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**GEOLOGICAL SURVEY OF CANADA
OPEN FILE 7756**

**Geochemical and indicator mineral data for
stream sediments and waters around the
Sisson Sn-W-Mo deposit, New Brunswick
(NTS 21-J/06, NTS 21-J/07)**

**M.B. McClenaghan, M.A. Parkhill, A.G. Pronk, M.W. McCurdy,
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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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Geochemical and indicator mineral data for stream sediments and waters around the Sisson W-Mo deposit, New Brunswick (NTS 21-J/06, NTS 21-J/07)

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ABSTRACT

Stream sediment and water samples were collected around the Sisson W-Mo deposit as part of the Geological Survey of Canada's (GSC) Targeted Geoscience Initiative 4 (TGI-4). The TGI-4 Program is 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 stream sampling is part of an indicator mineral case study around the Sisson deposit to document indicator mineral signatures of the deposit in bedrock as well as surficial media (till and stream sediments). Stream sediments have been eroded from till, not from the Sisson deposit, thus patterns in stream sediments reported here reflect both glacial transport and fluvial transport.

Indicator elements of the deposit in the <0.177 mm fraction of stream sediment are the main ore elements W and Mo, and pathfinder elements include As, Bi, Ag, Cu, Zn, In, Tl, and Cd. A total analysis method (INAA) is required to determine the total concentration of W and Mo in stream sediments. Aqua regia/ICP-MS is a suitable method for determining the content of the other pathfinder elements.

Indicator/pathfinder elements in stream waters include As, Cd, Cu, Cs, W, and Zn.

Indicator minerals of the deposit in the <2.0 mm heavy mineral fraction of stream sediments are the main ore minerals scheelite, wolframite, and molybdenite as well as other minerals including chalcopyrite, sphalerite, arsenopyrite, and pyrite. Fluvial dispersal of scheelite and wolframite from the deposit is detectable in stream sediments at least 4 km downstream from the north end of the deposit and 5 km southeast of the deposit in streams that drain the southeast-trending glacial dispersal train. Additional stream sediment sampling would be required to fully document the nature of dispersal of scheelite downstream from the deposit. Molybdenite is not a useful indicator mineral in stream sediments around the Sisson deposit because it is too soft to survive glacial and subsequent fluvial transport. A 2 km (4 km²) spacing of stream sediment samples is recommended to detect the W dispersal train from the Sisson deposit or similar styles of W-Mo mineralization.

INTRODUCTION

The use of stream sediments for W exploration globally is well documented, including studies in Turkey (e.g. Özcan and Çağatay, 1989), Spain (e.g. Zantop and Nespereira, 1979; Fernández-Turiel et al., 1992), Pakistan (e.g. Zeschke, 1961; Asrarullah, 1982), Malaysia (e.g. Rajah, 1982), Somalia (Frizzo and Hassan, 1983), USA (e.g. Theobald and Thompson, 1960), and India (e.g. de Smeth et al., 1985; Surya Prakash Rao et al., 1989). The main tungsten mineral, scheelite, has also been recovered from stream sediments in glaciated terrain, including Norway (e.g. Stendal, 1978), Greenland (e.g. Hallenstein et al., 1981; Steinfelt, 1987), Poland (Mikulski and Wierchowicz, 2013), and Canada (e.g. Maurice, 1986; Allen et al.,

1999). In some areas, scheelite content in stream sediments is sufficient for the sediments to be characterized as placer W deposits (e.g. Hess, 1917; Wildon and Hotz, 1955). The other major tungsten mineral, wolframite, also has been recovered in stream sediments around the world (e.g. Zantop and Nespereira, 1979; Fernández-Turiel et al., 1992), as well as from placer deposits (Hess, 1917), such as those in Thailand (e.g. Punggrassami, 1986), Burma (e.g. ESCAP Secretariat, 1982), and the USA (e.g. Johnson, 1910; Theobald and Thompson, 1960). Many of the reported studies for scheelite and wolframite in stream sediments are more than 20 years old and few if any have been carried out using the systematic indicator mineral recovery and grain-counting methods that are now commercially available (e.g. McClenaghan, 2011).

The Sisson W-Mo deposit in eastern Canada provides an ideal site for testing modern stream sediment indicator mineral and geochemical methods for detecting dispersal from a significant W source. The Sisson deposit was chosen for this study because the deposit (1) bedrock geology is well known; (2) subcrops and thus was exposed to glacial erosion; and (3) has previously identified till and stream sediment geochemical anomalies, such that metal-rich stream sediments should be available for sampling. A till and stream sediment + water study was carried out around the Sisson deposit as part of the Geological Survey of Canada (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 study is a collaborative effort between the GSC, the New Brunswick Department of Energy and Mines (NBDEM), Northcliff Resources Limited, and Hunter Dickinson Inc.

This open file provides a description and interpretation of the indicator mineral data for the stream sediment samples that were reported in GSC Open File 7387 (McClenaghan et al., 2013a). In addition, this open file reports geochemical data for stream sediments and water collected at the same sites. Indicator mineral data for mineralized and host rocks in the Sisson area have been described in GSC Open File 7431 (McClenaghan et al., 2013b). Sisson area till indicator mineral data have been reported in GSC Open File 7467 (McClenaghan et al., 2014a) and till matrix geochemical data have been reported in GSC Open File 7430 (McClenaghan et al., 2013c) and in McClenaghan et al. (2014b).

Location and access

The Sisson W-Mo deposit is located in west-central New Brunswick (Fig. 1) at UTM coordinates 5136900N and 650350E (NAD27) in the Coldstream NTS map area (NTS 21 J/06). It is 60 km northwest of Fredericton and is easily accessed by logging roads.

Previous stream sediment geochemical surveys in the Sisson area

Regional-scale stream sediment surveys were conducted by the GSC over NTS map sheets 21J/07 and 21J/06, which includes the Sisson deposit area. Results, which are published in Friske et al. (2002) and Pronk et al. (1997), show obviously elevated values of W (Fig. 2) and Mo (Fig. 3) in stream silt samples immediately downstream of the Sisson deposit.

Indicator mineral and geochemical patterns in till in the Sisson area

Recent bedrock and till sampling, conducted as part of

the TGI-4 study, revealed that indicator minerals for the Sisson W-Mo deposit include the primary ore minerals scheelite, wolframite, and molybdenite, as well as secondary ore minerals chalcopyrite, joseite, native Bi, bismutite, bismuthinite, galena, sphalerite, arsenopyrite, pyrrhotite, and pyrite (McClenaghan et al., 2013b, 2014a). Indicator minerals in till clearly define glacial dispersal at least 10 km down-ice (southeast) of the deposit. The presence of coarse (0.5–2.0 mm) indicator minerals in till close to the deposit (<1 km) is a strong indicator of proximity to source (McClenaghan et al., 2013b, 2014a). The <0.063 mm fraction of till clearly defines glacial dispersal at least 30 km down-ice of the deposit and indicator/pathfinder elements in till include the main ore elements W and Mo, as well as Sn, Bi, Cu, Zn, Pb, Ag, In, As, Cd, Zn, and Te (Lamothe, 1992; Seaman, 2003; Seaman and McCoy, 2008; McClenaghan et al., 2013c, 2014b).

GEOLOGY

Local bedrock geology

The Sisson deposit is a bulk tonnage W-Mo deposit that has been explored by various companies over the past 50 years. The geology of the deposit area is summarized below from Nast and William-Jones (1991), Marr (2009), Fyffe et al. (2008, 2010), and Rennie et al. (2012). The deposit occurs at the eastern contact of the Nashwaak Granite and Howard Peak Granodiorite plutons (Fig. 4). The Howard Peak Granodiorite grades eastward into and becomes intermixed with gabbro. Both the gabbro and granodiorite are transected by granite dykes that are likely offshoots of the Nashwaak Granite. These plutons are part of a group of Late Silurian to Early Devonian plutonic rocks that form a northeast-trending belt that underlies the Miramichi Highlands in central New Brunswick. The belt of intrusive rocks also hosts the Lake George Sb deposit 60 km south of the Sisson deposit, the Burnt Hill W, Sn, and Mo showings 30 km northeast of the Sisson deposit, and the Mount Pleasant Sn-W-Mo-Sn-In deposit 120 km to the south (Fig. 1).

East of the Howard Peak Granodiorite are Cambro-Ordovician tuffaceous volcanic and sedimentary rocks of the Turnbull Mountain Formation (Fig. 4) of the Tetagouche Group, a belt of strongly deformed Cambro-Ordovician rocks that extends from the Bathurst area in northern New Brunswick through the Sisson Brook area and into the southwestern corner of the New Brunswick. Immediately east of these Turnbull Mountain Formation rocks are quartzite and shale of the Miramichi Group. This package is overlain to the east by additional rocks of the Tetagouche Group, including pyritiferous black shale intercalated with felsic volcanic rocks and mafic volcanic rocks of

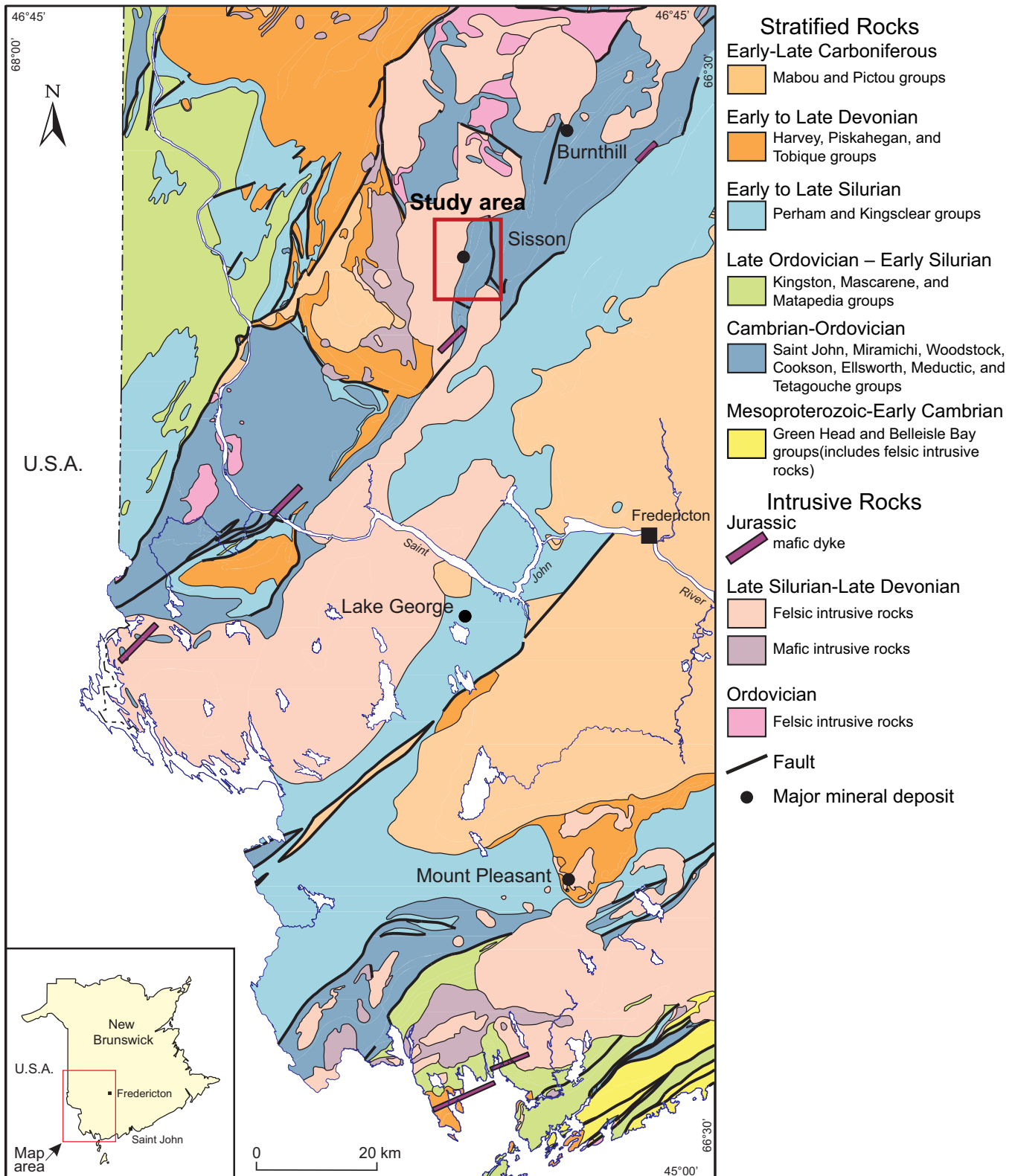


Figure 1. Bedrock geology of west-central and southern New Brunswick showing the location of the Sisson W-Mo deposit and other significant deposits (modified from Fyfe et al., 2010).

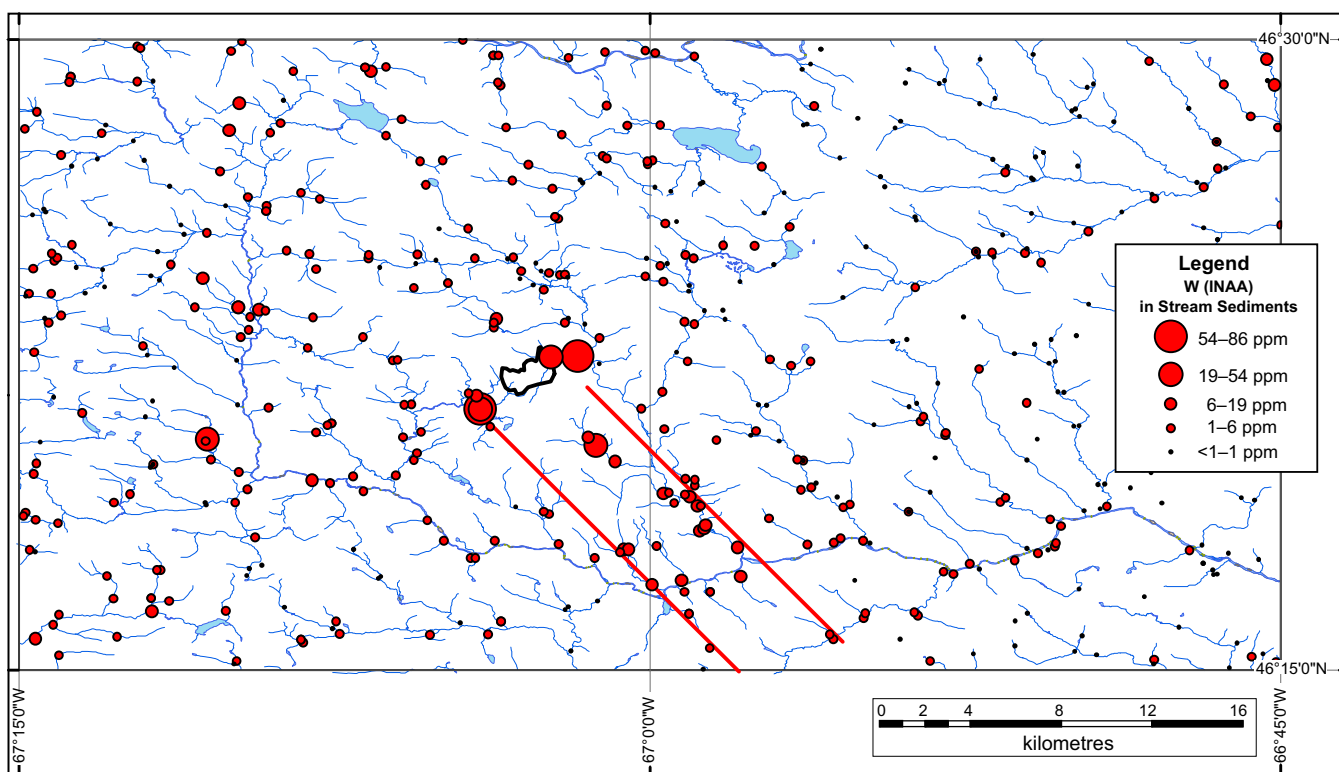


Figure 2. Distribution of W determined by instrumental neutron activation analysis in the <0.177 mm fraction of regional stream silt samples collected by the Geological Survey of Canada in NTS map sheets 21J/06 and 21J/07. Data from Friske et al. (2002) and Pronk et al. (1997). Deposit is outlined by a thick black line from Rennie et al. (2012). Red lines show approximate location of glacial dispersal train identified by Seaman and McCoy (2008).

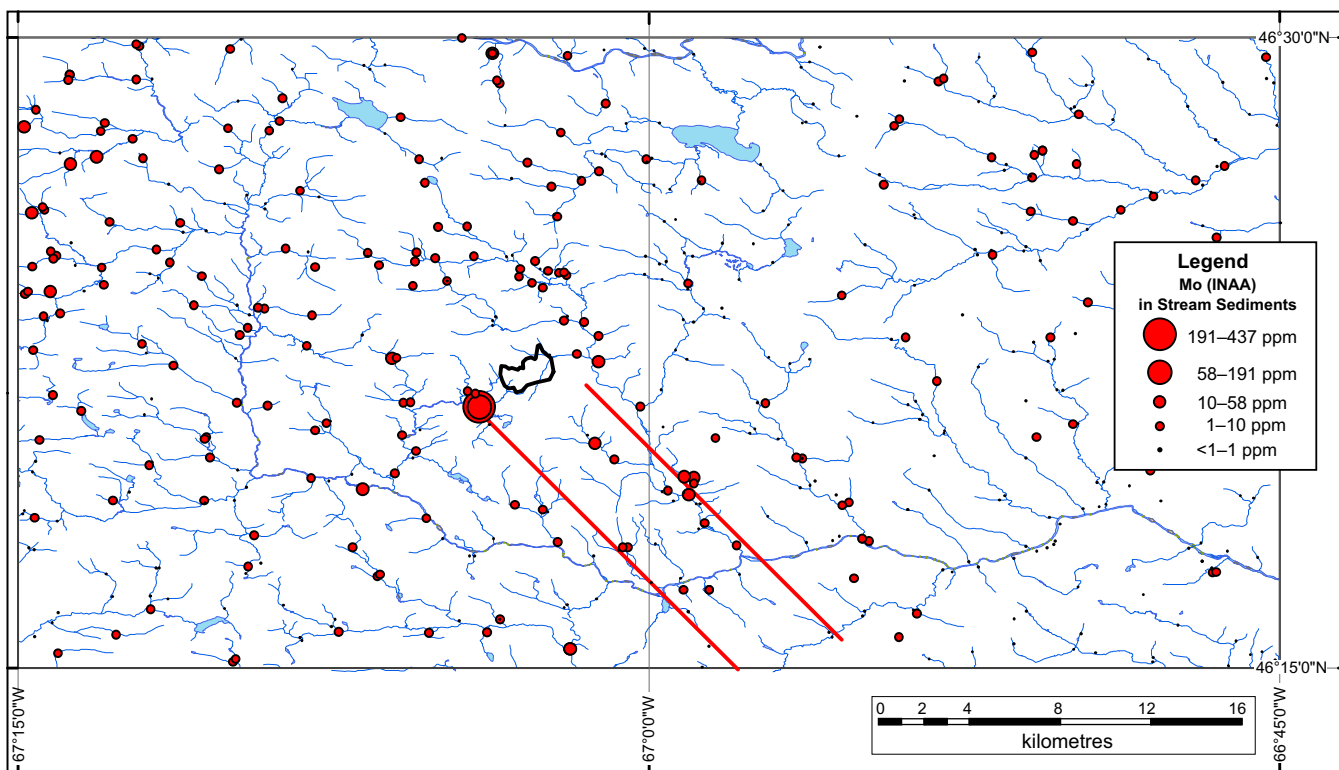


Figure 3. Distribution of Mo determined by instrumental neutron activation analysis in the <0.177 mm fraction of regional stream sediment samples collected by the Geological Survey of Canada in NTS map sheets 21J/06 and 21J/07. Data from Friske et al. (2002) and Pronk et al. (1997). Deposit is outlined by thick black line from Rennie et al. (2012). Red lines show approximate location of glacial dispersal train identified by Seaman and McCoy (2008).

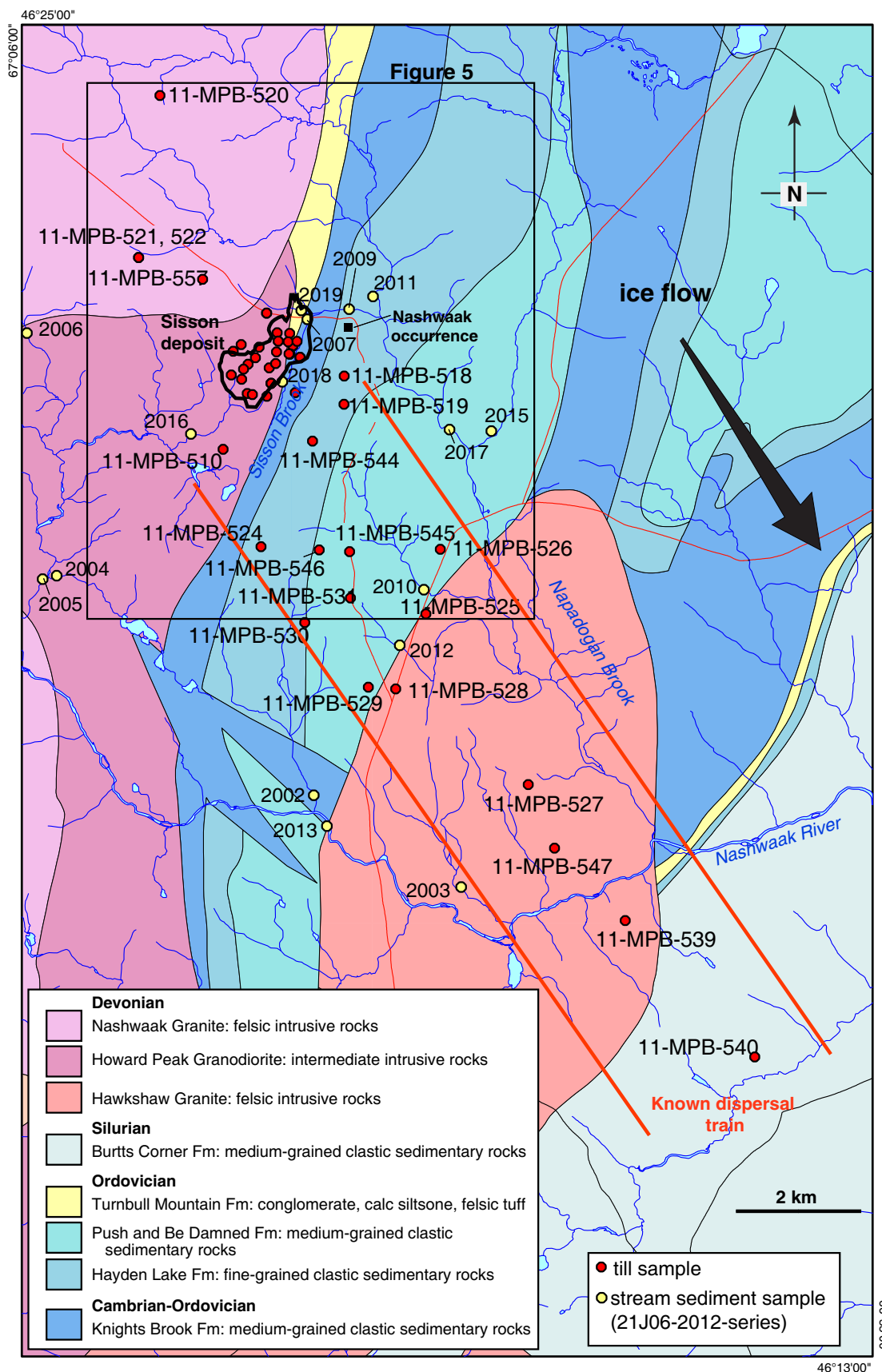


Figure 4. Local bedrock geology of the Sisson W-Mo deposit area, approximate location of glacial dispersal train (red lines) identified by Seaman and McCoy (2008), and location of GSC till (red dots) and stream samples (yellow dots) collected in 2012. Bedrock geology modified from Smith and Fyffe (2006a-d). Black deposit outline from Rennie et al. (2012).

the Hayden Lake Formation as well as wacke and shale of the Push and Be Dammed Formation (Fig. 4)

The Cambro-Ordovician volcanic and sedimentary rocks (Tetagouche Group), which underlie the east part of the Sisson area, are a continuation of the belt of rocks that host the Bathurst Mining Camp volcanogenic massive sulphide (VMS) deposits in north-eastern New Brunswick. For this reason, the Sisson area was the focus of major exploration programs from the 1950s into the 1990s. These activities led to the discovery of the small but high-grade Nashwaak Pb-Zn-Ag-Sb occurrence (Fig. 4) in 1960 that is only ~900 m west of Zone III in the Sisson deposit. The showing occurs in a stratabound pod and was originally interpreted as a syngenetic VMS showing (e.g. Snow and Coker, 1987). More recently, the Pb-Zn-Ag-Sb mineralization has been interpreted to be a vein-type showing related to the Sisson mineralizing system (Marr, 2009; Rennie et al., 2012; NBDEM mineral occurrence database, 2013).

Deposit geology

The Sisson deposit geology is summarized below from Nast and Williams-Jones (1991), Marr (2009), Fyffe et al. (2008, 2010), Rennie et al. (2012), and Bustard et al. (2013). The deposit is a large-tonnage, low-grade, structurally controlled, intrusion-related W-Mo deposit consisting of four wide and steeply-dipping zones of vein- and fracture-controlled W and Mo mineralization that straddle the strongly sheared contact of the Howard Peak Granodiorite Zone III (scheelite/molybdenite) and the adjacent Zones I and II (chalcopryrite, wolframite) of the Sisson deposit. It was discovered by Texasgulf Sulphur/Kidd Creek Mines Ltd. between 1978 to 1982 through geophysical surveys, trenching, soil sampling, and drilling (Snow and Coker, 1987; Marr, 2009; Rennie et al., 2012).

Zones I, II, and III strike roughly north-south and the Ellipse zone strikes northwest-southeast (Fig. 5). The zones merge and are part of a much larger hydrothermal mineralizing system of at least 9 km². Mineralization in all four zones subcrops at the till-bedrock interface and is open at depth. Zone III and the new Ellipse zone are the largest and best explored parts of the deposit and contain molybdenite and scheelite in sheeted quartz veins and stockworks. Zones I and II contain younger veins with chalcopryrite, wolframite, and more pyrite and pyrrhotite. The centre of Zone III contains the highest Mo concentrations. Moderate grades of Mo occur in the south part of Zone III and in the Ellipse Zone. Zones I and II and the north part of Zone III contain almost no Mo. The highest concentrations of Cu and associated elements are in Zones I and II. The deposit has elevated concentrations of Cu, Zn, Pb, Bi, and As that are directly related to late quartz-

scheelite and sulphide-rich veins and their sericite-sulphide envelopes. Scheelite ranges from <100 microns to 1 cm in size. Overall, wolframite is a minor mineral in the deposit. Mineralization is likely related to the presence of a buried granitic stock at depth that was the heat source for a hydrothermal system and metals. Rennie et al. (2012) reported resource estimates for the deposit of 383 Mt at 0.067% WO₃ and 0.021% Mo (measured and indicated), and 178 Mt at 0.051 WO₃ and 0.021% Mo (inferred). The deposit is approximately 2000 m northeast-southwest and 800 m wide (Figs. 4, 5). Table 1 lists the ore minerals present in the Sisson deposit.

Quaternary geology

Bedrock outcrop on the Sisson property and surrounding area is rare due to the extensive cover of till. Streams in the deposit area do not have access to the mineralization, only mineral-rich till. Till thickness varies from <2 m to 20 m over the deposit, and is on average ~8 m thick over Zone III (Marr, 2009). The deposit area is overlain by one to three till units. These units were described in detail by Seaman and McCoy (2008) and Fyffe et al. (2010). The stratigraphic interpretation of the tills overlying the deposit was subsequently revised by Seaman (2009) and Stea et al. (2011). The lowermost till exposed in the western end of an exploration trench, which was excavated through till overlying mineralization, is an Illinoian basal lodgement till deposited during the Northumberland Phase by an east-southeast-flowing ice sheet. This section is a reference section for Northumberland Till (Stea et al., 2011) in New Brunswick. It is clay-rich (~25% clay) and contains abundant weathered granite and metasedimentary clasts.

