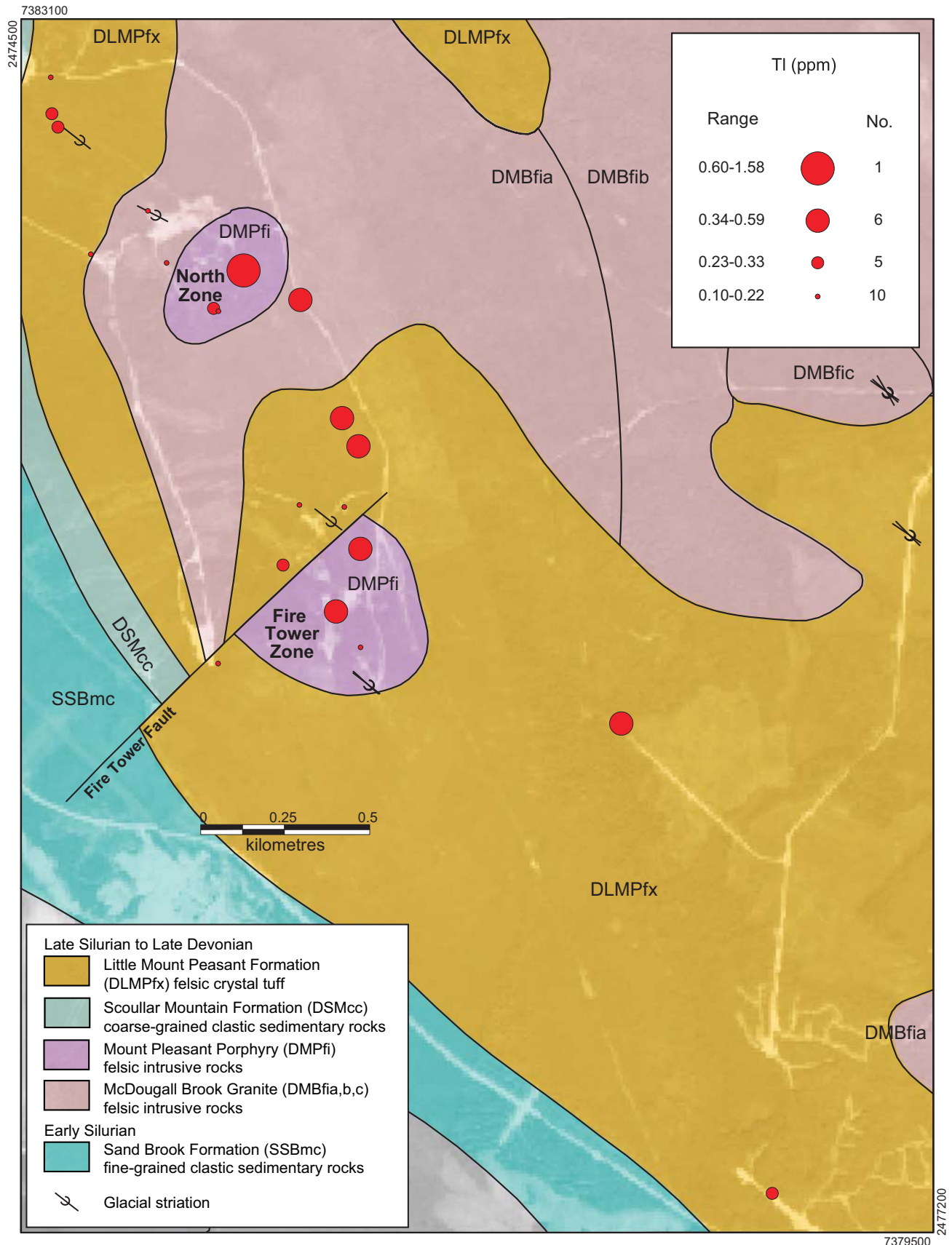
Map 9. Proportional dot map showing the cadmium (Cd) concentration in the <0.063 mm fraction of till samples. Bedrock geology modified from McLeod et al. (2005).

Appendix C continued.



