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BRITISH COLUMBIA | Ministry of Energy and Mines

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Front cover: Roadcut exposure of basal till, Chehalis valley, southwestern British Columbia.

Back cover: Northeast slope of Chehalis valley, about 1 km northwest of Seneca VMS occurrence.

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Application of lead isotopes in till for mineral exploration: a simplified method using ICP-MS

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Abstract

Elemental abundances and Pb isotopic ratios for 2.5N HCl leachates from Chehalis valley basal till samples (<0.063 mm fraction) highlight down-ice glacial dispersion of volcanogenic massive sulphide (VMS) occurrences. Despite the relatively young age of the Seneca VMS deposit and surrounding volcanic rocks (Middle Jurassic), the contrast in Pb isotopic ratios between tills derived from country rocks and tills containing ore material is 3-7%. This contrast is 2-3 orders of magnitude above the analytical uncertainties of state-of-the-art multi-collector inductively coupled plasma mass spectrometry (MC-ICP-MS). Our simplified method, in which Pb isotopic ratios are measured directly on bulk 2.5N HCl leachate solution by high-resolution inductively coupled plasma mass spectrometry (HR-ICP-MS), is consistent with the MC-ICP-MS results. It also has low analytical uncertainties (0.4-0.6%) capable of distinguishing between tills derived mainly from country rocks and those containing ore materials. Direct-leachate measurements using a quadrupole ICP-MS lack the resolution for tracing <10% isotopic contrast. Although elevated Pb, Zn, Cu, and Ba abundances in till overlying the Seneca deposit identify the latter, they show different down-ice dispersion patterns. In contrast, Pb isotopic ratios for leachates from the <0.063 mm till fraction appear to be robust indicators of down-ice glacial dispersion for the VMS mineralization. The Pb abundances and isotopic compositions are consistent with derivation of the Chehalis valley tills from isotopically heterogeneous local bedrock sources mixed with variable proportions of lead from VMS mineralization. The relatively inexpensive method of determining Pb isotopic ratios in tills by measuring 2.5N HCl leachates using HR-ICP-MS constitutes a robust exploration tool for a broad range of concealed Pb-rich deposits including relatively young deposits.

Keywords: Pb isotope ratios, basal till, glacial dispersal, volcanogenic massive sulphide deposits, Harrison Lake Formation, mineral exploration indicators, Seneca deposit, Canadian Cordillera

1. Introduction

Tills deposited by ice at the base of a glacier are commonly derived from nearby bedrock, and exploration geologists have long-used the lithological, mineralogical, and geochemical anomalies found in such tills to establish down-ice dispersion patterns (e.g., Shilts, 1976, DiLabio, 1990). Relative to multicyclic fluvial, lacustrine, and colluvial deposits, which have more complex histories of erosion, transport, temporary residence, and final deposition, overconsolidated silt-rich basal tills are minimally reworked and thus better reflect proximal source rock compositions. Once transport direction is understood, basal till geochemical anomalies can be traced to primary sources. In mountainous terrains flow paths are usually along linear, valley-controlled trends reflecting the most recent glacier movements (Levson, 2001).

Volcanogenic massive sulphide (VMS) deposits, important sources of copper, zinc, lead and precious metals, are formed in volcanic arcs or rifts by discharge of hydrothermal fluids onto the seafloor (e.g., Höy, 1991). Lead isotopes can effectively trace contributions to sedimentary deposits derived from isotopically distinct ore and country rocks and hence can be used to pinpoint Pb deposits (e.g., Gulson, 1986; Bell and Franklin, 1993; Bell and Murton, 1995; Simonetti et al., 1996; Hussein et al., 2003). Furthermore, weathering profiles retain the Pb isotopic ratios of parent ore bodies (Gulson, 1986).

Our study builds on the pioneering work of Bell and Franklin (1993), Bell and Murton (1995), and Simonetti et al. (1996), who established a method of using Pb isotopes in glacial overburden in the exploration of relatively old Archean (Manitouwadge, Ontario), Paleoproterozoic (Chisel Lake, Manitoba), and early Paleozoic (Buchans,

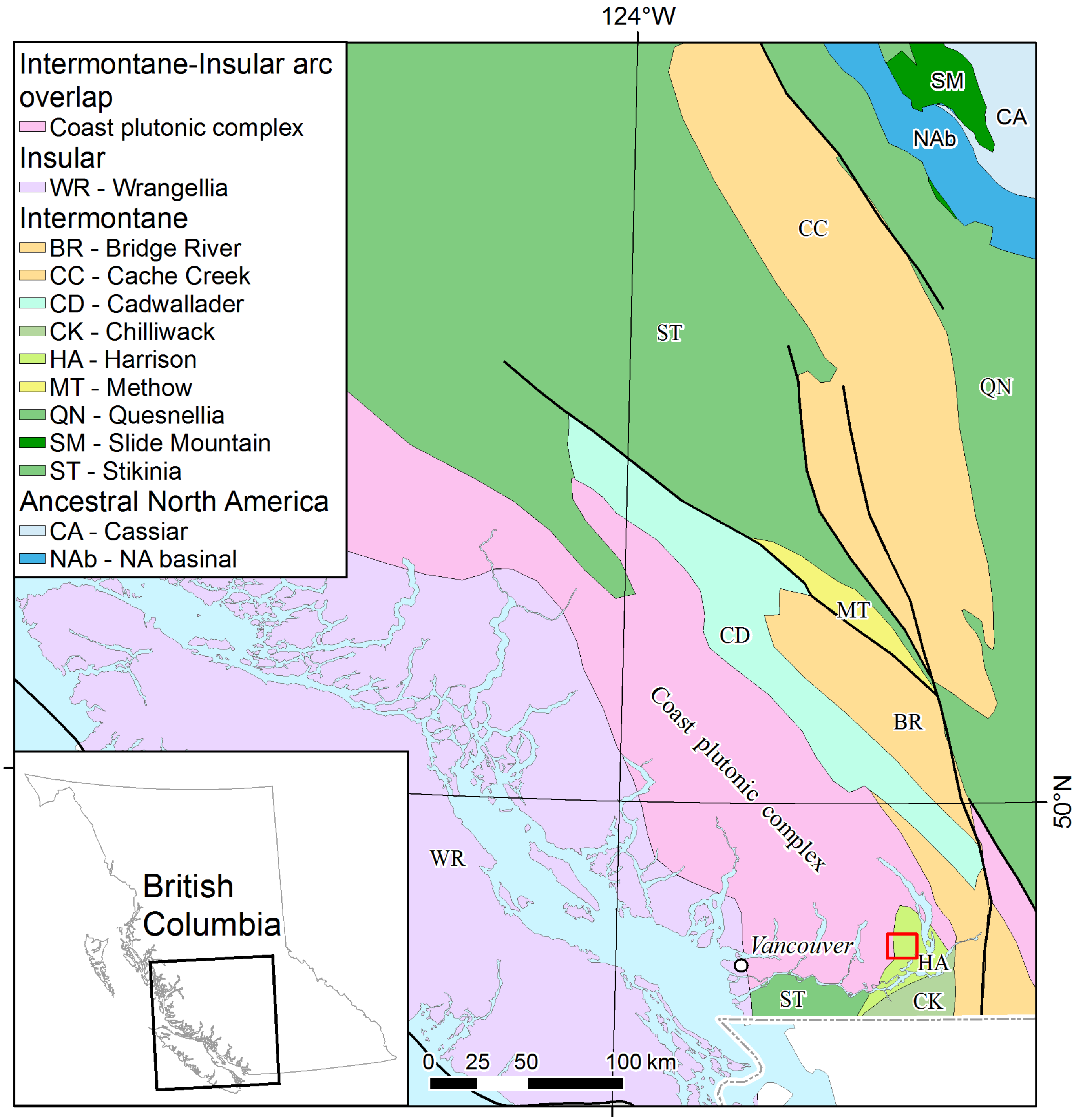

Fig. 1. Terranes (after Colpron and Nelson, 2011) and location of Chehalis valley study area (red box) in southwestern British Columbia.

Newfoundland) VMS deposits, and Hussein et al. (2003) who extended its application to another early Paleozoic deposit (Halfmile Lake, Bathurst, New Brunswick). The isotopic differences between the Pb from a VMS deposit and surrounding country rocks constitute the basis of this method. We refer the reader to Bell and Franklin (1993) and Bell and Murton (1995) for details of the theory behind Pb isotopes and till prospecting. Simonetti et al. (1996) also studied the effectiveness of several different selective extraction techniques and different grain-size fractions for the Pb isotopic analysis of tills.

Because most VMS deposits contain negligible U and Th but high Pb (up to a few wt.%), their Pb isotopic compositions remain little changed from the time they are emplaced. In contrast, the crustal rocks that host these deposits have much higher U and/or Th and much lower Pb contents and, as a result, develop distinctly more radiogenic present-day Pb isotopic compositions due to in situ decay of U and Th. In cases where mineralization is significantly younger than the host rocks, marked isotopic contrasts can originate as a primary feature. But because it generally takes time for in situ U and Th decay to increase radiogenic Pb concentrations in host rocks and raise the host rock-ore body Pb isotopic contrast to easily measured levels, previous studies have focused on older VMS deposits. In this study, we extend the application of Pb isotopes for tracing glacial dispersion from relatively young (Middle Jurassic) VMS deposits in Chehalis valley, southwestern British Columbia (Fig. 1). Our results demonstrate that Pb isotopes fingerprint the signature of these VMS deposits in overlying tills and provide an effective indicator for mineral exploration in the Canadian Cordillera. We also test the suitability of different instrumentation for the Pb isotopic analysis of till (<0.063 mm fraction) and rock samples. Our simplified method, in which Pb isotopes are measured directly in bulk 2.5N HCl leachate on a high-resolution ICP-MS (inductively coupled plasma mass spectrometer) provides suitable reproducibility for the isotopic contrast between country rock and ore.

2. Geology and physiography

The Chehalis valley study area is in the Coast Mountain Range, about 120 km east of Vancouver (Fig. 1). Most of the area is underlain by intermediate and felsic volcanic rocks of the Harrison Lake Formation (Early to Middle Jurassic) of the Harrison terrane (Fig. 1; Monger, 1970; Arthur et al., 1993; Monger and Journeay, 1994; Mahoney et al., 1995). These rocks host several Kuroko-style massive sulphide occurrences, including the Seneca Zn-Cu-Pb deposit (Höy, 1991; McKinley et al., 1994; 1995; McKinley, 2006). The Harrison terrane is intruded by Middle Jurassic porphyry stocks and plutons, made up of diorite, quartz diorite, granodiorite and tonalite, of the Coast Plutonic Complex (Fig. 2). Elevation in the study area varies from ~30 m above sea level at the confluence of the Chehalis and Harrison rivers, to headwater peaks >2,000 m. Outcrop is generally poor below the 500 m level. Forest cover ranges from recent clear-cut to mature stands of hemlock and cedar. Bedrock-controlled middle and upper slopes have moderate to steep gradients with rounded summits and ridges.

Downstream of Chehalis Lake, thick (>100 m) late Pleistocene sediments fill the Chehalis valley (Fig. 3). As described by Ward and Thomson (2004), these sediments span the transition from the middle Wisconsin interstadial, marked by a fluvial gravel unit, to the Late Wisconsin Fraser glaciation and Holocene nonglacial conditions. Fraser glaciation deposits include both advance- and retreat-phase laminated glaciolacustrine sediments, tills deposited by ice flowing down the Chehalis valley, and gravels interstratified with dropstone-bearing sand and silt, which represent subaqueous outwash deposits. Locally, thick (>50 m) bedded gravel foresets are capped by horizontally bedded gravel, likely marking deltas formed during deglaciation. Bedrock striations (Fig. 4) indicate ice flow towards the south-southeast, parallel to the Chehalis valley (Appendix 1; Fig. 2), perhaps by ice sourced in the upper valley (Ward and Thomson, 2004). The occurrence of older bedrock striations oblique to the valley may also record possible ice flow up, and perhaps westward across, the Chehalis valley from the Fraser lowland during the Late Wisconsin maximum or perhaps a pre-Late Wisconsin glaciation (Ward and Thomson, 2004).

3. Samples

We collected 26 till and 11 bedrock samples from Chehalis valley (Fig. 2). In addition, duplicates of till samples (2-3 kg) were collected at three randomly selected sample sites. Most of the till samples are from forestry roadcuts. Sample sites are distributed up and down ice of the VMS occurrences. Sampling density increases near the VMS occurrences; one sample was taken immediately above the Seneca pit. Details for till samples are given in Appendix 2. Most of the samples were collected at depths of >0.4 m. Care was taken to avoid rootlets and oxidized or reduced joint surfaces or horizons. The tills overlie laminated silt, bedded sand and gravel, or bedrock. For tills directly overlying bedrock, samples were collected 0-0.1 m above the contact. The till is generally massive, dense and weakly fissile, has a silty sand matrix, and contains 25%–55% clasts (Fig. 5). A crude stratification, owing to variation in clast size and abundance is locally developed (Fig. 5a). Subangular to subrounded granules and pebbles are predominant and clasts are commonly striated. Volcanic rocks of the Harrison Lake Formation are the main clast type (>60%), although one sample contains mainly diorites and granodiorites of the Mt. Jasper pluton (Fig. 6; Appendix 3), indicating glacial transport and bedrock sources within the study area. Till samples down ice from, and directly above, the Seneca pit contain abundant mineralized clasts, with up to 7% of rusty pseudomorphs (up to 4 mm in diameter) presumably after sulphide grains (Fig. 7).

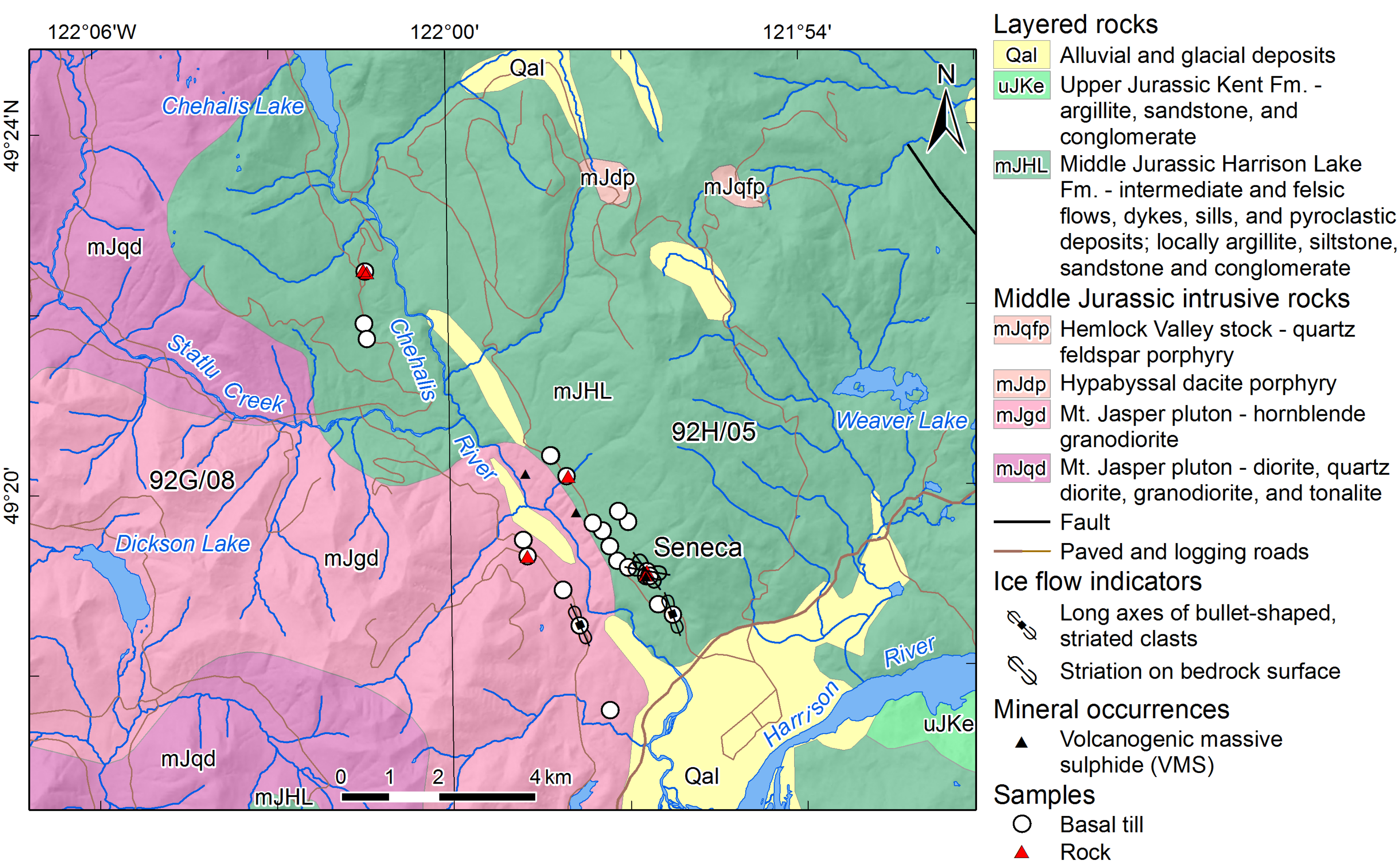

Fig. 2. Geology, sample locations, ice-flow indicators and mineral occurrences, Chehalis valley. Geology after Monger (1970), Arthur et al. (1993), Monger and Journeay (1994), and Mahoney et al. (1995).

Fig 3. Northeast slope of Chehalis valley, about 1 km northwest of Seneca VMS occurrence.

Fig. 4. Two sets of cross-cutting striations on bedrock overlain by till.

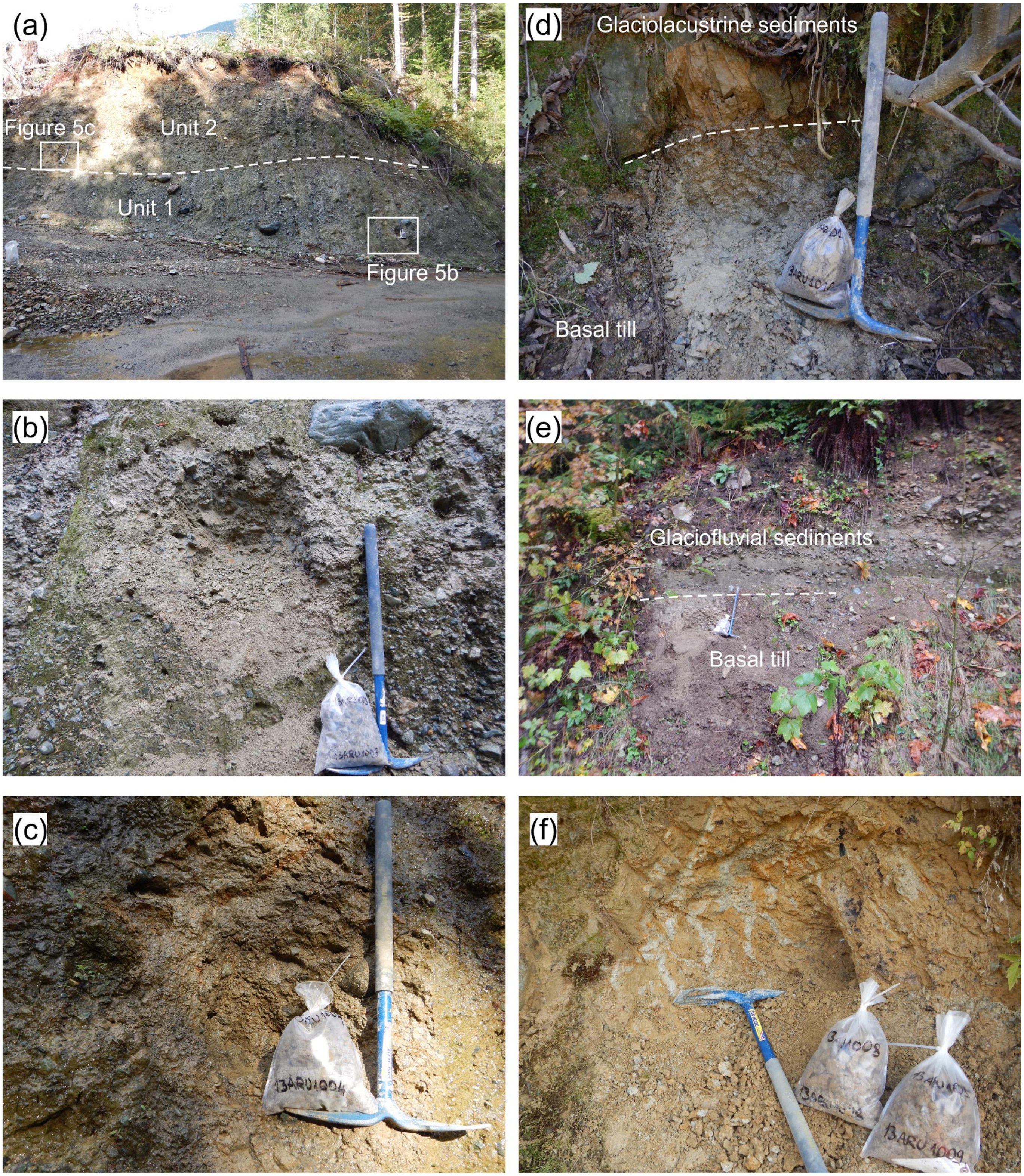

Fig. 5. Examples of basal till, Chehalis valley. **a)** Clast-rich till (unit 1) overlain by darker till with smaller, less abundant clasts (unit 2). **b)** Close up of unit 1, showing weakly oxidized, dense till with silty sand matrix and about 35% clasts. **c)** Close up of unit 2, showing more oxidized, less dense till with sandy matrix and about 30% clasts. **d)** Dense till with sandy silt matrix and about 35% clasts, overlain by retreat-phase glaciolacustrine silt and clay. **e)** Weakly oxidized, dense till with sandy silt matrix and about 30% clasts, overlain by bedded sand and gravel. **f)** Mottling, possibly after vegetation roots, in pervasively oxidized, dense till with sandy silt matrix and about 25% clasts.