Elsewhere in the trench, the bedrock surface and the oldest till are overlain by a younger sandier (62–82% sand) Early Wisconsinan lodgement till likely deposited by southeast glacial flow during the Caledonia Phase, and possibly reworked by south-southwest glacial flow during the Middle to Late Wisconsinan (Escuminac Phase). This till is blanketed discontinuously by approximately <1 m to 2.5 m of Younger Dryas (Collins Pond Phase) till, formed during a brief cold period at the very end of the Late Wisconsinan that saw the reactivation or regrowth of glaciers. This Younger Dryas till, which was deposited by westward-flowing ice, has a loose, sandy matrix (57–80% sand) that is texturally similar to the Caledonia till. This Younger Dryas till formed, in part, by reworking of Late Wisconsinan glaciofluvial and glaciolacustrine sediments. Although the Caledonia and Younger Dryas tills appear to be texturally similar, the Caledonia till is somewhat slightly more compact, slightly siltier, and geochemically distinct. The

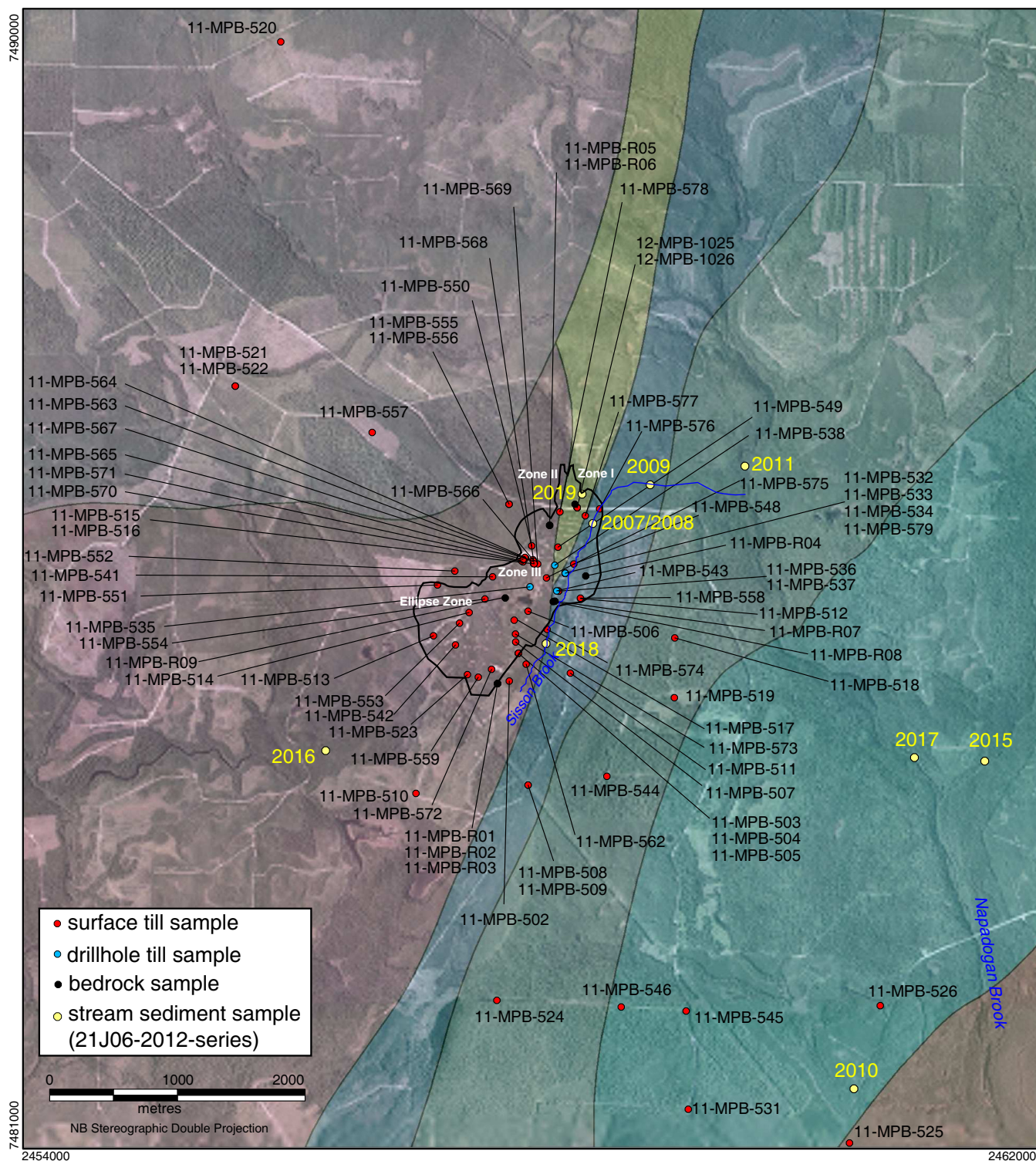


Figure 5. Detailed till, stream sediment, and bedrock sample location map for the deposit area. Deposit is outlined by thick black line from Rennie et al. (2012). Bedrock geology modified from Smith and Fyfe (2006a-d).

Younger Dryas till does not contain any metal-rich debris (W, Mo) derived from the Sisson deposit.

METHODS

Stream sediment and water samples were collected up stream, overlying, and downstream (southeast) of the

deposit (Figs. 4,5) by GSC and NBDEM in the summer of 2012 using GSC National Geochemical Reconnaissance (NGR) sampling protocols similar to those reported in Day et al. (2013) and McCurdy and McNeil (2014). At each of the 16 sites, three samples were collected:

Table 1. Indicator minerals in the Sisson W-Mo deposit (Nast and Williams-Jones 1991; Marr, 2009) and those found in bedrock polished thin sections (PTS) and heavy mineral concentrates (HMC), till heavy mineral concentrates (HMC), and stream heavy mineral concentrates (HMC) from this study.

Mineral	Formula	Specific gravity	Hardness	Presence in bedrock reported by others	Size range in PTS in this study (mm)	Size range in bedrock HMC in this study (mm)	Size range in till HMC in this study (mm)	Size range in stream sediment HMC in this study (mm)
scheelite	CaWO ₄	5.9-6.12	4-5	Nast & Williams-Jones (1991); Marr (2009)	0.1-0.5	0.025-2.0	0.025-2.0	0.05-2.0
wolframite	(Fe,Mn)WO ₄	7.1-7.5	4.5	Nast & Williams-Jones (1991); Marr (2009)	0.04-0.08	0.025-2.0	0.025-1.0	0.015-2.0
molybdenite	MoS ₂	5.5	1.0	Nast & Williams-Jones (1991); Marr (2009)	≤0.3	0.05-2.0	0.075-2.0	0.25-0.5
pyrite	FeS ₂	5-5.02	6.5	Nast & Williams-Jones (1991); Marr (2009)	0.015-2.2	0.025-2.0	0.025-0.05	0.05-0.5
marcasite	FeS ₂	4.89	6-6.5	no	not observed	0.025-0.10	not observed	not observed
chalcocopyrite	CuFeS ₂	4.1-4.3	3.5	Nast & Williams-Jones (1991); Marr (2009)	0.04-2.2	0.1-2.0	0.2-2.0	0.25-0.5
sphalerite	(Zn,Fe)S	3.9-4.2	3.5-4	Nast & Williams-Jones (1991); Marr (2009)	≤2.2	0.05-1.0	0.05-2.0	not observed
galena	PbS	7.2-7.6	2.5	Nast & Williams-Jones (1991); Marr (2009)	not observed	0.05-0.075	0.05	not observed
pyrrhotite	Fe _(1-x) S (x=0-0.17)	4.58-4.65	3.5-4	Nast & Williams-Jones (1991); Marr (2009)	0.05-2.2	0.025-0.25	not observed	0.25-0.5
arsenopyrite	FeAsS	6.1	5	Nast & Williams-Jones (1991); Marr (2009)	not observed	not observed	0.05-2.0	not observed
mottamite	Pb(Cu,Zn)(VO ₄)(OH)	5.9-6	3.5	no	not observed	not observed	0.25-0.5	not observed
bismuthinite	Bi ₂ S ₃	6.8-7.2	2.0	no	not observed	not observed	0.25-1.0	not observed
bismutite	Bi ₂ (CO ₃)O ₂	7.0	4.0	no	not observed	not observed	0.025-2.0	not observed
native bismuth	Bi	9.7-9.8	2-2.5	Nast & Williams-Jones (1991); Marr (2009)	0.01	not observed	0.025-1.0	not observed
joseite	Bi ₄ (S,Te) ₃	8.1	2.0	no	not observed	not observed	0.025-0.5	not observed
hessite	Ag ₂ Te	7.2-7.9	1.5-2	Nast & Williams-Jones (1991)	not observed	not observed	not observed	not observed
acanthite	Ag ₂ S	7.2-7.4	2-2.5	Nast & Williams-Jones (1991)	not observed	not observed	not observed	not observed
loellingite	FeAs ₂	7.1-7.7	5	no	not observed	not observed	not observed	0.25-0.5

1) *9 to 14 kg stream sediment sample for recovery of indicator minerals*

Bulk heavy-mineral samples were collected at the upstream ends of mid-channel boulder bars and behind mid-stream boulders. Sand-rich material was collected by shovel from one (preferred) or more holes dug in the stream bed, commonly to depths of a few 10s of cm. Material was wet-sieved through a 12-mesh (1.68 mm) stainless-steel sieve into a large plastic (labelled) sample bag inside a 20 litre (10 gallon) pail until a sample weight of between 10 and 15 kg was attained. The bag lining the pail, which was labelled with the sample number, was taped shut with black plastic (electrical) tape and placed into a second bag, also labelled with the sample number, and taped.

2) *200 g fine-grained (silt+fine sand) stream sediment sample for geochemical analysis and archiving*

Fine-grained (silt + sand) stream sediment was collected by hand from various points in the active channel while the sampler moved upstream, over a distance of 5 to 15 m. At each site, a Kraft paper bag (12.5 cm x 28.5 cm) was two-thirds filled with silt or fine- sand. The sample was collected after the water sample and before the bulk heavy-mineral sediment sample.

3) *60 ml stream water sample for geochemical analysis*

Waters were sampled in mid-channel, from flowing water where possible. One water sample was collected at each site. After rinsing, water was drawn into a 60 ml plastic syringe and filtered into a 60 ml HDPE bottle through a 0.45 µm disposable filter unit.

One field duplicate pair of water, silt, and heavy mineral samples, assigned sequential sample numbers,

was collected. The first sample of the pair was assigned a replicate status value of 10 and the second was assigned a replicate status value of 20. Routine (non-duplicate) field samples were assigned replicate status values of 0. Sample 21J06-2012-2008 is a duplicate of 21J06-2012-2007. The field note format is explained in Appendix A1, field data for each sample are listed in Appendix A2, and photos taken at each sample site are included in Appendix A3.

SAMPLE PROCESSING AND ANALYSIS

Stream sediment processing to recover indicator minerals

Seventeen stream sediment samples (16 samples + one field duplicate) and two blank samples were shipped to Overburden Drilling Management Limited (ODM), Ottawa, ON for processing, production of heavy mineral concentrates (HMC), and indicator mineral picking. Two 'blank' samples (21J06-2012-2001 and 21J06-2012-2014) were inserted into the batch by GSC prior to shipping, to monitor the quality of processing and picking at the laboratory. The blank samples are of the same type inserted into till sample batches for the Sisson study, i.e., weathered granite from New Brunswick (McClenaghan et al., 2012; Plouffe et al., 2013). The weight of all samples that were processed and the fractions that were produced are reported in McClenaghan et al. (2013a).

The <2.0 mm fraction of stream sediment samples was processed at ODM to produce a non-ferromagnetic heavy mineral concentrate for selection of indicator minerals as outlined in Figure 5 in McClenaghan et al. (2013a). Weights for all the fractions that were produced are reported in McClenaghan et al. (2013a).

First, 8 to 15 kg of the <2.0 mm material was passed over a shaking table and the heavy table concentrate recovered and micro-panned to recover any gold, sulphides, and tungsten minerals in the <0.25 mm fraction. The minerals in the panned concentrates were counted and their size and shape characteristics recorded; the minerals were then returned to the sample. Concentrates were then sieved at 0.25 mm. The 0.25 to 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. After panning and heavy liquid separation, the 0.25–2.0 mm 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, 1.0–2.0 mm. The <0.25 mm fraction of all samples was processed to recover the non-ferromagnetic fraction and then archived. The 0.25–0.5 mm fraction was further subjected to paramagnetic separations using a Carpc® magnetic separator to produce <0.6 amp (strongly paramagnetic), 0.6 to 0.8 amp (moderately paramagnetic), 0.8 to 1.0 amp (weakly paramagnetic), and >1.0 amp (non-paramagnetic fractions) to assist counting and picking indicator minerals in this fine-grained fraction. The 0.25–0.5 mm fraction was cleaned with oxalic acid to remove oxidation stains (tarnish) from the grains and restore their natural colour, which facilitates optical mineral identification most importantly for sulphide minerals.

Indicator mineral inspection and counting

The 0.25–0.5, 0.5–1.0, and 1.0–2.0 mm non-ferromagnetic fractions of stream sediment, samples were examined by ODM. Indicator minerals were counted/selected, including scheelite and wolframite, gold and sulphide minerals, as well as potential oxide and silicate indicators of massive sulphide deposits. ODM's magmatic or metamorphosed massive sulphide indicator mineral (MMSIM®) suite is an indicator mineral assemblage used to explore for a broad spectrum of sulphide-associated deposits (Averill, 2001). The visual identification of a number of limited mineral grains was verified with a scanning electron microscope (SEM). Scheelite fluoresces bright whitish blue under short-wave UV light. Mo-rich (molybdo-scheelite) scheelite from Zone III of the Sisson deposit (Marr, 2009) fluoresces bright yellow under short-wave UV light. This fluorescence was important to the visual identification and systematic counting of scheelite grains in stream sediment HMC in this study. The abundance of various mineral species in a random 100 grain point-count of the 0.25–0.5 mm non-ferromagnetic fraction of the stream sediment samples was carried out to document their mineralogy.

Table 2. Variables determined by Instrumental Neutron Activation analysis of the <0.177 mm fraction of stream sediment samples.

Variable	Detection Limit	Unit of Measure	Variable	Detection Limit	Unit of Measure
Ag	2	ppm ¹	Ni	10	ppm
As	0.5	ppm	Rb	5	ppm
Au	2	ppb ²	Sb	0.1	ppm
Ba	50	ppm	Sc	0.2	ppm
Br	0.5	ppm	Se	5	ppm
Cd	5	ppm	Sm	0.1	ppm
Ce	5	ppm	Sn	100	ppm
Co	5	ppm	Ta	0.5	ppm
Cr	20	ppm	Tb	0.5	ppm
Cs	0.5	ppm	Te	10	ppm
Eu	1	ppm	Th	0.2	ppm
Fe	0.2	pct ³	Ti	500	ppm
Hf	1	ppm	U	0.2	ppm
Ir	50	ppb	W	1	ppm
La	2	ppm	Weight	0.1	g ⁴
Lu	0.2	ppm	Yb	2	ppm
Mo	1	ppm	Zn	100	ppm
Na	0.02	pct	Zr	200	ppm

¹parts per million; ²parts per billion; ³percent; ⁴grams.

Stream sediment preparation and geochemical analysis

The brown Kraft paper bags containing the samples were placed into plastic bags, taped with electrical tape, and shipped directly to the GSC Laboratories in Ottawa, where they were unpacked and air-dried at temperatures below 40°C. After drying, samples were disaggregated and sieved to obtain the <0.177 mm (-80 mesh) material for analysis (Girard et al., 2004). Control reference and duplicate samples were inserted into each block of twenty samples at this time. Analytical data are reported in Appendix B1, worksheets 1 and 2.

Instrumental neutron activation analyses

Weighed and encapsulated stream silt samples, ~30 g, were packaged for irradiation at Becquerel Labs, Mississauga, Ontario along with international reference materials, and field and analytical duplicates. Samples and quality control insertions were irradiated together with neutron flux monitors in a two-megawatt pool-type reactor using their method BQ-NAA-1. After a seven-day decay period, samples were measured with a high-resolution germanium detector. Typical counting times were 500 seconds. Elements determined by instrumental neutron activation analysis (INAA) are listed in Table 2 and data are listed in Appendix B1, worksheet s.

Inductively coupled plasma mass spectrometry and other analyses

For the determination of the 65 elements listed in Table 3, a 0.5 g sample was leached with 6 mL/g of concen-

Table 3. Variables determined by Inductively Coupled Plasma – Emission Spectroscopy (ICP-ES)/Mass Spectroscopy (ICP-MS) for the <0.177 mm fraction of stream sediment samples.

Variable	Detection Limit	Unit of Measure	Analytical Method	Variable	Detection Limit	Unit of Measure	Analytical Method
Ag	2	ppb ¹	ICP-MS	Mo	0.01	ppm	ICP-MS
Al	0.01	pct ²	ICP-MS	Na	0.001	pct	ICP-MS
As	0.1	ppm ³	ICP-MS	Nb	0.02	ppm	ICP-MS
Au	0.2	ppb	ICP-MS	Nd	0.02	ppm	ICP-MS
B	20	ppm	ICP-MS	Ni	0.1	ppm	ICP-MS
Ba	0.5	ppm	ICP-MS	P	0.001	pct	ICP-MS
Be	0.1	ppm	ICP-MS	Pb	0.01	ppm	ICP-MS
Bi	0.02	ppm	ICP-MS	Pd	10	ppb	ICP-MS
Ca	0.01	pct	ICP-ES	Pt	2	ppb	ICP-MS
Cd	0.01	ppm	ICP-MS	Pr	0.02	ppm	ICP-MS
Ce	0.1	ppm	ICP-MS	Rb	0.1	ppm	ICP-MS
Co	0.1	ppm	ICP-MS	Re	1	ppb	ICP-MS
Cr	0.5	ppm	ICP-MS	S	0.02	pct	ICP-MS
Cs	0.02	ppm	ICP-MS	Sb	0.02	ppm	ICP-MS
Cu	0.01	ppm	ICP-MS	Sc	0.1	ppm	ICP-MS
Dy	0.02	ppm	ICP-MS	Se	0.1	ppm	ICP-MS
Er	0.02	ppm	ICP-MS	Sm	0.02	ppm	ICP-MS
Eu	0.02	ppm	ICP-MS	Sn	0.1	ppm	ICP-MS
Fe	0.01	pct	ICP-ES	Sr	0.5	ppm	ICP-MS
Ga	0.1	ppm	ICP-MS	Ta	0.05	ppm	ICP-MS
Gd	0.02	ppm	ICP-MS	Tb	0.02	ppm	ICP-MS
Ge	0.1	ppm	ICP-MS	Te	0.02	ppm	ICP-MS
Hf	0.02	ppm	ICP-MS	Th	0.1	ppm	ICP-MS
Hg	5	ppb	ICP-MS	Ti	0.001	pct	ICP-MS
Ho	0.02	ppm	ICP-MS	Tl	0.02	ppm	ICP-MS
In	0.02	ppm	ICP-MS	Tm	0.02	ppm	ICP-MS
K	0.01	pct	ICP-ES	U	0.1	ppm	ICP-MS
La	0.5	ppm	ICP-MS	V	2	ppm	ICP-MS
Li	0.1	ppm	ICP-MS	W	0.1	ppm	ICP-MS
LOI	0.1	pct	GRAV ⁴	Y	0.01	ppm	ICP-MS
Lu	0.02	ppm	ICP-MS	Yb	0.02	ppm	ICP-MS
Mg	0.01	pct	ICP-ES	Zn	0.1	ppm	ICP-MS
Mn	1	ppm	ICP-ES	Zr	0.1	ppm	ICP-MS

¹parts per billion; ²percent; ³parts per million; ⁴gravimetric

trated HCl, HNO₃, and demineralized water (2:2:2 v/v) at 95°C in a beaker for one hour at ACME Labs, Vancouver, British Columbia (ACME 1F04, 1F08, 1F09 packages). The sample solution was analyzed by inductively coupled plasma emission spectroscopy (ICP-ES) and inductively coupled plasma mass spectroscopy (ICP-MS). Data are listed in Appendix B1, worksheet 1.

Loss-on-ignition was determined at ACME Labs using a 1 g sample (ACME 2A05 package). Each sample was placed into a Leco® crucible and then into a 100°C muffle furnace and brought up to 500°C for one hour. The oven was then cooled to 100°C and the crucibles transferred to a desiccator followed by cooling to room temperature. The crucibles were re-weighed to determine the loss-on-ignition. Data are listed in Appendix B1, worksheet 2.

Stream water preparation and geochemical analysis

Filtered water samples were kept cool and away from light until shipment to GSC Laboratories in Ottawa, where they were acidified within 48 hours of arrival with 0.5 ml 8M HNO₃. Field duplicate water samples were included in the sample suite. Analytical data are listed in Appendix B1, worksheet 3.

Conductivity and pH

Conductivity and pH measurements were made using an Accumet AR50 dual channel pH/ion/conductivity meter with temperature compensation. The pH measurements were made using a Thermo Fisher Accumet combination double junction Ag/AgCl electrode (PN 13-620-221) and calibrated using buffers with a pH of 4.00, 7.00, and 10.00. The conductivity measurements

Table 4. Major and trace elements determined in stream waters.

Element		Detection Level	Laboratory Method	Element		Detection Level	Laboratory Method
<i>Waters –Filtered, Acidified (FA-Water)</i>				<i>Waters –Filtered, Acidified (FA-Water)</i>			
Al	Aluminum	2 ppb	ICP-MS	Mn	Manganese	0.1 ppb	ICP-MS
As	Arsenic	0.1 ppb	ICP-MS	Mo	Molybdenum	0.05 ppb	ICP-MS
B	Boron	0.5 ppb	ICP-MS	Na	Sodium	0.05 ppm	ICP-ES
Ba	Barium	0.2 ppb	ICP-MS	Nb	Niobium	0.01 ppb	ICP-MS
Be	Beryllium	0.005 ppb	ICP-MS	Nd	Neodymium	0.005 ppb	ICP-MS
Br	Bromine	0.05 ppb	ICP-ES	Ni	Nickel	0.2 ppb	ICP-MS
Ca	Calcium	0.02 ppm	ICP-ES	P	Phosphorus	0.05 ppm	ICP-ES
Cd	Cadmium	0.02 ppb	ICP-MS	Pb	Lead	0.01 ppb	ICP-MS
Ce	Cerium	0.01 ppb	ICP-MS	Pr	Praseodymium	0.005 ppb	ICP-MS
Cl	Chlorine	0.1 ppm	ICP-ES	Rb	Rubidium	0.05 ppb	ICP-MS
Co	Cobalt	0.05 ppb	ICP-MS	Re	Rhenium	0.005 ppb	ICP-MS
Cr	Chromium	0.1 ppb	ICP-MS	S	Sulphur	0.05 ppm	ICP-ES
Cs	Cesium	0.01 ppb	ICP-MS	Sb	Antimony	0.01 ppb	ICP-MS
Cu	Copper	0.1 ppb	ICP-MS	Si	Silicon	0.02 ppm	ICP-ES
Dy	Dysprosium	0.005 ppb	ICP-MS	Sm	Samarium	0.005 ppb	ICP-MS
Er	Erbium	0.005 ppb	ICP-MS	Sn	Tin	0.01 ppb	ICP-MS
Eu	Europium	0.005 ppb	ICP-MS	Sr	Strontium	0.5 ppb	ICP-MS
Fe	Iron	0.005 ppm	ICP-ES	Tb	Terbium	0.005 ppb	ICP-MS
Ga	Gallium	0.01 ppb	ICP-MS	Te	Tellurium	0.02 ppb	ICP-MS
Gd	Gadolinium	0.005 ppb	ICP-MS	Ti	Titanium	0.5 ppb	ICP-MS
Ge	Germanium	0.02 ppb	ICP-MS	Tl	Thallium	0.005 ppb	ICP-MS
Ho	Holmium	0.005 ppb	ICP-MS	U	Uranium	0.005 ppb	ICP-MS
K	Potassium	0.05 ppm	ICP-ES	V	Vanadium	0.1 ppb	ICP-MS
La	Lanthanum	0.01 ppb	ICP-MS	W	Tungsten	0.02 ppb	ICP-MS
Li	Lithium	0.02 ppb	ICP-MS	Y	Yttrium	0.01 ppb	ICP-MS
Lu	Lutetium	0.005 ppb	ICP-MS	Yb	Ytterbium	0.005 ppb	ICP-MS
Mg	Magnesium	0.005 ppm	ICP-ES	Zn	Zinc	0.5 ppb	ICP-MS

were made using Thermo Fisher Accumet 4-cell conductivity probes with automatic temperature compensation, with a 1.0 cm⁻¹ cell constant (PN 13-620-165) for samples in the 10 to 2000 micro S cm⁻¹ range and a 10.0 cm⁻¹ cell constant (13-620-166) for samples in the 1000 to 200,000 range. Commercial conductivity standards were used for calibration. Data are listed in Appendix B1, worksheet 3.

Trace and major element analyses

Acidified and filtered stream water samples were analyzed for trace metal and major elements at GSC Laboratories in Ottawa. A complete list of elements and stated detection limits are given in Table 4. Trace metal analysis was performed using a Thermo X Series 2 quadrupole inductively coupled plasma mass spectrometer (ICP-MS) with Xt cones, PlasmaScreen fitted, standard concentric nebulizer and Peltier cooled conical impact bead spray chamber (3°C) using Rh and Ir as internal standards. Most elements measured and corrections for spectral interferences are detailed in Hall et al. (1995, 1996). Data for Hf and Zr are not published because these elements are not sufficiently stabilized in

water by the addition of nitric acid. Data for In, Se, Ag, Ta, and Tl are not published because of inadequate detection limits and/or precision.

Major element analysis was performed using an axial Spectro Arcos, inductively coupled plasma optical emission spectrometer (ICP-ES) using a 1% CsNO₃ buffer (1:5 ratio) as a matrix modifier with a Burgener Teflon Mira Mist Nebulizer (uptake rate 1 mL/min) and a cyclonic spray chamber. The argon flow-rates are coolant 14.5 L/min⁻¹, auxiliary 0.9 L/min⁻¹, and nebulizer 0.8 L/min⁻¹. The RF power is 1500 watts. Inter-element correction factors were applied as required to correct for various spectral interferences. Data for Sc are not published because of inadequate detection limits and/or precision. Data are listed in Appendix B1, worksheet 3.

RESULTS

Stream sediment geochemical quality assurance/quality control

Analytical data for stream sediment field duplicates, certified reference standards, and analytical (blind)

duplicates are reported in Appendix B2, worksheets 1 to 4.

Accuracy

The accuracy of geochemical data for routine samples was evaluated by comparing the results from the analysis of the Certified Reference Materials (CRM) (Appendix B2, worksheets 1 and 2) with accepted values for these standards published in Lynch (1990, 1999) and Burnham and Schweyer (2004). One aliquot of each of the two Certified Reference Materials, STSD-2 and STSD-4, were included with the 17 stream silt samples submitted for analysis. Concentrations of elements in STSD-4, for which no published values were found (Pd, Re, S, Na, K, B, and Ge), were estimated from unpublished data ($n \geq 40$) from previous GSC geochemical surveys. Insufficient data were available for these elements for STSD-2. See Appendix B2, worksheet 1, Tables B1 and B2 for element listings.

Chemical analyses for the Sisson samples from commercial labs fall into two broad categories; 'partial' and 'total' (or near-total). Partial analyses employ a combination of hydrochloric and nitric acid (2:2) to digest a 0.5 g of sample material. The resulting solution is then passed through a mass spectrometer to estimate the concentration of elements dissolved in the solution. Although the concentrations of some elements estimated in this manner can be 'near-total', a portion of some elements can remain undissolved, locked in minerals resistant to dissolution by a partial extraction. Minerals resistant to partial acid digestion include spinels, beryl, tourmaline, chromite, zircon, monazite, niobates, tungstates, topaz, and cassiterite (Crock and Lamothe, 2011).

A method that is considered 'total' and involves no dissolution of sample is instrumental neutron activation analysis (INAA). Dried samples of ~30 g are irradiated with neutrons in a nuclear reactor for a measured time, removed, and the resulting gamma-ray spectrum is used to identify and quantify a range of trace metals (Alfassi, 2006).

Most of the INAA analytical data above detection limit was within one standard deviation (S.D.) of accepted values. The one exception, Yb in STSD-2, was just outside the ± 2 S.D. range. For elements Zr, Ag, Cd, Ir, Sn, Se, and Te, all or most values were below the detection level. For elements determined by a partial method, most analytical results were within two standard deviations of the accepted values. Concentrations of elements highlighted in bold in Appendix B2 (worksheet 1, Accuracy Data) fall outside the ± 2 S.D. range guidelines, however in most cases these elements, such as Zr (zircon), Nb (niobates), W (tungstates), Al (spinel, tourmaline, topaz),

Sn (cassiterite), and rare earth elements (monazite) may form constituents of resistate minerals in the CRMs. Other discrepancies may arise from the use of different combinations of nitric and hydrochloric acid used in the sample digestion process. In Appendix B2 (worksheet 1, Accuracy Data), 'Accepted Values' in red were taken from results published by Burnham and Schweyer (2004). The sample digestion these authors used was a modified aqua regia method employing a nitric-acid-rich 4:3 mixture of HNO₃ and HCl, rather than the traditional 1:3 ratio. It was created to work with organic-rich sediments, where a higher oxidizing power is required to breakdown the organic matrix (M. Burnham, pers. comm.).

Precision

Precision is a measure of the ability of an analytical method to reproduce the same value each time a sample is analyzed. Before submitting samples for analysis, 1 of the 16 routine samples in the 20 samples sent to commercial laboratories was divided into two samples and the split was given the number of the first position in the block of 20. Sample pairs were independently analyzed by the same method, using the same equipment, within short intervals of time. Sisson samples were included with a batch of 298 routine and control samples, including 19 analytical duplicate pairs, from a stream sediment survey in Nunavut collected around the same time (McCurdy et al., 2013). Both Nunavut and Sisson samples were analyzed at the same time and while results are not directly comparable (most elements in the Sisson samples are at higher concentrations), it is reasonable to assume that analytical precision, measured as the percent Relative Standard Deviation (RSD %) in samples from Nunavut, is applicable to the Sisson samples. For Nunavut samples with less than 12% of the values below detection limits, the RSD exceeded 20% for Ag and Th using a modified aqua regia digestion, suggesting that these elements, for mapping or statistics, at least at low concentrations, should be used with caution for mapping or calculating statistics. Duplicate data are reported in Appendix B2, worksheet 3.