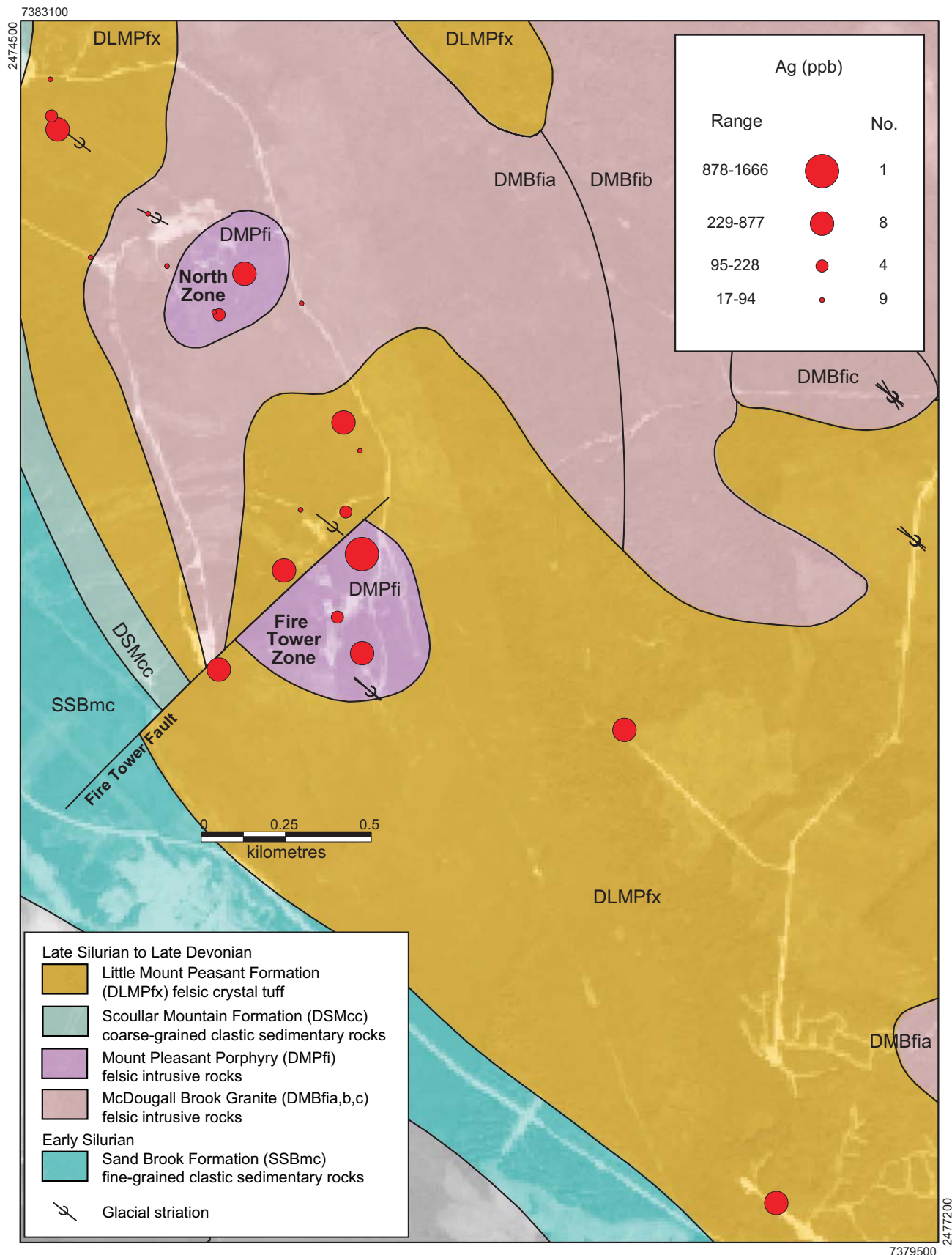
Map 10. Proportional dot map showing the indium (In) concentration in the <0.063 mm fraction of till samples. Bedrock geology modified from McLeod et al. (2005).

Appendix C continued.