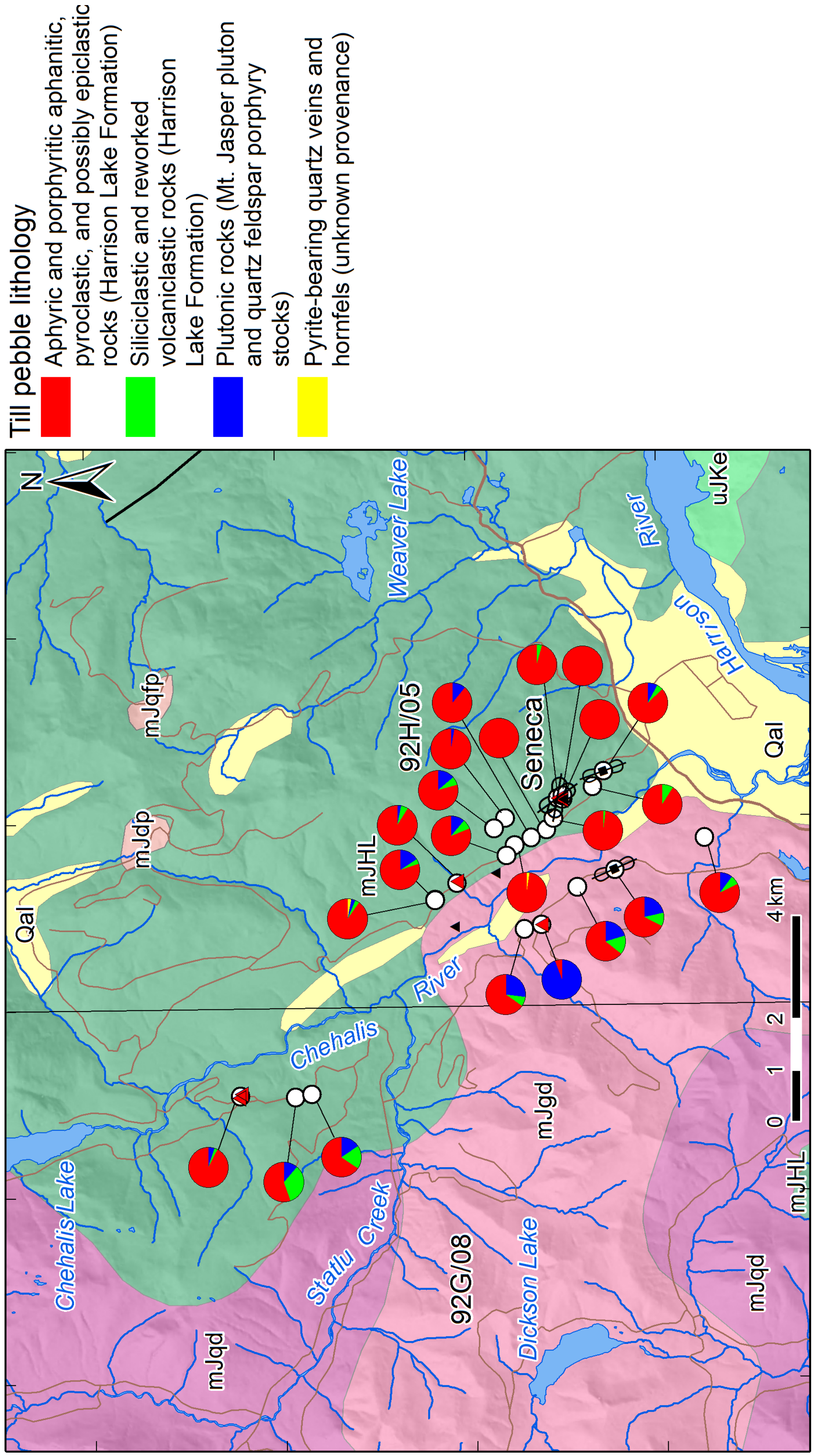

Fig. 6. Lithology of pebbles from till samples, Chehalis valley. Bedrock legend and other symbols as in Figure 2.

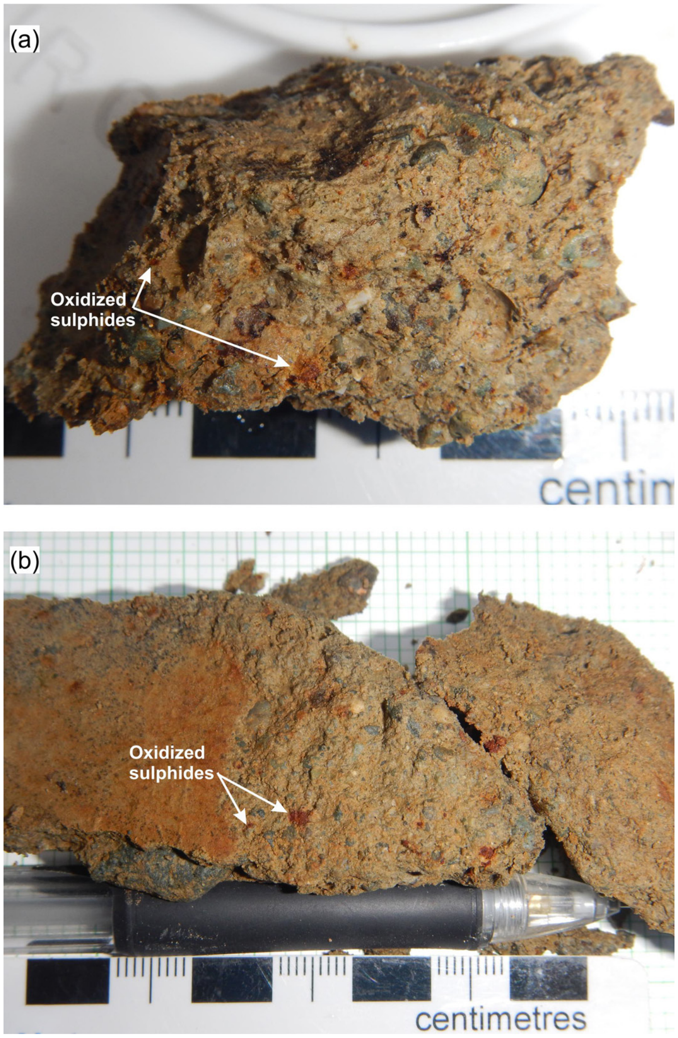

Fig. 7. Basal till with sand- to granule-size oxidized sulphides. **a)** Till collected about 1 km down ice from the Seneca pit. **b)** Till collected directly above the southeast wall of the Seneca pit.

Bedrock samples include Kuroko-style VMS mineralization from the Seneca deposit and nearby country rocks (Appendix 4). Samples of country rocks are mostly dacite and rhyodacite porphyries and tuffs of the Harrison Lake Formation and one sample of hornblende diorite from the Mt. Jasper pluton (Fig. 2). Dacite and rhyodacite have phenocrysts of plagioclase and orthoclase (total 5-15%), quartz (0-3%), and hornblende (1-2%), set in a dense, very fine-grained felsic groundmass. Feldspars are sericitized and altered to clay, and hornblende is completely replaced by pseudomorphs of chlorite±epidote±tremolite. Secondary chlorite, epidote and tremolite also form veinlets in the albitized or sericitized groundmass. Volcaniclastic rocks from Seneca pit area are lapilli tuff with disseminated pyrite (~4%) and sphalerite (<1%) in a silicified and sericitized matrix, and very fine-grained reworked felsic ash tuff. A subvertical gossanous zone (~1.5 m wide) within lapilli tuff at a roadcut outcrop ~2.5 km northwest of Seneca pit contains abundant pyrite cubes (up to 0.5 cm), clay, sericite, chlorite, minor epidote, and accessory sphalerite and titanite. Diorite from the Mt. Jasper pluton is a massive, weakly porphyritic rock with rare phenocrysts of plagioclase (up to 1 cm) and quartz (up to 6 mm) set in a medium-grained groundmass. The groundmass is made up of weakly sericitized and chloritized plagioclase, fresh or weakly chloritized and epidotized hornblende (6-7%), magnetite (1%), and interstitial quartz (4-5%) and chlorite. Accessory apatite forms euhedral inclusions in hornblende.

VMS mineralization in the Seneca Pit includes stratiform lenses of pyrite (15-60%), sphalerite (7-10%), chalcopyrite (1-5%), and minor galena (<1%) in strongly sericitized and silicified fragmental volcanic rocks, and veins and disseminated sulphides in altered dacite lava and epiclastic conglomerate. Barite is common and locally comprises up to 50% of the rock. Detailed descriptions of the geology, mineralization, and exploration history of the Seneca deposit can be found in McKinley et al. (1995) and McKinley (2006).

4. Analytical methods

Samples were prepared at the British Columbia Geological Survey (BCGS), where blind quality control samples were inserted. Till samples were oven dried at 40°C and sieved to <0.063 mm. Rock samples were jaw crushed, and fragments (>3 mm) selected to be free of weathered surfaces were pulverized using a steel mill. All equipment was thoroughly washed between samples to avoid cross contamination. In addition, a small portion of each sample was processed and discarded to 'pre-contaminate' the equipment.

Elemental abundances were determined by several different methods. Total contents of Cu, Zn, As, Rb, Sr, Zr, Mo and Pb were analyzed at BCGS using a Thermo Scientific Niton FXL 950 energy-dispersive X-ray fluorescence (XRF) spectrometer in hand-pressed, 32 mm-diameter sample pellets, made with a 4 µm-thick polypropylene bottom. We used an 8-mm X-ray spot diameter, automated sample spinner, 180 seconds counting time, and Compton internal standardization method with calibration factors of Rukhlov (2013; Appendix 5). Total C and S were determined by Leco combustion, loss-on-ignition (LOI) at 1000°C gravimetrically. After fusion of samples with lithium metaborate-tetraborate, major and minor oxides were determined by inductively coupled plasma atomic emission spectrometry (ICP-ES) and trace elements by inductively coupled plasma mass spectrometry (ICP-MS) at Acme Analytical Laboratories Ltd., Vancouver, B.C. (Acme; Appendix 6). Concentrations of Ag, As, Au, Bi, Cd, Cu, Hg, Mo, Ni, Pb, Sb, Se, Tl, and Zn were determined by hot aqua regia leaching of 0.5-g samples and ICP-MS analysis at Acme (Appendix 7). Samples were also analyzed for 35 elements by instrumental neutron activation analysis (INAA) at Activation Laboratories Ltd., Ancaster, Ontario (Actlabs; Appendix 8). Table 1 lists the minimum detection limits (DL) and percentage of results at or below DL per element for each method.

For Pb isotopic analyses, we used a conventional leaching technique that Simonetti et al. (1996) found to be more effective in enhancing the Pb isotopic contrast between the mineralized and background samples than complete dissolution or other selective extractions. In our modified procedure, 0.3 to 0.5 g samples were leached with 6-10 mL of 2.5N HCl at room temperature for ~2 hours and the leachate solutions were analyzed at three laboratories using different mass spectrometers (Appendix 9). Lead isotopic ratios were measured directly in centrifuged, decanted, and diluted bulk leachate solution on a Perkin Elmer Nexion quadrupole inductively coupled plasma mass spectrometer (quad ICP-MS) at Acme and, with addition of HNO_3, on a Thermo Scientific Finnigan ELEMENT 2 high-resolution, double focusing magnetic sector field inductively coupled plasma mass spectrometer (HR-ICP-MS) at Actlabs. Lead isotopic ratios for 14 selected samples were also measured on a Nu Plasma multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS) after leachate Pb purification by ion-exchange column separation at the Pacific Centre for Isotopic and Geochemical Research (PCIGR), University of British Columbia. Both leachate and digested residue were analyzed from a basalt standard JB-3 (Kimura et al., 2006). All Pb isotopic data were corrected for isobaric interference. Weis et al. (2006) provided analytical details for Pb isotopic measurements on MC-ICP-MS at PCIGR. The measured Pb isotopic ratios were corrected online for instrumental mass fractionation using $^{205}Tl/^{203}Tl$ ratio and normalized offline to the correct NIST SRM 981 values of Galer and Abouchami (1998) using a standard sample bracketing method (Albarède and Beard, 2004). The HR-ICP-MS data were also normalized to a Pb isotopic standard by Actlabs, whereas the quad ICP-MS data were not normalized by Acme.

Reproducibility and accuracy of the analyses were monitored by duplicates of <0.063 mm fraction of till samples and international geological standards. Relative difference for the duplicates is given as follows.

$$\text{Relative difference (\%)} = \frac{|X_1 - X_2|}{\bar{X}} \cdot 10^2$$

where X_1 and X_2 are duplicate results, and $\bar{X}$ is the average of duplicate pair. Average relative difference uncertainties for concentrations based on 4 duplicate pairs are estimated to be <10% for most determinations by XRF, fusion-ICP-ES/MS, and aqua regia-ICP-MS. Elements with concentration levels near the minimum detection limits have <40% uncertainty (Appendices 5-7). Reproducibility of the INAA results is <30% for most elements, except Ba, Ce, Cr, Eu, Nd, Rb, Th, U, and Zn (32-94%; Appendix 8). Scatterplots of till field duplicates and quality controls for selected elements are given in Appendices 10-13.

For the MC-ICP-MS results, based on 40 analyses of NIST NBS 981 carried out with the samples, 2σ errors are 0.010% for $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$, 0.013% for $^{208}Pb/^{204}Pb$, 0.008% for $^{207}Pb/^{206}Pb$, and 0.011% for $^{208}Pb/^{206}Pb$. Table 2 lists the estimated reproducibility for Pb isotopic ratios measured by different instruments based on average relative difference from duplicates (for details, see Appendix 9). Appendices 14-16 show Pb-Pb isotopic plots for leachates from till duplicate samples and for leachate-residue and bulk-dissolution results from geological standards. In summary, as expected, MC-ICP-MS results are more precise than HR-ICP-MS which are more precise than quad ICP-MS.

5. Results

5.1. Elemental abundances

Elemental concentrations for all samples are listed in Appendices 5–8. Tills and country rocks from Chehalis valley have very similar chemical compositions (Figs. 8 and 9), indicating local bedrock sources for the tills. The volcanic rocks of the Harrison Lake Formation and diorite of the Mt. Jasper pluton range from basaltic andesite to rhyolite and show a volcanic-arc affinity (Fig. 8). Normalized rare earth element (REE) and multi-element spider plots (Fig. 9) are also consistent with a subduction-related origin (Mahoney et al., 1995). Total REE contents (49-81 ppm) are about 20–30 times chondritic values, with the REE patterns indicating light rare earth element (LREE) enrichment (La_n/Yb_n = 2.3-8.5; La_n/Sm_n = 1.4-3.1), weak negative Eu anomalies, and flat heavy rare earth element (HREE) distributions (Fig. 9a). These REE patterns, coupled with Rb, Ba, K, and Th enrichment

Table 1. Minimum detection limits (DL) and percentage of results at or below DL.

Analyte	Unit	INAA	LICP	AICP	GRAV	LECO	PXRF
SiO_2	wt %	—	0.01 (0%)	—	—	—	—
Al_2O_3	wt %	—	0.01 (0%)	—	—	—	—
Fe_2O_3	wt %	—	0.04 (0%)	—	—	—	—
MgO	wt %	—	0.01 (0%)	—	—	—	—
CaO	wt %	—	0.01 (0%)	—	—	—	—
Na_2O	wt %	—	0.01 (2%)	—	—	—	—
K_2O	wt %	—	0.01 (0%)	—	—	—	—
TiO_2	wt %	—	0.01 (2%)	—	—	—	—
P_2O_5	wt %	—	0.01 (7%)	—	—	—	—
MnO	wt %	—	0.01 (0%)	—	—	—	—
Cr_2O_3	wt %	—	0.002 (2%)	—	—	—	—
LOI	wt %	—	—	—	0.1 (0%)	—	—
Total C	wt %	—	—	—	—	0.02 (44%)	—
Total S	wt %	—	—	—	—	0.02 (73%)	—
Ag	ppm	5 (93%)	—	0.1 (78%)	—	—	—
As	ppm	0.5 (7%)	—	0.5 (11%)	—	—	2 to 3 (12%)
Au	ppb	2 (84%)	—	0.5 (31%)	—	—	—
Ba	ppm	50 (36%)	1 (0%)	—	—	—	—
Be	ppm	—	1 (91%)	—	—	—	—
Bi	ppm	—	—	0.1 (80%)	—	—	—
Br	ppm	0.5 (73%)	—	—	—	—	—
Ca	wt %	1 (93%)	—	—	—	—	—
Ce	ppm	3 (7%)	0.1 (0%)	—	—	—	—
Cd	ppm	—	—	0.1 (53%)	—	—	—
Cu	ppm	—	—	0.1 (0%)	—	—	7 to 13 (9%)
Co	ppm	1 (24%)	0.2 (0%)	—	—	—	—
Cr	ppm	5 (9%)	—	—	—	—	—
Cs	ppm	1 (87%)	0.1 (11%)	—	—	—	—
Dy	ppm	—	0.05 (4%)	—	—	—	—
Er	ppm	—	0.03 (2%)	—	—	—	—
Eu	ppm	0.2 (29%)	0.02 (0%)	—	—	—	—
Ga	ppm	—	0.5 (0%)	—	—	—	—
Gd	ppm	—	0.05 (0%)	—	—	—	—
Fe	wt %	0.01 (0%)	—	—	—	—	—
Hf	ppm	1 (13%)	0.1 (0%)	—	—	—	—
Hg	ppm	1 (100%)	—	0.01 (18%)	—	—	—
Ho	ppm	—	0.02 (4%)	—	—	—	—
Ir	ppb	5 (100%)	—	—	—	—	—
La	ppm	0.5 (0%)	0.1 (0%)	—	—	—	—
Lu	ppm	0.05 (7%)	0.01 (0%)	—	—	—	—

Table 1. Continued.