Stream water geochemical quality assurance/quality control

One blank sample, one Certified Reference sample, and one field duplicate pair were included with Sisson Brook water samples (Appendix B2, worksheet 5). No discrepancies were noted.

Geochemical data

Stream sediment <0.177 mm fraction

Loss on ignition values in stream sediments range from 5.9 to 24.0%. Values are highest in stream samples col-

lected closest to the deposit (Appendix C1, map 1). Iron and Mn contents in stream silts vary between 1.1 and 5.1% and between 220 and 6452 ppm, respectively. The highest Fe contents are in samples from streams southeast of the deposit, which drain Silurian and Ordovician rocks (Appendix C, map 2). The highest Mn content (6542 ppm) is in sample 21J06-2012-2007, collected over the north end of the deposit (Appendix C, map 3). Tungsten data for samples were plotted using the same ranges used for the regional data in Figure 2. Tungsten values in stream sediment samples in this study vary between 2 and 297 ppm. The highest W values in stream silt are in samples collected overlying and immediately downstream of the north end of the deposit, as well as in streams that are 4.5 to 5.5 km southwest of the deposit and drain the southeast-trending glacial dispersal train (samples 21J06-2012-2010 and 21J06-2012-2012) (Appendix C1, map 4).

Molybdenum data for stream sediment samples were plotted using the same ranges used for the regional data that are plotted in Figure 3. Molybdenum values for samples from this study range from <1 to 69 ppm. The highest Mo values are in samples collected in the stream passes over the deposit and in streams that drain the immediate deposit area to the southwest (sample 21J06-2012-2016) and east (sample 21J06-2012-2009) (Appendix C1, map 5). Bismuth content in stream silt varies from 0.1 to 12.5 ppm, with the highest values from samples collected over the north end of the deposit and in sample 21J06-2012-2010, which was collected from a stream that drains the glacial dispersal train 4 km southeast of the deposit (Appendix C1, map 6).

Arsenic content in stream sediment varies from 3 to 169 ppm. The highest As values occur in samples collected over the deposit, immediately downstream to the east, and overlying Silurian to Cambrian rocks southeast of the deposit (Appendix C, map 7). The Ag content in stream sediment samples ranges between 57 and 887 ppb. The highest values (422–887 ppb) are in samples collected over the deposit and samples collected immediately downstream (296–472 ppb) to the east-southeast (samples 21J06-2012-2009, 21J06-2012-2017). Elevated values (272–378 ppb) also occur in samples from streams draining the glacial dispersal train to the southeast (samples 21J06-2012-2010 and 21J06-2012-2012) (Appendix C1, map 8).

Copper content of stream silt samples varies from 3 to 123 ppm. The highest Cu values are in samples collected over the deposit and immediately downstream to the east, as well as in sample 21J06-2012-2017, collected 4 km downstream, and in sample 21J06-2012-2012, collected in a stream that drains the glacial dispersal train southeast of the deposit (Appendix C1, map 9).

Zinc content in stream sediment ranges from 24 to 203 ppm. The greatest concentrations of Zn are in samples collected over and immediately downstream of the north end of the deposit, and in streams that drain Silurian to Cambrian rocks to the southeast (samples 21J06-2012-2015, 21J06-2012-2002) (Appendix C1, map 10). The Cd content of stream sediment samples in the study area varies between 0.25 and 4.54 ppm. The highest Cd values are in stream silt samples collected over the deposit as well as downstream of the deposit to the east (sample -2019) and southeast (sample -2017) (Appendix C1, map 11). Indium values in stream sediment vary between <0.02 and 0.07 ppm. The highest In values are in samples collected over the deposit and in streams that directly drain the deposit (samples 21J06-2012-2009, 21J06-2012-2017) and that drain the glacial dispersal train to the southeast (sample 21J06-2012-2010) (Appendix C1, map 12). Stream sediment Tl contents vary from 0.12 to 1.32 ppm. Values are highest in samples collected from streams overlying the deposit (samples 21J06-2012-2019, 21J06-2012-2007) and from streams that drain the deposit to the southwest (sample 21J06-2012-2016) and east (sample 21J06-2012-2009), as well as from streams that drain Ordovician rocks to the southeast (samples 21J06-2012-2017, 21J06-2012-2015) (Appendix C1, map 13).

Stream water

Stream water pH varies between 6.7 and 7.2. The highest pH values in waters are at sample sites overlying Cambrian to Ordovician rocks, east and southeast of the deposit (Appendix C2, map 14). Stream waters are CaNa-HCO₃ waters, with low salinities (conductivity < 55 µS/cm), which are typical of small streams in this setting (Leybourne et al., 2003). The distribution of Fe, Mn, and Ca in stream waters are plotted on maps 15 to 17 in Appendix C2. Geochemical patterns for these three elements appear to be unrelated to the presence of the Sisson deposit.

Tungsten concentrations in stream waters vary between <0.02 and 0.66 ppb. The highest values (0.12–0.66 ppb) are samples collected at sites overlying and immediately (<1 km from) draining the deposit towards the southwest and to the east (Appendix C2, map 18). Slightly elevated values (0.05–0.06 ppb) occur in water sample from site 21J06-2012-2017, 4 km downstream, and site 21J06-2012-2010 within the southeast-trending glacial dispersal train. Concentrations of Mo in stream water vary from 0.1 to 7.5 ppb. Similar to W, the highest Mo values are in samples from sites overlying and immediately (<1 km from) draining the deposit towards the southwest and to the east (Appendix C2, map 19).

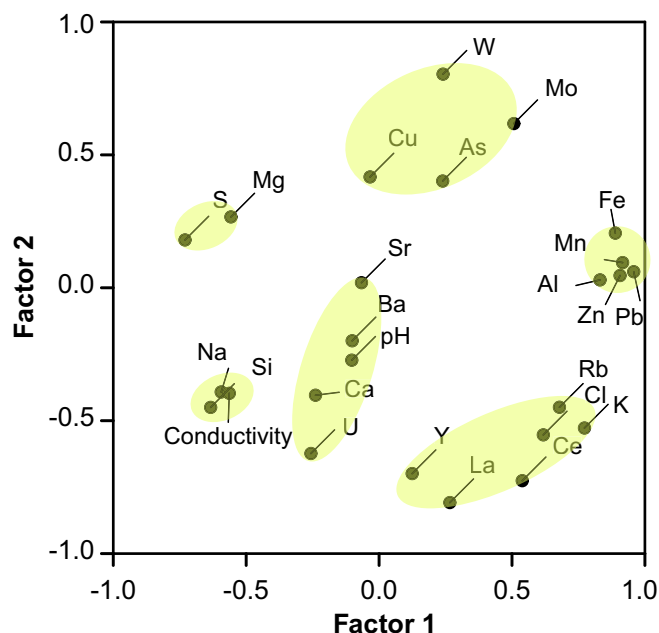


Figure 6. Plot of R-Mode factor analysis results for stream water data: Factor 1 versus Factor 2 with identified element groups highlighted in yellow (N=17).

Arsenic concentrations in stream waters range between 0.8 and 4.5 ppb. The highest As values (3.3–4.5 ppb) are from samples from sites immediately downstream of the deposit (samples 21J06-2012-2016, 21J06-2012-2009) and from one site (21J06-2012-2010) southeast of the deposit in a stream that drains the glacial dispersal train (Appendix C2, map 20). Stream waters contain between 0.2 and 2.3 ppb Cu. The highest Cu concentrations (0.6–2.4 ppb) are from samples collected at sites overlying and immediately draining the deposit to the southwest and to the east-southeast (Appendix C2, map 21).

Tungsten shows statistically significant strong correlations (95% confidence, 2 tailed test, Pearson Product Moment correlation) with Mo ($r = 0.8766$) and Cu (0.6890). For most other analytes, W shows poor correlation with the exception of Fe, with a correlation of $r = 0.4823$, although this is not statistically significant. Molybdenum, in addition to statistically significant positive correlations with W and Cu, is also positively correlated with Zn and Fe ($r = 0.5843$ and 0.6233, respectively). Arsenic is positively correlated with Cu ($r = 0.4631$) and Mo ($r = 0.4617$) but significantly with W ($r = 0.3891$). Zinc and Pb show positive, statistically significant correlations with each other, Mn, Fe, K, and Rb. Correlations between aqueous species are evident from factor analysis. Using R-Mode factor analysis, the first two factors account for 55% of the total variation, with six groups of elements in Factor 1 versus Factor 2 space: 1) W, Cu, Mo, As; 2) S, Mg; 3) Na, Si, conductivity; 4) Sr, Ba, pH, Ca, U; 5) Fe, Mn, Al, Zn, Pb; and 6) Rb, K, Cl, REE (Fig. 6).

Indicator mineral quality assurance/quality control

Indicator mineral data for the two Bathurst blank samples, 21J06-2012-2001 and 21J06-2012-2014, are reported in McClenaghan et al. (2013a) and summarized in Appendix B3. Blank samples contain no indicator minerals related to W-Mo deposits. These results indicate that no evidence of carryover contamination during sample processing was detected. Indicator mineral counts for the one field duplicate pair (samples 21J06-2012-2007 and 21J06-2012-2008) are reported in Appendix B3. Both samples contain similar contents of scheelite and wolframite in all size fractions.

Indicator mineral data

All indicator mineral data for stream sediment samples are listed in McClenaghan et al. (2013a). Raw and normalized abundance data for selected indicator minerals are summarized in Appendix B3. Normalized indicator mineral data for stream sediments are plotted as proportional symbol maps in Appendix C3 along with till data previously reported in McClenaghan et al. (2014a). Only normalized indicator mineral abundances are discussed below, not raw mineral abundance data. Background contents of indicator minerals were defined using samples collected upstream of the Sisson deposit (Fig. 4): samples 21J06-2012-2006, 21J06-2012-2011, and 21J06-2012-2015.

Scheelite was identified in stream sediment HMC by its pale yellow colour, cleavage, and bright blue-white to yellow fluorescence under short-wave UV light. It was recovered from stream sediment samples upstream, overlying, and downstream of the Sisson deposit (Appendix C3, maps 25 to 27) and is most abundant in the 0.25–0.5 mm fraction (Table 5). In the 0.25–0.5 mm fraction, background samples upstream contain between 2 and 8 scheelite grains. Samples from streams overlying the deposit contain 128 to 2041 grains (Appendix C3, map 25). In the 0.5–1.0 mm fraction, background samples contain between 0 and 3 scheelite grains and samples collected overlying the deposit and downstream contain between 0 and 255 coarse grains (Appendix C3, map 26). The 1.0–2.0 mm fraction contains no scheelite in background areas and between 3 and 41 grains in samples 21J06-2012-2007, -2018, and -2019, collected overlying the deposit, and sample 21J06-2012-2017, collect 4 km downstream (Appendix C3, map 27). Fine-grained scheelite (50–300 μm) was recovered only from the pan concentrate of three samples that overlie the deposit: samples 21J06-2012-2007, -2018, and -2019.

Wolframite was identified in stream sediment HMC by its black colour, prismatic crystal form, softness ($H=4.5$, can be scratched with a needle), and reddish

Table 5. Abundance of indicator minerals in heavy mineral pan concentrate, 0.25–0.5 mm, 0.5–1.0 mm, and the 1–2.0 mm fractions of mineralized bedrock and stream sediment samples normalized to 10 kg sample weight. Data from McClenaghan et al. (2013b).

Sample Media	Sample Number	Interpretation	Distance from Deposit (m)	Scheelite				Wolframite				Molybdenite	Chalcopyrite	Arsenopyrite	Sphalerite	Bi minerals	Pyrite	Spessartine
				pan conc	0.25-0.5 mm	0.5-1.0 mm	1.0-2.0 mm	pan conc	0.25-0.5 mm	0.5-1.0 mm	1.0-2.0 mm	0.25-0.5 mm	0.25-0.5 mm	0.25-0.5 mm	0.25-0.5 mm	0.25-0.5 mm	0.25-0.5 mm	0.25-0.5 mm
bedrock* stream sediments**	11-MPB-R05	mineralized quartz vein	0.0	81433	179365	29894	1140	0	89682	4780	774	0	107622	0	17940	0	2989	0
	21J06-2012-2006	background up stream	-6.0	0	8	1	0	0	0	0	0	0	0	0	0	0	0	0
	21J06-2012-2005	background up stream	-4.5	0	2	3	0	0	0	0	0	0	0	0	0	0	1	4
	21J06-2012-2015	background up stream	-4.0	0	5	3	0	0	0	0	0	0	0	0	0	0	1	0
	21J06-2012-2011	background up stream	-1.5	0	2	0	0	0	0	0	0	0	1	1	1	0	2475	2970
	21J06-2012-2007	overlying	0.0	510	2041	255	41	2	153	82	23	2	2	2	0	0	0	0
	21J06-2012-2018	overlying	0.0	171	128	43	1	0	1	0	0	0	0	0	0	0	0	26
	21J06-2012-2019	overlying	0.0	50	300	57	3	0	5	0	0	0	0	0	0	0	0	0
	21J06-2012-2009	downstream	0.5	0	730	36	0	0	36	4	0	0	0	0	0	0	0	0
	21J06-2012-2016	downstream	1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0
	21J06-2012-2017	downstream	4.0	0	75	16	1	0	12	4	2	0	4	0	0	0	7	14151
	21J06-2012-2010	downstream of dispersal train	4.5	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0
	21J06-2012-2012	downstream of dispersal train	5.0	0	75	7	0	0	0	0	0	0	3	0	0	0	1	9
	21J06-2012-2002	downstream of dispersal train	6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	21J06-2012-2004	downstream	7.0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	19
21J06-2012-2003	downstream of dispersal train	9.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	190	
21J06-2012-2013	downstream	16.0	0	7	1	0	0	0	0	0	0	2	2	0	0	19	20	

* normalized to 1 kg sample weight

** normalized to 10 kg sample weight

brown streak. It was recovered from 5 of 16 stream sediment samples (Table 5): samples 21J06-2012-2007, -2018, and -2019 overlying the deposit, sample 21J06-2012-2009, collected 750 m downstream, and sample 21J06-2012-2017, collected 4 km downstream (Appendix C3, map 28). The low abundance of wolframite in stream sediments (maximum 153 grains/0.25–0.5 mm fraction) relative to scheelite (maximum 2041 grains/0.25–0.5 mm fraction) reflects its lower content in the Sisson deposit compared to scheelite. Coarse (0.5–2.0 mm) wolframite grains were recovered from three samples, 21J06-2012-2007 collected overlying the deposit, sample 21J06-2012-2009 collected 0.75 km downstream, and sample 21J06-2012-2017 collected 4 km downstream (Table 5). Fine-grained wolframite (150–250 µm) was recovered from the pan concentrate of sample 21J06-2012-2007 (Table 5).

One stream sediment sample (21J06-2012-2007) overlying the deposit contains two molybdenite grains (Appendix C3, map 29). This site is 0.5 km northeast of the few till samples (11-MPB-532 to -536, 11-MPB-567, -568) that were found to contain visible molybdenite grains (McClenaghan et al., 2014a). The presence of molybdenite in only one stream sediment sample reflects its extreme softness ($H=1$) and thus, its inability to survive glacial and subsequent fluvial transport.

Other sulphide minerals present in stream sediments include rare arsenopyrite (Appendix C3, map 30), sphalerite, or chalcopyrite grains. Sample 21J06-2012-2007, collected overlying the deposit, contains two chalcopyrite, two arsenopyrite, and one loellingite (FeAs_2) grain in the 0.25–0.5 mm fraction. Background sample 21J06-2012-2011, overlying Ordovician rocks to the northeast, contains one grain each of sphalerite, chalcopyrite, and arsenopyrite. A few grains of pyrite are present in most stream sediment samples; however, one sample (21J06-2012-2011) contains 1000s of grains (Appendix C3, map 31).

Most stream sediment samples contain few to no spessartine grains (0–26 grains) (Appendix C3, Map 32). Two stream sediment samples (21J06-2012-2011, 21J06-2012-2017) are noteworthy because they contain 1000s of spessartine grains. These two samples overlie Ordovician rocks to the northeast and east of the Sisson deposit.

DISCUSSION

Source of high metal contents in stream sediment and water

The Sisson deposit contains an estimated resource of 383 Mt at 0.069% WO_3 (Rennie et al., 2012), thus it is not unexpected for stream sediments, derived from metal-rich glacial sediments that in turn were eroded

from the deposit, to contain significant (100s ppm) W concentrations in the <0.177 mm fraction, 100s to 1000s of scheelite grains in the HMC fraction (Table 5) and 10s to 100s ppt in stream waters (Table 5). Rennie et al. (2012) also reported that the Sisson deposit has a significant grade of Mo (0.023%) hosted by molybdenite and Mo-rich scheelite, which they refer to as molybdoscheelite. As a result, stream silts overlying and downstream of the deposit contain 10s ppm Mo, and stream waters contain 100s of ppb Mo. One stream sediment HMC sample contains visible molybdenite (sample 21J06-2012-2007: Table 5).

Elevated Cu values (100s ppm) in some stream sediment and stream water samples at Sisson likely reflect the presence of chalcopyrite in the mineralized rocks and metal-rich till. Sphalerite is likely the source of elevated Zn as well as a source for trace elements contained in sphalerite (Cd, In, Tl) (Cook et al., 2009; Pfaff et al., 2011) in stream sediments and stream waters overlying and just downstream of the deposit. Silver-bearing minerals in the deposit include hessite and acanthite (Nast and Williams-Jones, 1991) and these minerals may be the source of elevated Ag in stream sediments near the deposit. Arsenopyrite is present in the deposit and in the heavy mineral fraction of metal-rich till overlying the deposit (McClenaghan et al., 2013a, 2014a), and is the most likely source of the highest As values in stream sediments and stream waters.

Utility of surface water chemistry for exploration

A number of studies have demonstrated the utility of aqueous geochemistry, both ground and surface water, in geochemical mineral exploration (Leybourne and Cameron, 2010; Leybourne et al., 2003). However, few, if any studies exist that have used water chemistry as a tool for exploration of W mineralization. Tungsten typically occurs as an oxyanion in most ground and surface waters, i.e., WO_4^{2-} (most stable in its 6+ form in waters) (Baes and Mesmer, 1976). There are relatively few studies of W concentrations in surface waters in general, so it is difficult to establish background and anomalous concentrations. However, in ocean waters and based on some estimates of river waters, W likely is typically on the order of 10s of parts per trillion, at most. Around the Sisson deposit, proximal surface waters have dissolved W concentrations that are clearly above what would be considered background (i.e. 1000s of ppt rather than 10s). More detailed sampling along the streams draining the Sisson deposit would be needed to determine the potential dispersion distances of W in stream waters, but the anomalous concentrations proximal to the deposit indicate that WO_4^{2-} is a potentially powerful tool for geochemical exploration for W mineralization. Based on the ele-

mental associations, the pathfinder elements in water include Cu, As, and Mo. Aqueous dispersion of Cu will be limited by its cation form in water, which results in strong affinity for Fe- and Mn-oxyhydroxide surfaces. Conversely, W, As, and Mo all form oxyanions at the pH and redox conditions, typical of third- and fourth-order streams in New Brunswick (Leybourne et al., 2003), so that dispersion of these oxyanions will be greater than for base metals (e.g. Leybourne and Cameron, 2008).

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 W is the optimal indicator element for the Sisson deposit in stream sediments and stream water. Molybdenum is also an indicator element in stream sediments and stream water, but to a much less extent.

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 stream silt downstream of the Sisson deposit include Ag, As, Bi, Cd, In, Tl, Cu, and Zn. Pathfinder elements in stream water include As, Cd, Cu, Cs, and Zn.

The extensive suite of indicator/pathfinder elements identified at Sisson reflects, in part, the polymetallic nature of the deposit as well as the ability of modern ICP-MS techniques to determine a broad suite of elements at lower detection limits.

An analytical technique that reports the total content of W is necessary for stream sediment analysis as aqua regia does not fully digest W-bearing oxides. In this study, INAA was used to determine the total W, Mo, and Fe content of stream sediment samples. The pathfinder elements listed above were determined by aqua regia digestion as they are derived from sulphide and telluride minerals (Table 1) that are easily digested by aqua regia.

Indicator minerals species

The ore minerals in bedrock samples from the Sisson deposit include scheelite, wolframite, and molybdenite (McClenaghan et al., 2013b). These are heavy minerals (Table 1) that are visually distinct and easily recovered by common surficial sample processing methods (cf. McClenaghan, 2011) used to recover indicator minerals. All three ore minerals were recovered from stream sediments around the Sisson deposit. Other indicator minerals of the deposit that were found in stream sediments include chalcopyrite, sphalerite, arsenopyrite, pyrite, and possibly spessartine. These other minerals are much less abundant in the deposit and thus are

Table 6. Stream sediment geochemical data and indicator mineral abundances (normalized to a 10 kg sample weight) in the 0.25–0.5 mm heavy mineral fraction for samples listed according to distance downstream from the Sisson deposit. Heavy mineral data from McClenaghan et al. (2013b).

Sample	Interpretation	Distance		W		Mo		As		Bi		Sch		Wo		Mo		Ccp		Apy		Sph		Py	
		downstream	from deposit	stream silt	stream water	stream silt	stream water	stream silt	stream water	stream silt	stream water	0.25–0.5 mm	0.25–0.5 mm	0.25–0.5 mm	0.25–0.5 mm	0.25–0.5 mm	0.25–0.5 mm	0.25–0.5 mm	0.25–0.5 mm	0.25–0.5 mm	0.25–0.5 mm	0.25–0.5 mm	0.25–0.5 mm	0.25–0.5 mm	0.25–0.5 mm
21J06-2012-2006	background upstream	-6.0	5	<0.02	0.64	197	0.64	69	6.60	169	2.2	4.7	2041	153	2	2	2	0	0	0	0	0	0	0	0
21J06-2012-2005	background upstream	-4.5	2	0.04	0.47	23	0.47	3	0.63	3	1.5	0.3	128	1	0	0	0	0	0	0	0	0	0	1	0
21J06-2012-2015	background upstream	-4.0	2	<0.02	0.11	42	0.11	19	0.38	55	0.9	4.6	300	5	0	0	0	0	0	0	0	0	0	1	0
21J06-2012-2011	background upstream	-1.5	3	<0.02	0.53	115	0.53	18	3.66	79	4.2	3.7	730	36	0	0	0	0	0	0	0	0	1	2475	0
21J06-2012-2007	overlying	0.0	18	0.57	0.06	6	0.06	5	0.51	45	1.4	1.0	75	12	0	4	0	0	0	0	0	0	0	0	0
21J06-2012-2018	overlying	0.0	23	0.47	0.05	41	0.05	2	0.25	32	4.5	7.2	15	0	0	0	0	0	0	0	0	0	0	0	0
21J06-2012-2019	overlying	0.0	42	0.11	0.02	33	0.02	2	0.14	29	1.0	2.6	75	0	0	3	0	0	0	0	0	0	0	0	0
21J06-2012-2009	downstream	0.5	115	0.53	0.02	2	0.02	2	0.12	44	1.3	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
21J06-2012-2016	downstream	1.0	18	0.57	0.02	7	0.02	1	0.11	5	0.9	0.1	3	0	0	0	0	0	0	0	0	0	0	0	0
21J06-2012-2017	downstream	4.0	6	0.06	0.02	8	0.02	1	0.34	6	0.9	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0
21J06-2012-2010	downstream of dispersal train	4.5	41	0.05	0.02	3	0.02	2	0.14	29	1.0	2.6	75	0	0	3	0	0	0	0	0	0	0	0	0
21J06-2012-2012	downstream of dispersal train	5.0	33	0.02	0.02	2	0.02	2	0.12	44	1.3	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
21J06-2012-2002	downstream of dispersal train	6.5	2	<0.02	0.02	2	0.02	2	0.12	44	1.3	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
21J06-2012-2004	downstream	7.0	7	<0.02	0.02	8	0.02	1	0.34	6	0.9	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0
21J06-2012-2003	downstream of dispersal train	9.5	8	0.02	0.02	3	0.02	2	0.24	15	0.8	0.3	7	0	0	2	0	0	0	0	0	0	0	0	0
21J06-2012-2013	downstream	16.0	3	<0.02	0.02	3	0.02	2	0.24	15	0.8	0.3	7	0	0	2	0	0	0	0	0	0	0	0	19

Abbreviations: Apy = arsenopyrite, Ccp = chalcopyrite, Mo = molybdenite, Py = pyrite, Sch = scheelite, Sph = sphalerite, Wo = wolframite

much less abundant in stream sediments. This suite of indicator minerals will be useful for W-Mo exploration in the region using till and stream sediment sampling. These indicator minerals are most abundant in the pan concentrate (<0.25 mm) and the 0.25–0.5 mm fraction of stream sediments.

The bedrock source of spessartine in stream sediments is not known. Gardiner and Venugopal (1992) have reported the presence of spessartine in the Sisson deposit. Thus the grains in stream sediments may be derived from the Sisson deposit, metamorphosed massive sulphide mineralization northeast of the Sisson deposit in Tetagouche Group rocks, or from regional metamorphosed rocks.

Indicator mineral size

The size of indicator minerals in stream sediments is controlled primarily by the size of the mineral grains in the source rock and the durability of the mineral during glacial and subsequent fluvial transport. Table 1 lists the size of indicator minerals seen in mineralized bedrock and stream sediment samples in this study. Mineral durability is indicated by the mineral hardness. Scheelite and wolframite grains of up to 2 mm were recovered from bedrock and stream sediment samples downstream. Most grains occur in the pan concentrate and 0.25–0.5 mm fractions of stream sediments. Scheelite and wolframite grains 0.5–1.0 mm and 1.0–2.0 mm in size were recovered in stream sediments up to 4 km downstream.

Distance of fluvial transport

The Sisson deposit is covered by 3 to >8 m of till; no stream directly erodes the bedrock surface of the deposit. Thus, W-Mo indicator minerals recovered in stream sediments have been eroded from till and fluvially transported to their present stream locations. Indicator mineral abundances in stream sediment samples are summarized in Table 6, along with their estimated distance downstream from the deposit or from the glacial dispersal train. Data in the table may be used as a guide as to which minerals might be expected at which fluvial transport distance downstream from a W-Mo mineralized source in glaciated terrain.

Scheelite and wolframite were recovered from stream sediments at least 4 km downstream, within the drainage system directly draining the north end of the Sisson deposit. This drainage system includes site 21J06-2012-2018 in Sisson Brook immediately east of the deposit, site 21J06-2012-2007 in Sisson Brook and overlying the deposit, site 21J06-2012-2019 in a tributary stream to Sisson Brook and overlying the deposit, site 21J06-2012-2009 in Sisson Brook 0.5 km downstream to the east, and site 21J06-2012-2017 4 km downstream from the deposit in Napadogan Brook.

Between 15 and 75 scheelite grains were recovered from sites in two streams 5 km southeast of the Sisson deposit (samples 21J06-2012-2010 and 21J06-2012-2012, Table 6). These streams drain the southeast-trending glacial dispersal train but do not drain the deposit area. The simplest explanation for the presence of the large numbers of scheelite grains in stream sediments at these sites is that they were first glacially transported southeastward and deposited in till within the dispersal train, and subsequently transported fluvially to their current location. Maximum fluvial transport distance for these sample sites would be the distance between the stream sample sites and the headwaters of each drainage system, which for sample 21J06-2012-2010 is 3 km, and for sample site 21J06-2012-2012 is 1.25 km.

Wolframite was only recovered in one till sample (12-MPB-1026) around the Sisson deposit and this sample contained 112 grains (McClenaghan et al. 2014a). In contrast, wolframite was recovered from five stream sediment samples, the largest number of grains being 153. Wolframite is more abundant and widespread in stream sediments downstream of the deposit compared to till samples for two reasons: 1) several stream sediment samples were collected from streams crossing the wolframite-bearing zone of the deposit; 2) streams have washed and concentrated wolframite grains from till such that they are present in sufficient quantities to be detectable in a 14 kg stream sediment sample.

Comparison of stream silt geochemistry and indicator mineral signatures

Stream sediment geochemistry is compared to indicator mineral abundances versus distance downstream in Table 6. Sample sites that have elevated contents of W (>7 ppm) and Mo (>3.2 ppm) in stream silts also contain scheelite grains in the 0.25–0.5 mm HMC samples. At one site, however, only the indicator mineral data indicate the presence of W mineralization upstream. Stream sediment sample 21J06-2012-2017, collected 4 km downstream, contains 75 grains of scheelite and 12 grains of wolframite. However, the stream silt sample at this site contains only background contents of W (6 ppm). This one site indicates that stream sediment geochemistry should be used in combination with heavy mineral sampling.

CONCLUSIONS

No streams directly erode the bedrock surface of the Sisson W-Mo deposit. Indicator minerals and trace element concentrations in stream sediments have been eroded from till and fluvially transported to their present stream locations.

Indicator elements in stream sediments for this type of W-Mo deposit are the main ore elements W and Mo. Pathfinder elements include As, Bi, Ag, Cu, Zn, In, Tl, and Cd. A total digestion method (INAA) is required to determine the total concentration of W and Mo in stream sediments. Aqua regia/ICP-MS is a suitable method for determining the content of the other pathfinder elements. Pathfinder elements in stream water include As, Cd, Cu, Cs, and Zn.