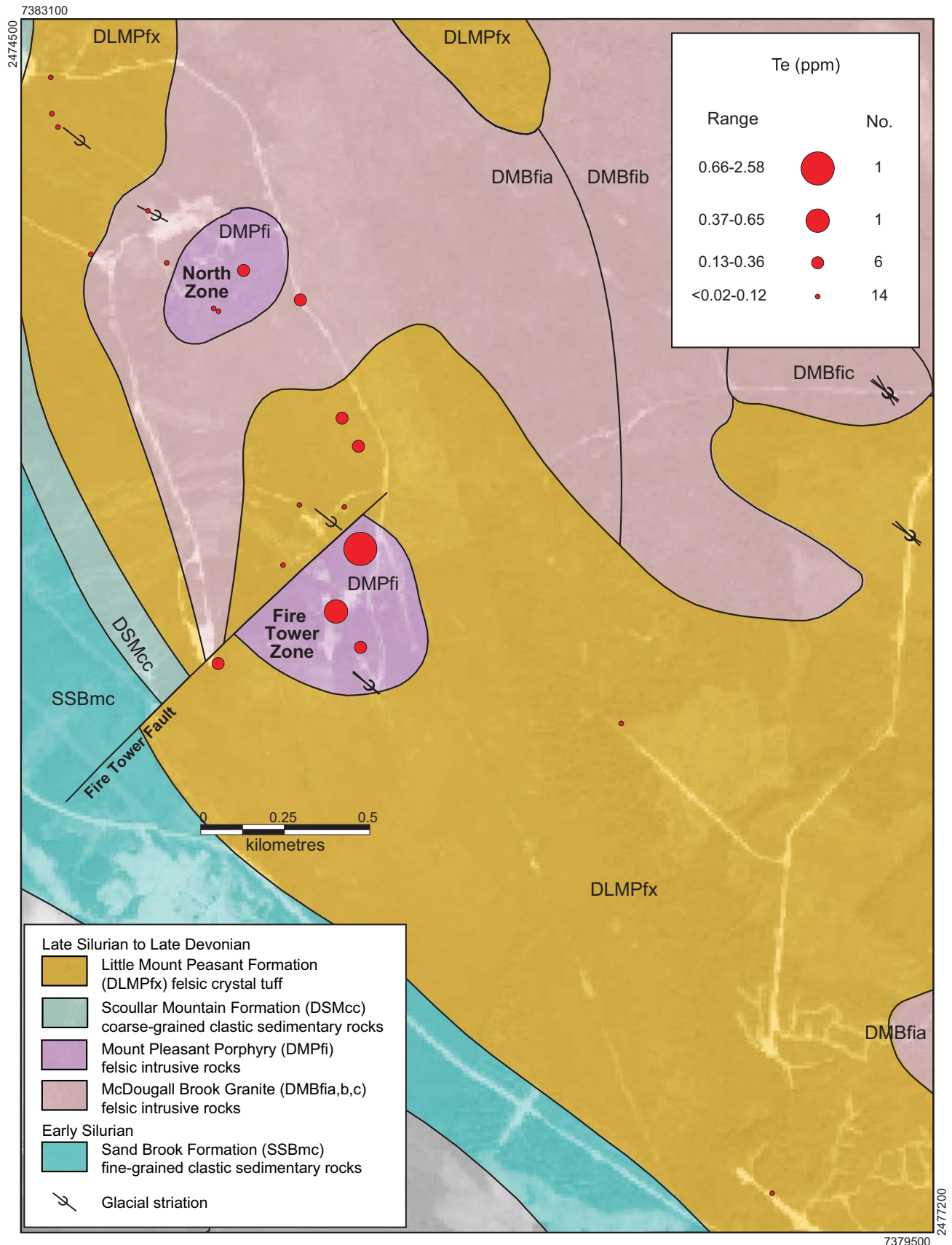
Map 11. Proportional dot map showing the thallium (TI) concentration in the <0.063 mm fraction of till samples. Bedrock geology modified from McLeod et al. (2005).

Appendix C continued.



Map 12. Proportional dot map showing the silver (Ag) concentration in the <0.063 mm fraction of till samples. Bedrock geology modified from McLeod et al. (2005).

Appendix C continued.



Map 13. Proportional dot map showing the tellurium (Te) concentration in the <0.063 mm fraction of till samples. Bedrock geology modified from McLeod et al. (2005).