Analyte	Unit	INAA	LICP	AICP	GRAV	LECO	PXRF
Mo	ppm	1 (82%)	—	0.1 (13%)	—	—	2 to 3 (72%)
Na	wt %	0.01 (0%)	—	—	—	—	—
Nb	ppm	—	0.1 (0%)	—	—	—	—
Nd	ppm	5 (56%)	0.3 (2%)	—	—	—	—
Ni	ppm	20 (100%)	20 (93%)	0.1 (0%)	—	—	—
Pb	ppm	—	—	0.1 (2%)	—	—	2 (0%)
Pr	ppm	—	0.02 (0%)	—	—	—	—
Rb	ppm	15 (89%)	0.1 (0%)	—	—	—	0.6 (0%)
Sb	ppm	0.1 (16%)	—	0.1 (27%)	—	—	—
Sc	ppm	0.1 (0%)	1 (4%)	—	—	—	—
Se	ppm	3 (100%)	—	0.5 (64%)	—	—	—
Sm	ppm	0.1 (2%)	0.05 (0%)	—	—	—	—
Sn	ppm	200 (100%)	1 (89%)	—	—	—	—
Sr	ppm	500 (100%)	0.5 (0%)	—	—	—	0.8 (0%)
Ta	ppm	0.5 (100%)	0.1 (13%)	—	—	—	—
Tb	ppm	0.5 (100%)	0.01 (0%)	—	—	—	—
Th	ppm	0.2 (22%)	0.2 (4%)	—	—	—	—
Tl	ppm	—	—	0.1 (82%)	—	—	—
Tm	ppm	—	0.01 (2%)	—	—	—	—
U	ppm	0.5 (80%)	0.1 (0%)	—	—	—	—
V	ppm	—	8 (0%)	—	—	—	—
W	ppm	1 (100%)	0.5 (62%)	—	—	—	—
Y	ppm	—	0.1 (0%)	—	—	—	—
Yb	ppm	0.2 (7%)	0.05 (0%)	—	—	—	—
Zn	ppm	50 (71%)	—	1 (0%)	—	—	3 (0%)
Zr	ppm	—	0.1 (0%)	—	—	—	1 to 24 (7%)

Footnotes:
Percentages of results at or below DL (in parentheses); total 45 samples analyzed.
Method codes: **INAA** = instrumental neutron activation analysis; **LICP** = lithium methaborate-tetraborate fusion with a combination of inductively coupled plasma emission spectrometry (ICP-ES) and inductively coupled plasma mass spectrometry (ICP-MS) finish; **AICP** = aqua-regia extraction at 90°C with ICP-MS finish; **GRAV** = gravimetric determination of loss-on-ignition (LOI) after ignition at 1000°C; **LECO** = LECO combustion; **PXRF** = energy-dispersive X-ray fluorescence spectrometry on hand-pressed, 32 mm-diameter samples (>10 g), covered with 4 µm-thick polypropylene film.
Units: **ppb** = parts per billion; **ppm** = parts per million; **wt %** = weight per cent.

relative to mid-ocean ridge basalts (Bevins et al., 1984) and relative Ta, Nb, and Ti depletion (Fig. 9b), are characteristic of island-arc magmatism (e.g., Ryerson and Watson, 1987). Depletion in Ni is consistent with olivine fractionation, and moderate depletion in Sr of the volcanic rocks, coupled with slightly negative Eu anomalies, may indicate plagioclase fractionation (Mahoney et al., 1995). Diorite of the Mt. Jasper pluton has lower Rb, Ba, K, Ta and Zr contents and higher Sr, P, and Ti contents than those of volcanic rocks of the Harrison Lake Formation. Mineralized samples from Seneca VMS deposit contain up to 19.4 wt.% Ba, 9.2 wt.% Zn, 4.4 wt.% Cu, and 0.2 wt.% Pb, which are about 10 to 1000 times greater than those of local country rocks (Fig. 9c).

Trace-element patterns of tills are generally similar to those of Harrison Lake Formation volcanic rocks and diorite of the Mt. Jasper pluton. Elevated metals values (e.g., As, Au, Cu, Pb, and Zn) in some till samples are bracketed by whole rock values from the Seneca VMS deposit and the country rocks (Fig. 9; Appendices 5-8).

Table 2. Reproducibility of Pb isotopic ratios (%) based on average relative difference from duplicates.

Instrument [1]	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$
MC-ICP-MS	0.10	0.01	0.04	0.09	0.06
HR-ICP-MS	0.6	1.2	0.6	0.6	0.4
Quad ICP-MS	3.1	3.4	1.8	1.5	3.4

[1] **MC-ICP-MS** = multi-collector inductively coupled plasma mass spectrometer; **HR-ICP-MS** = high-resolution, double focusing magnetic sector field inductively coupled plasma mass spectrometer; **Quad ICP-MS** = quadrupole inductively coupled plasma mass spectrometer.

5.2. Lead isotopic ratios

5.2.1. Leaching versus bulk dissolution

For Pb isotopic analysis, we have adopted a conventional leaching (i.e. 2.5N HCl at room temperature) which Simonetti et al. (1996) found to be effective in enhancing Pb isotopic contrast between mineralized and background till samples. For a detailed discussion of the leachate-residue and bulk dissolution experiments, we refer the reader to Simonetti et al. (1996). Because conventional leaching has been applied successfully in previous Pb isotopic studies (e.g., Simonetti et al., 1996; Hussein et al., 2003), we analyzed leachate-residue for selected geological reference materials to compare with the literature leachate-residue and bulk dissolution data. A comparison between Pb isotopic ratios measured for geological reference materials on leachates and residues using the 2.5N HCl extraction in this study and bulk-dissolution results from the literature (Kimura et al., 2006; Weis et al., 2006; Chauvel et al., 2011) indicates that the extraction technique is effective for labile Pb such as sulphide mineralization, thus enhancing the Pb isotopic contrast between the mineralization and background (see data in Appendix 9 and Pb-Pb isotopic plots in Appendices 14-16). Leachates for all rock reference materials in this study have lower $^{208}Pb/^{204}Pb$ values than those of corresponding residues and bulk-dissolution determinations (Kimura et al., 2006; Weis et al., 2006). The $^{206}Pb/^{204}Pb$ values for leachates are similar to, or slightly lower than, those for residues and bulk-dissolution values, and are similar to some leachate values of Weis et al. (2006). All rock reference materials have consistent leachate-residue and bulk dissolution $^{207}Pb/^{204}Pb$ ratios, except rhyolite RGM-1 reference material, which has a lower bulk-dissolution $^{207}Pb/^{204}Pb$ value (Weis et al., 2006). For basalt JB-3 reference material, leachate has lower $^{208}Pb/^{206}Pb$ and $^{208}Pb/^{204}Pb$ values than those of the residue, which has a Pb isotopic composition similar to bulk-dissolution values of Kimura et al. (2006). Leachate for a lake sediment reference material (LKSD-1) has $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{207}Pb/^{206}Pb$ values similar (within the analytical uncertainty) to bulk-dissolution values of Chauvel et al. (2011) but higher $^{208}Pb/^{204}Pb$ and $^{208}Pb/^{206}Pb$ ratios.

Overall, leachates in this study tend to have a less radiogenic Pb isotopic composition than the corresponding residues and bulk-dissolution analyses thus confirming the effectiveness of the 2.5N HCl extraction for enhancing isotopic contrast between anomalous ('ore-like') and background (more radiogenic) till samples (Simonetti et al., 1996).

5.2.2. Lead isotopic ratios in tills and rocks

The Pb isotopic results for 2.5N HCl leachates from Chehalis valley tills (<0.063 mm fraction), and VMS mineralization and the surrounding background rocks are given in Appendix 9 and shown in Figures 9–12. For MC-ICP-MS results on selected samples, the data in Pb-Pb isotopic plots form near-linear arrays over a wide range of values. Similar findings were reported for tills associated with VMS deposits from Chisel Lake, Manitoba (Bell and Franklin, 1993; Bell and Murton, 1995); Buchans, Newfoundland (Bell and Murton, 1995); Manitouwadge, Ontario (Simonetti et al., 1996); and Bathurst, New Brunswick (Hussein et al., 2003). Samples of VMS mineralization have the lowest $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ ratios, and the highest $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ ratios, all very similar to the isotopic composition of galena from the Seneca deposit (Godwin et al., 1988). Diorite from the Mt. Jasper pluton has the most radiogenic values (Fig. 10). Lead isotopic ratios for tills are continuously distributed over a range of values from the isotopic signature of the VMS mineralization towards more radiogenic compositions ($^{206}Pb/^{204}Pb$ = 18.33–18.73; $^{207}Pb/^{204}Pb$ = 15.53–15.58; $^{208}Pb/^{204}Pb$ = 37.93–38.33; $^{207}Pb/^{206}Pb$ = 0.832–0.848; $^{208}Pb/^{206}Pb$ = 2.045–2.069). Also shown in these diagrams for reference are present-day isotopic compositions of

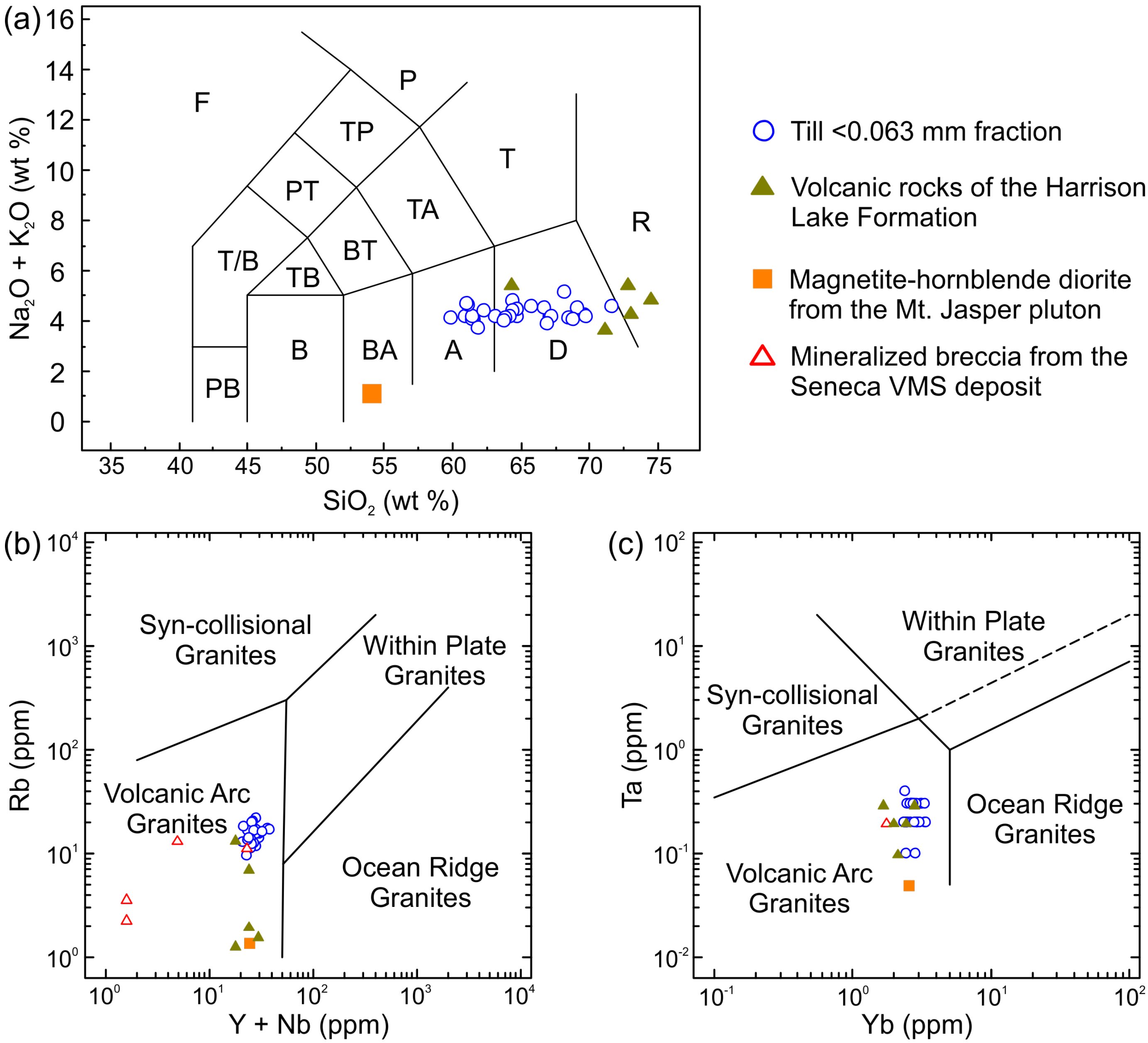

Fig. 8. Geochemical discrimination diagrams for Chehalis valley till (<0.063 mm fraction) and whole-rock samples. **a)** Total alkali ($Na_2O + K_2O$) vs. SiO_2 (anhydrous wt.%) classification for volcanic rocks, showing the fields of andesite (A), basalt (B), basaltic andesite (BA), basaltic trachyandesite (BT), dacite (D), foidite (F), phonolite (P), phonotephrite (PT), picrobasalt (PB), rhyolite (R), tephriphonolite (TP), tephrite and basanite (T/B), trachyandesite (TA), trachybasalt (TB), and trachyte and trachydacite (T) after Le Bas et al. (1986). **b)** (Y + Nb) vs. Rb and **c)** Yb vs Ta tectonic discrimination diagrams for granitoids after Pearce et al. (1984); dash line shows boundary between granites from anomalous ocean ridges and within-plate granites.

depleted MORB mantle (DMM) end-member (Hart, 1988), and upper continental crust and “orogene”, considered to be a mixture of both upper mantle and continental crust (Zartman and Doe, 1981). The VMS ore has more radiogenic $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ but lower $^{208}Pb/^{204}Pb$ ratios than those of DMM. More radiogenic isotopic ratios from tills approach the present-day isotopic composition of the 'orogene' (Zartman and Doe, 1981), whereas diorite of Mt. Jasper pluton shows much higher $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios, which are more radiogenic than the present-day isotopic composition of upper continental crust (Zartman and Doe, 1981).

The leachate data for all till and whole-rock samples by the HR-ICP-MS show more scatter than the MC-ICP-MS results for selected samples on Pb-Pb isotopic diagrams (Figs. 11 and 12). Although some of the scatter is certainly due to the larger uncertainties of the HR-ICP-MS measurements (~40-100 times MC-ICP-MS), the

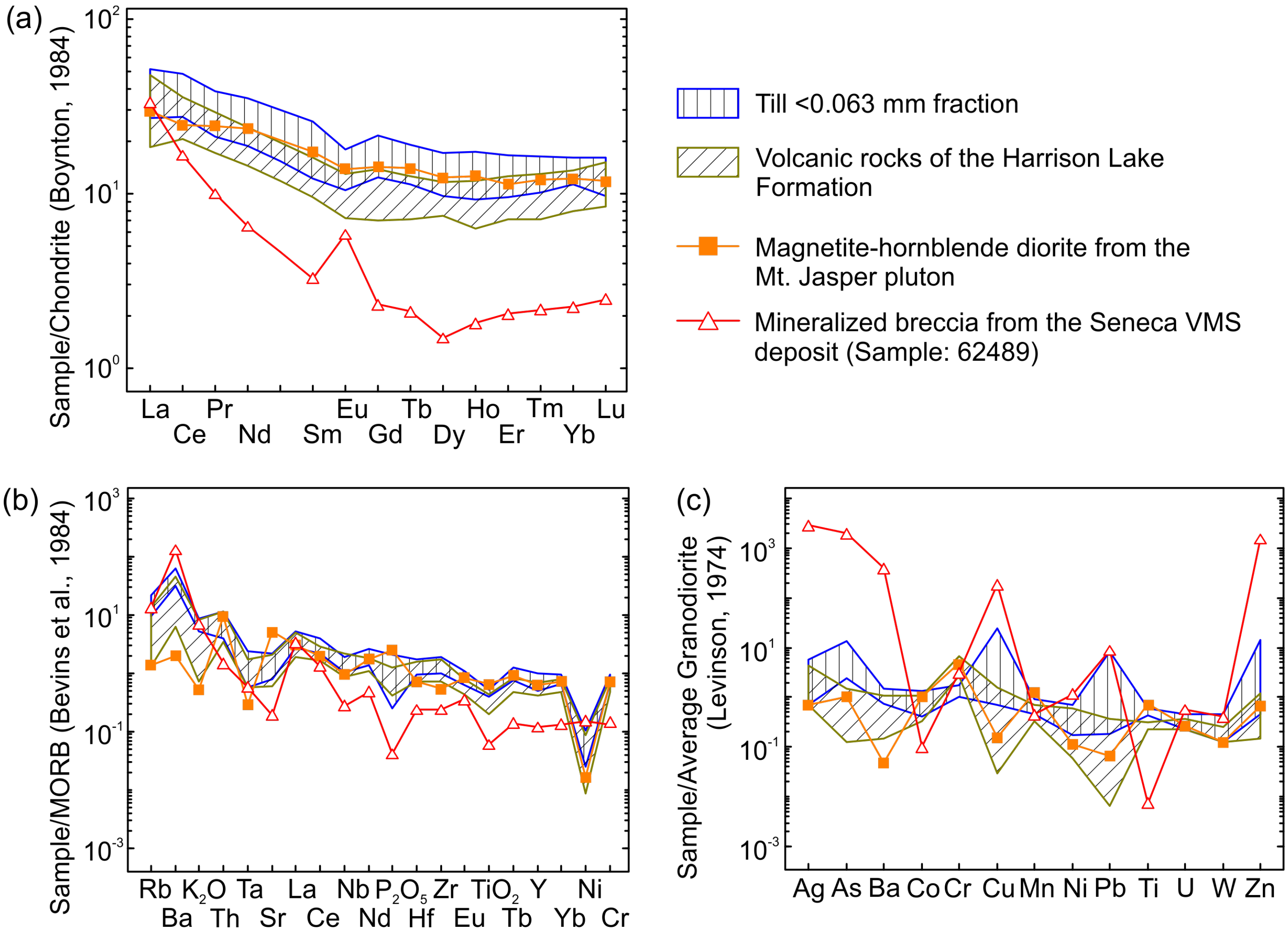

Fig. 9. Spider diagrams for Chehalis valley till (<0.063 mm fraction) and whole-rock samples. **a)** Chondrite-normalized rare earth element plot, using normalization of Boynton (1984). **b)** Mid-ocean ridge basalt (MORB)-normalized spider plot, using normalization of Bevins et al. (1984). **c)** Average granodiorite-normalized spider plot, using normalization of Levinson (1974).

range of values is significantly greater than our quoted reproducibility for the analyses. Generally, the Pb isotopic ratios measured directly in bulk leachate solution using the HR-ICP-MS are consistent with those using state-of-the-art MC-ICP-MS. In both modes of measurement the VMS mineralization has the lowest $^{206}Pb/^{204}Pb$ and the highest $^{207}Pb/^{206}Pb$ ratios, similar to those of galena in the Seneca deposit (Godwin et al., 1988). For the HR-ICP-MS results, the Pb isotopic ratios for leachates from the volcanic rocks of the Harrison Lake Formation hosting the Seneca deposit and from diorite of the Mt. Jasper pluton show considerable variation ($^{206}Pb/^{204}Pb$ = 18.46–20.01; $^{207}Pb/^{204}Pb$ = 15.13–16.18; $^{208}Pb/^{204}Pb$ = 36.78–39.89; $^{207}Pb/^{206}Pb$ = 0.787–0.844; $^{208}Pb/^{206}Pb$ = 1.94–2.09). In Pb-Pb isotopic ratio diagrams, data from these rocks define envelopes, scattering from less radiogenic compositions, approaching those of the mineralized samples, perhaps reflecting their genetic relationship to the VMS ore, to highly radiogenic $^{206}Pb/^{204}Pb$ values at variable $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$, typical of continental crust (Fig. 11). Leachates from tills and country rocks show similar patterns (Fig. 11) except that the tills show more restricted variations, ranging from the least radiogenic values similar to those of the VMS mineralization to more radiogenic compositions, but not as extreme as those of the country rocks. The direct-leachate measurements by quad ICP-MS (uncorrected for mass fractionation) show the widest range of values due to much larger analytical uncertainties (~3-9 times) than HR-ICP-MS (Fig. 12).

The measured range of Pb isotopic ratios from tills (3–7% difference) is 40%–80% of the overall Pb isotopic contrast between the VMS mineralization and the surrounding background rocks from Chehalis valley. This range is 2-3 orders of magnitude greater than the uncertainties of the state-of-the-art MC-ICP-MS analyses using purified Pb solution and 5-10 times greater than those of the direct-leachate analyses on HR-ICP-MS but is within, or only slightly exceeds, the reproducibility

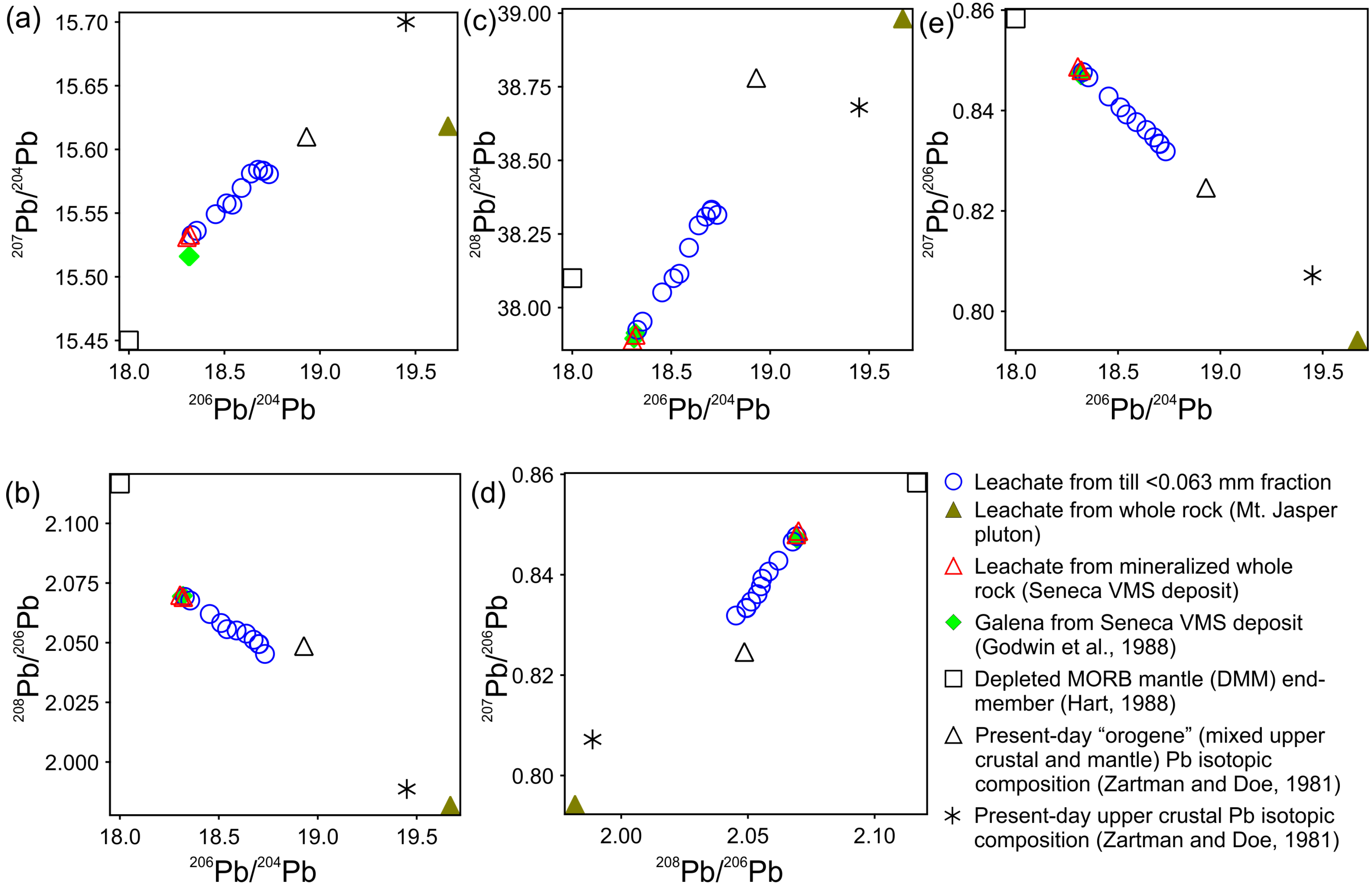

Fig. 10. Pb-Pb isotopic plots showing MC-ICP-MS results for leachates from Chehalis valley till (<0.063 mm fraction) and whole-rock samples. Uncertainties are smaller than the size of the symbols. Literature galena analyses from the Seneca deposit and present-day Pb isotopic compositions for depleted MORB mantle (DMM), upper crustal, and “orogene” (mixed upper crust and mantle) reservoirs are shown for comparison.