Indicator minerals in stream sediments for the Sisson deposit are the main ore minerals scheelite, wolframite, and molybdenite as well as other minerals chalcopyrite, sphalerite, arsenopyrite, pyrite, and possibly spessartine. Fluvial dispersal of scheelite and wolframite from the deposit is detectable in stream sediments at least 4 km downstream from the north end of the deposit and 5 km southeast of the deposit in streams that drain the southeast-trending glacial dispersal train. Additional stream sediment sampling would be required to fully document the nature of the dispersal of scheelite downstream from the deposit. Molybdenite is not a useful indicator mineral in stream sediments around the Sisson deposit because it is too soft to survive glacial and subsequent fluvial transport. A 2 km (4 km²) spacing of stream samples is recommended to detect the W dispersal train from the Sisson deposit or similar styles of W-Mo mineralization.

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REFERENCES

- Alfassi, Z.B., 2006. Instrumental neutron activation analysis; Encyclopedia of Analytical Chemistry.
- Allen, T.L., Hart, C.J.R., and March, E.E., 1999. Placer gold and associated heavy minerals of the Clear Creek Drainage, central Yukon: past to present, *In: Yukon Exploration and Geology* 1998, (ed.) C.F. Roots and D.S. Emonds; Exploration and

- Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 197–214.
- Asrarullah, 1982. Investigations for tungsten in Pakistan; *In: Tungsten Geology Symposium, Jangxi, China*, (ed.) J.V. Hepworth; ESCAP/RMRDC Bandung, Indonesia, p. 9–13.
- Averill, S.A., 2001. The application of heavy indicator mineralogy in mineral exploration with emphasis on base metal indicators in glaciated metamorphic and plutonic terrains, *In: Drift Exploration in Glaciated Terrain*, (ed.) M.B. McClenaghan, P.T. Bobrowsky, G.E.M. Hall, and S.J. Cook; Geological Society of London, Special Publication 185, p. 69–81.
- Baes, C. F., Jr. and Mesmer, R.E., 1976. *The Hydrolysis of Cations*; Wiley and Sons, New York.
- Burnham, O.M. and Schweyer, J., 2004. Trace element analysis of geological samples by inductively coupled plasma mass spectrometry at the Geoscience Laboratories: revised capabilities due to improvements to instrumentation, *In: Summary of Field Work and Other Activities*; Ontario Geological Survey, Open File Report 6145, p.54-1 to 54-20.
- Bustard, A., Zhang, W., McFarlane, C.R.M., and Lentz, D., 2013. Tungsten mineralization processes at the Sisson Brook W-Mo-Cu deposit, central New Brunswick: the role of formation of titaniferous phases at reaction fronts; *Acta Geologica Sinica (English Edition)*, v. 87 Supp., p. 672–675
- Cook, N.J., Ciobanu, C.L., Pring, A., Skinner, W., Shimizu, M., Danyushevsky, L., Saini-Eidukat, B., and Melcher, F., 2009. Trace and minor elements in sphalerite: a LA-ICPMS study; *Geochimica et Cosmochimica Acta*, v. 73, p. 4761–4791.
- Crock, J.G. and Lamothe, P.J., 2011. *Inorganic chemical analysis of environmental materials – a lecture series*; U.S Geological Survey, Open-File Report 2011-1193, 117 p.
- Day, S.J.A., Wodicka, N., and McMartin, I., 2013. Preliminary geochemical, mineralogical and indicator mineral data for heavy mineral concentrates and waters, Lorillard River area Nunavut (parts of NTS 56-A, -B, and -G); Geological Survey of Canada, Open File 7428.
- de Smeth, J.B., Rao, K.S., and Schuling, R.D., 1985. Gold-scheelite mineralization in the Veligallu schist belt, Andhra Pradesh, India; *Economic Geology*, v. 80, p. 1996–2000.
- ESCAP Secretariat, 1982. Note on tungsten occurrences in Burma, *In: Tungsten Geology Symposium, Jangxi, China*, (ed.) J.V. Hepworth; ESCAP/RMRDC Bandung, Indonesia, p. 45–48.
- Fernández-Turiel, J.L., Durán, M.E., Querol, X., and López-Soler, A., 1992. Comparison between analytical and mineralometric methods in regional scheelite exploration; *Journal of Geochemical Exploration*, v. 43, p. 205–211.
- Frizzo, P. and Hassan, A.H., 1983. Scheelite in stream sediments in the crystalline basement of northern Somalia (area NNE of Hargheisa); *Bollettino della Societa Geologica Italiana*, v. 102, p. 385–390.
- Friske, P.W.B., Pronk, A.G., McCurdy, M.W., Day, S.J.A., McNeil, R.J., and Boldon, R., 2002. Regional stream sediment and water geochemical data, central New Brunswick; Geological Survey of Canada, Open File 4112.
- Fyffe, L.R., Thorne, K., Dunning, G.R., and Martin, D.A., 2008. U-Pb geochronology of the Sisson Brook granite porphyry, York County, west-central New Brunswick, *In: Geological Investigations in New Brunswick for 2007*, (ed.) G.L. Martin; New Brunswick Department of Natural Resources; Minerals, Policy and Planning Division, Mineral Resource Report 2008-1, p. 35–54.
- Fyffe, L.R., Seaman, A., Thorne, K., and Martin, D.A., 2010. Part 1: Sisson Brook W-Mo-Cu deposit, *In: Polymetallic deposits of Sisson Brook and Mount Pleasant, New Brunswick, Canada*, (comp) L.R Fyffe and K. Thorne; New Brunswick Department Natural Resources, Field Guide No. 3, p. 7–33.
- Gardiner, W.W. and Venugopal, D.V., 1992. Spessartine-quartz rock (cotile) occurrences in New Brunswick, Canada, and their use in exploration for massive sulphide, tin-tungsten and gold deposits; *Transactions of the Institution of Mining and Metallurgy, Section B: Applied Earth Science*, v. 101, p. B147–B158.
- Girard, I., Klassen, R.A., and Laframboise, R.R., 2004. *Sedimentology laboratory manual*, Terrain Sciences Division; Geological Survey of Canada, Open File 4823.
- Hall, G.E.M., Vaive, J.E., and McConnell, J.W., 1995. Development and application of a sensitive and rapid analytical method to determine the rare-earth elements in surface waters; *Chemical Geology*, v. 120, p. 91–109.
- Hall, G.E.M., Vaive, J.E., and Pelchat, J.C., 1996. Performance of inductively coupled plasma – mass spectrometric methods used in the determination of trace elements in surface waters in hydrogeochemical surveys; *Journal of Analytical Atomic Spectrometry*, v. 11, p. 779–786.
- Hallenstein, C.P., Pedersen, J.L., and Stendal, H., 1981. Exploration for scheelite in East Greenland- a case study; *Journal of Geochemical Exploration*, v. 15, p. 381–392.
- Hess, F.L., 1917. Tungsten minerals and deposits; United States Geological Survey, Bulletin 652.
- Johnson, B.L., 1910. Occurrence of wolframite and cassiterite in the gold placers of Deadwood Creek, Birch Creek district (Alaska), *In: Mineral Resources of Alaska: Report on Progress of Investigations in 1909*; United States Geological Survey, Bulletin 442, p. 246–250.
- Lamothe, M., 1992. Pleistocene stratigraphy and till geochemistry of the Miramichi Zone, New Brunswick; Geological Survey of Canada, Bulletin 433, 58 p.
- Leybourne, M.I. and Cameron, E.M., 2008. Source, transport, and fate of rhenium, selenium, molybdenum, arsenic, and copper in groundwater associated with porphyry-Cu deposits, Atacama Desert, Chile; *Chemical Geology*, v. 247, p. 208–228.
- Leybourne, M.I. and Cameron, E.M., 2010. Groundwater in geochemical exploration; *Geochemistry: Exploration, Environment, Analysis*, v. 10, p. 99–118.
- Leybourne, M.I., Boyle, D.R., and Goodfellow, W.D., 2003. Interpretation of stream water and sediment geochemistry in the Bathurst Mining Camp, New Brunswick: Applications to mineral exploration, *In: Massive Sulphide Deposits of the Bathurst Mining Camp, New Brunswick, and Northern Maine*, (ed.) W.D. Goodfellow, S.R. McCutcheon, and J.M. Peter; Society of Economic Geologists, Littleton, CO, p. 741–762.
- Lynch, J.J., 1990. Provisional elemental values for eight new geochemical lake sediment and stream sediment reference materials, LKSD-1, LKSD-2, LKSD-3, LKSD-4, STSD-1, STDS-2, STSD-3 and STSD-4; *Geostandards Newsletter*, v. 14, p. 153–167.
- Lynch, J.J., 1999. Additional provisional elemental values for LKSD-1, LKSD-2, LKSD-3, LKSD-4, STSD-1, STDS-2, STSD-3 and STSD-4; *Geostandards Newsletter*, v. 23, p. 251–260.
- Marr, J. M., 2009. Sisson Brook tungsten molybdenum deposit, New Brunswick, preliminary economic assessment (2009 Technical and Economic Update), September 16th, 2009; National Instrument 43-101 technical report by Geodex Minerals Ltd.
- Maurice, Y.T., 1986. Interpretation of a reconnaissance geochemical heavy mineral survey in the Eastern Townships of Quebec, *In: Current Research, Part A*; Geological Survey of Canada, Paper 86-1A, p. 307–317.
- McClenaghan, M.B., 2011. Overview of common processing methods for recovery of indicator minerals from sediment and bedrock in mineral exploration; *Geochemistry: Exploration,*

- Environment, Analysis, v. 11, p. 265–278.
- McClenaghan, M.B., Budulan, G., Averill, S.A., Layton-Matthews, D., and Parkhill, M.A., 2012. Indicator mineral abundance data for bedrock and till samples from the Halfmile Lake Zn-Pb-Cu volcanogenic massive sulphide deposit, Bathurst Mining Camp, New Brunswick; Geological Survey of Canada, Open File 7076.
- McClenaghan, M.B., Parkhill, M.A., Averill, S.A., Pronk, A.G., Seaman, A.A., Boldon, R., McCurdy, M.W., and Rice, J.M., 2013a. Indicator mineral abundance data for bedrock, till, and stream sediment samples from the Sisson W-Mo deposit, New Brunswick; Geological Survey of Canada, Open File 7387.
- McClenaghan, M.B., Parkhill, M.A., Averill, S.A., and Kjarsgaard, I.M., 2013b. Indicator mineral signatures of the Sisson W-Mo deposit, New Brunswick: part 1 bedrock samples; Geological Survey of Canada, Open File 7431.
- McClenaghan, M.B., Parkhill, M.A., Seaman, A.A., Pronk, A.G., Pyne, M., Rice, R.M., and Hashmi, S., 2013c. Till geochemical signatures of the Sisson W-Mo deposit, New Brunswick; Geological Survey of Canada, Open File 7430.
- McClenaghan, M.B., Parkhill, M.A., Seaman, A.A., Pronk, A.G., Averill, S.A., Rice, J.M., and Pyne, M., 2014a. Indicator mineral signatures of the Sisson W-Mo deposit, New Brunswick: Part 2 till; Geological Survey of Canada, Open File 7467.
- McClenaghan, M.B., Seaman, A.A., Parkhill, M.A., and Pronk, A.G., 2014b. Till geochemical signatures associated with the Sisson W-Mo deposit, New Brunswick; *Atlantic Geology*, v. 50, p. 116–137.
- McCurdy, M.W. and McNeil, R.J., 2014. Geochemical data from stream silts and surface waters in the Pine Point Mining District, Northwest Territories (NTS 85-B); Geological Survey of Canada, Open File 7577.
- McCurdy, M.W., Berman, R.G., Kerr, D.E., and Vaive, J.E., 2013. Geochemical, mineralogical and kimberlite indicator mineral data for silts, heavy mineral concentrates and waters, Duggan Lake area (NTS 76-H and 76-I South); Geological Survey of Canada, Open File 7471.
- Mikulski, S.Z. and Wierchowicz, J., 2013. Placer scheelite and gold from alluvial sediments as indicators of primary mineralization - examples from SW Poland; *Geological Quarterly*, v. 57, p. 503–514.
- Nast, H.J. and Williams-Jones, A.E., 1991. The role of water-rock interaction and fluid evolution in the forming of the porphyry-related Sisson Brook W-Cu-Mo deposit, New Brunswick; *Economic Geology*, v. 86, p. 302–317.
- New Brunswick Department of Energy and Mines, 2013. Nashwaak, Reference Number 209, New Brunswick Department of Energy and Mines, Mineral Occurrence Database.
- Özcan, A. and Çağatay, M.N., 1989. Tungsten exploration in semi-arid environment: Central Anatolian massif, Turkey; *Journal of Geochemical Exploration*, v. 31, p. 185–199.
- Pfaff, K., Koenig, A.E., Wenzel, T., Ridley, I., Hildebrandt, L.H., Leach, D.L., and Markl, G., 2011. Trace and minor element variations and sulfur isotopes in crystalline and colloform ZnS: Incorporation mechanisms and implications for their genesis; *Chemical Geology*, v. 286, p. 118–134.
- Plouffe, A., McClenaghan, M.B., Paulen, R.C., McMartin, I., Campbell, J.E., and Spirito, W.A., 2013. Processing of unconsolidated glacial sediments for the recovery of indicator minerals: protocols used at the Geological Survey of Canada; *Geochemistry: Exploration, Environment, Analysis*, v. 13, p. 303–316.
- Pronk, A.G., Boldon, R., Friske, P.W.B., McCurdy, M.W., and Day, S.J.A., 1997. National Geochemical Reconnaissance, stream sediment and water survey, central New Brunswick (NTS 21J/02 east and 21J/07); Geological Survey of Canada, Open File 3486.
- Punggrassami, T., 1986. Cassiterite and wolframite deposits in and around the Hat Yai Basin, Songkhla Province, Thailand, *In: Proceedings of the Workshop on Economic Geology, Tectonics, Sedimentary Processes and Environment of the Quaternary in Southeast Asia*, p. 135–155.
- Rajah, S.S., 1982. Tungsten mineralization in peninsular Malaysia, *In: Tungsten Geology Symposium, Jangxi, China*, (ed.) J.V. Hepworth; ESCAP/RMRDC Bandung, Indonesia, p. 179–195.
- Rennie, D.W., Friedman, D., Gray, J., Bolu, M., Pozder, S., and Greskovich, G., 2012. Canadian National Instrument 43-101 technical report on the Sisson Project, New Brunswick, Canada, Samuel Engineering Inc., SEDAR website: <http://www.sedar.com/DisplayCompanyDocuments.do?lang=EN&issuerNo=00030606>.
- Rose, A.W., Hawkes, H.E., and Webb, J.S., 1979. *Geochemistry in Mineral Exploration*; Academic Press, London.
- Seaman, A.A., 2003. Follow up till geochemistry, Coldstream (NTS 21J/06) map area and part of the adjacent Napadogan (NTS 21J/07) map area, York and Carleton counties, New Brunswick; New Brunswick Department of Natural Resources, Open File 2003-11.
- Seaman, A.A., 2009. The Appalachian Glacier Complex, and the Middle to Late Pleistocene history of west-central New Brunswick, Canada, *In: Geological Investigations in New Brunswick for 2008*, (ed.) G.L. Martin; New Brunswick Department of Natural Resources, Mineral Resource Report 2009 2, p. 66 140.
- Seaman, A.A. and McCoy, S.M., 2008. Multiple Wisconsinan tills in the Sisson Brook exploration trench of Geodex Minerals Ltd., York County, west-central New Brunswick, *In: Geological Investigations in New Brunswick for 2007*, (ed.) G.L. Martin; New Brunswick Department of Natural Resources; Minerals, Policy and Planning Division, Mineral Resource Report 2008-1, p. 1–34.
- Smith, E.A. and Fyffe, L.R. (compilers), 2006a. Bedrock Geology of the Burtt's Corner area (NTS 21 J/02), York County, New Brunswick; New Brunswick Department of Natural Resources, Map Plate 2006-3.
- Smith, E.A. and Fyffe, L.R. (compilers), 2006b. Bedrock Geology of the Millville area (NTS 21 J/03), York and Carleton counties, New Brunswick; New Brunswick Department of Natural Resources, Map Plate 2006-4.
- Smith, E.A. and Fyffe, L.R., (compilers) 2006c. Bedrock Geology of the Coldstream area (NTS 21 J/06), York and Carleton counties, New Brunswick; New Brunswick Department of Natural Resources, Map Plate 2006-7.
- Smith, E.A. and Fyffe, L.R. (compilers), 2006d. Bedrock Geology of the Napadogan area (NTS 21 J/07), York and Carleton counties, New Brunswick; New Brunswick Department of Natural Resources, Map Plate 2006-8.
- Snow, R.J. and Coker, W.B., 1987. Overburden geochemistry related to W-Cu-Mo mineralization at Sisson Brook, New Brunswick, Canada: an example of short- and long-distance glacial dispersal, *In: Geochemical Exploration 1985*, (ed.) R.G. Garrett; *Journal of Geochemical Exploration*, v. 28, p. 353–368.
- Stea, R.R., Seaman, A.A., Pronk, T., Parkhill, M.A., Allard, S., and Utting, D., 2011. The Appalachian Glacier Complex in Maritime Canada, Chapter 48 *In: Quaternary Glaciations - Extent and Chronology - A Closer Look* (ed.) J. Ehlers, P.L. Gibbard, and P.D. Hughes; *Developments in Quaternary Science*, 15, Elsevier, Amsterdam, p. 631–659.
- Steenfelt, A., 1987. Geochemical mapping and prospecting in Greenland- a review of results and experience; *Journal of Geochemical Exploration*, v. 29, p. 183–205.

- Stendal, H., 1978. Heavy minerals in stream sediments, southwest Norway; *Journal of Geochemical Exploration*, v. 10, p. 91–102.
- Surya Prakash Rao, K., Sastry, R.S.N., and Raju, S.V., 1989. Scheelite as a prospecting tool in the Ramagiri greenstone belt, Andhra Pradesh, India; *Journal of Geochemical Exploration*, v. 31, p. 307–317.
- Theobald, P.K. and Thompson, C.E., 1960. Geochemical prospecting with heavy-mineral concentrates used to locate a tungsten deposit; United States Geological Survey, Circular 411.
- Wildon, R. and Hotz, P.E., 1955. A gold-scheelite-cinnabar placer in Humboldt County, Nevada; *Economic Geology*, v. 50, p. 661–668.
- Zantop, H. and Nespereira, J., 1979. Heavy-mineral panning techniques in the exploration for tin and tungsten in NW Spain, *In: Geochemical Exploration 1978*, (ed.) J.R. Watterson and P.K. Theobald; Association of Exploration Geochemists, p. 329–336.
- Zeschke, G., 1961. Prospecting for ore deposits by panning heavy minerals from river sands; *Economic Geology*, v. 56, p.1250–1257.

Appendix A3. Field site photographs of the stream sites sampled by the Geological Survey of Canada



Sample site 021J06-12-2005.



Sample site 021J06-12-2006.



Sample site 021J06-12-2007 and -2008.



Sample site 021J06-12-2009.

Appendix A3 continued.



Sample site 021J06-12-2010.



Sample site 021J06-12-2011.



Sample site 021J06-12-2012.



Sample site 021J06-12-2013.

Appendix A3 continued.



Sample site 021J06-12-2015.



Sample site 021J06-12-2016.



Sample site 021J06-12-2017.

Appendix A3 continued.

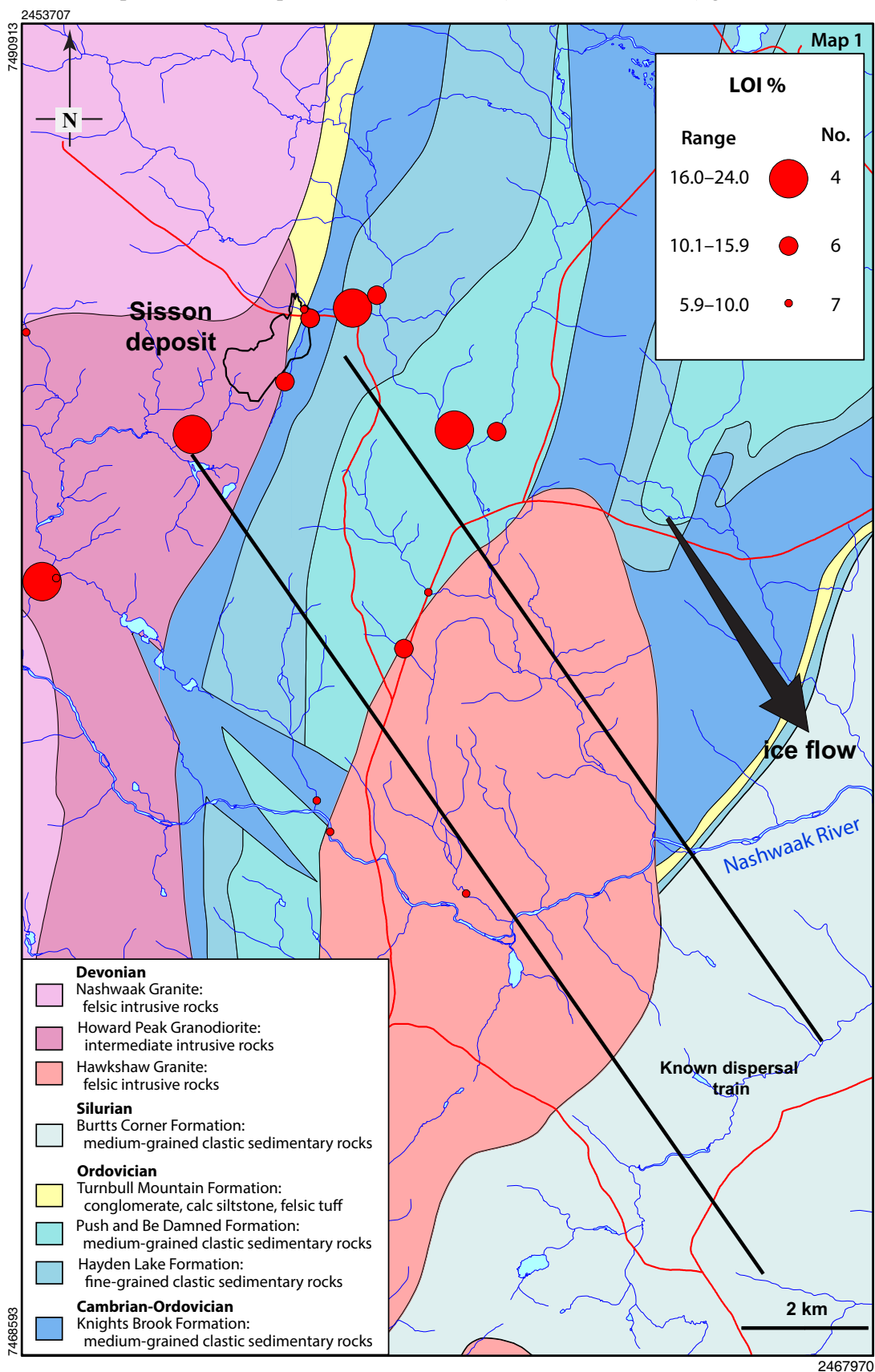


Sample site 021J06-12-2018.



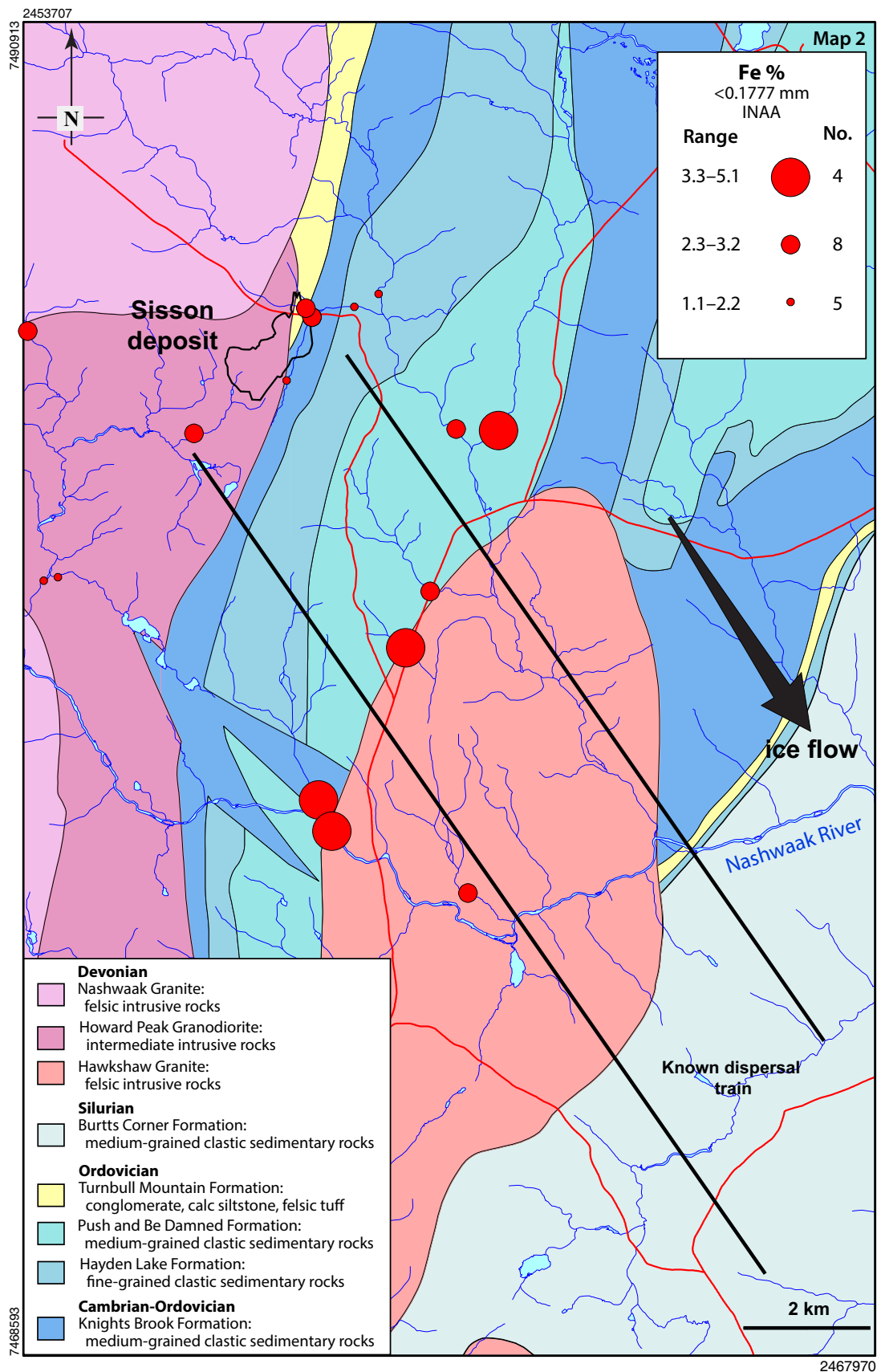
Sample site 021J06-12-2019.

APPENDIX C1. Proportional dot maps for stream sediment (<0.177 mm fraction) geochemical data.



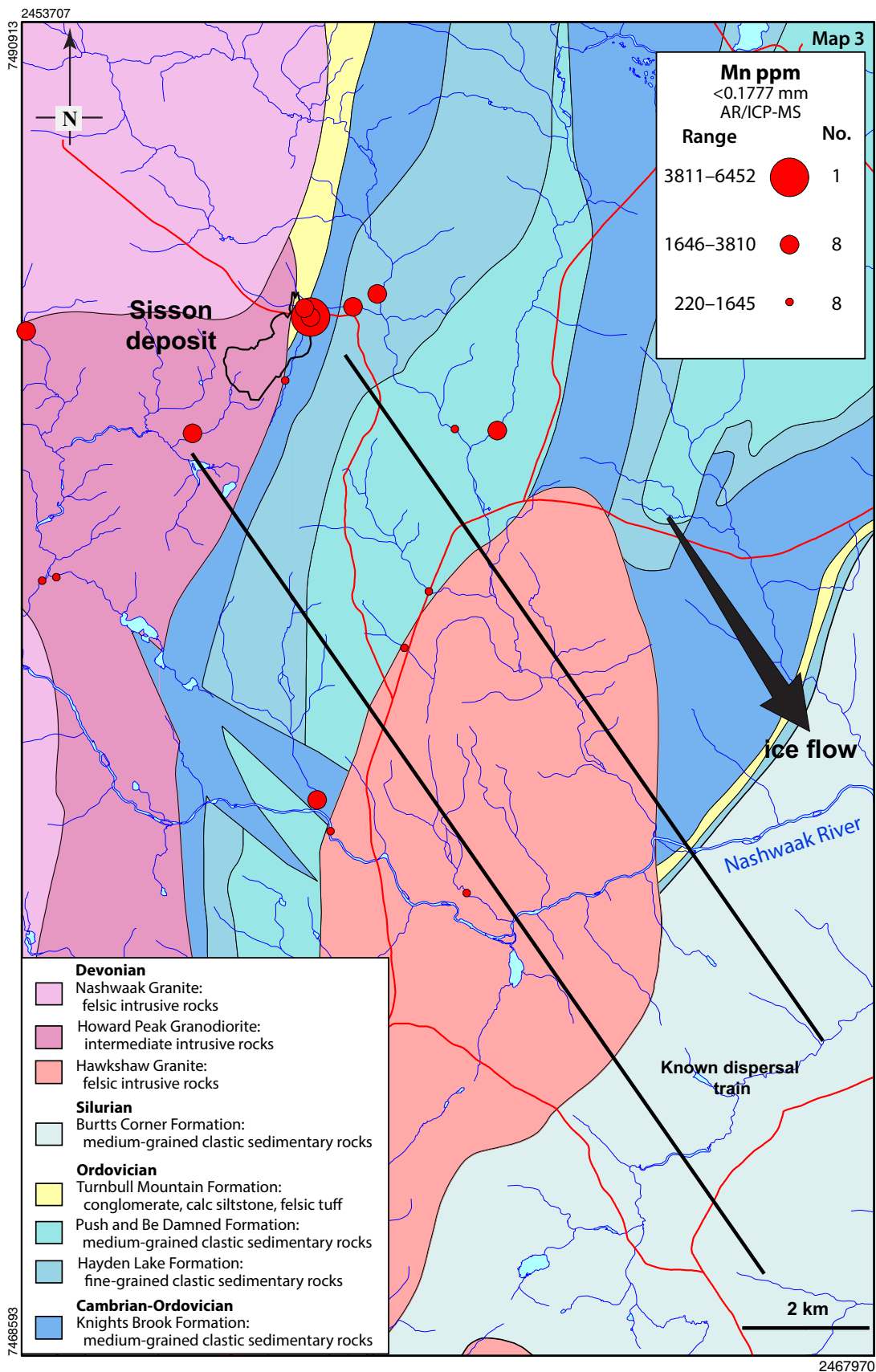
Map 1. Proportional dot map showing the loss on ignition in the <0.177 mm fraction of stream sediment samples. Bedrock geology modified from Smith and Fyfe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C1 continued.