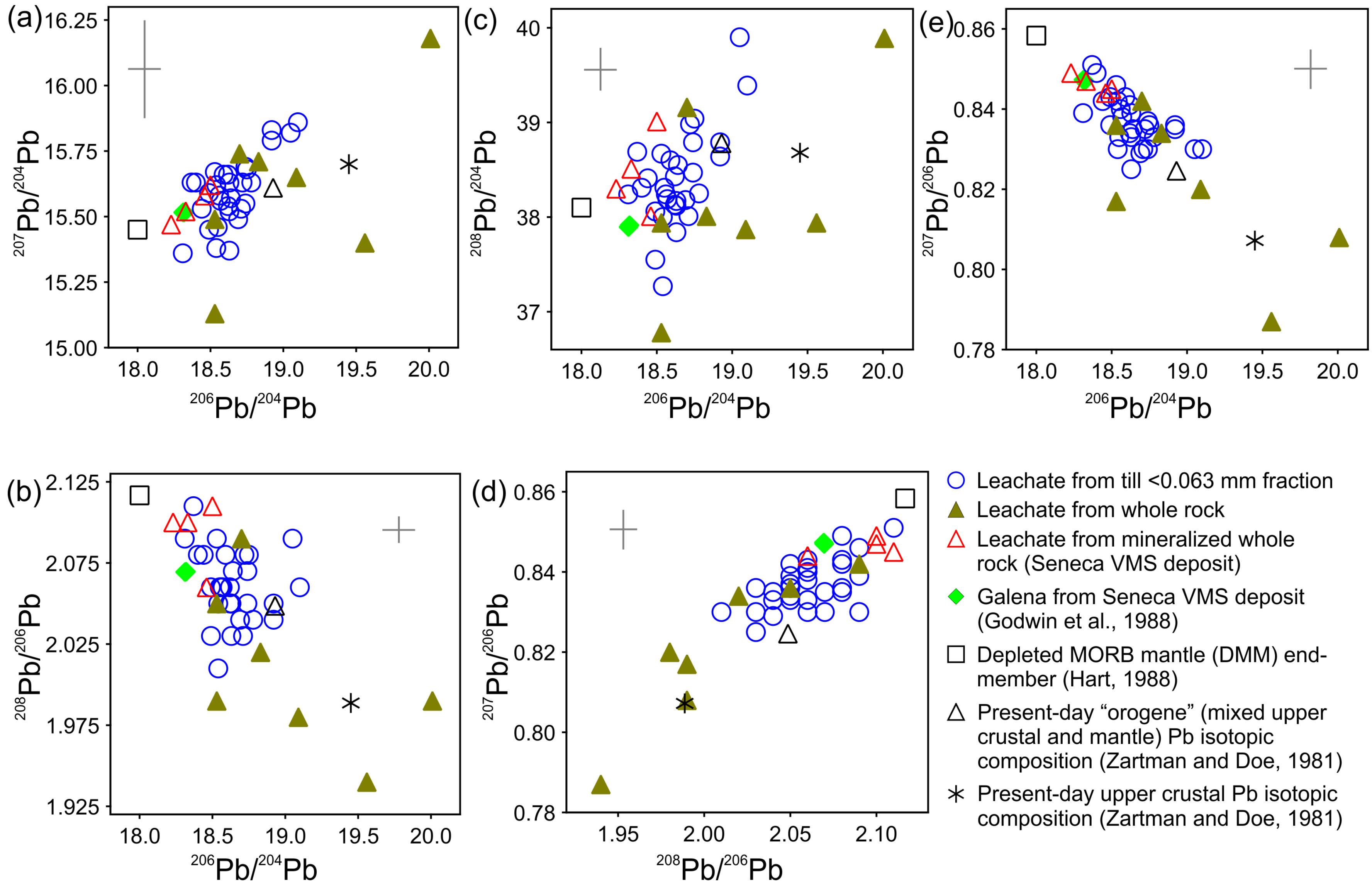

Fig. 11. Pb-Pb isotopic plots showing HR-ICP-MS results for leachates from Chehalis valley till (<0.063 mm fraction) and whole-rock samples. Uncertainty bars show average relative difference from till <0.063 mm-fraction duplicates. Literature galena analyses from the Seneca deposit and the present-day Pb isotopic compositions for depleted MORB mantle (DMM), upper crustal, and “orogene” (mixed upper crust and mantle) reservoirs are shown for comparison.

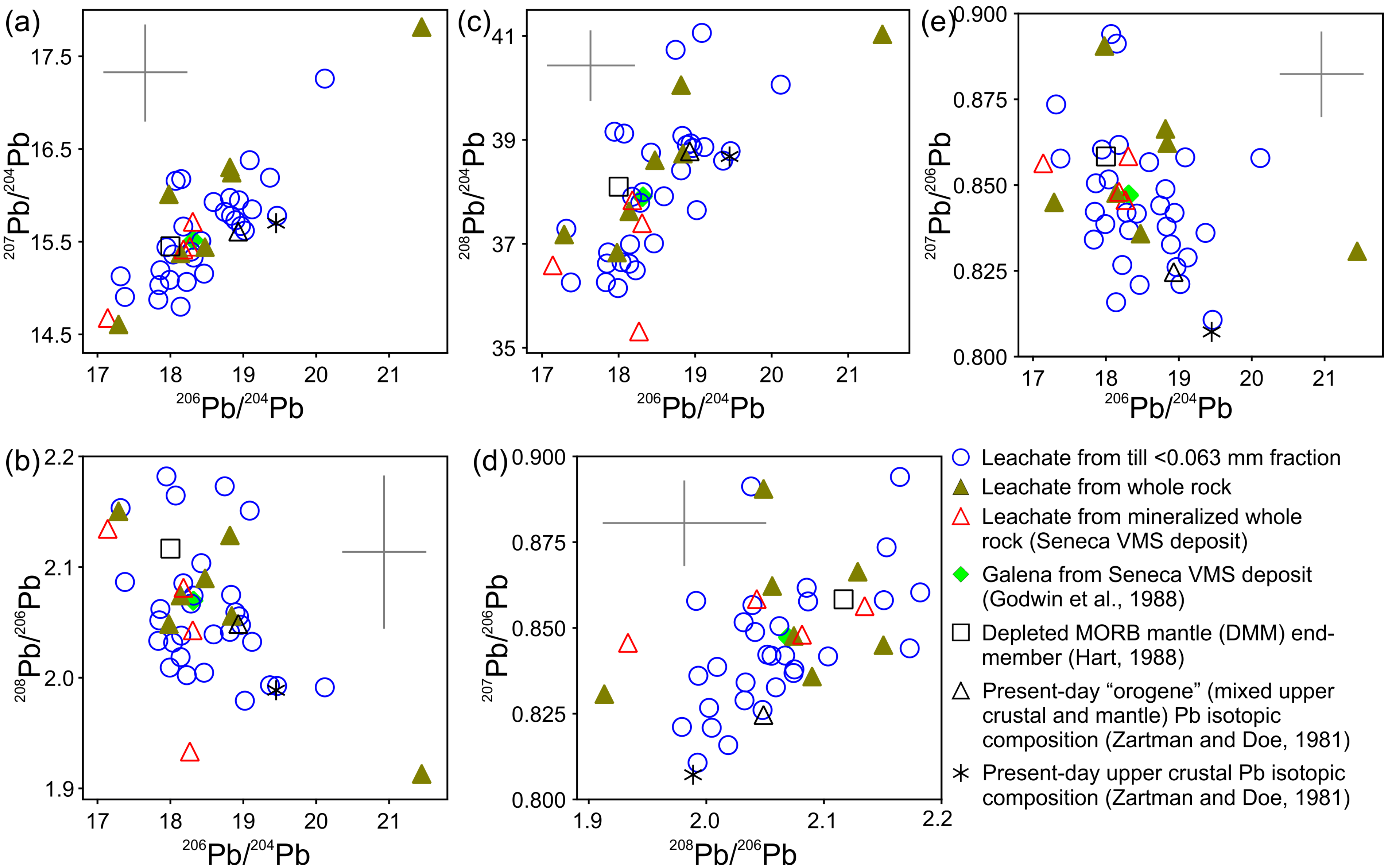

Fig. 12. Pb-Pb isotopic plots showing quadrupole ICP-MS results for leachates from Chehalis valley till (<0.063 mm fraction) and whole-rock samples. Uncertainty bars show average relative difference from till <0.063 mm-fraction duplicates. Literature galena analyses from the Seneca deposit and the present-day Pb isotopic compositions for depleted MORB mantle (DMM), upper crustal, and "orogene" (mixed upper crust and mantle) reservoirs are shown for comparison.

of the quad ICP-MS results. Because the variations of Pb isotopic ratios are much greater than analytical uncertainties, both MC-ICP-MS and HR-ICP-MS are useful to identify VMS anomalies in tills.

6. Summary and discussion

6.1. Mixing of Pb from local heterogeneous sources

Lead isotopic ratios in tills (<0.063 mm fraction) near the Seneca deposit reflect contributions from both VMS mineralization and surrounding country rocks. This is shown by near-linear arrays in Pb-Pb isotopic ratio plots for the MC-ICP-MS results, where one end corresponds to the isotopic signature of VMS mineralization (with the lowest $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ ratios, and the highest $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ ratios) similar to that of galena from the Seneca deposit (Godwin et al., 1988; Fig. 10) and the other to the surrounding country rocks. A similar linear relationship was documented by Bell and Franklin (1993), Bell and Murton (1995), Simonetti et al. (1996), and Hussein et al. (2003) in their Pb isotope studies of tills at Chisel Lake, Buchans, Manitouwadge, and Bathurst. Although the HR-ICP-MS data for all samples are more scattered than the MC-ICP-MS data for selected samples and define broad envelopes in Pb-Pb isotopic diagrams, the least radiogenic ratios from the tills are still similar to those of the ore samples and galena from Seneca deposit (Fig. 11). The till data range between the isotopic signature of the ore and the more radiogenic compositions of the surrounding country rocks, suggesting that most of the Pb was derived from local heterogeneous bedrock sources via glacial dispersion. Furthermore, the close multi-element similarity between tills and rocks from Chehalis valley (Fig. 9) is consistent with local derivation.

The apparent variation in $^{207}Pb/^{204}Pb$ ratio for a given $^{206}Pb/^{204}Pb$ ratio (Fig. 11a) measured by HR-ICP-MS could be due to the larger analytical uncertainty for the $^{207}Pb/^{204}Pb$ ratio than those for other Pb isotopic ratios measured on HR-ICP-MS. Alternatively, if the variation in $^{207}Pb/^{204}Pb$ ratio for a given $^{206}Pb/^{204}Pb$ ratio in the volcanic rocks and related VMS deposit is real, it would suggest a contribution of Pb from an ancient source such as the sub-continental lithosphere. The large variations in $^{208}Pb/^{204}Pb$ ratio for a given $^{206}Pb/^{204}Pb$, well in excess of the analytical uncertainty, indicate that the scatter in the $^{206}Pb/^{204}Pb$ versus $^{208}Pb/^{204}Pb$ diagram reflects the variable Th/U ratio in the Seneca deposit and the surrounding country rocks or the time-integrated Th/U ratio in their source (Fig. 11c). This is not surprising, given that variations of ~3% in $^{208}Pb/^{206}Pb$ and ~4% in $^{207}Pb/^{206}Pb$, well outside of analytical errors (0.1–0.2 %), were reported for a single crystal of galena from the Buick Mississippi Valley-type deposit, Missouri, covering the range of values found for the whole of the mineralized area (Hart et al., 1981).

The large variations in the Pb isotopic ratios in the tills reflect both the initial Pb isotopic variations and added radiogenic Pb produced by in situ decay of U and Th in the bedrock sources. Galena has U/Pb and Th/Pb ratios of 0; country rocks have U/Pb ratios that range from 0 to 7, and Th/Pb ratios that range from 0 to 14. Because galena contains most of the Pb in VMS deposits (Fig. 9c), till samples containing Pb derived mainly from VMS deposits will have less radiogenic Pb isotopic ratios, approaching those of galena, than tills derived mainly from country rocks.

Linear arrays have been interpreted as either relict secondary isochrons (e.g., Bell and Franklin, 1993; Simonetti et al., 1996) or binary mixing lines with or without geochronologic significance (e.g., Bell and Murton, 1995; Simonetti et al., 1996; Hussein et al., 2003). Bell and Franklin (1993) attributed a similar linear array in the $^{206}Pb/^{204}Pb$ vs. $^{207}Pb/^{204}Pb$ diagram for glacigenic sediments derived from the Chisel Lake VMS deposit, Manitoba to a relict secondary isochron associated with Amisk Group volcanic rocks (Paleoproterozoic) and related ores. These authors suggested that the glacigenic sediments at Chisel Lake preserved the secondary isochron due to incomplete mechanical mixing of materials derived from the ores and enclosing country rocks of the same age. The interpretation of the Pb-Pb arrays as relict secondary isochrons was later extended to a similar linear relationship for tills at Manitouwadge, Ontario (Simonetti et al., 1996). Alternatively, Bell and Murton (1995), Simonetti et al. (1996), and Hussein et al. (2003) interpreted similar linear relationships for tills at Chisel Lake, Manitowadge, and Bathurst in terms of binary mixing of leads from the VMS ores and the surrounding country rocks. In the present example, if interpreted as a secondary isochron, the slope of the linear array (n = 13; excluding diorite analysis from Mt. Jasper pluton) in the $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ diagram (Fig. 10a) corresponds to an age of 2131±180 Ma (95% confidence), with the lower intercept of the Stacey and Kramers (1975) growth curve at 2271 Ma. The mean square of the weighted deviation of 28 indicates that not all of the data points fit a straight line within the estimated uncertainties. This age is much older than the age of the Seneca VMS deposit and the related volcanic-arc rocks (Middle Jurassic). If the linear array has a geochronological significance, it would imply that both the Seneca VMS deposit and the enclosing volcanic-arc rocks contain Pb derived from a closed-system, Paleoproterozoic source with a variable time-integrated U/Pb ratio, such as the sub-continental lithosphere. However, this conclusion is contradicted by geochemical and Nd and Sr isotopic evidence that the Harrison Lake Formation records juvenile arc magmatism (Mahoney et al. 1995). Hence we interpret that the linear arrays reflect simple mixing of two isotopically distinct end-members and that tills from Chehalis valley contain a mixture of leads derived from the VMS ores and isotopically heterogeneous country rocks (Fig. 11).

Hyperbolic data arrays in the Pb abundance versus Pb isotopic ratio diagrams for the MC-ICP-MS results are best explained as binary mixing of debris from the Seneca deposit and background country rocks (Fig. 13; for mixing formulation see Langmuir et al., 1978). The Seneca end member has the lowest $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ ratios, and the highest $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ ratios and Pb contents. The background end member (i.e. country rocks) has the highest $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ ratios, and the lowest $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ ratios and Pb content. Similar hyperbolic relationships were documented by Bell and Murton (1995) and Hussein et al. (2003) for tills at Chisel Lake, Buchans, and Bathurst. The HR-ICP-MS and quad ICP-MS results for all samples show more scattered Pb isotopic ratios from tills and rocks with decreasing Pb concentrations, indicating isotopically heterogeneous country rocks (Figs. 14–15). These data are consistent with the model that Chehalis valley tills represent mixtures of debris from the local bedrock sources and have variable proportions of Pb derived from the isotopically distinct VMS mineralization in keeping with the findings from other VMS deposits (Bell and Murton, 1995; Simonetti et al., 1996; Hussein et al., 2003).

6.2. Elemental abundances and glacial dispersion

Abundances of Pb, Zn, Cu, and Ba display different dispersion patterns down-ice of the Seneca VMS deposit (Fig. 16). Till samples directly above and within ~1 km of known VMS occurrences contain elevated Pb and Zn, which fall to background levels farther away. Copper and barium contents in till samples directly overlying Seneca pit are clearly anomalous (>98th percentile) relative to average till in the area but samples within ~1 km of other known VMS occurrences are indistinguishable from background values. Elevated Cu and Ba in some till samples away from known VMS occurrences indicate sources unrelated to known bedrock occurrences of the ores. Although there is an expected decrease in elemental values away from Seneca VMS deposit, down-ice dispersal is not well defined, probably due to low sample density, geographically restricted sample site locations and/or the possibility of two ice-flow events (south-southeast and west).

6.3. Lead isotopes as glacial dispersion indicators

As emphasized by Bell and Franklin (1993), Bell and Murton (1995), Simonetti et al., (1996) and Hussein et al. (2003), lead concentrations alone cannot identify the source of tills derived from eroded VMS deposits. Because radiogenic Pb is produced by decay of U and Th in country rocks but not in galena or other Pb-bearing ore minerals that lack U and Th, an isotopic contrast between country rocks and ores is generated. Up until now the use of Pb isotopes in glacial till has been largely restricted to Early Paleozoic and older deposits, but it is clear from our study that VMS deposits as young as Middle Jurassic can be pinpointed using inexpensive modern ICP-MS instrumentation. This may also be true for other Pb-rich deposits such as SEDEX, Pb-Zn skarn, and porphyries. In addition, Pb isotopic ratios are partly independent of Pb abundances, as shown by significant isotopic variations in the tills with low Pb contents (Fig. 14). Thus sediment consisting mainly of debris derived from Pb-rich deposits may have a distinct Pb isotopic signature fingerprinting the ore source (Bell and Franklin, 1993; Bell and Murton, 1995; Simonetti et al., 1996; Hussein et al., 2003).