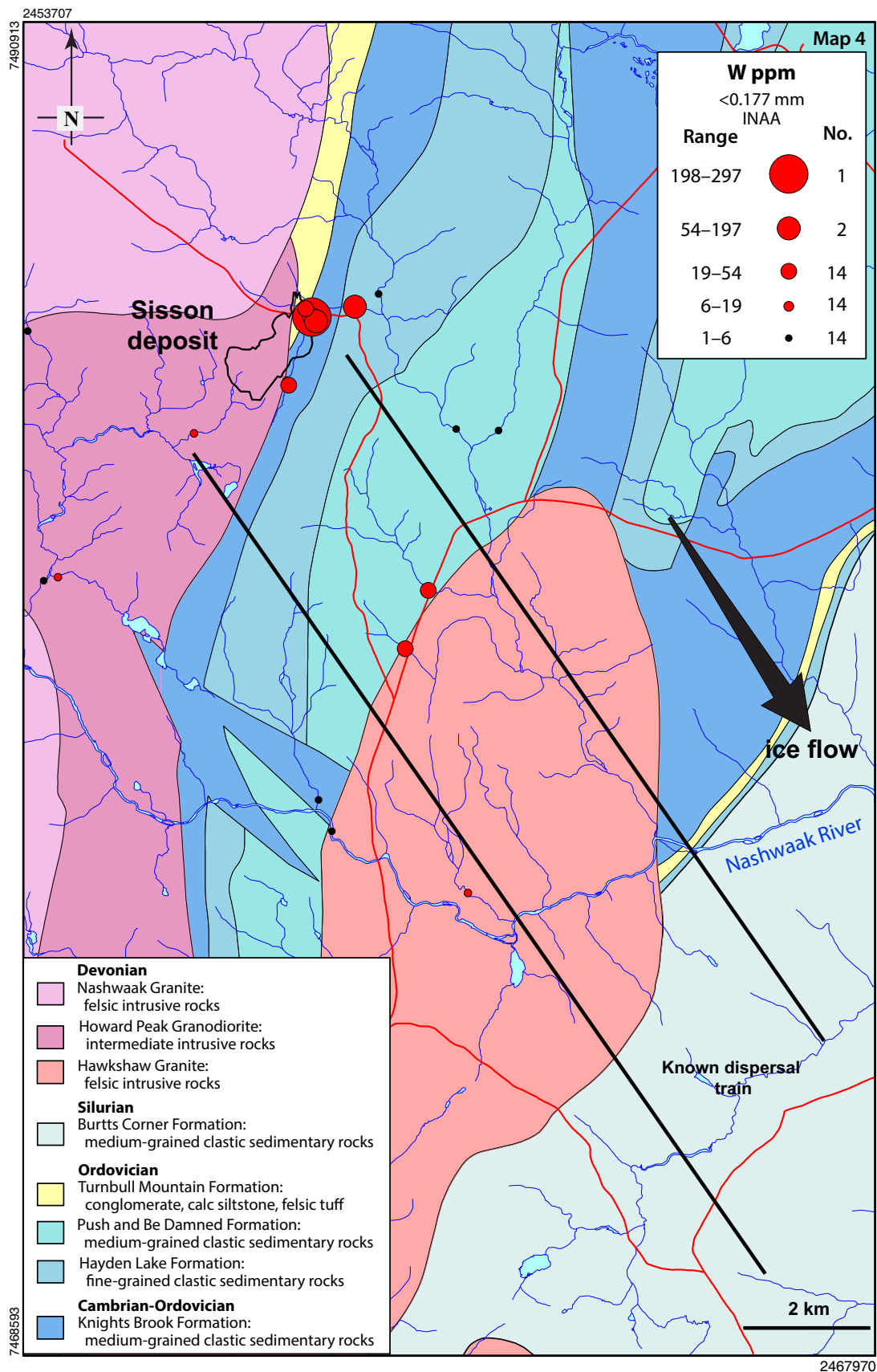
Map 2. Proportional dot map showing the iron (Fe) content in the <0.177 mm fraction of stream sediment samples. Bedrock geology modified from Smith and Fyffe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C1 continued.



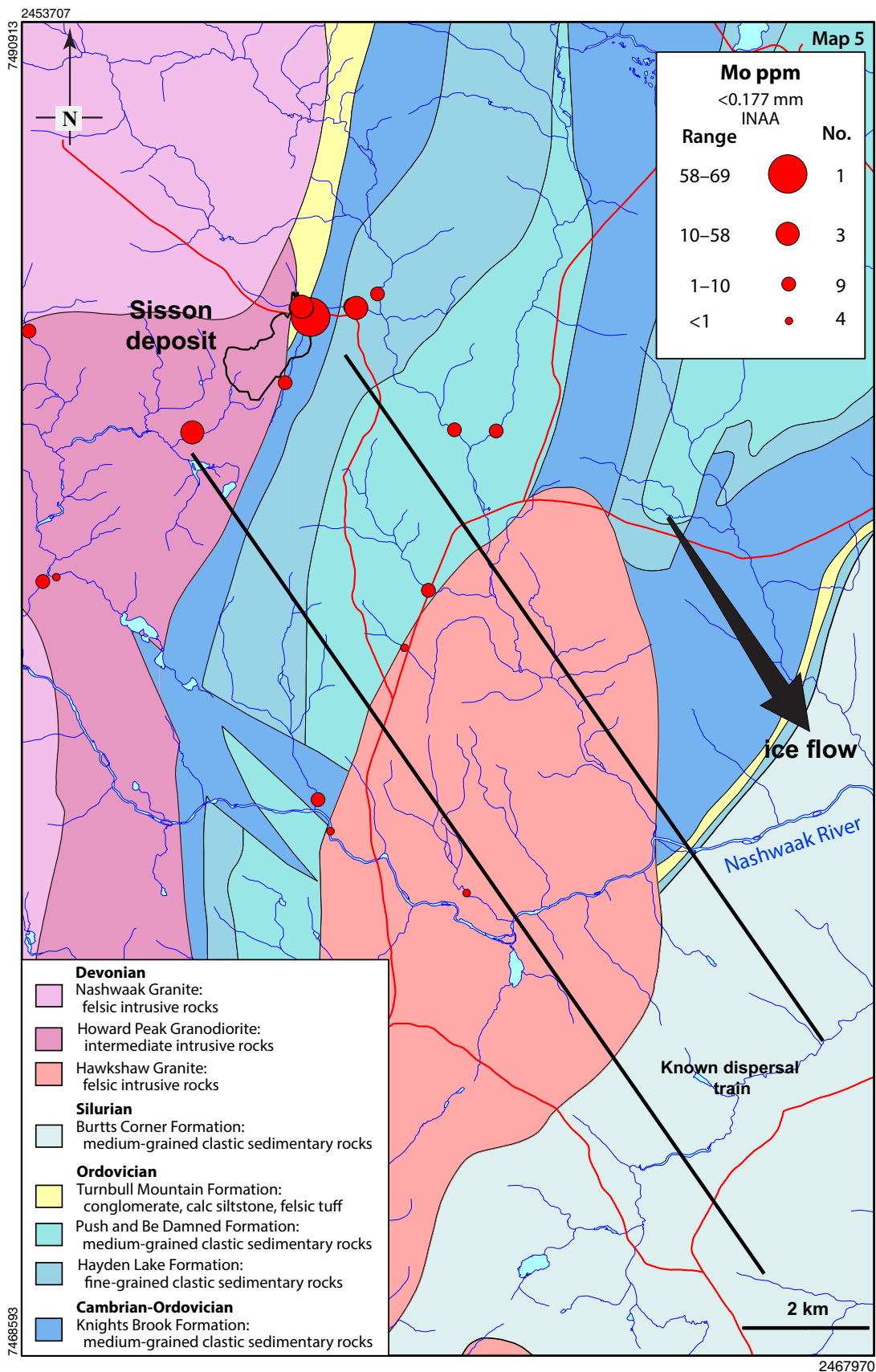
Map 3. Proportional dot map showing the manganese (Mn) content in the <0.177 mm fraction of stream sediment samples. Bedrock geology modified from Smith and Fyffe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C1 continued.



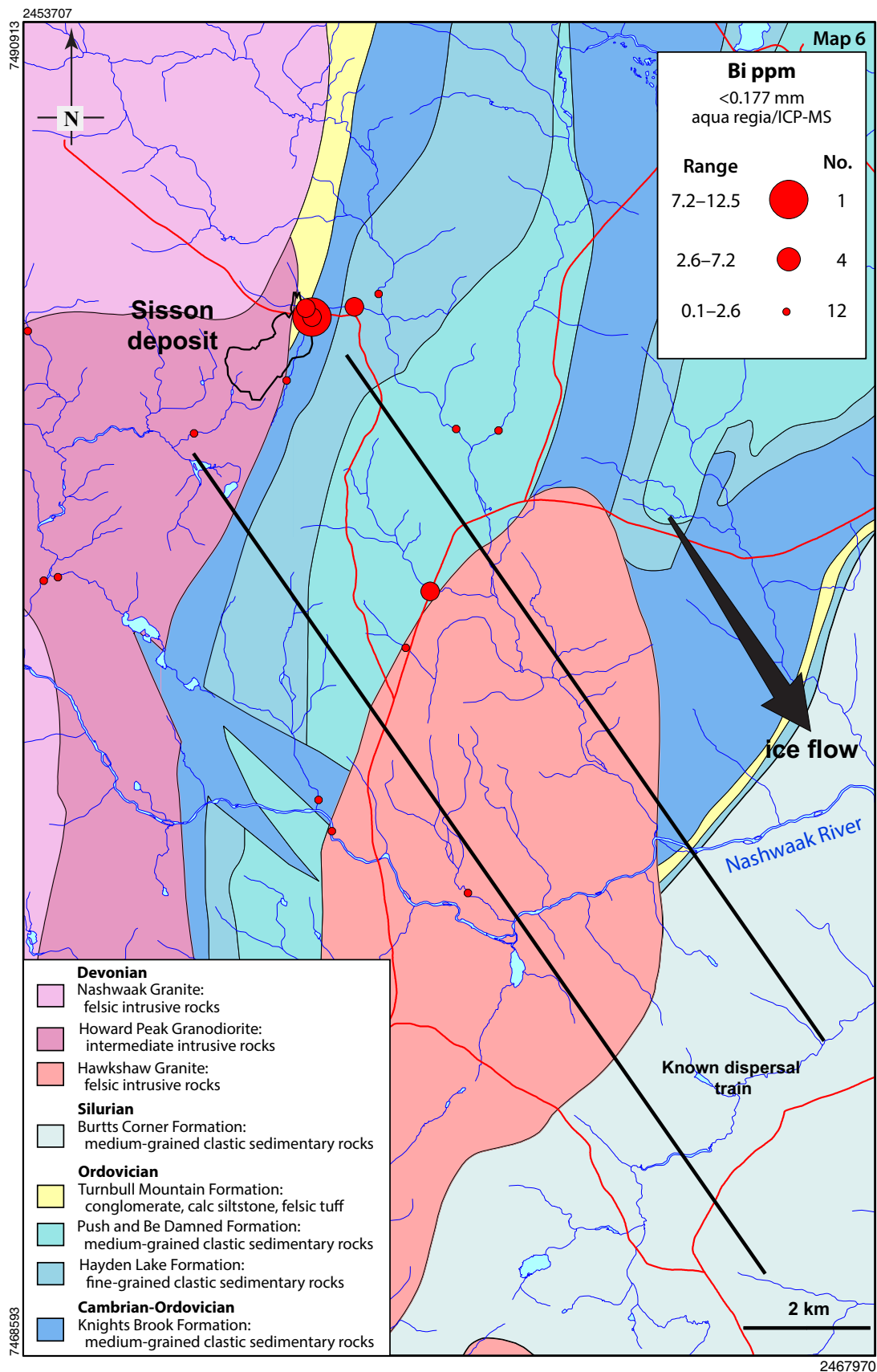
Map 4. Proportional dot map showing the tungsten (W) content in the <0.177 mm fraction of stream sediment samples. Bedrock geology modified from Smith and Fyffe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C1 continued.



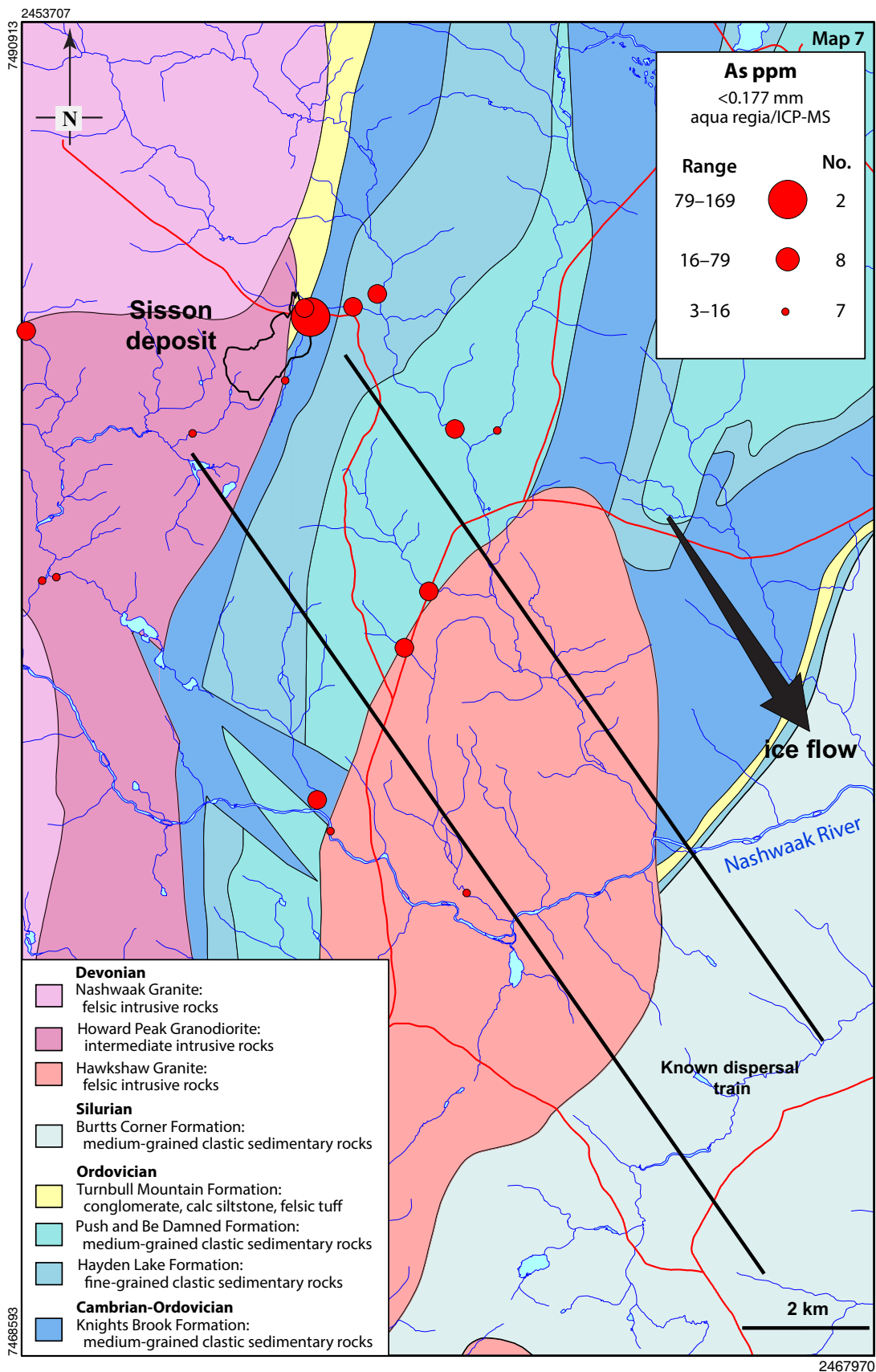
Map 5. Proportional dot map showing the molybdenum (Mo) content in the <0.177 mm fraction of stream sediment samples. Bedrock geology modified from Smith and Fyffe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C1 continued.



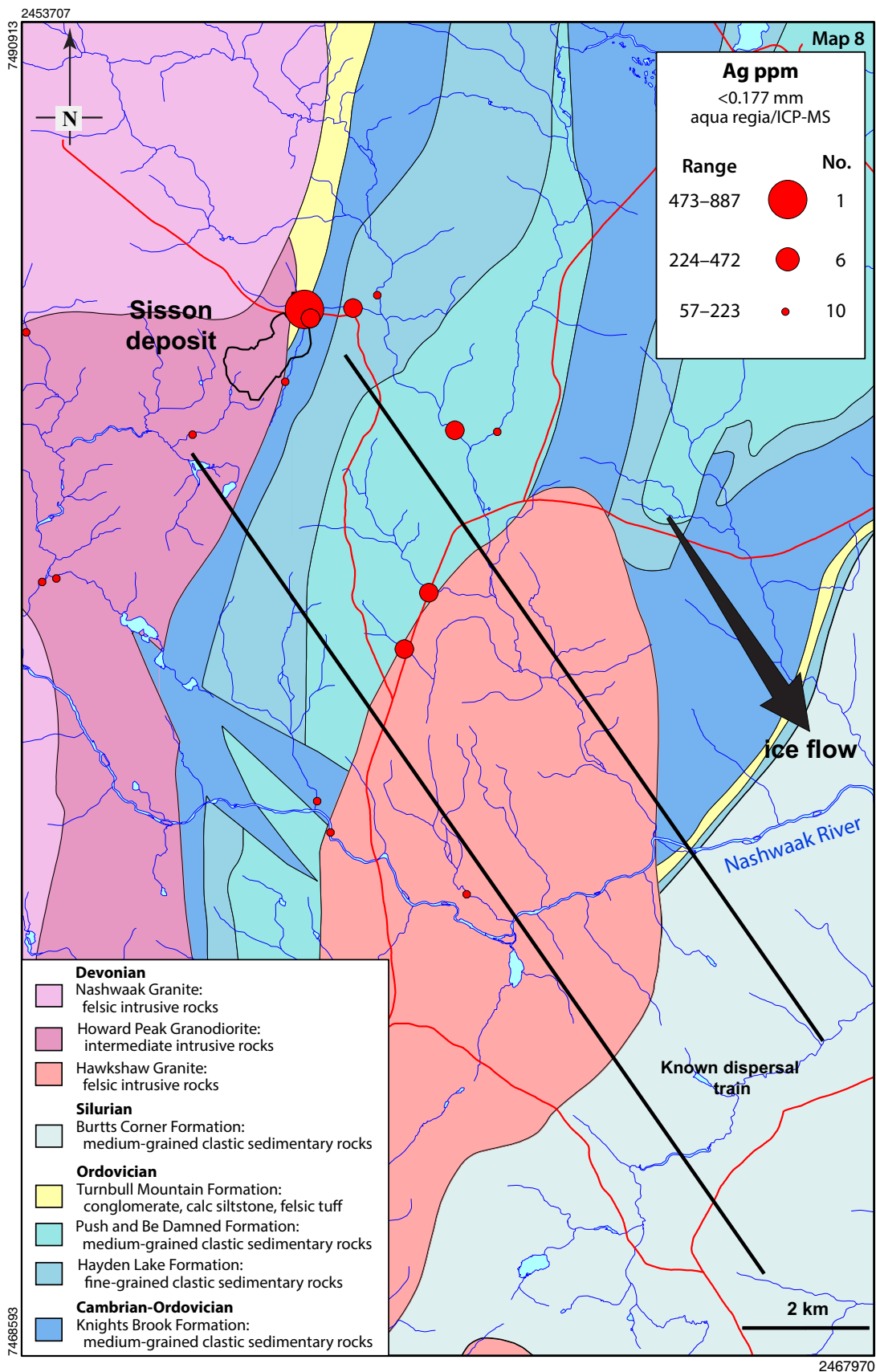
Map 6. Proportional dot map showing the bismuth (Bi) content in the <0.177 mm fraction of stream sediment samples. Bedrock geology modified from Smith and Fyffe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C1 continued.



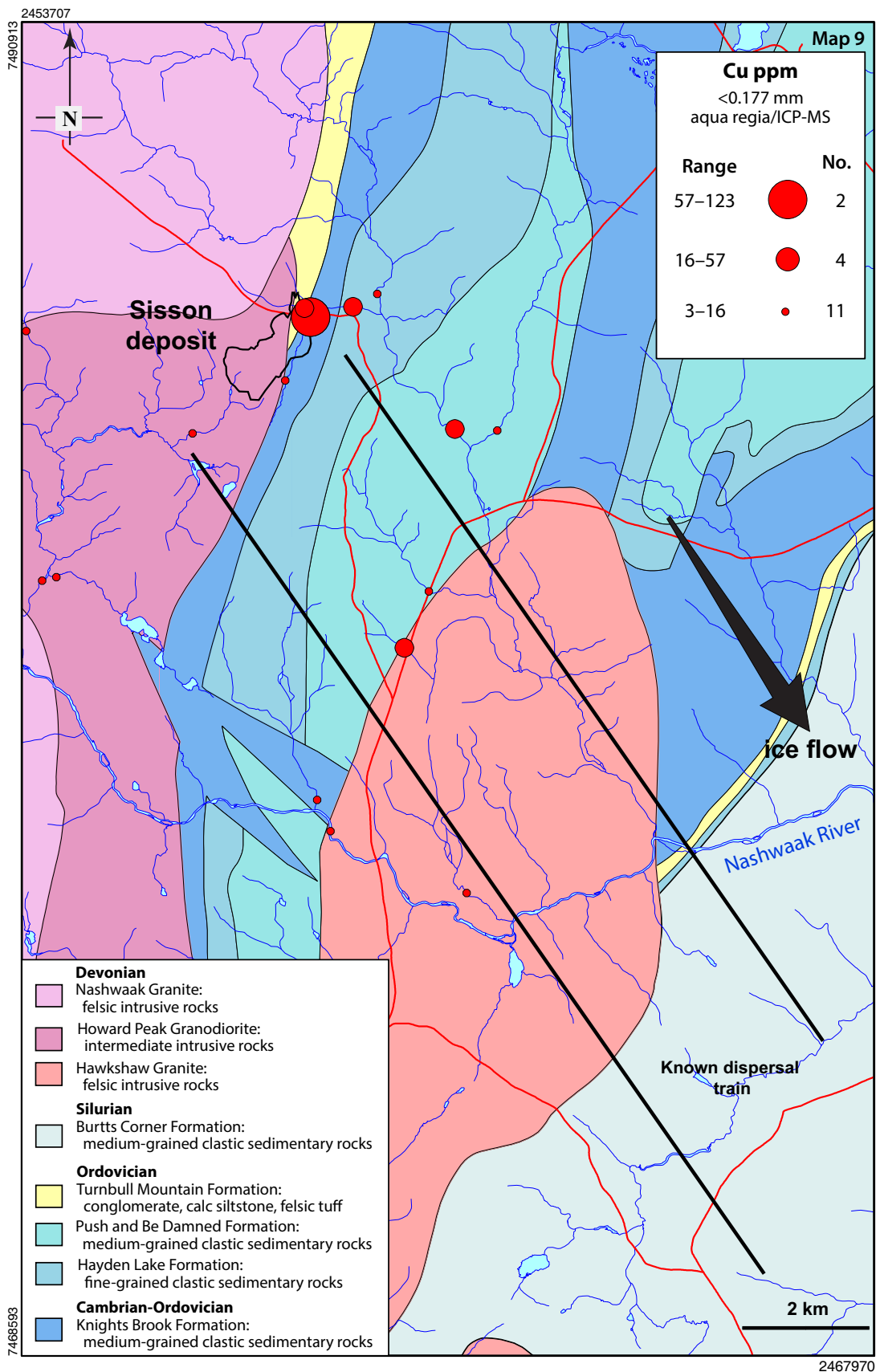
Map 7. Proportional dot map showing the arsenic (As) content in the <0.177 mm fraction of stream sediment samples. Bedrock geology modified from Smith and Fyffe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C1 continued.



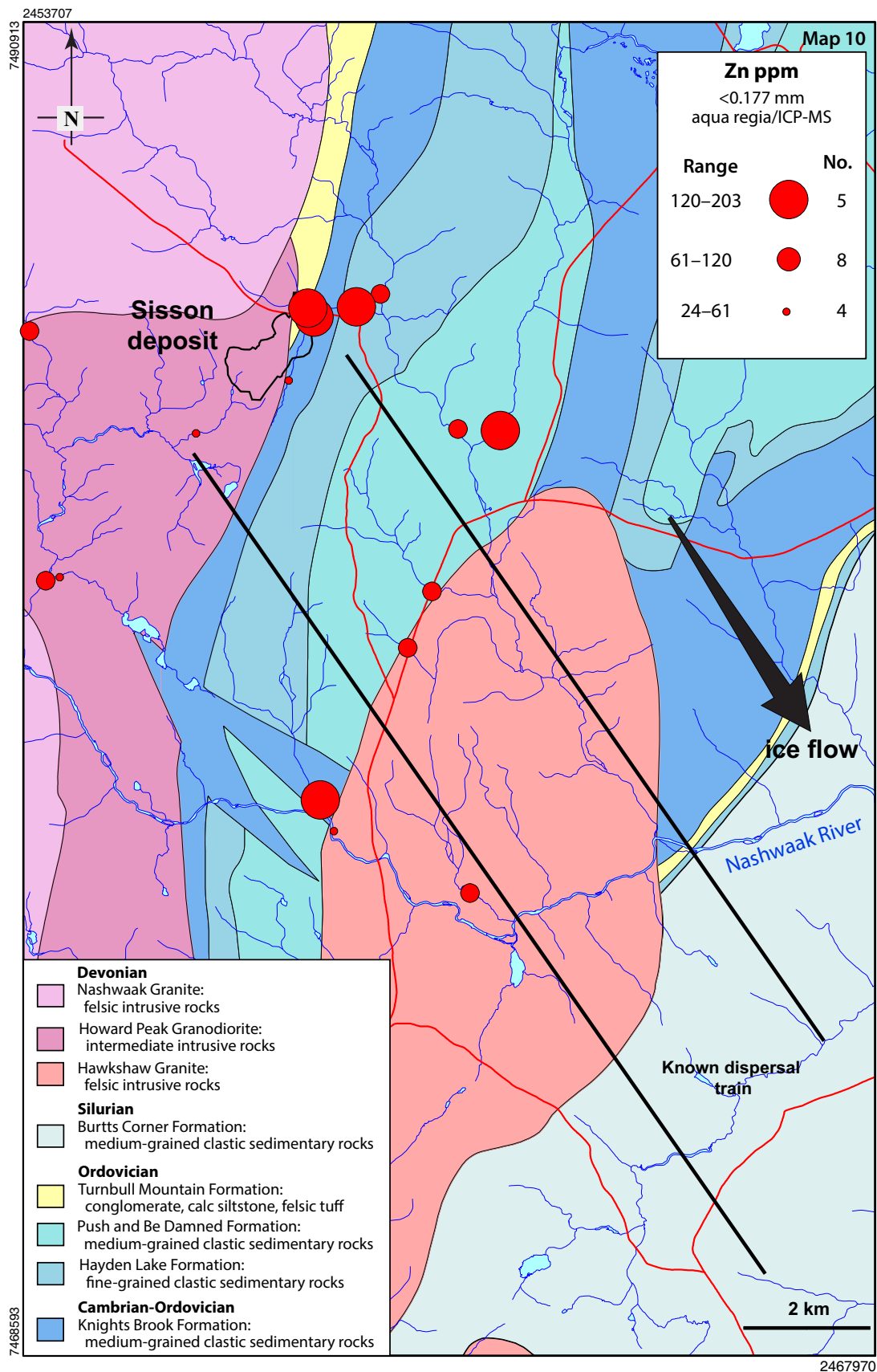
Map 8. Proportional dot map showing the silver (Ag) content in the <0.177 mm fraction of stream sediment samples. Bedrock geology modified from Smith and Fyffe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C1 continued.