In Figures 17–19, Pb isotopic ratios for leachates from till samples (<0.063 mm fraction) are given as δ values

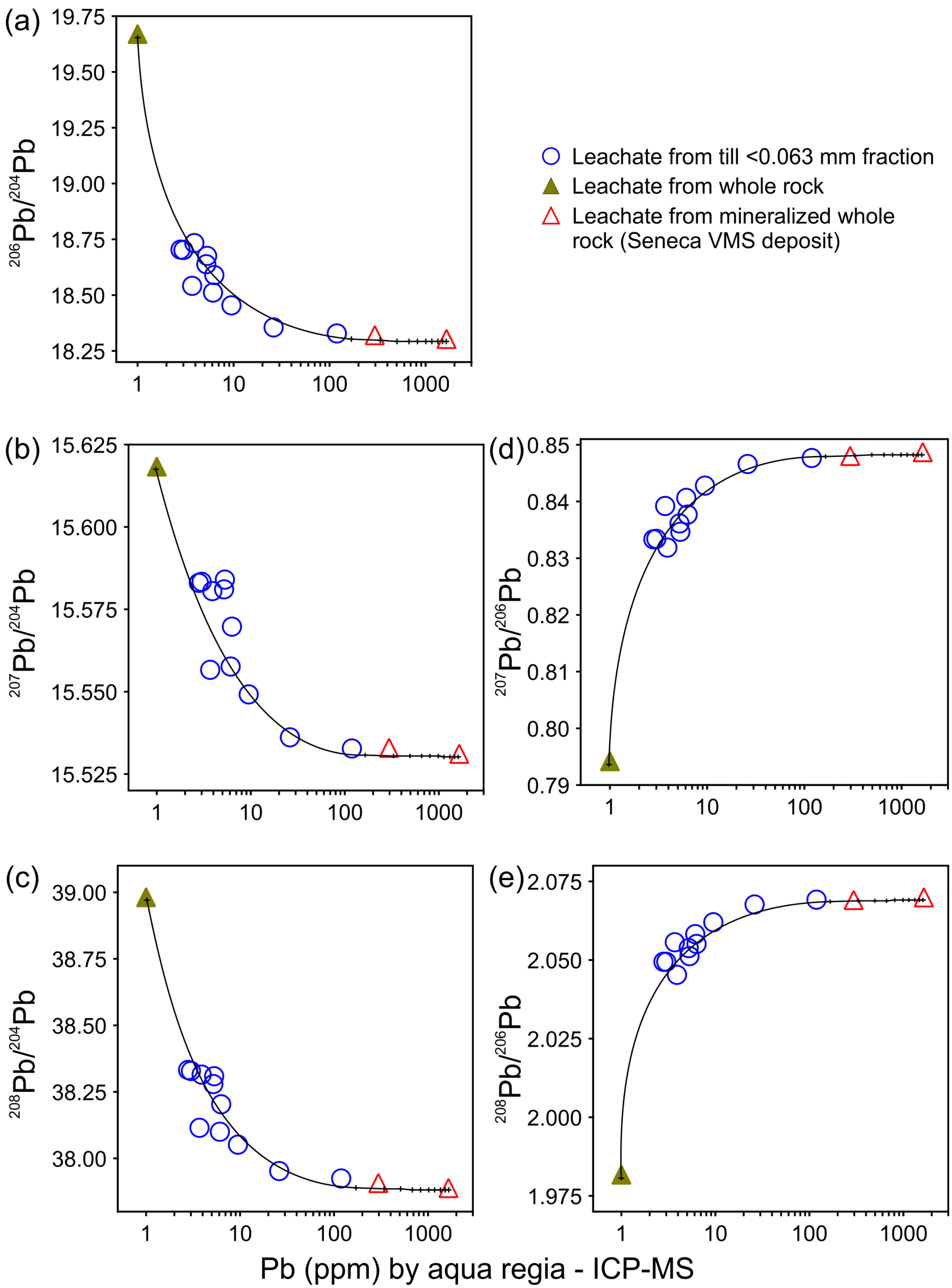

Fig. 13. Plots of Pb isotopic ratios by MC-ICP-MS vs. Pb concentrations for leachates from Chehalis valley till (<0.063 mm fraction) and whole-rock samples showing binary mixing models (after Langmuir et al., 1978) calculated using PetroGraph programme (Petrelli et al., 2005). Ticks on the model curves mark 10% increments. Lead concentrations are by aqua regia extraction-ICP-MS. Uncertainties are smaller than the size of the symbols.

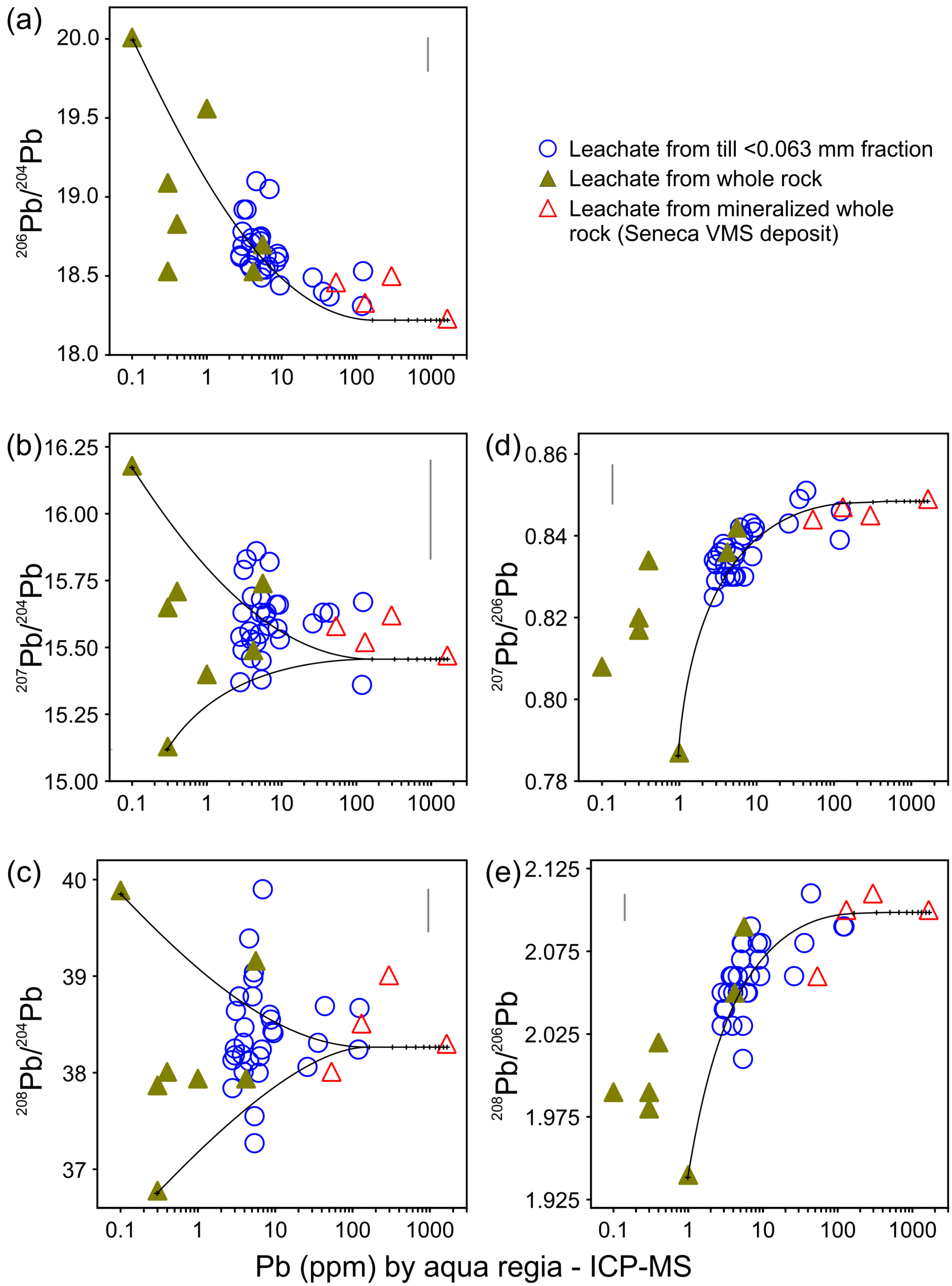

Fig. 14. Plots of Pb isotopic ratios by HR-ICP-MS vs. Pb concentrations for leachates from Chehalis valley till (<0.063 mm fraction) and whole-rock samples showing binary mixing models (after Langmuir et al., 1978) calculated using PetroGraph programme (Petrelli et al., 2005). Ticks on the model curves mark 10% increments. Pb concentrations are by aqua regia extraction-ICP-MS. Uncertainty bars for isotopic ratios show average relative difference from till <0.063 mm-fraction duplicates. Average relative difference for Pb concentrations in the duplicates is smaller than the size of the symbols

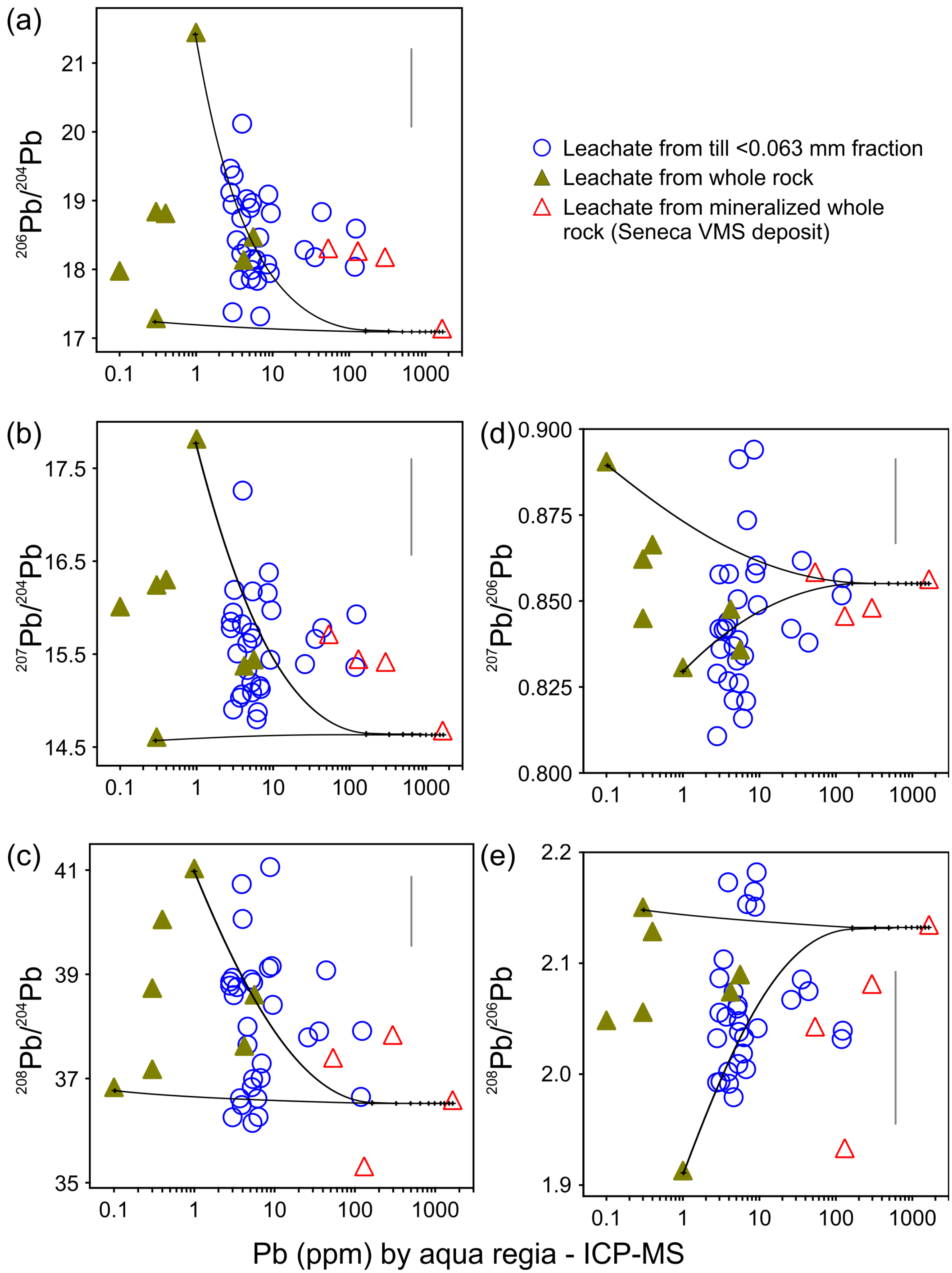

Fig. 15. Plots of Pb isotopic ratios by quadrupole ICP-MS vs. Pb concentrations for leachates from Chehalis valley till (<0.063 mm fraction) and whole-rock samples showing binary mixing models (after Langmuir et al., 1978) calculated using PetroGraph programme (Petrelli et al., 2005). Ticks on the model curves mark 10% increments. Pb concentrations are by aqua regia extraction-ICP-MS. Uncertainty bars for isotopic ratios show average relative difference from till <0.063 mm-fraction duplicates. Average relative difference for Pb concentrations in the duplicates is smaller than the size of the symbols.

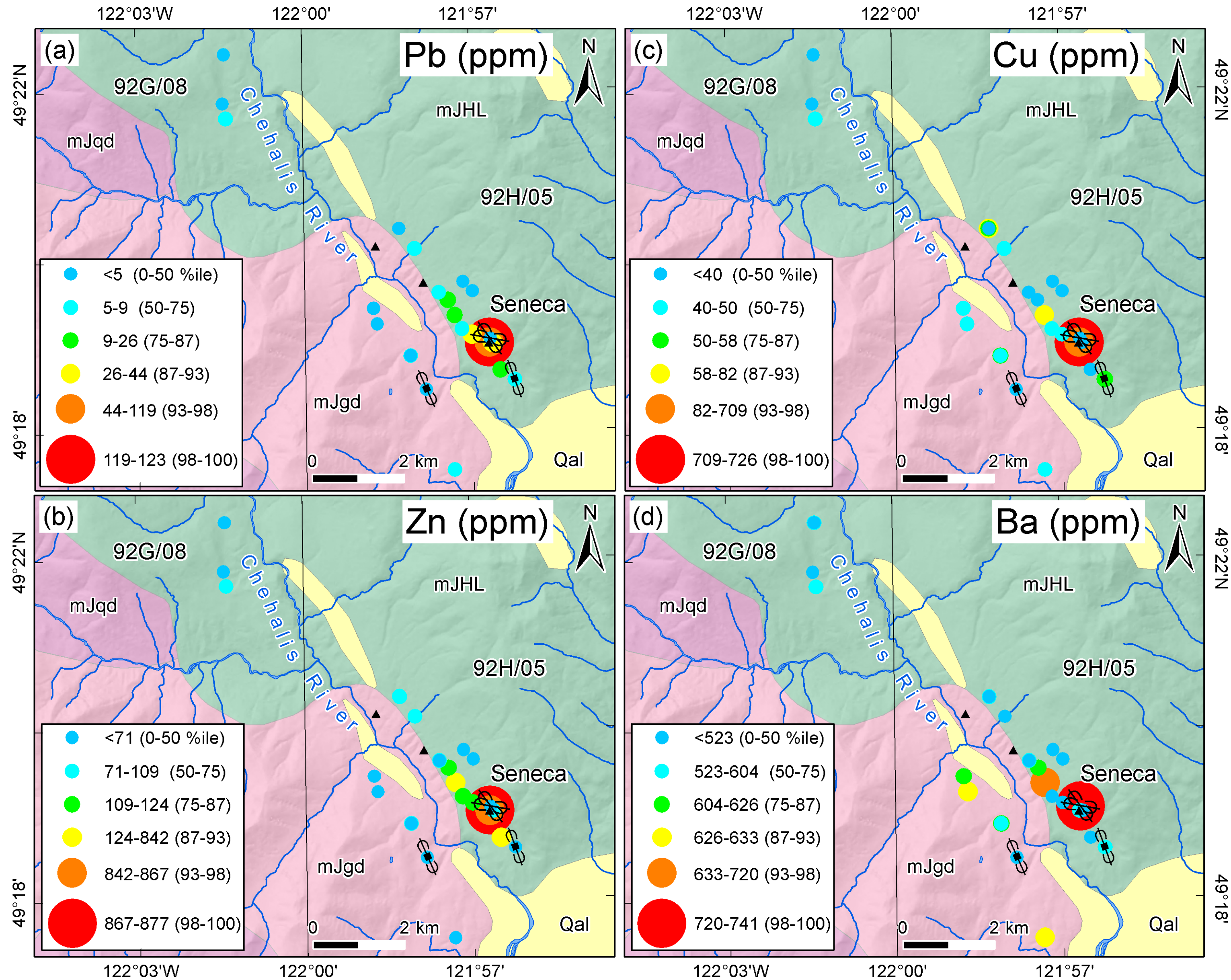

Fig. 16. Abundances and percentiles (by symbol colour and diameter) of selected elements by aqua regia extraction-ICP-MS from till samples (<0.063 mm fraction), Chehalis valley. Bedrock legend and other symbols as in Figure 2. **a)** Pb (ppm); **b)** Zn (ppm); **c)** Cu (ppm); **d)** Ba (ppm).

(in %) calculated relative to the Seneca VMS values as follows.

$$\delta^{206}Pb/^{204}Pb = 1 - \frac{(^{206}Pb/^{204}Pb)_S - (^{206}Pb/^{204}Pb)_{VMS}}{(^{206}Pb/^{204}Pb)_{VMS}} \cdot 10^2$$

$$\delta^{208}Pb/^{204}Pb = 1 - \frac{(^{208}Pb/^{204}Pb)_S - (^{208}Pb/^{204}Pb)_{VMS}}{(^{208}Pb/^{204}Pb)_{VMS}} \cdot 10^2$$

$$\delta^{207}Pb/^{206}Pb = \frac{(^{207}Pb/^{206}Pb)_S - (^{207}Pb/^{206}Pb)_{VMS}}{(^{207}Pb/^{206}Pb)_{VMS}} \cdot 10^2$$

$$\delta^{208}Pb/^{206}Pb = \frac{(^{208}Pb/^{206}Pb)_S - (^{208}Pb/^{206}Pb)_{VMS}}{(^{208}Pb/^{206}Pb)_{VMS}} \cdot 10^2$$

where

- $(^{206}Pb/^{204}Pb)_S$, $(^{208}Pb/^{204}Pb)_S$, $(^{207}Pb/^{206}Pb)_S$, and $(^{208}Pb/^{206}Pb)_S$ are the isotopic ratios of the till sample
- $(^{206}Pb/^{204}Pb)_{VMS}$ and $(^{208}Pb/^{204}Pb)_{VMS}$ are the lowest $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios of whole rock analyses from the Seneca VMS deposit
- $(^{207}Pb/^{206}Pb)_{VMS}$ and $(^{208}Pb/^{206}Pb)_{VMS}$ are the highest $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ ratios of whole-rock analyses from the Seneca VMS deposit.

Similar to the notation used for stable isotopes, the δ values relate Pb isotopic ratios measured in tills to those in the VMS ore. Bell and Murton (1995) first used δ notation for Pb isotopic results from tills at Chisel Lake and Buchans. In our modified notation, a δ value of 1% for $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios shows that the till has an isotopic ratio identical to the VMS deposit, whereas values <1% indicate that the till has a more radiogenic Pb isotopic composition. For $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ ratios, a δ value of 0% indicates a VMS-like isotopic signature, and negative δ values mark till samples having more radiogenic ratios.

Spatial patterns of δ values for the MC-ICP-MS results from Chehalis valley highlight tills containing mainly material derived from known VMS occurrences (Fig. 17). The highest δ values (~0.9 for $\delta^{206}Pb/^{204}Pb$ and $\delta^{208}Pb/^{204}Pb$, ca. -0.1 for $\delta^{207}Pb/^{206}Pb$, and ~0 for $\delta^{208}Pb/^{206}Pb$), approaching the Pb isotopic signature of the VMS deposit, as would be expected, are from till directly above the Seneca pit. This till also has the highest Pb content (~120 ppm) of all till samples in this study. Till samples >1 km away from known VMS occurrences show more radiogenic (i.e. lower) δ values, indicating dilution by Pb derived from background country rocks. For the direct-leachate HR-ICP-MS results, the $\delta^{206}Pb/^{204}Pb$ and $\delta^{207}Pb/^{206}Pb$ values highlight dispersal down ice from the Seneca VMS deposit, consistent with the MC-ICP-MS results (Figs. 18a and c). However, the $\delta^{208}Pb/^{204}Pb$ and $\delta^{208}Pb/^{206}Pb$ values show more complex areal patterns (Figs. 18b and d), perhaps reflecting variations due to the chemical differences of U and Th or the natural isotopic heterogeneity of country rocks (Fig. 11) and poor analytical resolution, particularly for $^{208}Pb/^{204}Pb$ ratios. For the quad ICP-MS results, the δ values show no systematic areal patterns because of the resolution of the method (Fig. 19).

In summary, our findings demonstrate that Pb isotopic ratios for 2.5N HCl leachates from <0.063 mm fraction of tills can detect Middle Jurassic VMS deposits from Chehalis valley and can be used as a robust tool to explore for a broad range of concealed Pb-rich mineral deposits in the Canadian Cordillera.

7. Conclusions

Elemental abundances and Pb isotopic ratios for 2.5N HCl leachates from till (<0.063 mm fraction) and whole-rock samples from Chehalis valley indicate that the tills represent mixtures of debris derived from isotopically heterogeneous volcanic rocks and related VMS deposits. Concentrations of Pb, Zn, Cu, and Ba from the Seneca VMS deposit are 10 to 1000 times greater than typical crustal values and local country rocks (Fig. 9c). Compared to results derived from bulk dissolution (Kimura et al., 2006; Weis et al., 2006), results from relatively inexpensive 2.5N HCl leachates increase the Pb isotopic contrast between anomalous, 'ore-like', and background samples, enhancing the mineralized signal to guide exploration (Simonetti et al., 1996). Despite the relatively young age (Middle Jurassic) of the VMS deposit and surrounding country rocks, Pb

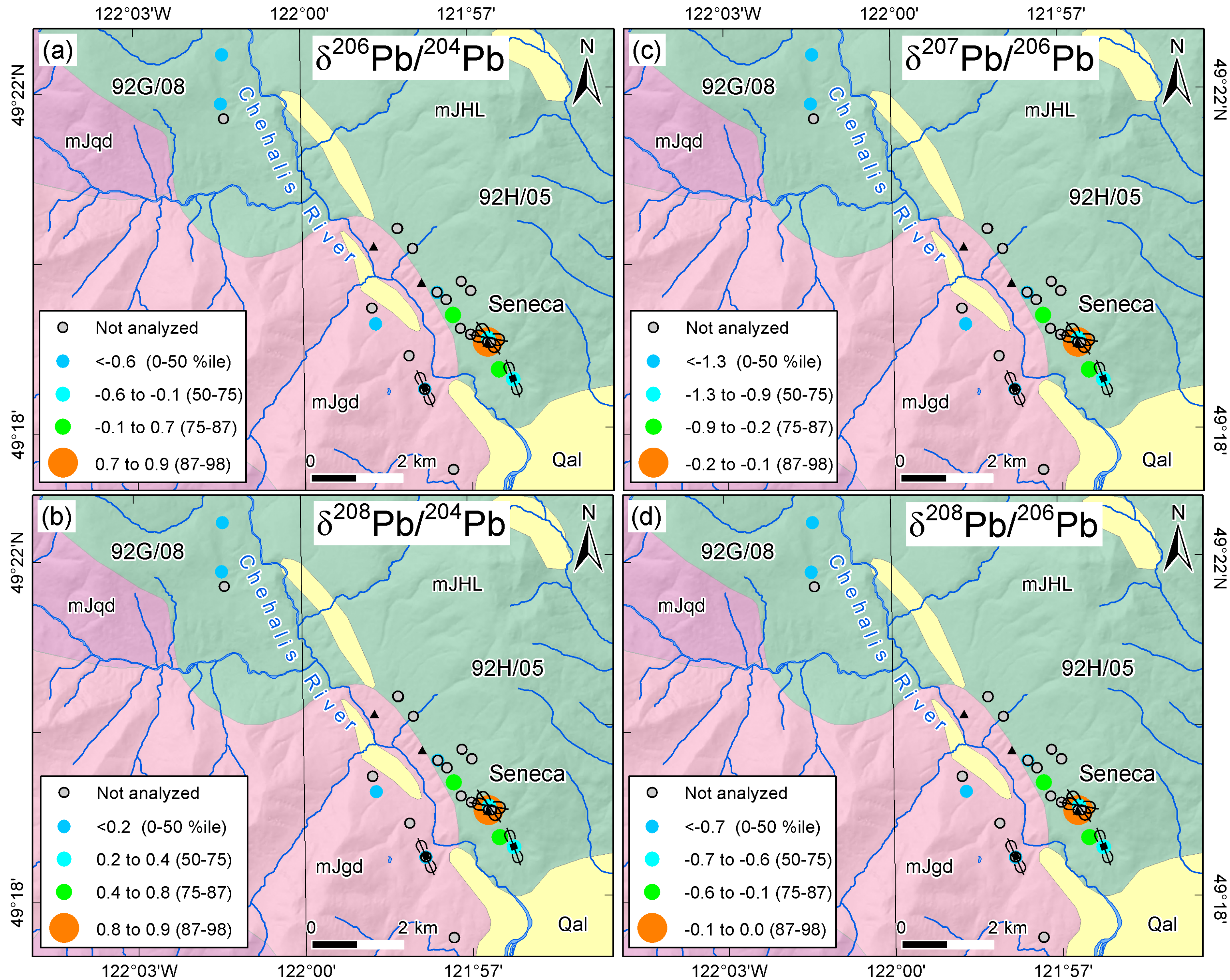

Fig. 17. δ values and percentiles (by symbol colour and diameter) of Pb isotopic results by MC-ICP-MS for leachates from till samples (<0.063 mm fraction), Chehalis valley. The δ values are obtained by normalizing the isotopic ratios of sample to the least radiogenic ratio of whole-rock analyses from the Seneca VMS deposit (see text for detail). Bedrock legend and other symbols as in Figure 2. **a)** $\delta^{206}Pb/^{204}Pb$; **b)** $\delta^{208}Pb/^{204}Pb$; **c)** $\delta^{207}Pb/^{206}Pb$; **d)** $\delta^{208}Pb/^{206}Pb$.

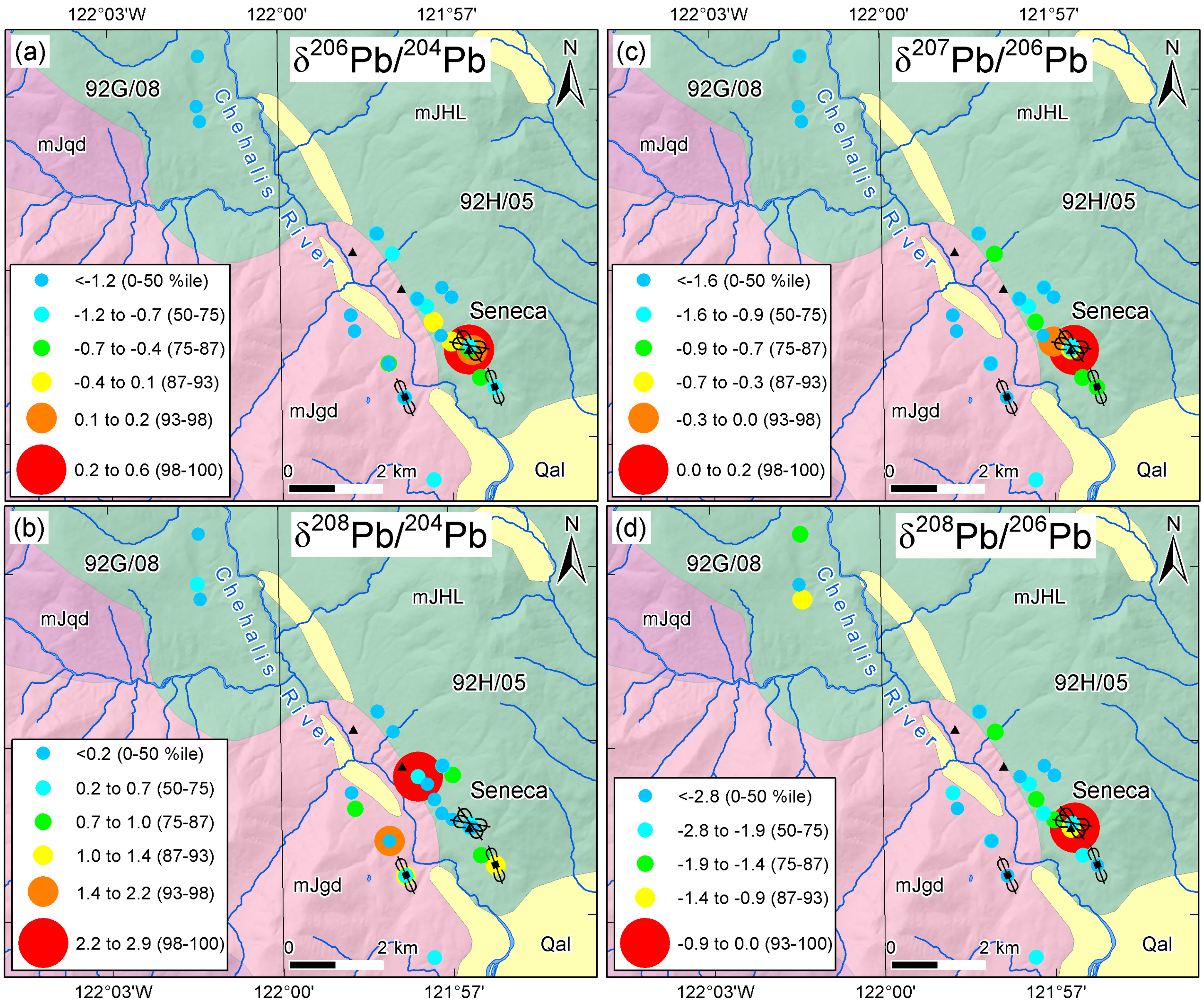

Fig. 18. δ values and percentiles (by symbol colour and diameter) of Pb isotopic results by HR-ICP-MS for leachates from till samples (<0.063 mm fraction), Chehalis valley. The δ values are obtained by normalizing the isotopic ratios of sample to the least radiogenic ratio of whole-rock analyses from the Seneca VMS deposit (see text for detail). Bedrock legend and other symbols as in Figure 2. **a)** $\delta^{206}Pb/^{204}Pb$; **b)** $\delta^{208}Pb/^{204}Pb$; **c)** $\delta^{207}Pb/^{206}Pb$; **d)** $\delta^{208}Pb/^{206}Pb$.

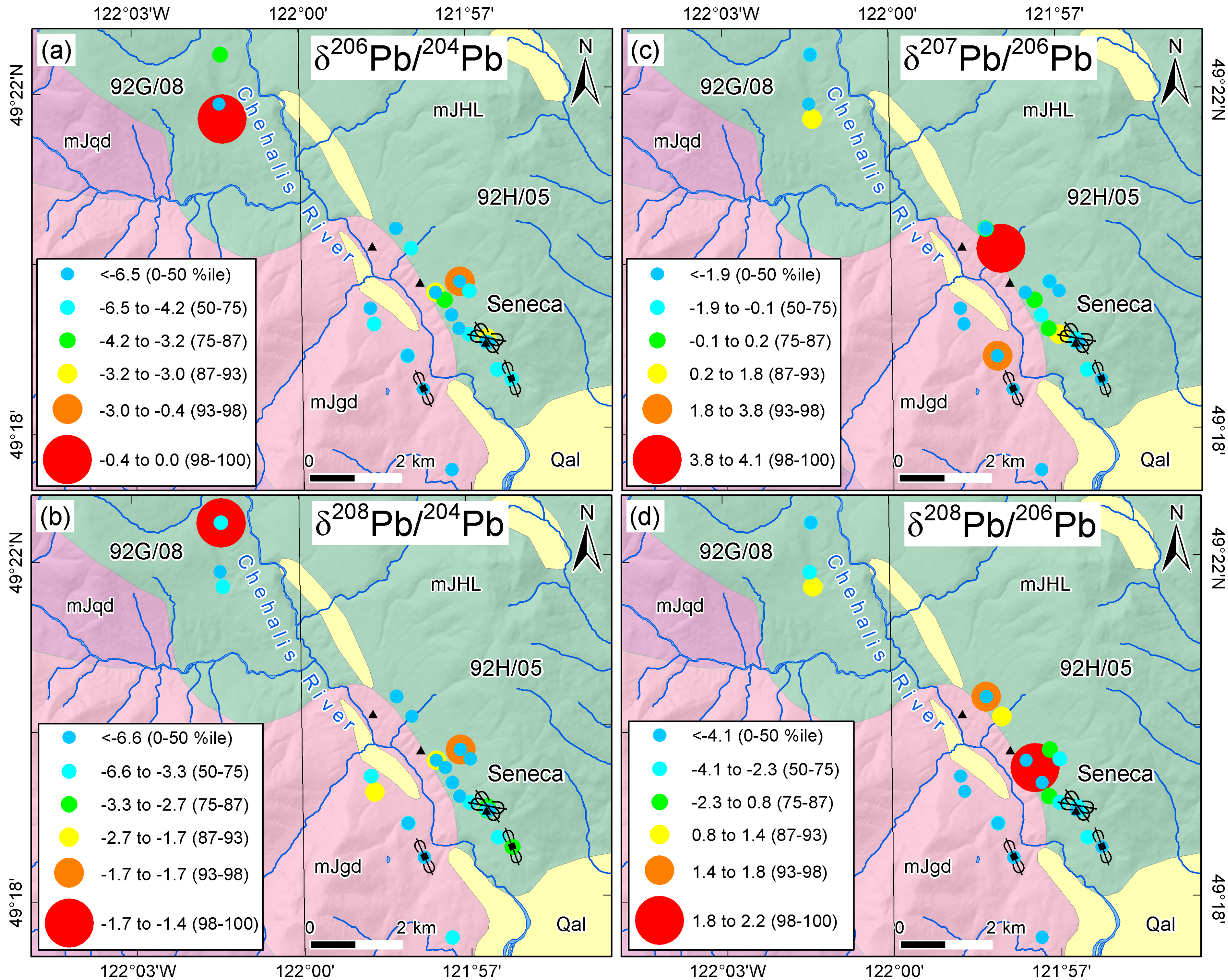

Fig. 19. δ values and percentiles (by symbol colour and diameter) of Pb isotopic results by quadrupole ICP-MS for leachates from till samples (<0.063 mm fraction), Chehalis valley. The δ values are obtained by normalizing the isotopic ratios of sample to the least radiogenic ratio of whole-rock analyses from the Seneca VMS deposit (see text for detail). Bedrock legend and other symbols as in Figure 2. a) $\delta^{206}Pb/^{204}Pb$; b) $\delta^{208}Pb/^{204}Pb$; c) $\delta^{207}Pb/^{206}Pb$; d) $\delta^{208}Pb/^{206}Pb$.

isotope ratios show significant spread, with $^{206}Pb/^{204}Pb$ from 18.30 to 20.00, $^{207}Pb/^{204}Pb$ from 15.13 to 16.18, $^{208}Pb/^{204}Pb$ from 36.78 to 39.89, $^{207}Pb/^{206}Pb$ from 0.79 to 0.85, and $^{208}Pb/^{206}Pb$ from 1.98 to 2.07. In Pb-Pb isotopic ratio diagrams (Figs. 10–12), data from the tills form broad envelopes, with values continuously distributed from the least radiogenic compositions identical to those of the VMS ore and published galena Pb isotopic ratios at Seneca (Godwin et al., 1988) towards more radiogenic $^{206}Pb/^{204}Pb$ at variable $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios, characteristic of isotopically heterogeneous country rocks. Consistent with findings from previous Pb isotopic studies of tills at Chisel Lake, Manitouwadge, Buchans, and Bathurst (Bell and Franklin, 1993; Bell and Murton, 1995; Simonetti et al., 1996; Hussein et al., 2003), hyperbolic data arrays in Pb abundance vs. Pb isotopic ratio diagrams (Fig. 13) are best interpreted as binary mixing curves that reflect derivation from background country rocks and the Seneca deposit, with the tills containing variable proportion of Pb (up to ~10%) derived from the latter.

Direct-leachate HR-ICP-MS and quad ICP-MS results for all samples are consistent with mixing of leads in tills derived from the isotopically heterogeneous country rocks and the isotopically distinct VMS mineralization (Figs. 14–15). The relatively wide range in Pb isotope compositions displayed by the tills, therefore, reflects both initial Pb isotopic variations and added radiogenic Pb produced by in situ decay of U and Th in the bedrock sources. Because galena lacks measurable U and Th but contains Pb values that are orders of magnitude greater than those of country rocks, till samples containing Pb sourced mainly from VMS deposits have Pb isotopic compositions similar to that of galena (Bell and Franklin, 1993; Bell and Murton, 1995; Simonetti et al., 1996; Hussein et al., 2003).

Concentrations of Pb, Zn, Cu, and Ba are highest near the Seneca VMS deposit but show inconsistent areal patterns of glacial dispersion (Fig. 16). Whereas Pb and Zn contents fall to within background range in tills >1 km away from known VMS occurrences, some distal tills contain elevated Cu and Ba (Figs. 16c and d), indicating bedrock sources unrelated to known occurrences of ores. The least radiogenic Pb isotopic ratios, approaching those of ore samples and galena (Godwin et al., 1988), highlight till anomalies within ~1 km down-ice from the Seneca VMS occurrence. Tills away from known VMS occurrences, containing Pb mainly derived from background country rocks, show more radiogenic Pb isotope compositions (Fig. 17). Hence, unlike the distribution patterns of elemental concentrations, Pb isotopic ratios from till fingerprint the source of Pb and provide a way to target mineral exploration (Bell and Franklin, 1993; Simonetti et al., 1996; Hussein et al., 2003).

Although our findings mimic those of Bell and Franklin (1993), Bell and Murton (1995), Simonetti et al. (1996), and Hussein et al. (2003) in delineating VMS deposits, their use of solid-source mass spectrometry (TIMS) is more time consuming and costly. The relatively inexpensive method of measuring Pb isotopic ratios directly in bulk-leachate solution on HR-ICP-MS instrumentation provides the resolution needed to define isotopic contrasts, particularly for $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{206}Pb$ ratios, and produces results consistent with the state-of-the-art MC-ICP-MS measurements (Figs. 18a and c). However, results from quadrupole ICP-MS (uncorrected for mass fractionation) show no systematic areal patterns (Fig. 19) due to high analytical uncertainties for tracing <10% isotopic contrast.

Our findings demonstrate that Pb isotopic ratios for 2.5N HCl leachates from <0.063 mm fraction of tills effectively trace glacial dispersion from relatively young (Middle Jurassic) VMS deposits in Chehalis valley. This method can serve as a robust exploration tool for a broad range of concealed Pb-rich mineral deposits in the Canadian Cordillera and elsewhere.

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Appendix 1. Ice-flow indicators.

ID	Field ID	NTS	Zone	UTM83 Easting	UTM83 Northing	Latitude	Longitude	Elevation	Year	Date	Indicator	Azimuth
1	13ARU1018	92H/05	10	575316	5462209	49.307994	-121.963853	227	2013	06\10	Till clast orientation	156\336
2	13ARU1028	92H/05	10	577240	5462429	49.309787	-121.937407	159	2013	08\10	Till clast orientation	160\340
3	13ARU1030	92H/05	10	576703	5463322	49.317843	-121.944534	337	2013	08\10	Bedrock striations, grooves	90\270
4	13ARU1030	92H/05	10	576703	5463322	49.317843	-121.944534	337	2013	08\10	Bedrock striations, grooves	100\280
5	13ARU1030	92H/05	10	576703	5463322	49.317843	-121.944534	337	2013	08\10	Bedrock striations	144\324
6	WPT 047	92H/05	10	576760	5463304	49.317659	-121.943778	341	2013	08\10	Bedrock striations	296\116

Appendix 1. Continued.

ID	Dip	Dip Azimuth	Plunge	Plunge Azimuth	Description	Bedrock Lithology	Rock Unit
1	18	246			AB-plane of a heavily striated, bullet-shaped clast with keel in place.		MJgd
2					Long axes of cigar-shaped (some with keel) clasts.		lJHL
3					Minimum azimuth for older set of moderately- to poorly-well preserved, abundant, fine striae and grooves (up to 1 cm deep, and up to 6 cm wide) on bedrock surface (surface dip 22°, dip azimuth 84°) right below till sample 13ARU1030.	Finely laminated, very fine-grained green felsic ash tuff.	lJHL
4					Maximum azimuth for older set of moderately- to poorly-well preserved, abundant, fine striae and grooves (up to 1 cm deep, and up to 6 cm wide) on bedrock surface (surface dip 22°, dip azimuth 84°) right below till sample 13ARU1030.	Finely laminated, very fine-grained green felsic ash tuff.	lJHL
5					Younger set of moderately- to poorly-well preserved, seemingly less abundant striae on bedrock surface (surface dip 22°, dip azimuth 84°) right below till sample 13ARU1030.	Finely laminated, very fine-grained green felsic ash tuff.	lJHL
6			19	116	Bedrock knob outcrop with striations on surface (surface dip 59°, dip azimuth 196°).	Volcanic rocks.	lJHL

Appendix 1. Continued.

ID	Surficial Unit	Aspect	Slope	Topography	Exposure	Depth	Bedrock	Notes
1	Mb	70	3	Level	Roadcut	450	None	Till overlain by retreat phase lacustrine silt and clay
2	Mb	358	28	Hill slope	Roadcut	118	Within 10 m laterally	Till underlain by lacustrine sand and silt
3	Mb	199	27	Hill slope	Roadcut	121	At site, right below till	Bedrock overain by till
4	Mb	199	27	Hill slope	Roadcut	121	At site, right below till	Bedrock overain by till
5	Mb	199	27	Hill slope	Roadcut	121	At site, right below till	Bedrock overain by till
6	R			Hill slope	Roadcut	0	At site	

Explanation of headings:

ID	Sequential order of data records
Field ID	Unique ID number for each data record
NTS	National Topographic System (NTS)1:50,000 scale mapunderlying sample site
Zone	Site location UTM zone
UTM83 Easting	Site location UTM easting (NAD83)
UTM83 Northing	Site location UTM northing (NAD83)
Latitude	NAD83 latitude (decimal degrees)
Longitude	NAD83 longitude (decimal degrees)
Elevation	Site elevation (asl, metres)
Year	Year of observation
Date	Day\month of observation
Indicator	Type of ice-flow indicator
Azimuth	Azimuth of ice-flow
Dip	Dip of ice-flow indicator
Dip Azimuth	Dip azimuth of ice-flow indicator
Plunge	Plunge of ice-flow indicator
Plunge Azimuth	Plunge azimuth of ice-flow indicator
Description	Description of ice-flow indicator
Bedrock Lithology	Bedrock lithology underlying site
Rock Unit	Geology map unit after Monger (1970), Arthur et al (1993), Monger and Journeay (1994), and Mahoney et al (1995)
Surficial Unit	Surficial geology map unit
Aspect	General direction of site surface face
Slope	General slope angle of site overlying surface
Topography	General position on topographic feature
Exposure	Site exposure type
Depth	Depth of site from original surface (centimetres)
Bedrock	Observed bedrock outcrop
Notes	Site stratigraphy

Appendix 2. Till samples.