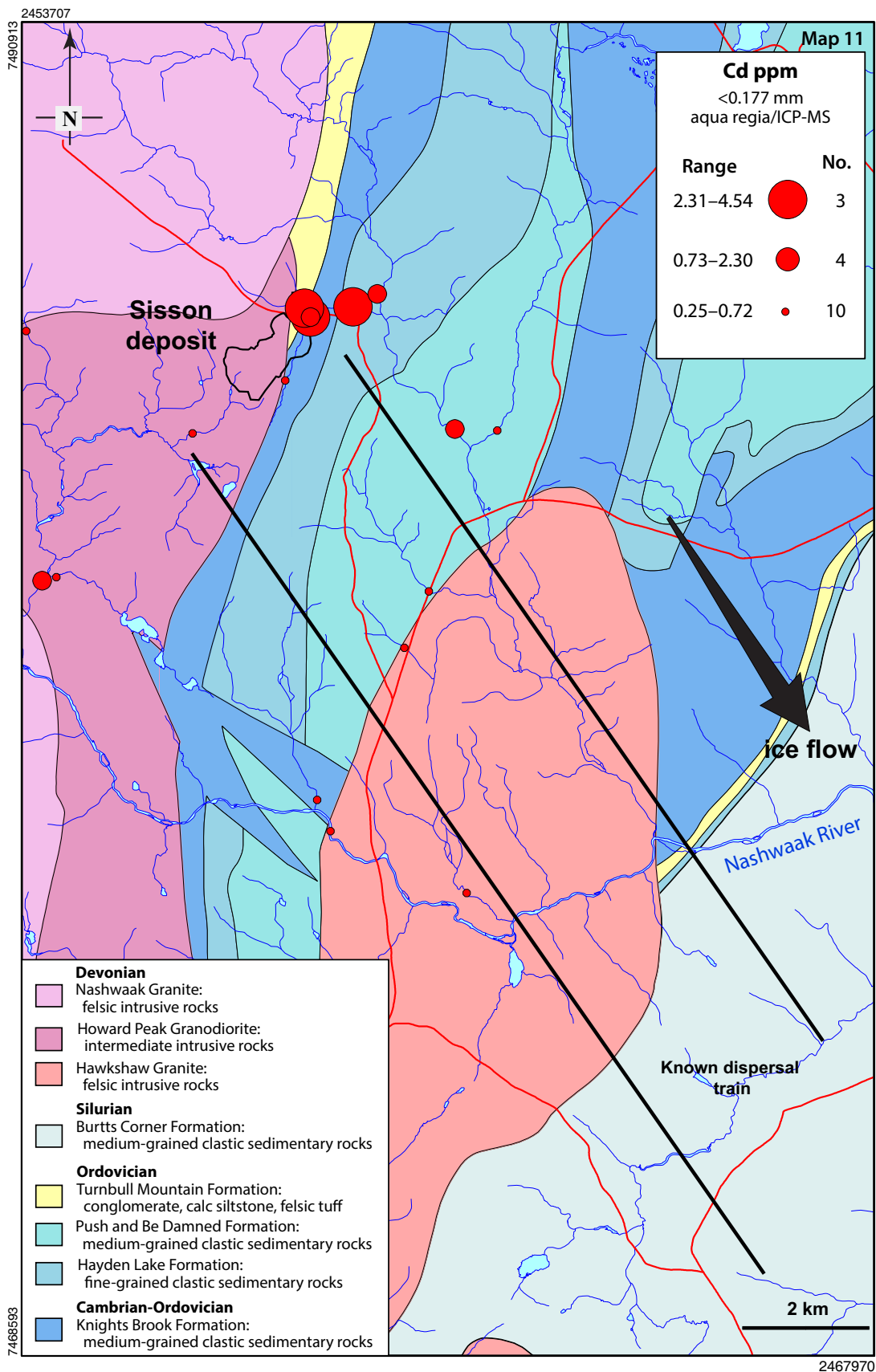
Map 9. Proportional dot map showing the copper (Cu) content in the <0.177 mm fraction of stream sediment samples. Bedrock geology modified from Smith and Fyffe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C1 continued.



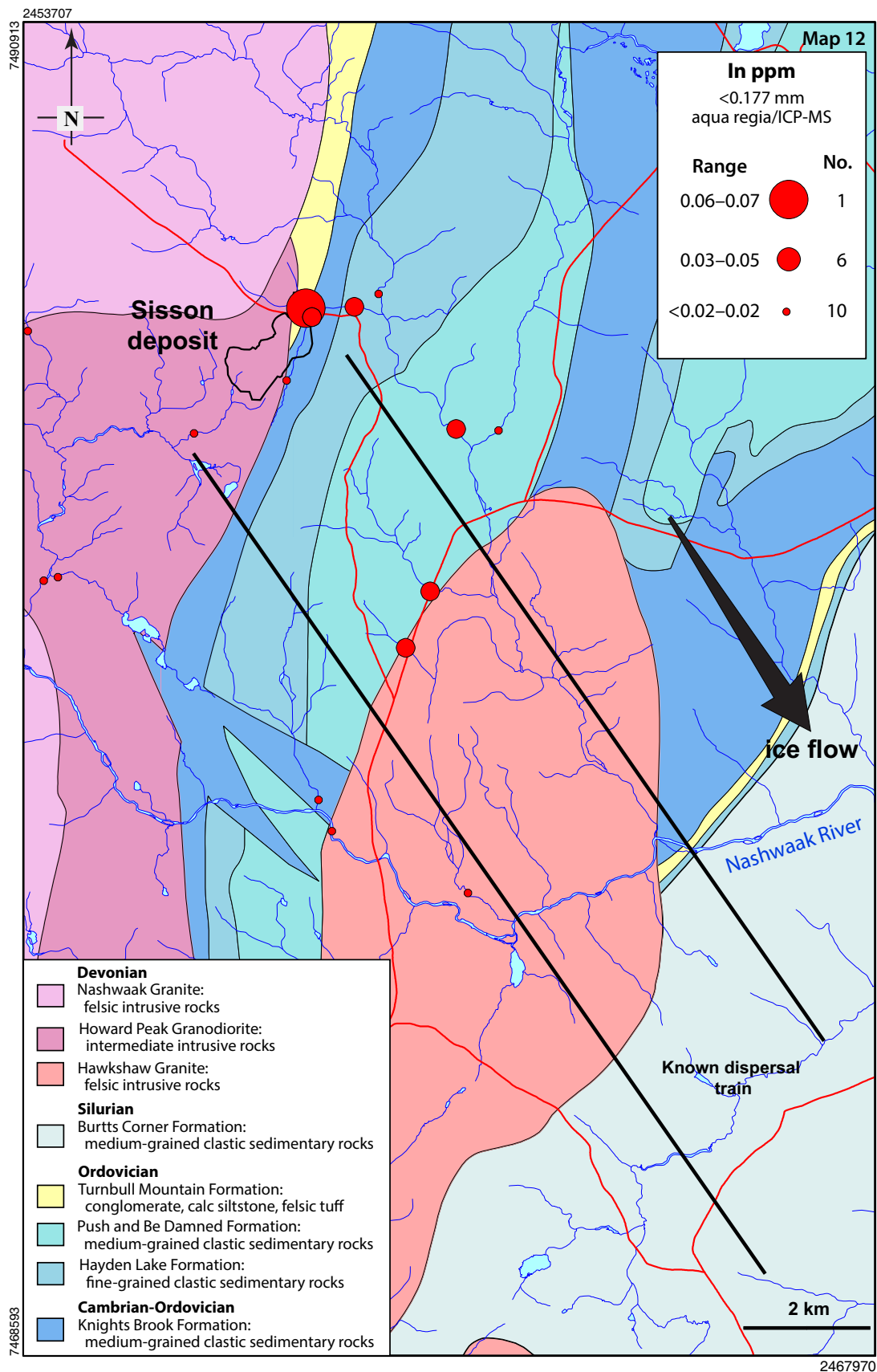
Map 10. Proportional dot map showing the zinc (Zn) content in the <0.177 mm fraction of stream sediment samples. Bedrock geology modified from Smith and Fyfe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C1 continued.



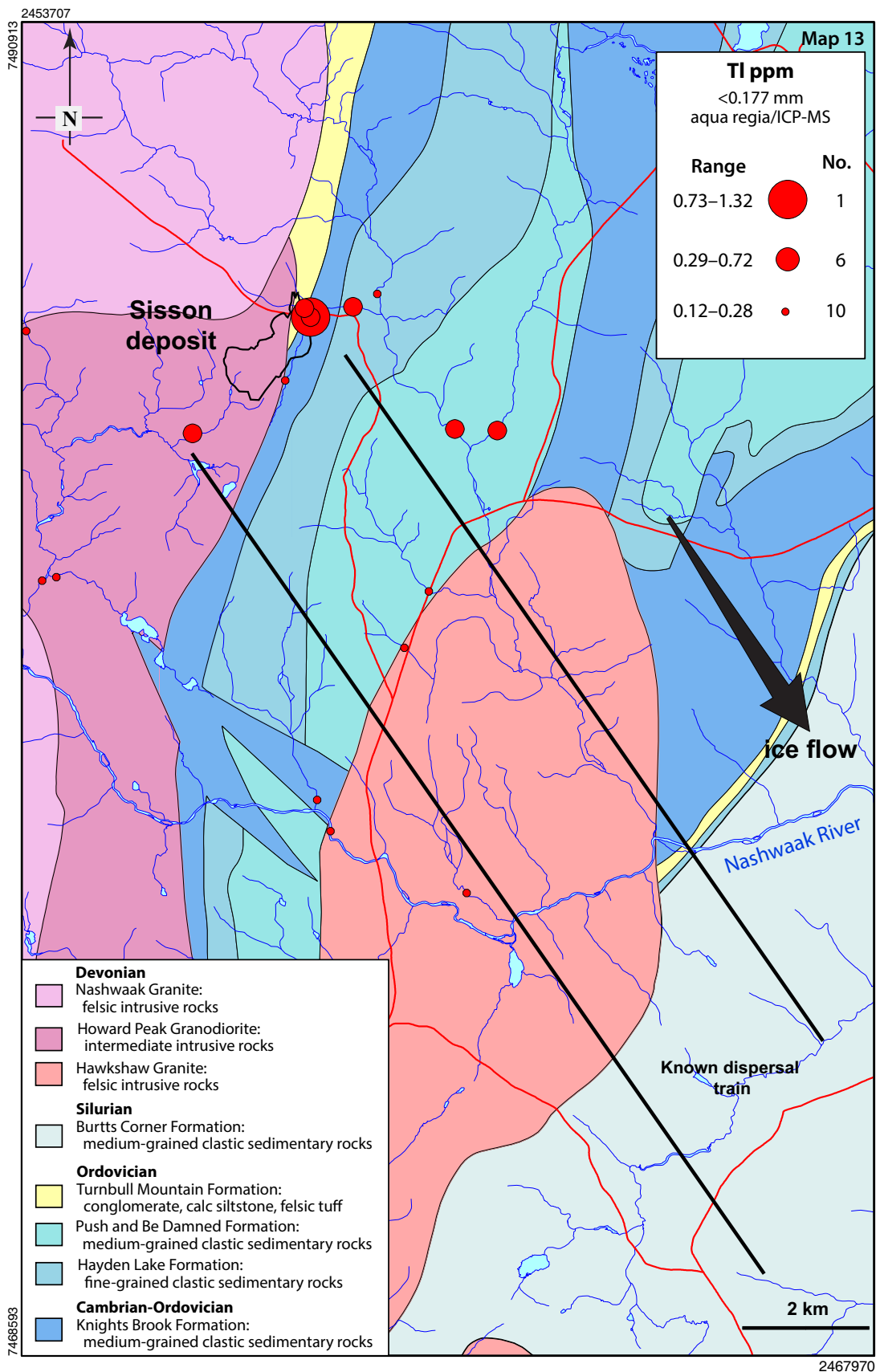
Map 11. Proportional dot map showing the cadmium (Cd) content in the <0.177 mm fraction of stream sediment samples. Bedrock geology modified from Smith and Fyffe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C1 continued.



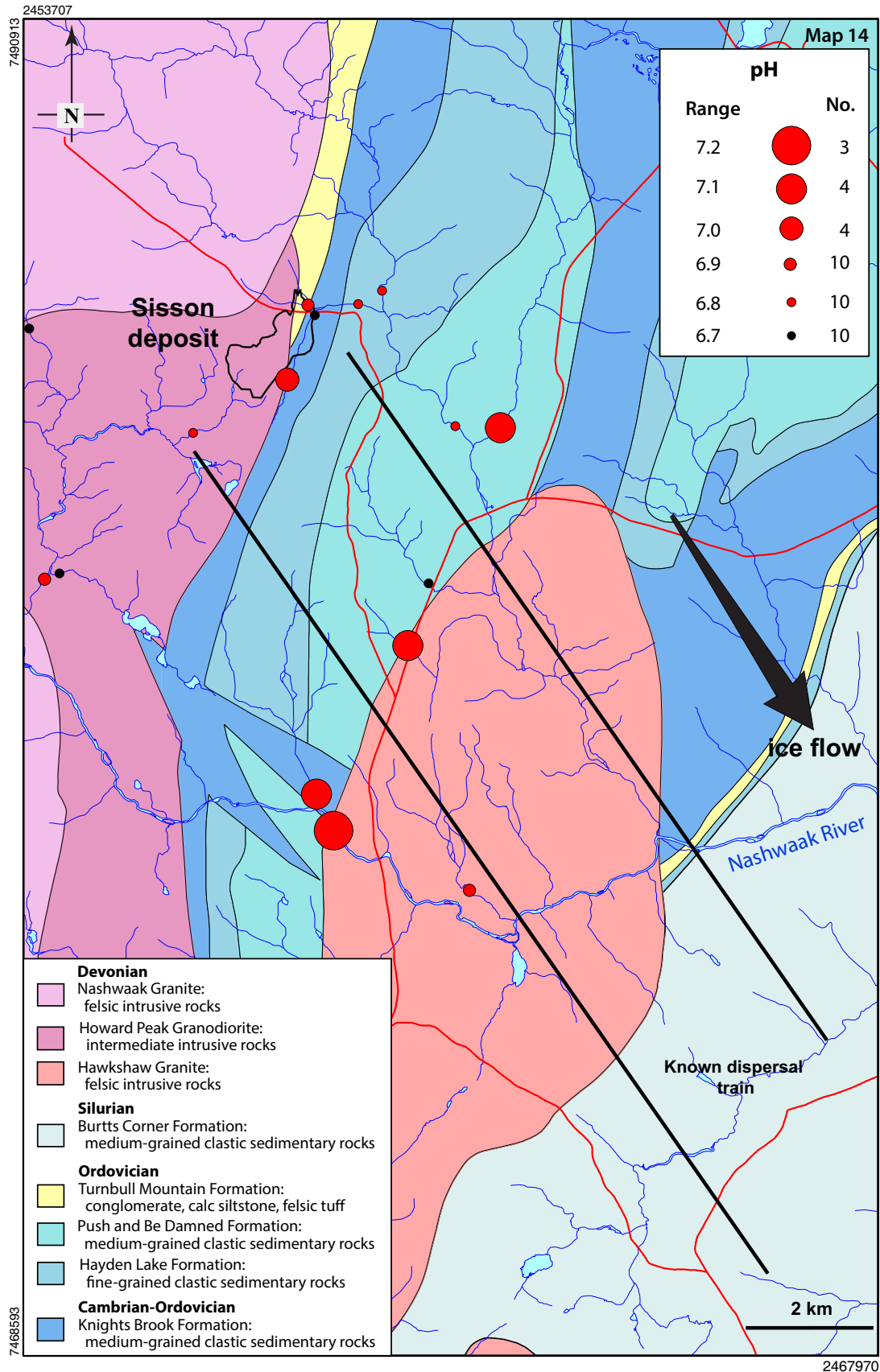
Map 12. Proportional dot map showing the indium (In) content in the <0.177 mm fraction of stream sediment samples. Bedrock geology modified from Smith and Fyffe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C1 continued.



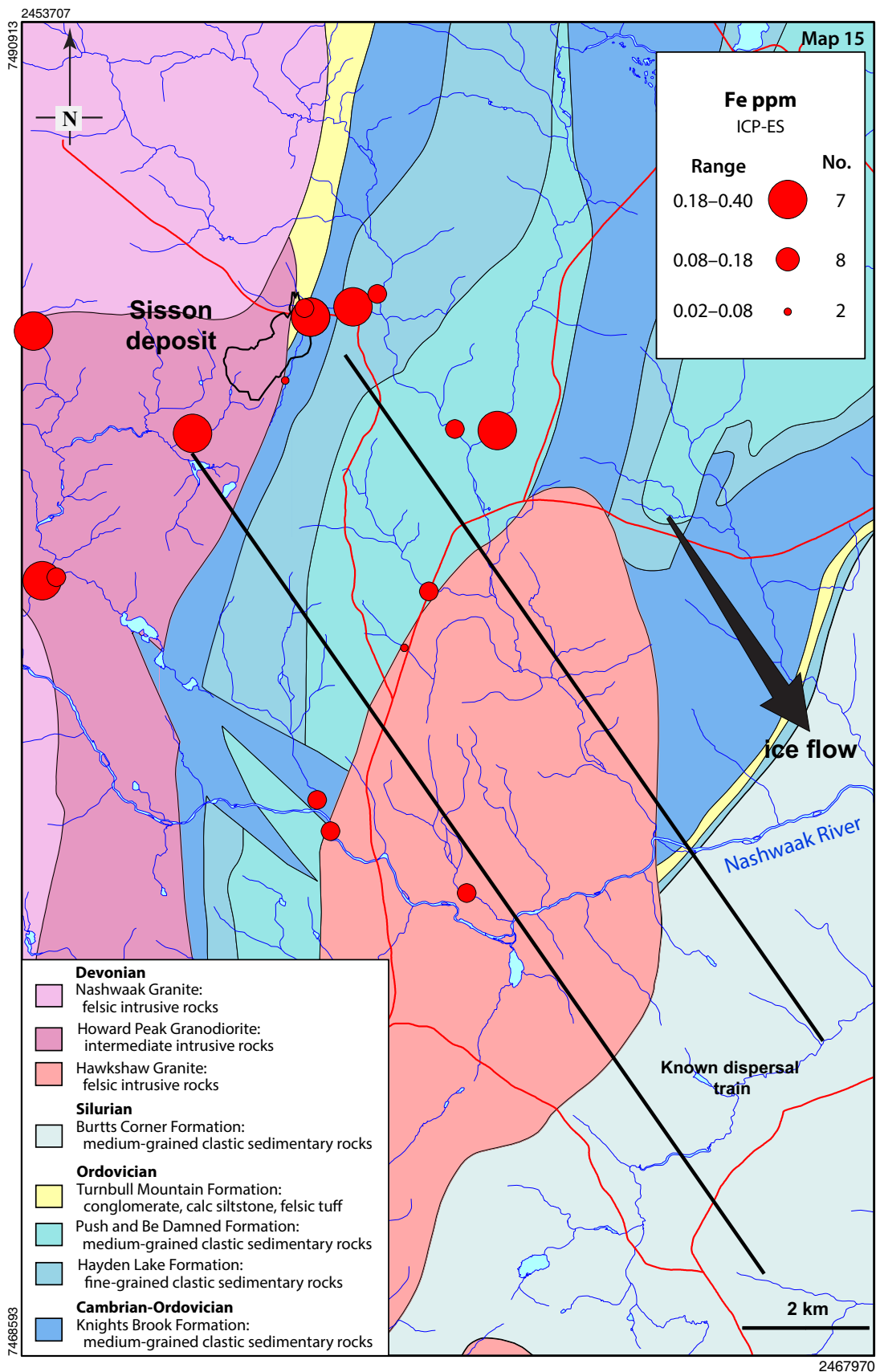
Map 13. Proportional dot map showing the thallium (Tl) content in the <0.177 mm fraction of stream sediment samples. Bedrock geology modified from Smith and Fyfe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C2. Proportional dot maps of stream water geochemical data.



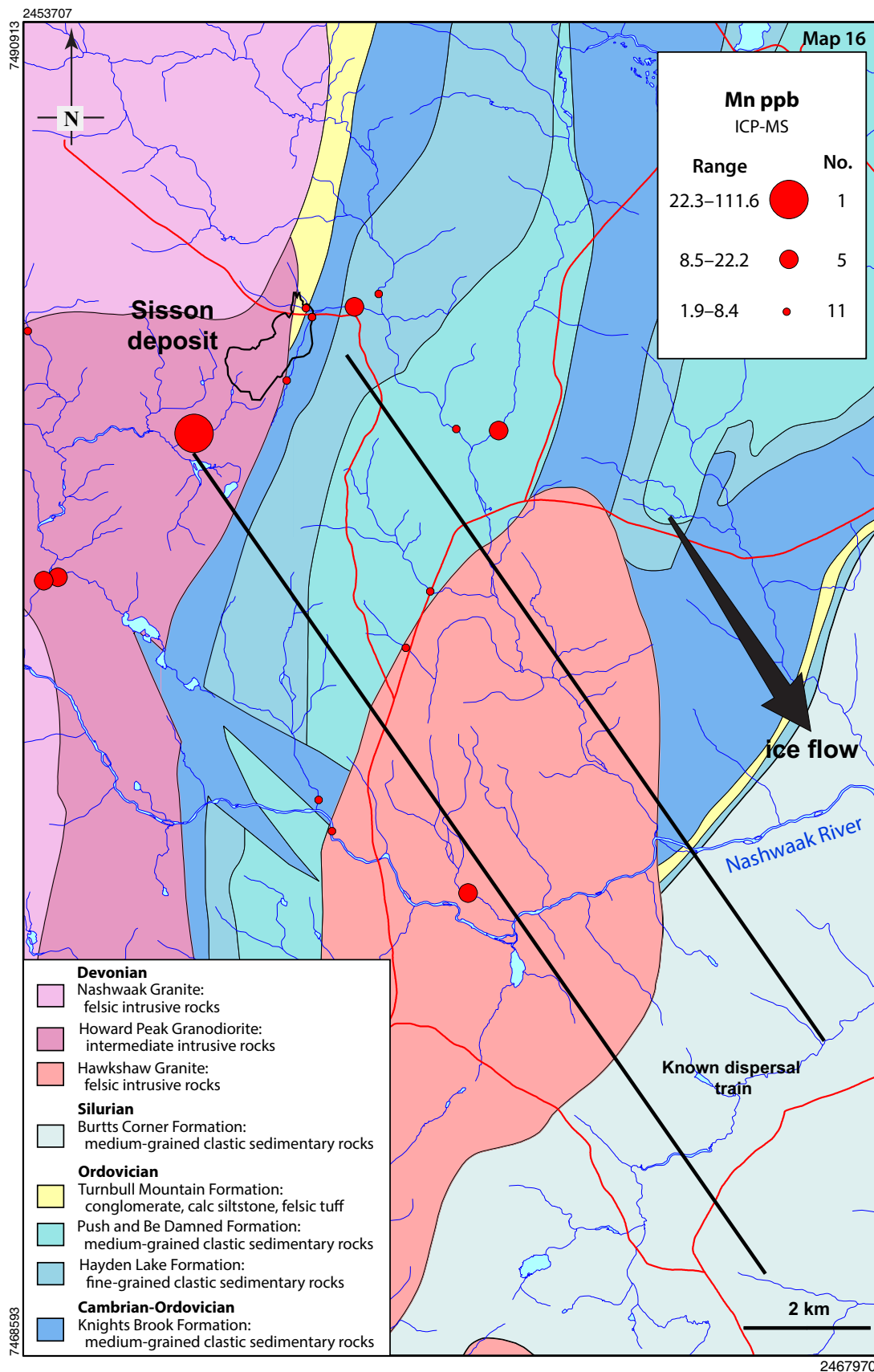
Map 14. Proportional dot map showing the pH of the stream water samples. Bedrock geology modified from Smith and Fyffe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C2 continued.



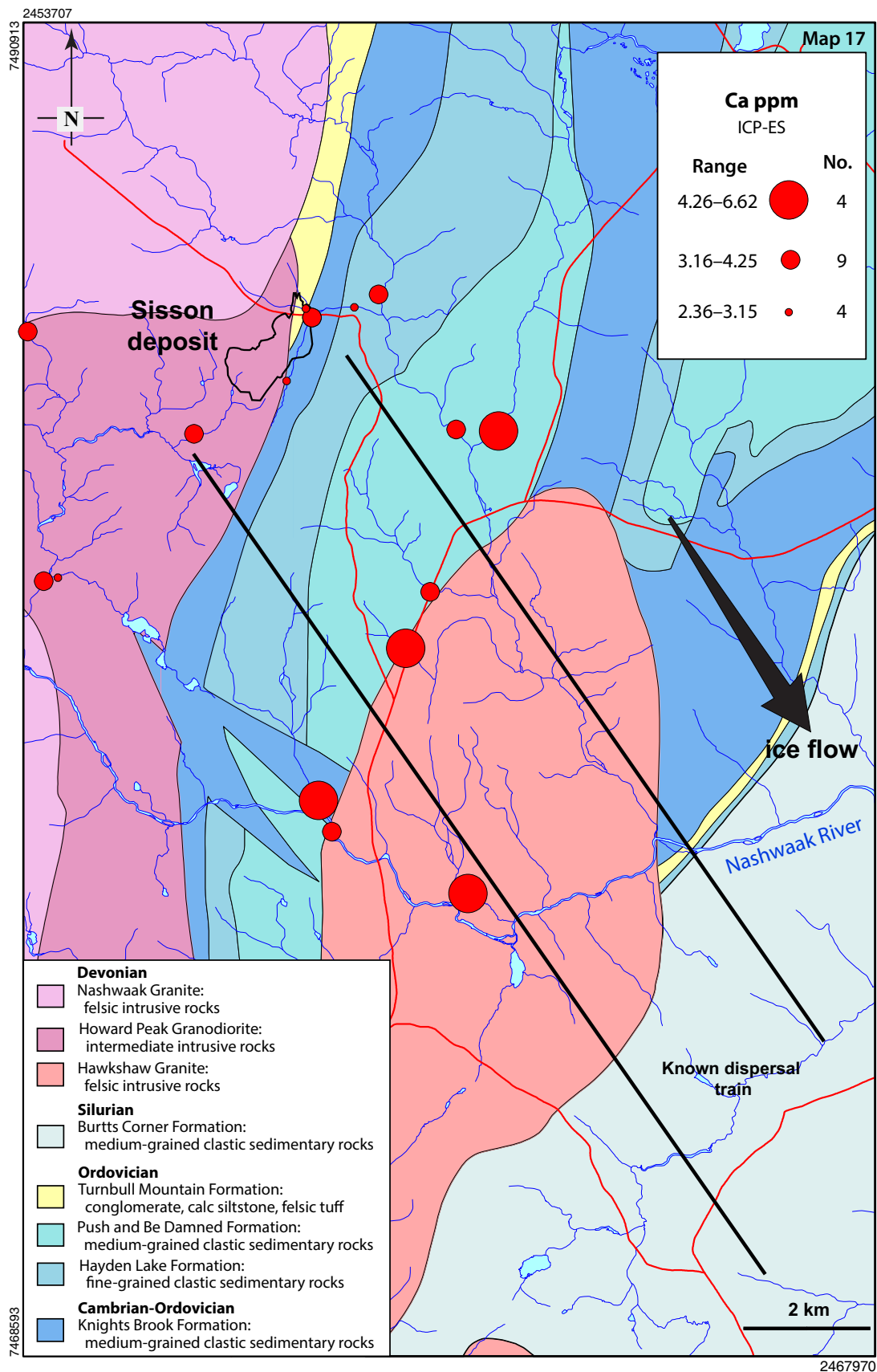
Map 15. Proportional dot map showing the iron (Fe) content of the stream water samples. Bedrock geology modified from Smith and Fyffe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C2 continued.