Sample ID	Field ID	Type	Status	NTS	Zone	UTM83 Easting	UTM83 Northing	Latitude	Longitude	Elevation	Year	Date	Rock Unit
62445	13ARU1001	Till	Dup1-1	92H/05	10	574713	5465710	49.339536	-121.971542	292	2013	03\10	lJHL
62446	13ARU1002	Till	Routine	92G/08	10	570872	5468420	49.364274	-122.023819	364	2013	02\10	lJHL
62447	13ARU1003	Till	Routine	92H/05	10	574718	5465707	49.339500	-121.971454	290	2013	03\10	lJHL
62448	13ARU1004	Till	Dup1-2	92H/05	10	574713	5465710	49.339536	-121.971542	292	2013	03\10	lJHL
62449	13ARU1005	Lake sedi-ment	Std										
62450	13ARU1006	Till	Routine	92H/05	10	575050	5465278	49.335645	-121.966929	282	2013	03\10	lJHL
62451	13ARU1007	Till	Routine	92H/05	10	576315	5464351	49.327090	-121.949722	406	2013	04\10	lJHL
62452	13ARU1008	Till	Field Dup1-1	92H/05	10	576108	5464558	49.329014	-121.952525	362	2013	04\10	lJHL
62453	13ARU1009	Till	Field Dup1-2	92H/05	10	576108	5464558	49.329014	-121.952525	362	2013	04\10	lJHL
62454	13ARU1010	Till	Dup2-1	92G/08	10	570896	5469493	49.373993	-122.023392	332	2013	05\10	lJHL
62455	13ARU1011	Till	Dup2-2	92G/08	10	570896	5469493	49.373993	-122.023392	332	2013	05\10	lJHL
62456	13ARU1012	Rock	Std										
62457	13ARU1013	Till	Routine	92G/08	10	570936	5468098	49.361438	-122.023097	366	2013	05\10	lJHL
62458	13ARU1014	Till	Routine	92H/05	10	574157	5463969	49.323946	-121.979502	227	2013	05\10	MJgd
62459	13ARU1015	Till	Routine	92H/05	10	574247	5463635	49.320905	-121.978343	289	2013	06\10	MJgd
62460	13ARU1016	Till	Field Dup2-1	92H/05	10	574975	5462942	49.314621	-121.968411	230	2013	06\10	MJgd
62461	13ARU1017	Till	Field Dup2-2	92H/05	10	574975	5462942	49.314621	-121.968411	230	2013	06\10	MJgd
62462	13ARU1018	Till	Dup3-1	92H/05	10	575316	5462209	49.307994	-121.963853	227	2013	06\10	MJgd
62463	13ARU1019	Till	Routine	92H/05	10	575937	5460460	49.292150	-121.955663	176	2013	06\10	MJgd
62464	13ARU1020	Till	Routine	92H/05	10	576090	5463535	49.319792	-121.953018	238	2013	07\10	lJHL
62465	13ARU1021	Till	Routine	92H/05	10	575779	5464157	49.325433	-121.957148	260	2013	07\10	lJHL

Appendix 2. Till samples.

Sample ID	Field ID	Type	Status	NTS	Zone	UTM83 Easting	UTM83 Northing	Latitude	Longitude	Elevation	Year	Date	Rock Unit
62445	13ARU1001	Till	Dup1-1	92H/05	10	574713	5465710	49.339536	-121.971542	292	2013	03\10	lJHL
62446	13ARU1002	Till	Routine	92G/08	10	570872	5468420	49.364274	-122.023819	364	2013	02\10	lJHL
62447	13ARU1003	Till	Routine	92H/05	10	574718	5465707	49.339500	-121.971454	290	2013	03\10	lJHL
62448	13ARU1004	Till	Dup1-2	92H/05	10	574713	5465710	49.339536	-121.971542	292	2013	03\10	lJHL
62449	13ARU1005	Lake sedi-ment	Std										
62450	13ARU1006	Till	Routine	92H/05	10	575050	5465278	49.335645	-121.966929	282	2013	03\10	lJHL
62451	13ARU1007	Till	Routine	92H/05	10	576315	5464351	49.327090	-121.949722	406	2013	04\10	lJHL
62452	13ARU1008	Till	Field Dup1-1	92H/05	10	576108	5464558	49.329014	-121.952525	362	2013	04\10	lJHL
62453	13ARU1009	Till	Field Dup1-2	92H/05	10	576108	5464558	49.329014	-121.952525	362	2013	04\10	lJHL
62454	13ARU1010	Till	Dup2-1	92G/08	10	570896	5469493	49.373993	-122.023392	332	2013	05\10	lJHL
62455	13ARU1011	Till	Dup2-2	92G/08	10	570896	5469493	49.373993	-122.023392	332	2013	05\10	lJHL
62456	13ARU1012	Rock	Std										
62457	13ARU1013	Till	Routine	92G/08	10	570936	5468098	49.361438	-122.023097	366	2013	05\10	lJHL
62458	13ARU1014	Till	Routine	92H/05	10	574157	5463969	49.323946	-121.979502	227	2013	05\10	MJgd
62459	13ARU1015	Till	Routine	92H/05	10	574247	5463635	49.320905	-121.978343	289	2013	06\10	MJgd
62460	13ARU1016	Till	Field Dup2-1	92H/05	10	574975	5462942	49.314621	-121.968411	230	2013	06\10	MJgd
62461	13ARU1017	Till	Field Dup2-2	92H/05	10	574975	5462942	49.314621	-121.968411	230	2013	06\10	MJgd
62462	13ARU1018	Till	Dup3-1	92H/05	10	575316	5462209	49.307994	-121.963853	227	2013	06\10	MJgd
62463	13ARU1019	Till	Routine	92H/05	10	575937	5460460	49.292150	-121.955663	176	2013	06\10	MJgd
62464	13ARU1020	Till	Routine	92H/05	10	576090	5463535	49.319792	-121.953018	238	2013	07\10	lJHL
62465	13ARU1021	Till	Routine	92H/05	10	575779	5464157	49.325433	-121.957148	260	2013	07\10	lJHL

Appendix 2. Continued.

Sample ID	Surficial Unit	Aspect	Slope	Drainage	Topography	Vegetation	Soil	Exposure	Medium
62445	Mb	216	19	mod.well	hill slope	hemlock, aspen, maple	disturbed	roadcut	sDmm
62446	Mb?	86	44	mod.well	hill slope	cedar, hemlock	disturbed	roadcut	zsDmm
62447	Mb	186	16	mod.well	hill slope	hemlock, aspen, maple	disturbed	roadcut	zsDmm
62448	Mb	216	19	mod.well	hill slope	hemlock, aspen, maple	disturbed	roadcut	sDmm
62449									
62450	Mb	160	42	well	hill slope	hemlock, cedar, alder	disturbed	roadcut	zsDmm
62451	Mb	260	30	well	hill slope	hemlock	disturbed	overgrown roadcut	zsDmm
62452	Mb	306	20	well	hill slope	hemlock, cedar, recent clearcut	disturbed	roadcut	szDmm
62453	Mb	306	20	well	hill slope	hemlock, cedar, recent clearcut	disturbed	roadcut	szDmm
62454	Mb	48	25	mod.well	hill slope	hemlock, cedar, recent clearcut	disturbed	roadcut	szDmm
62455	Mb	48	25	mod.well	hill slope	hemlock, cedar, recent clearcut	disturbed	roadcut	szDmm
62456									
62457	Mb	316	25	well	hill slope	hemlock, cedar, alder	disturbed	streamcut	zsDmm
62458	Mb	349	35	well	hill slope	cedar, hemlock, edge of clearcut	disturbed	roadcut	sDmm
62459	Mv	16	40	well	hill slope	hemlock, cedar; recent clearcut	disturbed	roadcut	sDmm
62460	Mb	40	40	well	hill slope	cedar, hemlock	disturbed	roadcut	zsDmm
62461	Mb	40	40	well	hill slope	cedar, hemlock	disturbed	roadcut	zsDmm
62462	Mb	70	3	mod.well	level	cedar, hemlock, aspen	disturbed	roadcut	szDmm
62463	Mb	202	25	well	hill slope	cedar, hemlock	disturbed	roadcut	zsDmm
62464	Mb	243	24	well	hill slope	maple, hemlock, cedar, alder	disturbed	roadcut	zsDmm
62465	Mb/Mv	248	10	well	gentle hill slope	hemlock, cedar, maple, birch, alder	disturbed	roadcut	szDmm
62466	Mb	70	3	mod.well	level	cedar, hemlock, aspen	disturbed	roadcut	szDmm

Appendix 2. Continued.

Sample ID	Surficial Unit	Aspect	Slope	Drainage	Topography	Vegetation	Soil	Exposure	Medium
62467									
62468	Mb	186	9	well	almost level hill slope	fir, hemlock, cedar, maple, alder	disturbed	roadcut	szDmm
62469	Mb	186	9	well	almost level hill slope	fir, hemlock, cedar, maple, alder	disturbed	roadcut	szDmm
62470	Mb	226	9	well	gentle hill slope	cedar, aspen, maple	disturbed	roadcut	zsDmm
62471	Mb	203	9	well	almost level terrace slope	hemlock, aspen, maple; clearcut	disturbed	roadcut	zsDmm
62472	Mb	358	28	well	hill slope	cedar, hemlock, maple, aspen	disturbed	roadcut	zsDmm
62473	Mb	189	18	poor	hill slope	hemlock, maple, cedar, alder; clearcut.	disturbed	roadcut, streamcut	zsDmm
62474	Mb	199	27	poor	hill slope	alder, hemlock, aspen, maple; edge of clearcut.	disturbed	roadcut	zsDmm
62475	Mv		0	well	level	hemlock, aspen	disturbed-0 cm, LFH-9 cm, Ah-0.5 cm, Ae-0 cm, Bm-12 cm, other-0 cm.	soil pit	zsDmm
62476	Mv		0	well	level	hemlock, aspen	disturbed-0 cm, LFH-9 cm, Ah-0.5 cm, Ae-0 cm, Bm-12 cm, other-0 cm.	soil pit	zsDmm
62477									
62478	Mv	230	27	well	gentle hill slope	clearcut	disturbed	roadcut	zsDmm

Appendix 2. Continued.

Sample ID	Depth	Density	Jointing	Fissility	Oxidation	Matrix (%)	Colour	Texture	Clast Max	Clast Shape
62445	400	moderate	none	weak	moderate	70	brown	s	40	SA
62446	250	moderate	none	weak	none	45	l.grey	zs	55	SA, SR
62447	900	dense	none	weak	weak	65	l.brown	zs	45	SR
62448	400	moderate	none	weak	moderate	70	brown	s	40	SA
62449										
62450	240	very dense	none	weak	moderate	75	l.brown	zs	39	SA, R
62451	123	dense	none	weak	strong	65	orange-brown	zs	23	A, SA
62452	93	dense	none	weak	strong	75	orange-brown	sz	19	SA
62453	93	dense	none	weak	strong	75	orange-brown	sz	19	SA
62454	146	dense	none	moderate	none	75	l.grey	sz	11	SA, SR
62455	146	dense	none	moderate	none	75	l.grey	sz	11	SA, SR
62456										
62457	99	very dense	none	none	weak	75	l.grey	zs	8	SR
62458	210	dense	none	none	none	65	l.grey	s	73	SR, R
62459	46	dense	none	weak	weak	70	l.grey	s	13	A, SA, SR
62460	210	moderate	none	weak	weak	70	l.grey	zs	9	SA, SR, R
62461	210	moderate	none	weak	weak	70	l.grey	zs	9	SA, SR, R
62462	450	dense	none	weak	none	65	l.grey	sz	8.5	SR
62463	95	dense	none	weak	moderate	75	d.brown	zs	7	SR
62464	185	dense	none	none	weak	70	l.brown	zs	11	SA
62465	60	dense	none	none	weak	70	l.brown	sz	20	SR
62466	450	dense	none	weak	none	65	l.grey	sz	8.5	SR
62467										

Appendix 2. Continued.

Sample ID	Depth	Density	Jointing	Fissility	Oxidation	Matrix (%)	Colour	Texture	Clast Max	Clast Shape
62468	50	dense	none	none	weak	75	l.brown	sz	17	SR
62469	50	dense	none	none	weak	75	l.brown	sz	17	SR
62470	66	dense	none	none	moderate	65	l.brown	zs	11	SA
62471	105	dense	none	none	moderate	65	l.brown	zs	25	SA, SR
62472	118	dense	none	none	moderate	60	brown	zs	25	SR
62473	133	moderate	none	weak	moderate	65	l.brown	zs	14	SA
62474	121	dense	none	none	weak	70	l.brown	zs	9	SA
62475	34	dense	none	none	moderate	70	l.brown, orange	zs	10	SA, SR
62476	34	dense	none	none	moderate	70	l.brown, orange	zs	10	SA, SR
62477										
62478	40	dense	none	weak	none	70	l.grey	zs	6	SA, SR

Appendix 2. Continued.

Sample ID	Clast Striae	Bedrock	Structures	Comments
62445	abundant	none	Sandy upper unit with fewer and smaller clasts in a crudely stratified till; stratification apparent from changes in colour and clast abundance.	Upper unit: darker-brown, less dense, more oxidized (locally pervasive), fewer clasts; 12 m 297°N from sample 13ARU1003.
62446	rare	none	Subhorizontal lens of till within 5 m laterally of bedded gravely sands.	Poorly exposed
62447	abundant	none	Clast-rich lower unit at the base of crudely stratified till exposure; stratification apparent from changes in colour and clast abundance.	Lower unit: light-brown, clast-rich to clast-poor upward with larger clasts; possibly lodgement till.
62448	abundant	none	Sandy upper unit with fewer and smaller clasts in a crudely stratified till exposure; stratification apparent from changes in colour and clast abundance.	Upper unit: darker-brown, less dense, more oxidized (locally pervasive), fewer clasts; 12 m 297°N from sample 13ARU1003.
62449				CCRMP LKSD-1 lake sediment standard
62450	common	~15 m SE; rusty-weathering, greenish grey dacite porphyry and lithic-crystal lapilli tuffs cut by a series of subvertical, subparallel pyritic, clay-rich gossans within ~1.5 m-wide shear zone.		Oxidation appears restricted around pebbles many of which contain disseminated sulphides up to 3-5% but locally is pervasive.
62451	rare	none		Pervasive oxidation; common rootlets avoided.
62452	none	none	Fe-Mn oxides along fractures; mottling due to decomposed rootlets.	Pervasively oxidized, secondary mottling due to decomposed rootlets and Fe-Mn oxides along fractures; black and rusty films and reduced portions avoided in the sample.
62453	none	none	Fe-Mn oxides along fractures; mottling due to decomposed rootlets.	Pervasively oxidized, secondary mottling due to decomposed rootlets and Fe-Mn oxides along fractures; black and rusty films and reduced portions avoided in the sample.
62454	none	34 m SE (azimuth 120°N) and 50 m NW (azimuth 300°N) from the till exposure (~30 m laterally); grey hornblende dacite to rhyodacite.	Overlain by loose silty sand with rare clasts (colluvium?).	Roadcut till exposure bound by bedrock outcrops on both sides; mottling due to oxidized and reduced areas disappears deeper into the roadcut.

Appendix 2. Continued.

Sample ID	Clast Striae	Bedrock	Structures	Comments
62455	none	34 m SE (azimuth 120°N) and 50 m NW (azimuth 300°N) from the till exposure (~30 m laterally); grey hornblende dacite to rhyodacite.	Overlain by loose silty sand with rare clasts (colluvium?).	Roadcut till exposure bound by bedrock outcrops on both sides; mottling due to oxidized and reduced areas disappears deeper into the roadcut.
62456				USGS BCR-2 basalt standard
62457	rare	none		Thick till section exposed in roadcut and below the road in an active creek galley (sample site).
62458	common	none	Till, probably >2 m-thick, underlain by advance phase silty lacustrine and sand and gravel deposits.	Unusual diamict/till with mainly sand; possibly incorporated underlying advance phase sand and gravel and lacustrine material.
62459	none	0-10 cm below the sample; medium-grained magnetite-hornblend diorite.		Sandy till veneer 0-10 cm above bedrock contact, immediately below soil B-horizon.
62460	common	immediately below till; light-grey coarse-grained granodiorite.	Till, shows fining upward the section with clast-supported material at the bottom followed by matrix-supported till on top.	Sample from matrix-supported horizon above clast-rich till overlying bedrock (contact with till covered by colluvium).
62461	common	immediately below till; light-grey coarse-grained granodiorite.	Till exposure shows fining upward the section with clast-supported material at the bottom followed by matrix-supported till on top.	Sample from matrix-supported horizon above clast-rich till overlying bedrock (contact with till covered by colluvium).
62462	common	none	Till overlain by retreat phase lacustrine silt and clay; actual contact is obscured by the silt slump (~1.5 m wide).	Ice-flow indicator measurement by AB plane orientation of heavily striated, bullet-shaped clast with keel in place.
62463	none	immediately below till; coarse-grained hornblende diorite.	Subhorizontal, subparallel oxidized horizons; reduced areas around rootlets.	Till above outcrop of coarse-grained hornblende diorite; contact obscured by slumping; avoided oxidized and reduced areas in the sample.
62464	none	none	Till overlain by bedded, loose sand and gravel.	Sample within 40 cm below till contact with overlying sand and gravel.
62465	none	none	Possibly till veneer, oxidized areas around clasts.	Sample may be till veneer; weathered; oxidized areas were avoided in the sample
62466	common	none	Till overlain by retreat phase lacustrine silt and clay; contact is obscured by the silt slump (~1.5 m wide).	Ice-flow indicator measurement by AB plane orientation of well striated, bullet-shaped clast with keel in place.

Appendix 2. Continued.

Sample ID	Clast Striae	Bedrock	Structures	Comments
62467				USGS RGM-1 rhyolite standard
62468	none	none	Oxidized fractures.	Poorly exposed; abundant oxidation along rootlets and tensile fractures, all of which were avoided in the sample; abundant rusty spots (1-2 mm) may indicate up to 4 % oxidized sulphides; collected on very rainy day.
62469	none	none	Oxidized fractures.	Poorly exposed; abundant oxidation along rootlets and tensile fractures, all of which were avoided in the sample; abundant rusty spots (1-2 mm) may indicate up to 4 % oxidized sulphides; collected on very rainy day.
62470	none	none		Near surface sample from small till exposure, weathered, oxidized till; locally 3-5 % rusty spots (1-3 mm), possibly after sulphides, in till matrix; green dacite clasts with 5-7 % disseminated sulphides (up to 3-4 mm); small, probably seasonal or rainfall creek within 2 m.
62471	none	none	Till overlain by colluvial(?) or glaciofluvial sand and gravel deposits forming a terrace.	Near surface till sample but less modified by post-depositional oxidation and reduction along rootlets and fractures compared to 13ARU1026; all oxidation appears to be restricted to oxidized clasts, which are common.
62472	none	within 10 m laterally from the till exposure; Harrison Lake Formation rocks.	Till underlain by lacustrine sand and silt sediments; contact is obscured by a slump.	Weathered till with 2-3 % of rusty spots (up to 1.5 mm), probably oxidized sulphides, in the matrix; ice-flow indicator measurement by orientation of long axes of cigar-shaped, keeled clasts
62473	rare	<100 m N-NW.		Directly S-SE down-ice from the Seneca Pit, roadcut exposure of till in a small galley with rainfall creek washing fines away while collecting the sample on a very rainy day; the field observations and the quality of the sample might have been compromised; one keel-shaped, elongate clast of green dacite or tuff contains ~1 % disseminated sulphides (~1 mm); abundant oxidized, very angular clasts in the overlying colluvium.

Appendix 2. Continued.