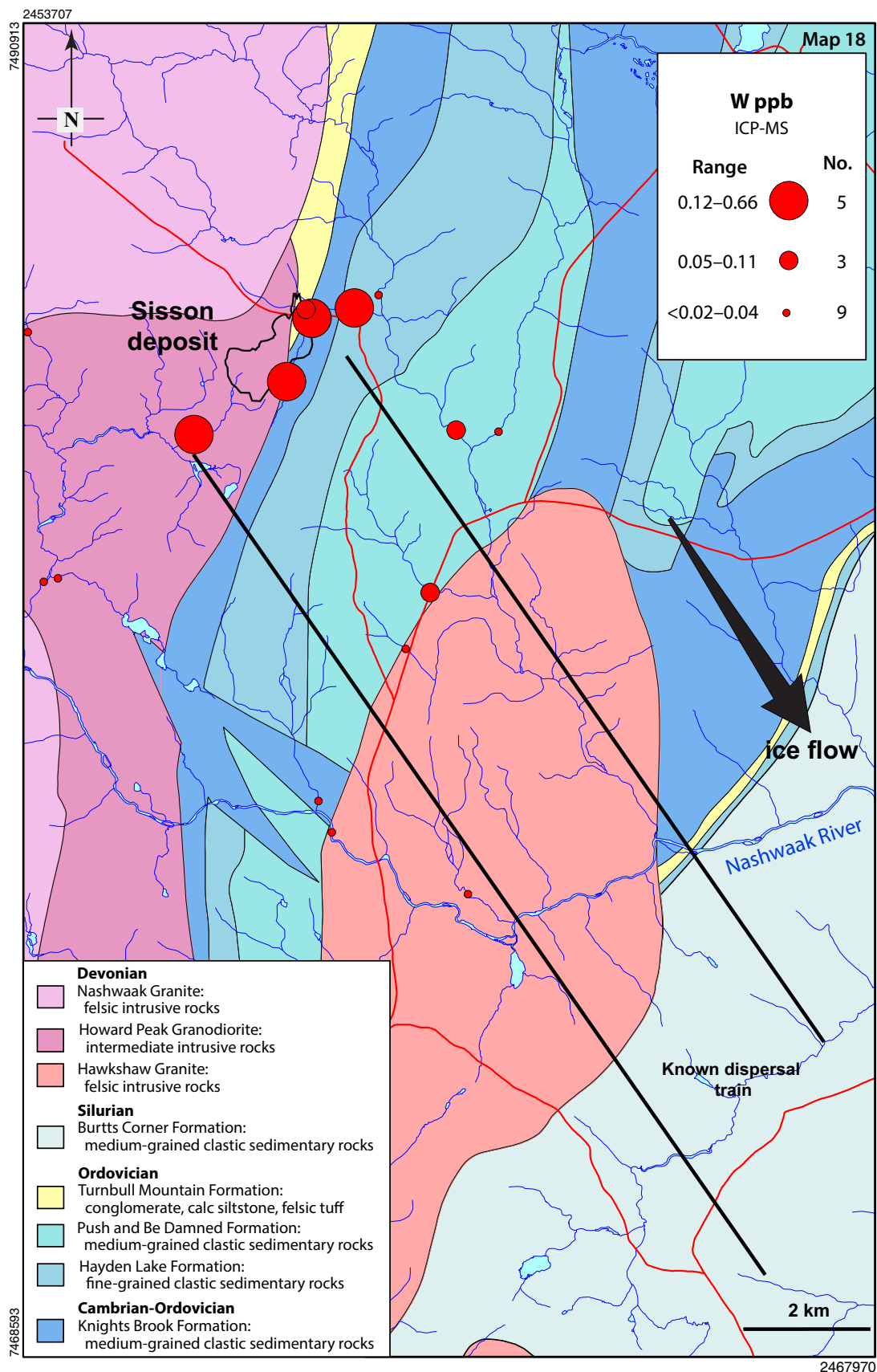
Map 16. Proportional dot map showing the manganese (Mn) content of the stream water samples. Bedrock geology modified from Smith and Fyfe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C2 continued.



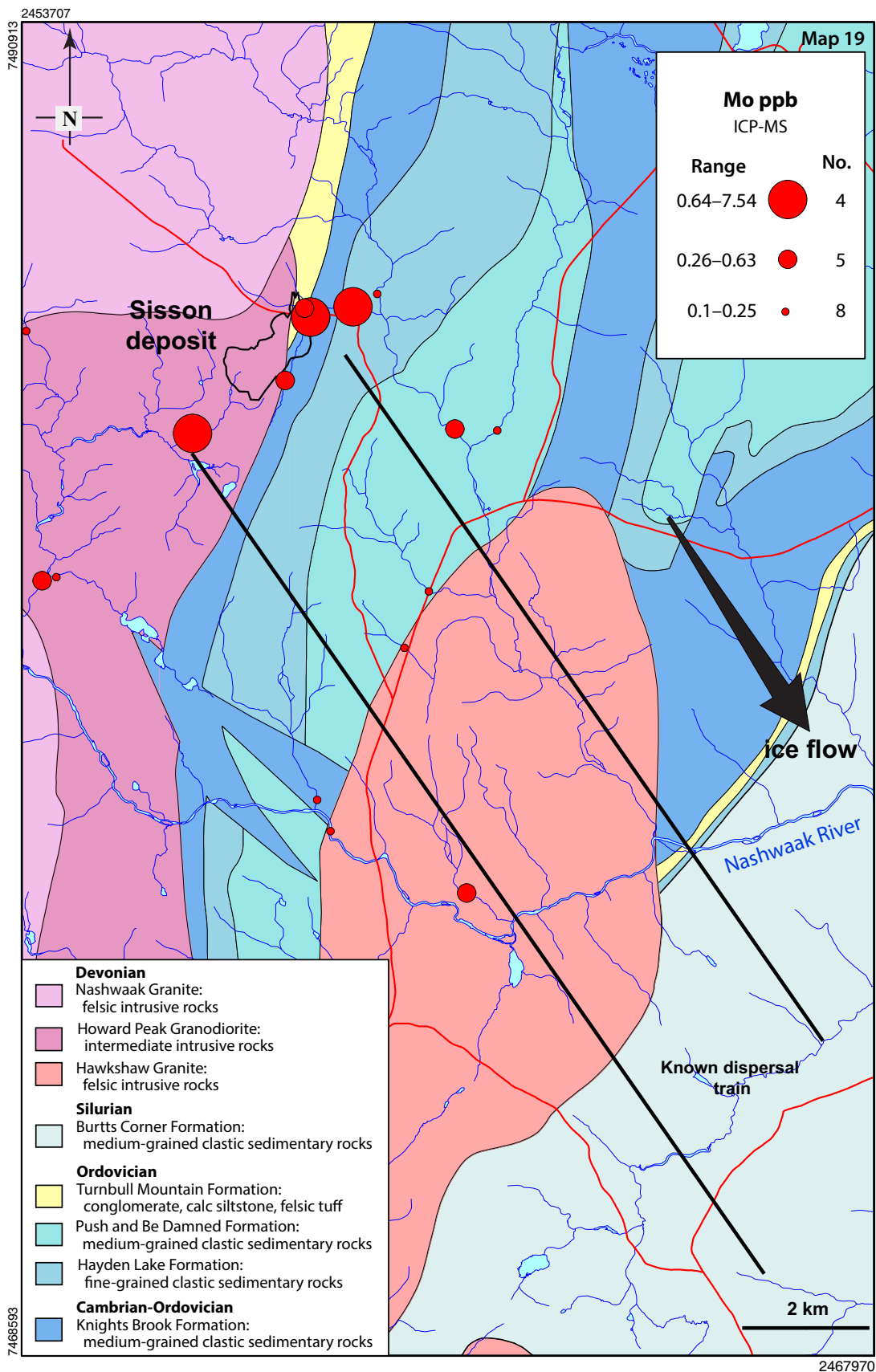
Map 17. Proportional dot map showing the calcium (Ca) content of the stream water samples. Bedrock geology modified from Smith and Fyffe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C2 continued.



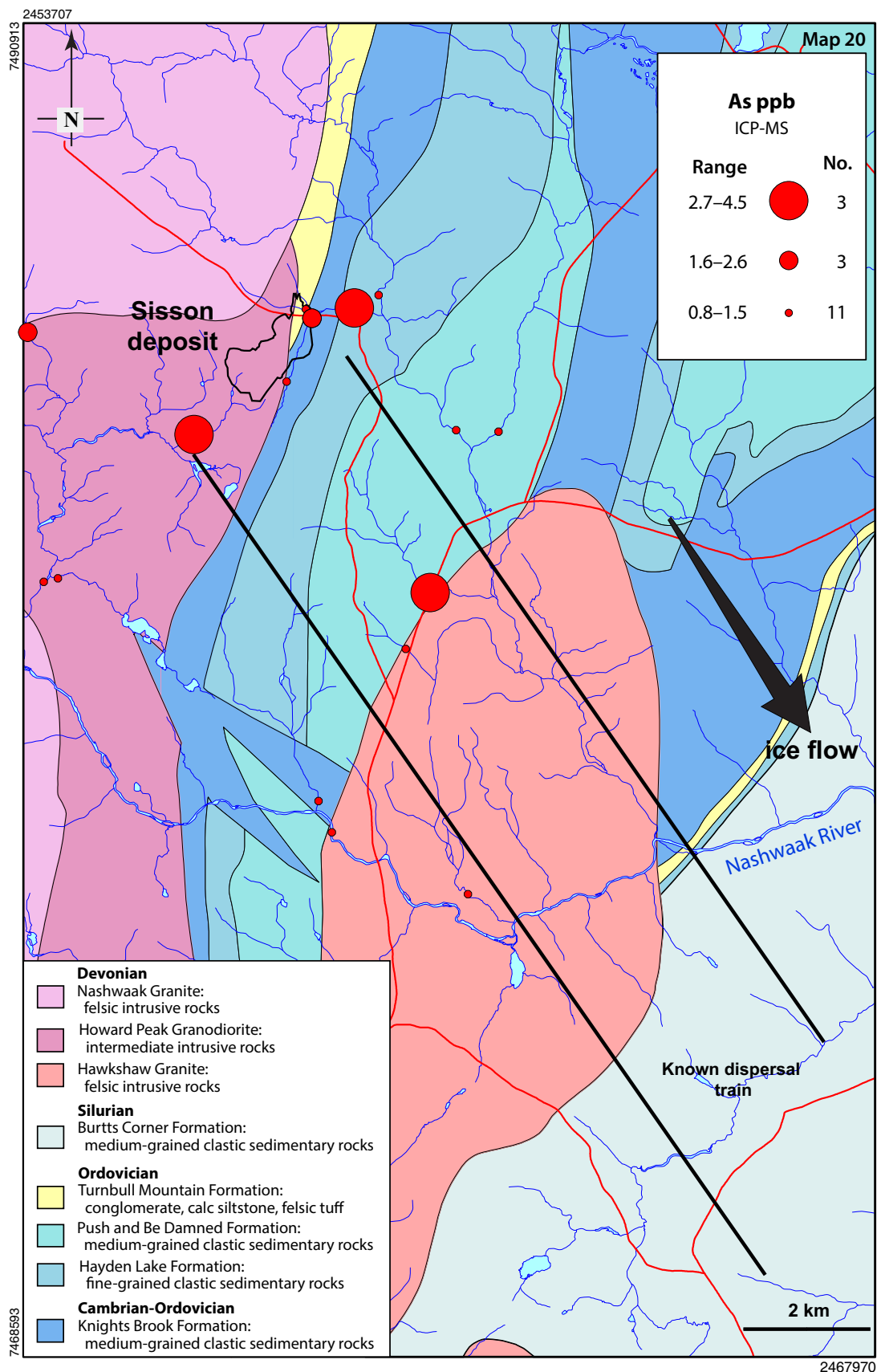
Map 18. Proportional dot map showing the tungsten (W) content of the stream water samples. Bedrock geology modified from Smith and Fyfe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C2 continued.



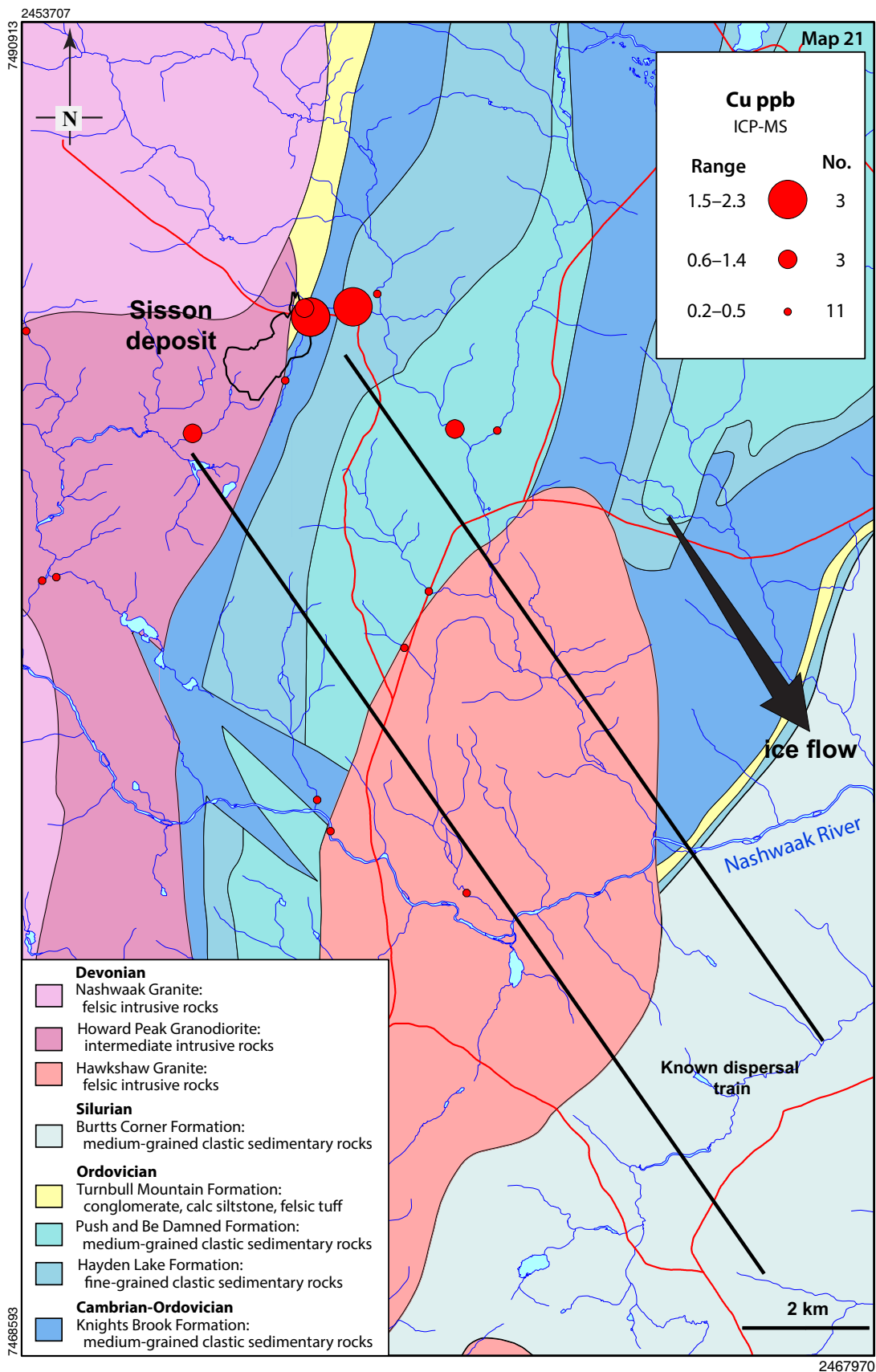
Map 19. Proportional dot map showing the molybdenum (Mo) content of the stream water samples. Bedrock geology modified from Smith and Fyfe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C2 continued.



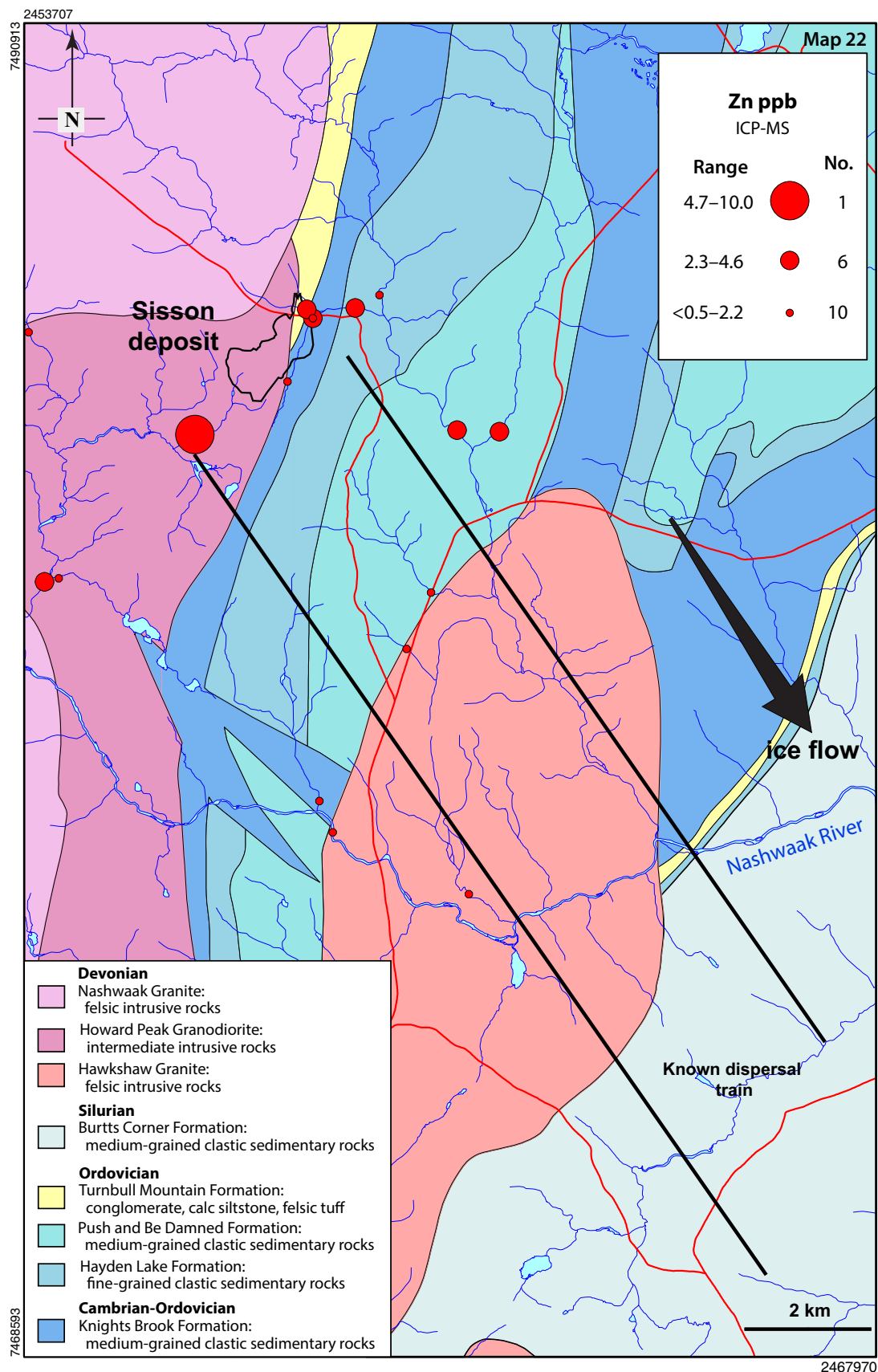
Map 20. Proportional dot map showing the arsenic (As) content of the stream water samples. Bedrock geology modified from Smith and Fyfe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C2 continued.



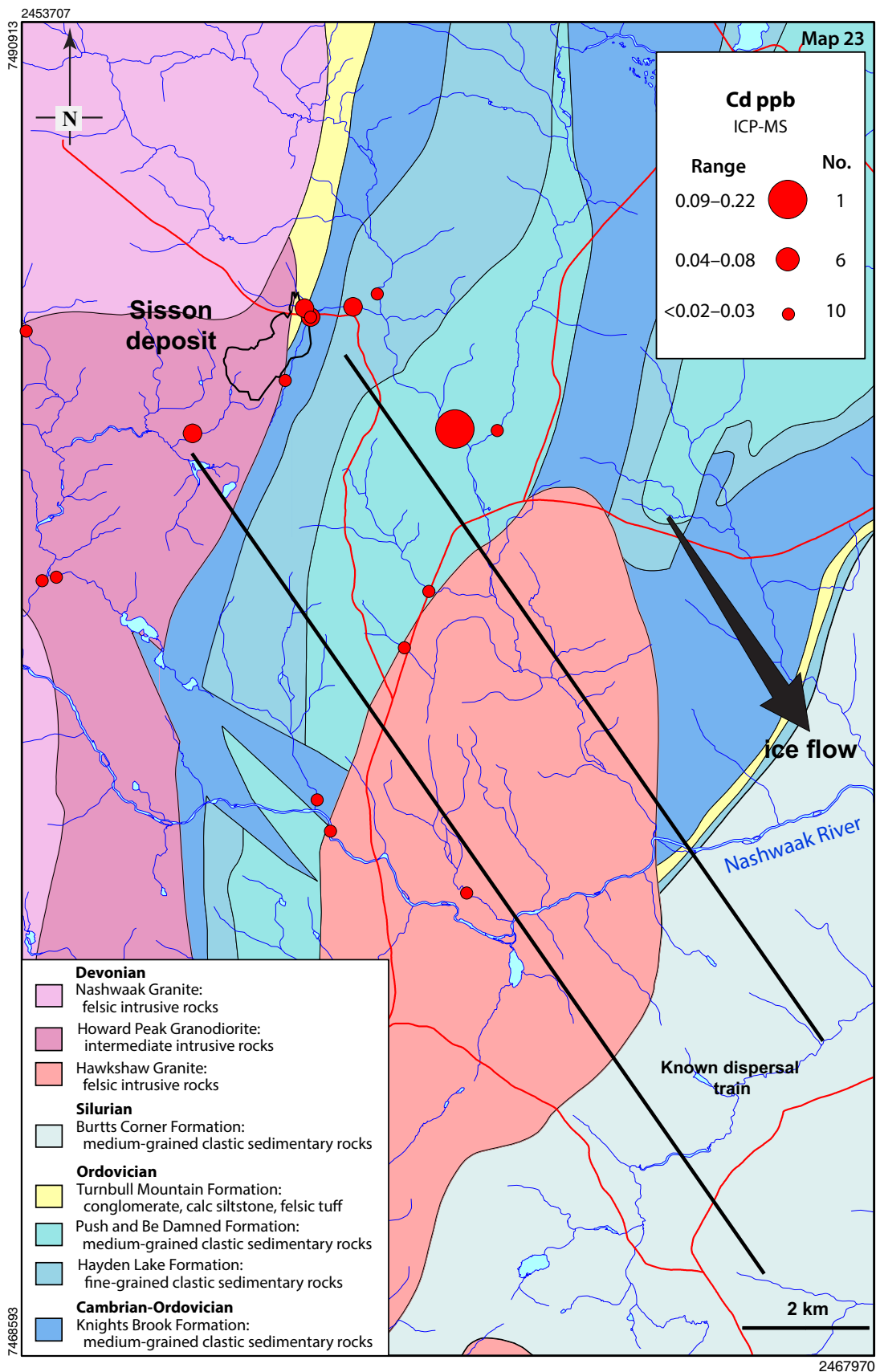
Map 21. Proportional dot map showing the copper (Cu) content of the stream water samples. Bedrock geology modified from Smith and Fyfe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C2 continued.



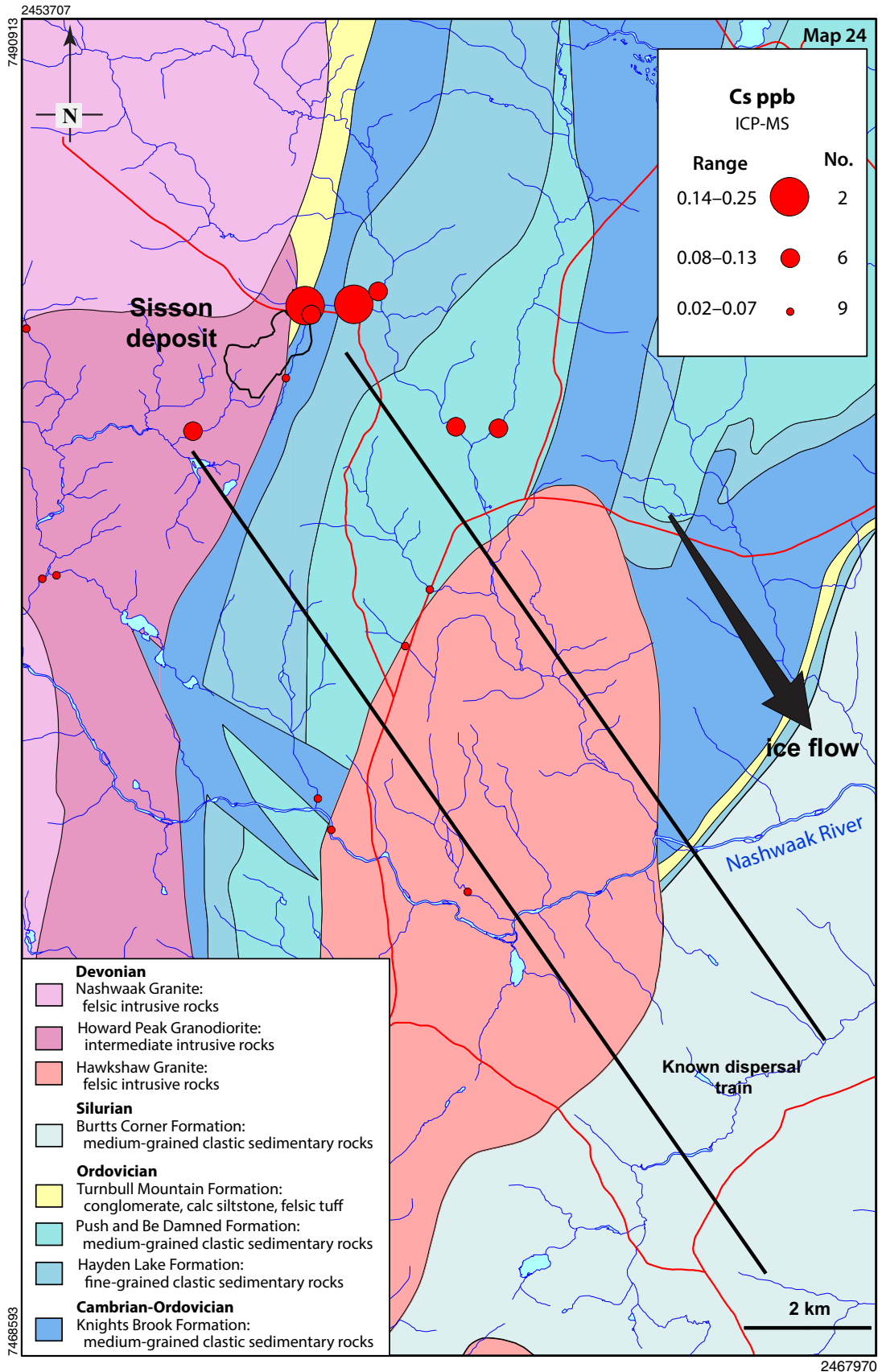
Map 22. Proportional dot map showing the zinc (Zn) content of the stream water samples. Bedrock geology modified from Smith and Fyfe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C2 continued.



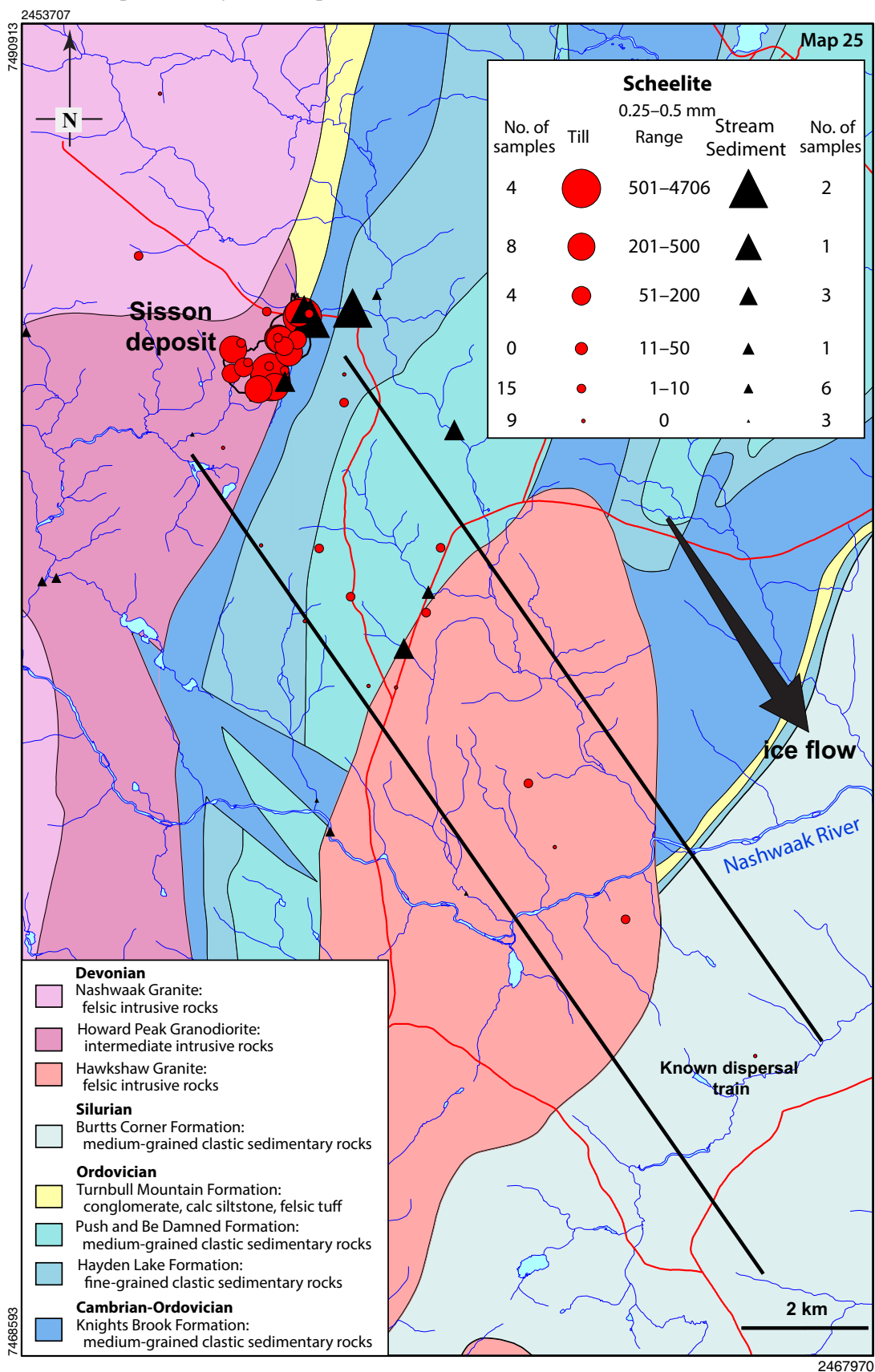
Map 23. Proportional dot map showing the cadmium (Cd) content of the stream water samples. Bedrock geology modified from Smith and Fyfe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C2 continued.



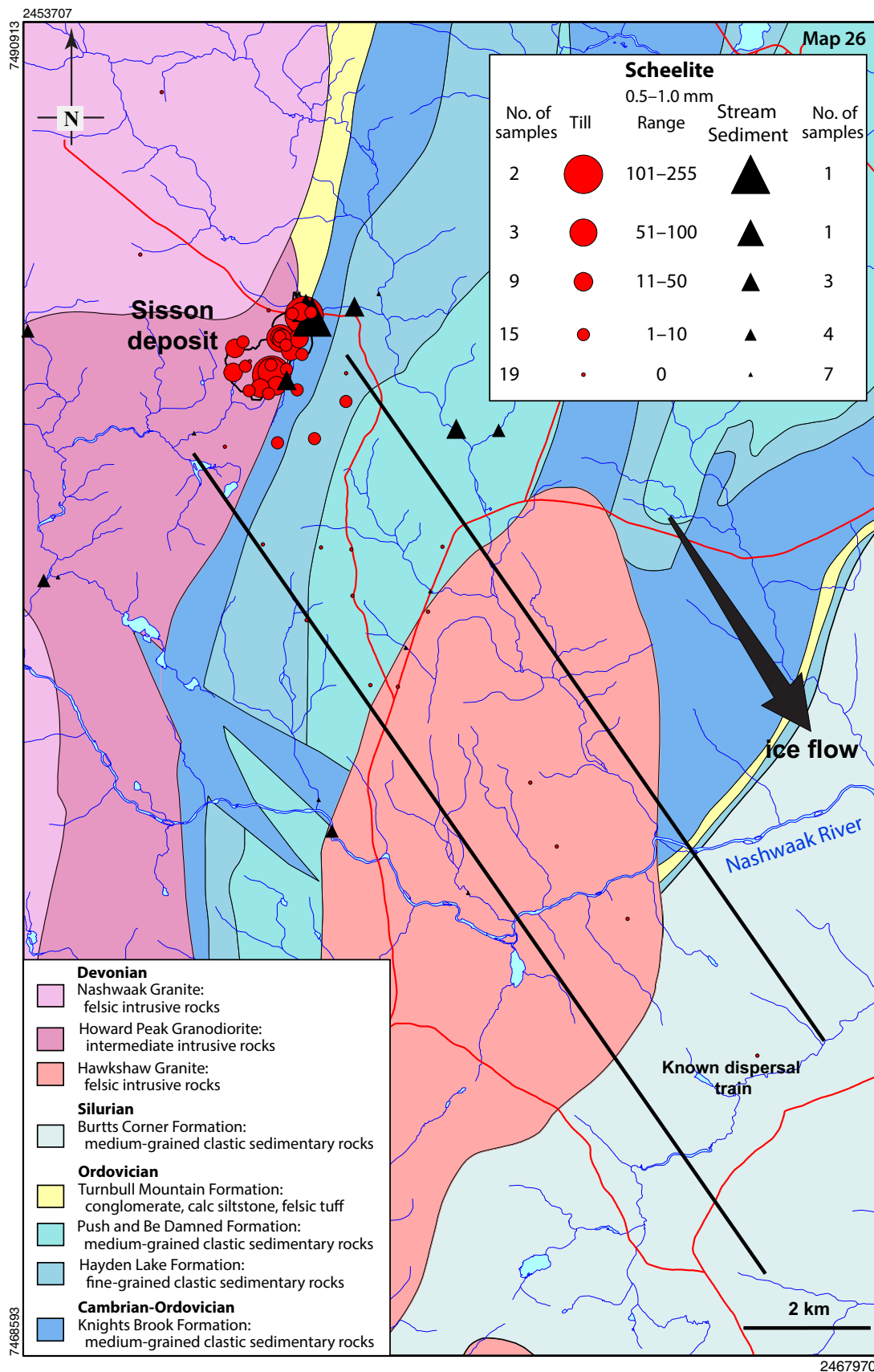
Map 24. Proportional dot map showing the cesium (Cs) content of the stream water samples. Bedrock geology modified from Smith and Fyfe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C3. Proportional symbol maps for stream sediment and till indicator mineral data.



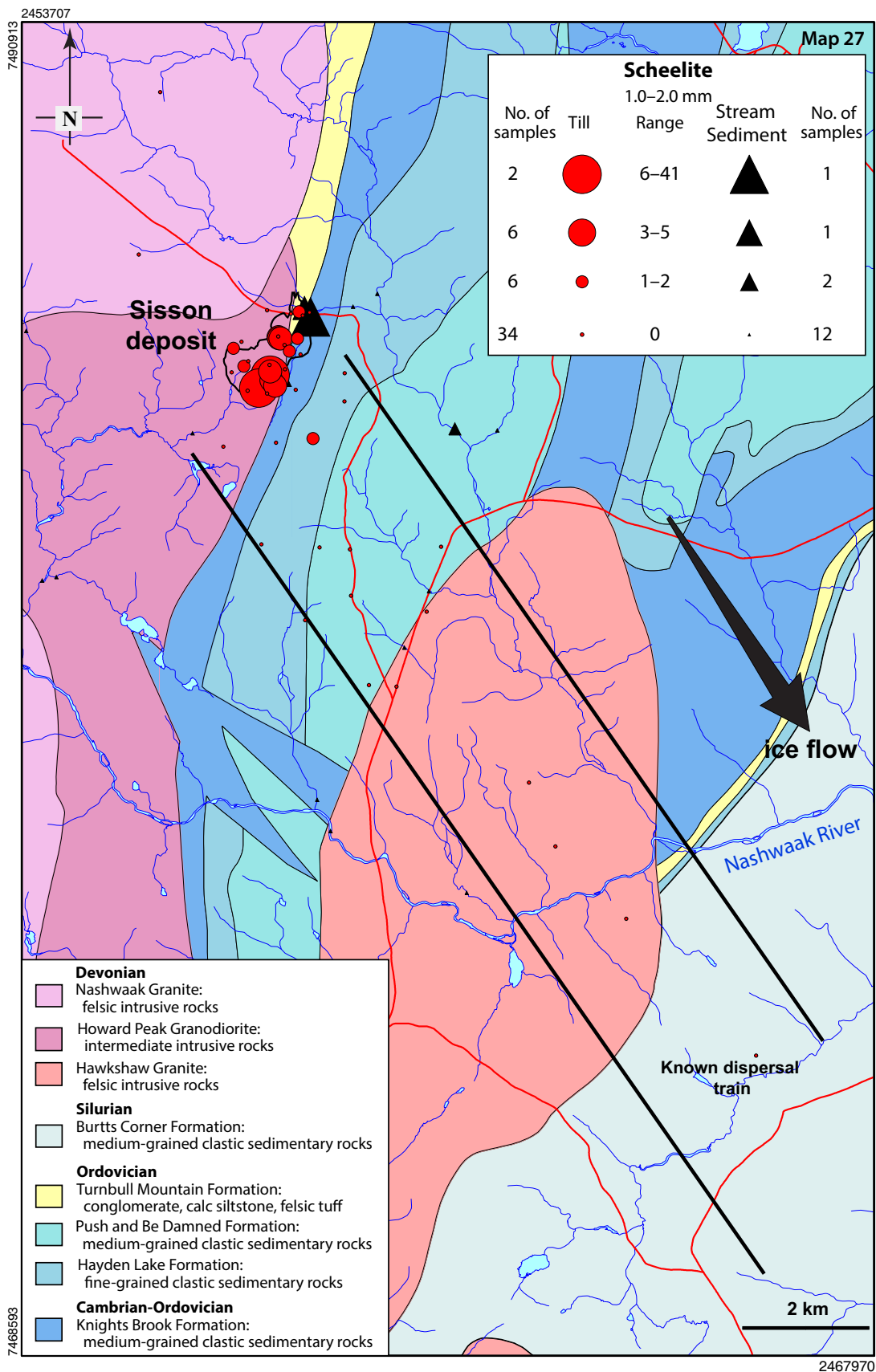
Map 25. Proportional symbol map showing the scheelite content in the 0.25–0.5 mm fraction of the stream sediment and till samples. Counts are normalized to 10 kg <2 mm material (table feed). Bedrock geology modified from Smith and Fyfe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C3 continued.



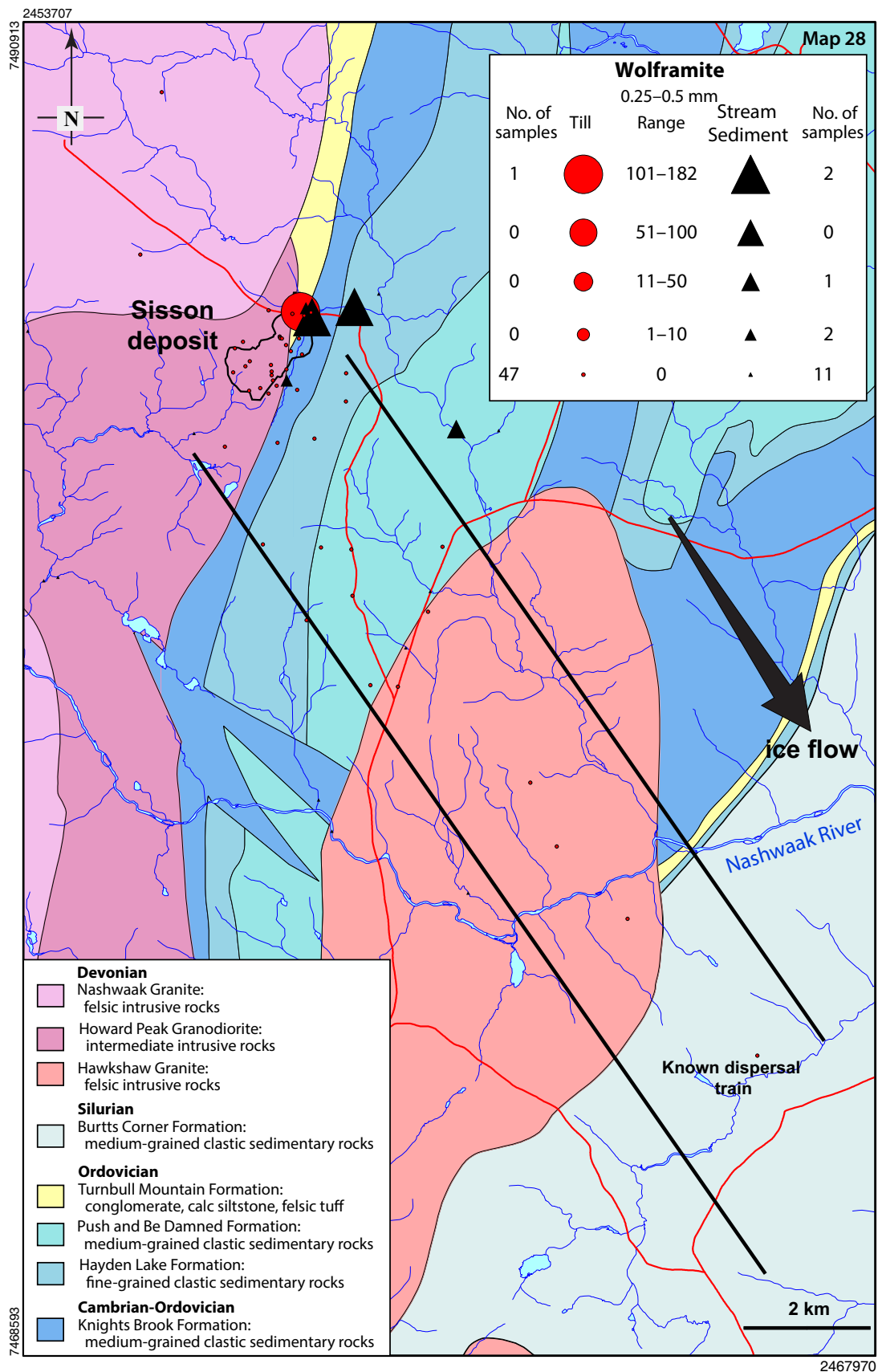
Map 26. Proportional symbol map showing the scheelite content in the 0.5–1.0 mm fraction of the stream sediment and till samples. Counts are normalized to 10 kg <2 mm material (table feed). Bedrock geology modified from Smith and Fyffe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C3 continued.



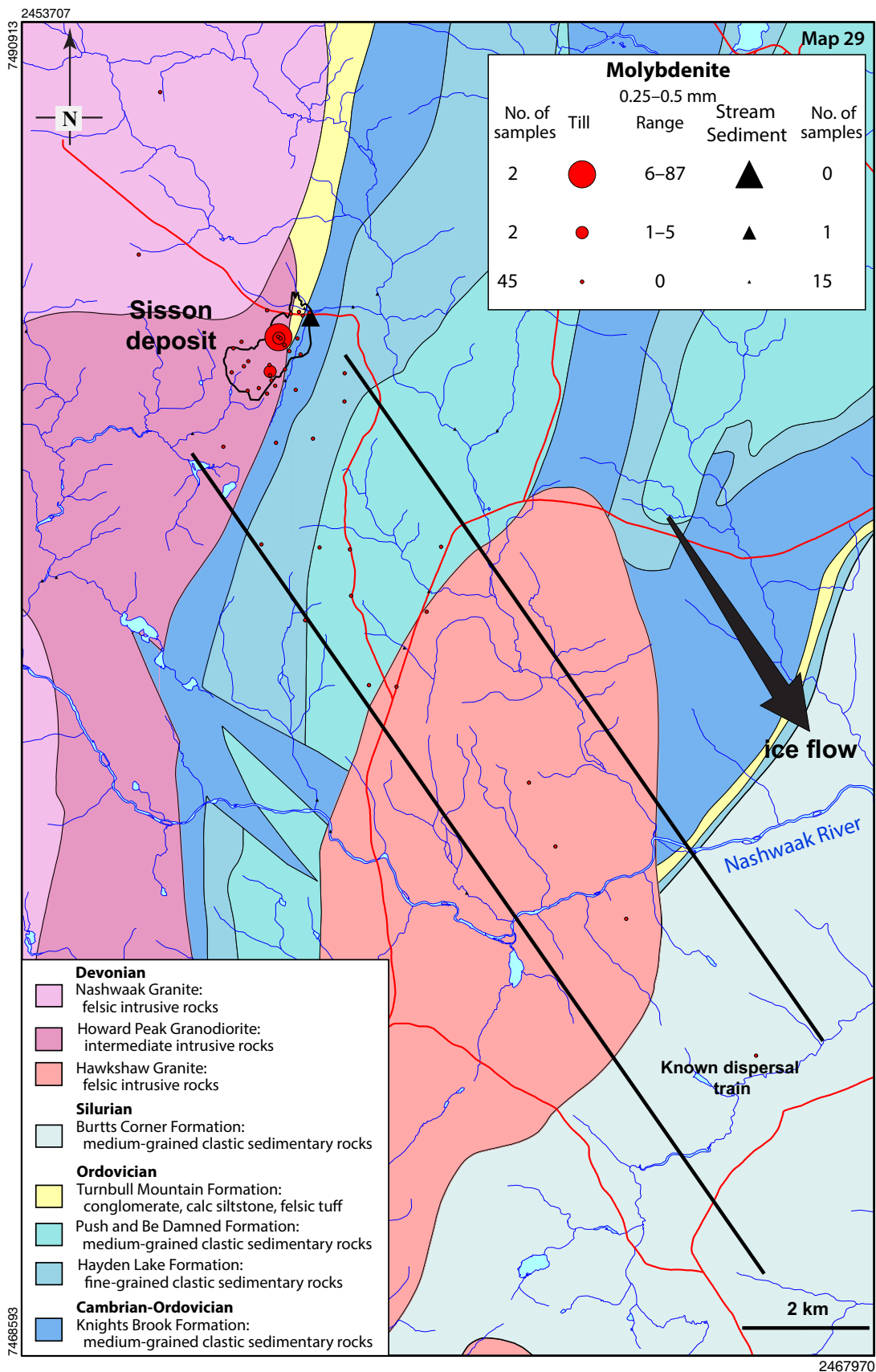
Map 27. Proportional symbol map showing the scheelite content in the 1.0–2.0 mm fraction of the stream sediment and till samples. Counts are normalized to 10 kg <2 mm material (table feed). Bedrock geology modified from Smith and Fyffe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C3 continued.



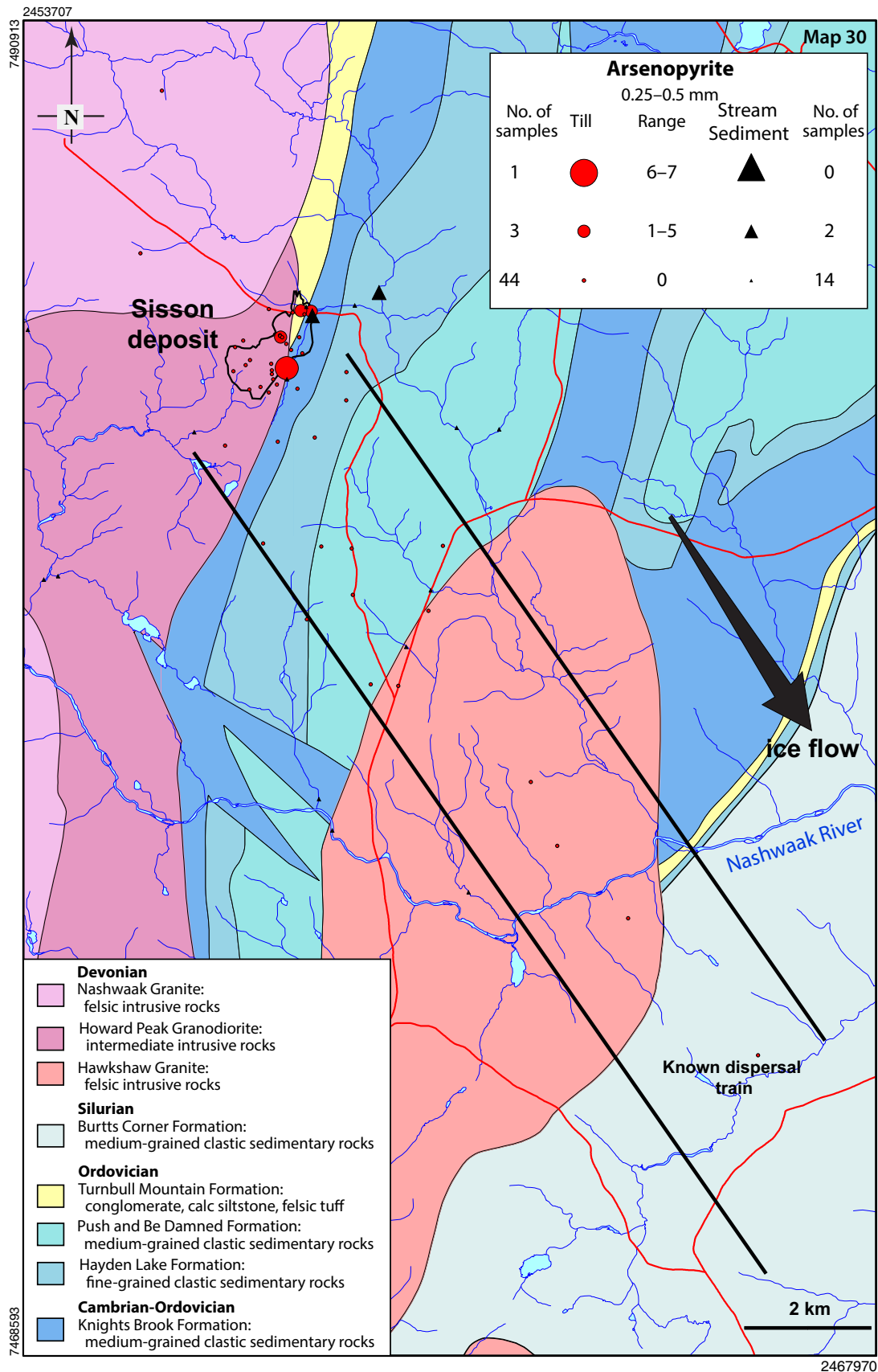
Map 28. Proportional symbol map showing the wolframite content in the 0.25–0.5 mm fraction of the stream sediment and till samples. Counts are normalized to 10 kg <2 mm material (table feed). Bedrock geology modified from Smith and Fyfe (2006a–d). Deposit outline from Rennie et al. (2012).

APPENDIX C3 continued.



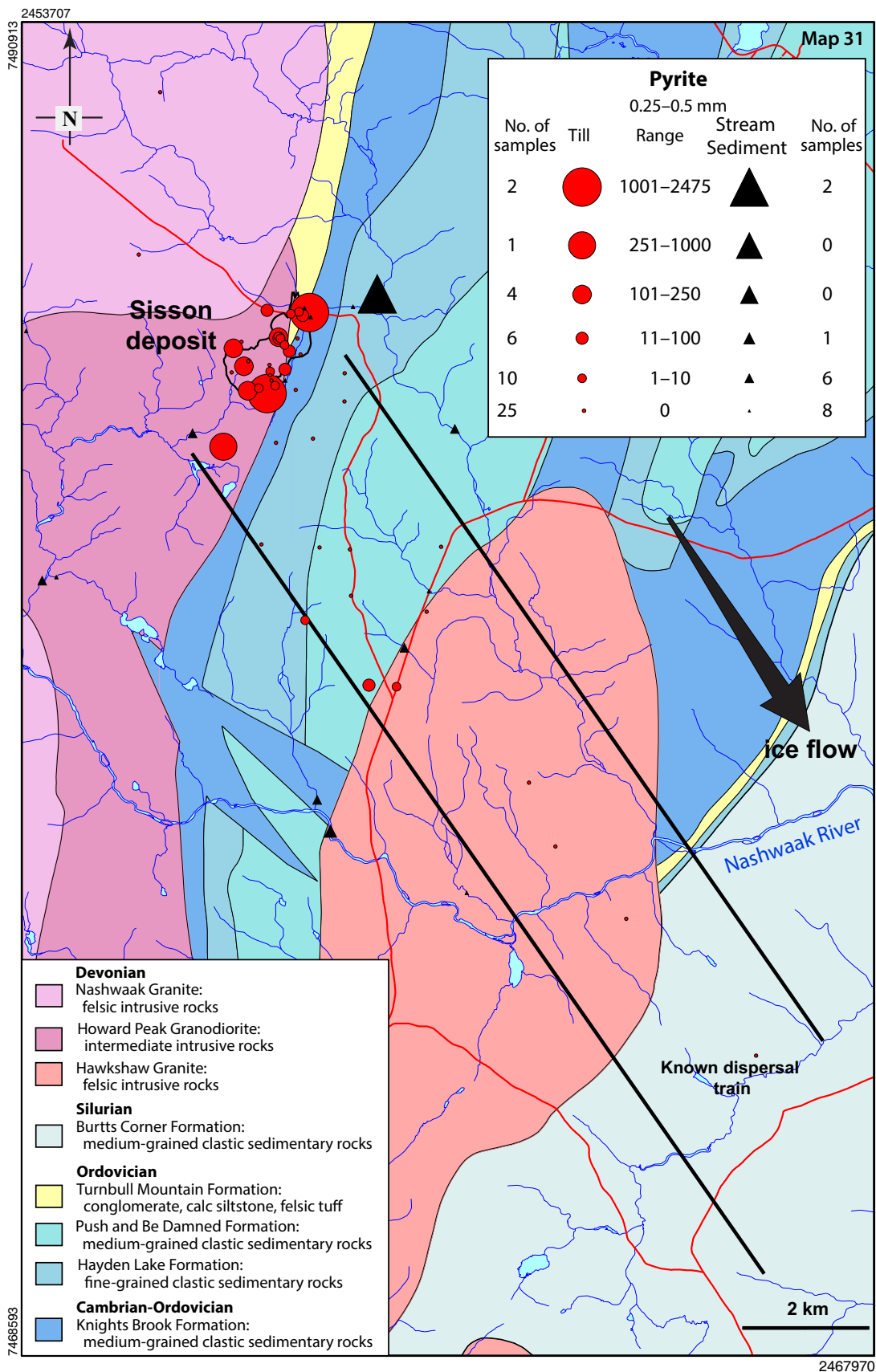
Map 29. Proportional symbol map showing the molybdenite content in the 0.25–0.5 mm fraction of the stream sediment and till samples. Counts are normalized to 10 kg <2 mm material (table feed). Bedrock geology modified from Smith and Fyfe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C3 continued.



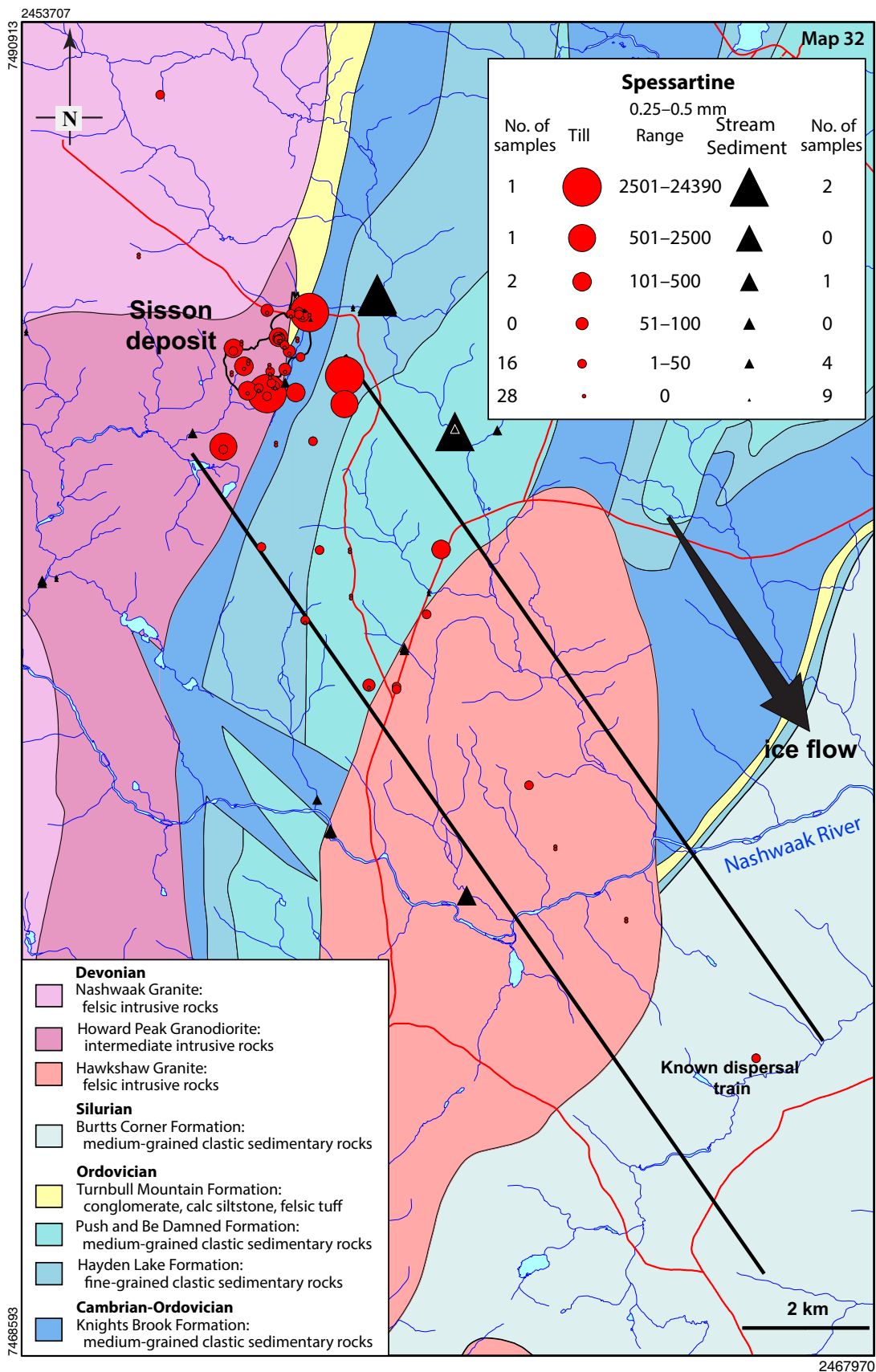
Map 30. Proportional symbol map showing the arsenopyrite content in the 0.25–0.5 mm fraction of the stream sediment and till samples. Counts are normalized to 10 kg <2 mm material (table feed). Bedrock geology modified from Smith and Fyffe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C3 continued.



Map 31. Proportional symbol map showing the pyrite content in the 0.25–0.5 mm fraction of the stream sediment and till samples. Counts are normalized to 10 kg <2 mm material (table feed). Bedrock geology modified from Smith and Fyffe (2006a-d). Deposit outline from Rennie et al. (2012).

APPENDIX C3 continued.



Map 32. Proportional symbol map showing the spessartine content in the 0.25–0.5 mm fraction of the stream sediment and till samples. Counts are normalized to 10 kg <2 mm material (table feed). Bedrock geology modified from Smith and Fyfe (2006a-d). Deposit outline from Rennie et al. (2012).