Sample ID	Clast Striae	Bedrock	Structures	Comments
62474	rare	3 cm below the sample; rusty-weathering, green, finely laminated to massive, very fine-grained felsic ash tuff with hematite along bedding and fractures.	Till underlain by moderately oxidized, sorted sediment (~3 cm-thick zone)	Till sample 3-10 cm above outcrop; ~3 cm-thick; ice-flow indicators measured by orientation of two sets of striae on the bedrock surface immediately below the till sample.
62475	rare	immediately below till sample; mineralized felsic volcanic breccia.	Till veneer (<1 m-thick) underlain by bedrock and overlain by soil B-horizon (12 cm-thick).	Till veneer exposure (~1 m-thick) directly above mineralized bedrock in SE vertical wall of the Seneca Pit; till sample from about 0.5 x 0.5 m soil pit dug out from the top surface above the till exposure in vertical wall; abundant oxidized clasts and sand- to granule-oxidized sulphides (up to 4 mm; 5-7 %).
62476	rare	immediately below till sample; mineralized felsic volcanic breccia.	Till veneer (<1 m-thick) underlain by bedrock and overlain by soil B-horizon (12 cm-thick).	Till veneer exposure (~1 m-thick) directly above mineralized bedrock in SE vertical wall of the Seneca Pit; till sample from about 0.5 x 0.5 m soil pit dug out from the top surface above the till exposure in vertical wall; abundant oxidized clasts and sand- to granule-oxidized sulphides (up to 4 mm; 5-7 %).
62477				CCRMP TILL-2 till standard
62478	none	immediately below till sample; volcanic rocks.	Till veneer ~10 cm-thick underlain by bedrock 40 cm below the surface.	Till veneer directly above bedrock pinches out and becomes oxidized deeper into vertical exposure.

Appendix 2. Continued.

Explanation of headings:

Sample ID	Unique ID for each sample.
Field ID	Unique field ID for each sample.
Type	Type of sample.
Status	Identifies routine samples, duplicate sample pairs and quality controls: **Dup** - duplicate splits of <0.063 mm till fraction, **Field Dup** - duplicate bulk till samples collected from a single site, **Std** - certified standard reference materials.
NTS	National Topographic System (NTS) 1:50,000 scale map underlying site.
Zone	Site location UTM zone.
UTM83 Easting	Site location UTM easting (NAD83).
UTM83 Northing	Site location UTM northing (NAD83).
Latitude	NAD83 latitude (decimal degrees).
Longitude	NAD83 longitude (decimal degrees).
Elevation	Site elevation (asl, metres).
Year	Year of sample collection.
Date	Day\month of sample collection.
Rock Unit	Geology map unit after Monger (1970), Arthur et al. (1993), Monger and Journeay (1994), and Mahoney et al. (1995).
Surficial Unit	Surficial geology map unit.
Aspect	Azimuth for general direction of sample surface face (degrees).
Slope	General slope angle of overlying surface (degrees).
Drainage	Capacity of site to drain water.
Topography	General topographic position of sample site.
Vegetation	Types of vegetation observed near sample site.
Soil	Description of soil profile above till sample.
Exposure	Sample exposure type.
Medium	Non-genetic sediment description.
Depth	Depth of sample from original surface (centimetres).
Density	Consolidation of the sample.
Jointing	Degree of jointing or vertical partings present.
Fissility	Degree of fissility or horizontal partings present.
Oxidation	Degree of sample oxidation.
Matrix (%)	Percentage of till matrix to clasts.
Colour	Colour of sample matrix.
Texture	Matrix texture: sand (s) and silt (z).
Clast Mode	Most common pebble or cobble size.
Clast Max	B-axis measurement of largest clast (centimetres).
Clast Shape	Degree of clast roundness.
Clast Striae	Presence of striation on clasts.
Bedrock	Bedrock exposures near sample site.
Structures	Sedimentary structures observed at sample site.
Comments	Other observations and notes.

Appendix 3.Pebble-count data for till samples.

Sample ID	Field ID	Clast Total Count	Volcanic (%)	Siliciclastic (%)	Plutonic (%)	Other (%)	Probable Source Major	Probable Source Minor	Clast Description
62445	13ARU1001	31	90	3	3	3	Harrison Lake Formation	Mt. Jasper pluton	Subangular; mafic to felsic volcanic rocks, siltstone, lapilli to ash tuffs, coarse-grained biotite granodiorite, pyrite-bearing quartz vein; some felsic porphyries and tuffs contain sulphides.
62446	13ARU1002	27	56	33	11	0	Harrison Lake Formation	Mt. Jasper pluton	Subangular; intermediate to felsic porphyry, siltstone, medium-grained diorite; 2-5% pyrite in silicified siltstone or ash tuff.
62447	13ARU1003	25	80	4	16	0	Harrison Lake Formation	Mt. Jasper pluton	Subangular to subrounded, striated; mafic to felsic volcanic rocks, siltstone or ash tuff, medium-grained granodiorite to diorite; some felsic porphyries contain sulphides.
62450	13ARU1006	34	91	6	3	0	Harrison Lake Formation	Mt. Jasper pluton	Subangular to subrounded; mafic to felsic volcanic rocks, lapilli tuff, chert, hornblende quartz diorite; many felsic volcanic rocks contain disseminated sulphides.
62451	13ARU1007	37	97	0	3	0	Harrison Lake Formation	Mt. Jasper pluton	Angular to subrounded; mafic to felsic porphyritic to aphyric volcanic rocks, lapilli and ash tuffs, medium-grained diorite; some porphyries and tuffs pervasively oxidized; rare disseminated sulphides.
62452	13ARU1008	29	79	7	14	0	Harrison Lake Formation	Hemlock Valley stock?	Subangular; mafic to feslic volcanic rocks, ash tuff, quartz porphyry with medium- to fine-grained groundmass, siltstone, sandstone; some clasts with oxidized rinds and fractures, two porphyritic dacite clasts contain up to 4% sulphides.
62454	13ARU1010	42	93	2	5	0	Harrison Lake Formation	Mt. Jasper pluton	Subangular to subrounded; rare angular, mafic to felsic volcanic rocks, ash tuff, coarse-grained biotite granodiorite, fine-grained sandstone; felsic porphyries contain up to 2% sulphides (pyrrhotite up to 6x3 mm).
62457	13ARU1013	32	66	19	16	0	Harrison Lake Formation	Mt. Jasper pluton	Subangular to rounded; mafic to felsic volcanic rocks, ash lapilli tuffs, medium-grained hornblende diorite, granite and gabbro, siltstone, chert; some pyritized (<2 %).
62458	13ARU1014	26	65	8	27	0	Harrison Lake Formation	Mt. Jasper pluton	Angular to rounded; mafic to felsic volcanic rocks, welded tuff with fiamme, lapilli to ash tuffs, black siltstone, chert, fine- to coarse-grained biotite-hornblende diorite, microdiorite and granodiorite; some tuffs with up to 3% disseminated sulphides.

Appendix 3.Continued

Sample ID	Field ID	Clast Total Count	Volcanic (%)	Siliciclastic (%)	Plutonic (%)	Other (%)	Probable Source Major	Probable Source Minor	Clast Description
62459	13ARU1015	36	6	0	94	0	Mt. Jasper pluton	Harrison Lake Formation	Angular to subrounded; weakly porphyritic to equigranular, medium- to coarse-grained light grey hornblende diorite to granodiorite with rare quartz veinlets and sericitic alteration; black very fine-grained aphyric basalt, greenish light grey aphanitic rhyolite(?); some clasts with 2 mm-thick oxidation rinds.
62460	13ARU1016	78	64	15	21	0	Harrison Lake Formation	Mt. Jasper pluton	Angular to rounded, most of the clasts are subangular to subrounded; mafic to felsic volcanic rocks, welded ash tuff, lithic to crystal lapilli-ash tuffs, porphyries; black sandstone and siltstone; medium-grained dark grey gabbro and grey hornblende diorite to quartz diorite; some clasts pervasively to moderately oxidized (rinds, fractures); rare clasts with disseminated sulphides (up to 4 %).
62462	13ARU1018	37	68	11	22	0	Harrison Lake Formation	Mt. Jasper pluton	Subangular to subrounded, commonly striated; light grey to green and brown dacite to rhyolite porphyries and lithic-crystal lapilli- to ash tuffs, moderately to weakly oxidized (rinds, fractures), 5 clasts with disseminated sulphides (up to 3 %); one clast of black very fine-grained basalt; dark grey sandstone and siltstone; grey medium-grained hornblende diorite and coarse-grained biotite granite.
62463	13ARU1019	39	82	8	10	0	Harrison Lake Formation	Mt. Jasper pluton	Subangular to rounded; mafic to felsic volcanic rocks, greenish grey dacite porphyry with oxidized rinds, up to 5% disseminated sulphides, light brown rhyolite porphyry, black very fine-grained basalt to andesite(?), some amygdaloidal, oxidized rinds; black basaltic and grey intermediate to felsic crystal-lithic (one pebble - vitric) lapilli- to ash tuffs, none to pervasive oxidation (fractures, disseminated sulphides); light grey to purple siltstone and sandstone (hematitic?); fine- to medium-grained biotite-hornblende diorite and granodiorite.
62464	13ARU1020	40	100	0	0	0	Harrison Lake Formation		Angular to subungular, rare subrounded clasts, some striated; mainly greenish grey and light brown (rhyo)dacite porphyries and lapilli- to ash tuffs (some contain minor sulphides); strongly oxidized rhyolite (silicified?) tuff; subordinate clasts of mafic volcanic rocks.

Appendix 3.Continued

Sample ID	Field ID	Clast Total Count	Volcanic (%)	Siliciclastic (%)	Plutonic (%)	Other (%)	Probable Source Major	Probable Source Minor	Clast Description
62465	13ARU1021	44	98	0	0	2	Harrison Lake Formation	Unknown	Angular to subangular, rare striated clasts; mafic to felsic porphyrtic and aphyric volcanic rocks and lapilli- to ash tuffs; most abundant clasts are greenish grey and light brown porphyrticdacite and rhyolite; dark green to grey mafic-intermediate volcanic rocks; one subangular clast of pervasively oxidized, red rhyolite; one subrounded clast of banded hornfels; some clasts of pyroclastic rocks contain limonite in vesicles.
62468	13ARU1024	37	81	8	11	0	Harrison Lake Formation	Mt. Jasper pluton	Angular to subrounded, rare striated clasts; mafic to felsic volcanic rocks, mainly greenish grey intermediate and white felsic lapilli- and ash tuffs (some with up to 2% disseminated sulphides), dacite porphyry, dark grey intermediate aphyric rock, crystal tuff and welded tuff with fiamme; grey sandstone and siltstone; grey medium- and coarse-grained hornblende diorite (with 3-4% pyrite) and tonalite.
62470	13ARU1026	38	89	0	11	0	Harrison Lake Formation	Mt. Jasper pluton, Hemlock Valley stock?	Angular to subangular; mainly greenish grey rhyodacitepoprhyry, brown dacite porphyry; greenish dark grey intermediate lapilli- to ash tuffs (some contain 5-7% limonite pseudomorphs after pyrite cubes); rusty-weathering, white rhyolite porphyry or tuff with 5-7 % sulphides (1 mm); one clast of brown, oxidized ignimbrite; black and dark grey porphyritic and aphyric mafic-intermediate rocks (some amygdaloidal); light grey siltstone; pervasive, moderate-strong oxidation (after disseminated sulphides); dark grey medium-grained hornblende quartz diorite, grey biotite tonalite; one clast of light grey medium-grained quartz poprhyry.
62471	13ARU1027	45	98	2	0	0	Harrison Lake Formation		Angular to rounded, mainly greenish grey and light brown dacite and rhyodacite porphyries and black, dark grey and greenish grey lapilli- and ash tuffs (lithic and crystal); one angular clast of amygdaloidal basalt or andesite; one subangular clast of grey fragmental rock (felsic tuff?) with abundant, very fine-grained disseminated sulphides; buff sandstone (1 clast); clasts of volcaniclastic rocks are commonly weathered, with one angular cobble of rhyolite tuff pervasively oxidized (rusty) and sulphide-rich clast having oxidation rind.

Appendix 3.Continued

Sample ID	Field ID	Clast Total Count	Volcanic (%)	Siliciclastic (%)	Plutonic (%)	Other (%)	Probable Source Major	Probable Source Minor	Clast Description
62472	13ARU1028	39	87	5	8	0	Harrison Lake Formation	Mt. Jasper pluton	Mainly subangular to subrounded, with rare rounded clasts, commonly striated; mainly greenish grey dacite and rhyodacite porphyries and black, dark grey and greenish grey lapilli- and ash tuffs and aphyric basalt or andesite; light grey volcanic sandstone; two clasts of grey medium-grained hornblende quartz diorite and coarse-grained hornblende tonalite; one subangular clast of felsic lapilli lithic-crystal tuff or epiclastic rock with disseminated sulphides and rounded fragments of massive sulphides; clasts are fresh or oxidized along fractures.
62473	13ARU1029	43	91	9	0	0	Harrison Lake Formation		Angular to subangular, some striated; mainly greenish grey dacite porphyry and black (mafic?) and dark grey and grey intermediate and felsic lapilli- and ash tuffs; three angular clasts of felsic tuff or epiclastic rock with lapilli-size massive-sulphide fragments (3-4%) and disseminated sulphides (5-6%); four clasts of buff and grey sandstone and siltstone; one sulphide-bearing clast has an oxidation rind about 1 cm wide.
62474	13ARU1030	28	96	4	0	0	Harrison Lake Formation		Angular to subangular, commonly striated; light brown and greenish grey dacite and rhyodacite porphyries and dark grey (mafic?) and greenish grey and light grey intermediate and felsic lapilli- and ash tuffs, rare porphyritic and aphyric basalts or andesites; one clast of black welded tuff with fiamme contains about 5% sulphides; once clast of grey siltstone; some clasts of volcaniclastic rocks are oxidized along fractures.
62475	13ARU1031	48	100	0	0	0	Harrison Lake Formation		Angular to subangular, some striated; mainly black (mafic?) and dark grey, greenish grey and white intermediate and felsic lapilli- and ash tuffs, subordinate clasts of greenish grey and light brown dacite porphyries and porphyritic and aphyric basalts or andesites; clasts commonly contain minor fresh or pseudomorphed (limonite) sulphides, particularly white rhyolitic tuffs; one clast of felsic tuff cut by quartz veinlet is sulphide-rich; clasts vary from relatively fresh to strongly oxidized along fractures or pervasively (typically sulphide-bearing felsic tuffs).

Appendix 3.Continued

Sample ID	Field ID	Clast Total Count	Volcanic (%)	Siliciclastic (%)	Plutonic (%)	Other (%)	Probable Source Major	Probable Source Minor	Clast Description
62478	13ARU1034	26	100	0	0	0	Harrison Lake Formation		Angular, mainly mafic or intermediate and felsic lapilli- and ash lithic-crystal tuffs; four clasts of grey porphyritic dacite and andesite and one clasts of black porphyritic basalt or andesite or crystal tuff; clasts vary from fresh to strongly oxidized.

Explanation of headings:

Sample ID	Unique ID for each sample.
Field ID	Unique field ID for each sample.
Clast Total Count	Clast total count.
Volcanic (%)	Percentage of clasts derived from variably oxidized and mineralized, mafic to felsic, massive and amygdaloidal, aphyric to porphyritic rocks with aphanitic groundmass and pyroclastic (±epiclastic) rocks of the Middle Jurassic Harrison Lake Formation.
Siliciclastic (%)	Percentage of clasts derived from sandstone, siltstone and chert of the Middle Jurassic Harrison Lake Formation, possibly including some reworked volcaniclastic rocks.
Plutonic (%)	Percentage of clasts derived from light- to dark grey, fine- to coarse-grained biotite- and hornblende-diorite, quartz diorite, granodiorite and grey, medium-grained gabbro of the Middle Jurassic Mt. Jasper pluton; and light grey, quartz porphyry with fine- to medium-grained groundmass, possibly from the Middle Jurassic Hemlock Valley quartz feldspar porphyry stock.
Other (%)	Percentage of clasts derived from hornfels and pyrite-bearing quartz veins of unknown provenance.
Probable Source Major	Probable source geologic unit for predominant clast lithologies.
Probable Source Minor	Probable source geologic unit for subordinate clast lithologies.
Clast Description	Field description of clast lithology, shape and other comments.

Appendix 4. Rock samples.

Sample ID	Field ID	NTS	Year	Date	Zone	UTM83 Easting	UTM83 Northing	Latitude	Longitude	Elevation	Geology	Map Unit
62479	13ARU001-1	92H/05	2013	01\10	10	576673	5463245	49.317111	-121.945045	304	Harrison Lake Fm.	lJHL
62480	13ARU007-2	92H/05	2013	08\10	10	576673	5463245	49.317111	-121.945045	304	Harrison Lake Fm.	lJHL
62481	13ARU007-3	92H/05	2013	08\10	10	576673	5463245	49.317111	-121.945045	304	Harrison Lake Fm.	lJHL
62482	13ARU002-1	92G/08	2013	05\10	10	570861	5469515	49.374217	-122.023753	336	Harrison Lake Fm.	lJHL
62483	13ARU002-2	92G/08	2013	05\10	10	570861	5469515	49.374217	-122.023753	336	Harrison Lake Fm.	lJHL
62484	13ARU003-1	92G/08	2013	05\10	10	570939	5469470	49.373798	-122.022798	326	Harrison Lake Fm.	lJHL
62485	13ARU003-2	92G/08	2013	05\10	10	570939	5469470	49.373798	-122.022798	326	Harrison Lake Fm.	lJHL
62486	13ARU004	92H/05	2013	06\10	10	574247	5463635	49.320905	-121.978343	289	Mt. Jasper pluton	MJgd
62487	13ARU005	92H/05	2013	07\10	10	575081	5465275	49.335571	-121.966539	270	Harrison Lake Fm.	lJHL
62488	13ARU006	92H/05	2013	08\10	10	576703	5463322	49.317843	-121.944534	337	Harrison Lake Fm.	lJHL
62489	13ARU007-1	92H/05	2013	08\10	10	576673	5463245	49.317111	-121.945045	304	Harrison Lake Fm.	lJHL

Appendix 4. Continued.

Sample ID	Rock Class	Rock Name	Description	Alteration
62479	Volcanic-hydrothermal	Mineralized felsic breccia	Fragmental, subhedral to euhedral (up to 2 x 6 mm) and framboidal pyrite (15%); anhedral sphalerite (up to 1.0 x 1.2 mm; 10%); barite prisms (0.2 x 4.0 mm; 15%); anhedral chalcopyrite (up to 0.2 x 0.3 mm; 1-2%); and anhedral galena (up to 0.2 x 0.5 mm; <1%) in silicified felsite.	Silicification, barite.
62480	Volcanic-hydrothermal	Mineralized felsic breccia	Fragmental, subhedral to euhedral (0.6 x 0.7 mm), and framboidal (0.015 mm) pyrite (40-45%); barite prisms (0.3 x 1.0 mm) and radial aggregates (locally up to 50%); anhedral to subhedral sphalerite (0.8 x 1.2 mm; ~7%); anhedral chalcopyrite (0.2 x 0.5 mm; 3-5%); and accessory anhedral galena (0.010 mm; <<1%) in silicified felsite.	Silicification, barite.
62481	Volcanic	Altered intermediate-felsic lapilli tuff	Porphyritic dacite-rhyodacite lapilli with phenocrysts of feldspars and quartz (up to 0.5 x 0.7 mm; <1%), chlorite amygdules, and disseminated euhedral pyrite (up to 0.4 x 0.5 mm; 3-4%) and anhydral sphalerite (up to 0.06 x 0.20 mm; <1%) in silicified and sericitized (with minor epidote) fine-grained matrix.	Silicification, sericite, epidote.

Appendix 4. Continued.

Sample ID	Rock Class	Rock Name	Description	Alteration
62482	Volcanic-subvolcanic	Rhyodacite	Light grey, massive, porphyritic rhyodacite with phenocrysts of sericitized and clay-altered plagioclase and orthoclase (total 10-15%), quartz (2-3%) and hornblende (completely replaced by tremolite-chlorite-epidote) set in the fine-grained, albitized groundmass crosscut by veinlets of secondary chlorite, epidote and tremolite.	Chlorite, epidote, tremolite, albite.
62483	Volcanic-subvolcanic	Hornblende rhyodacite	Light grey massive, porphyritic rhyodacite with phenocrysts of sericitized and clay-altered plagioclase and orthoclase (total 6-7%; up to 1.8 x 1.8 mm), subhedral to euhedral quartz (up to 1.8 mm in diameter; 2-3%), and chloritized hornblende (up to 1 x 1 mm; 1-2%) set in the dense, very fine-grained felsic groundmass.	Chlorite, epidote, sericite, clay.
62484	Volcanic-subvolcanic	Hornblende dacite	Grey massive, porphyritic dacite with sericitized and clay-altered plagioclase and orthoclase phenocrysts and chlorite-epidote pseudomorphs after hornblende phenocrysts in very fine-grained felsic groundmass crosscut by veinlets of secondary epidote.	Chlorite, epidote, sericite, clay.
62485	Volcanic-subvolcanic	Hornblende dacite	Grey massive, porphyritic dacite with sericitized feldspar phenocrysts (5-6%), chlorite-epidote pseudomorphs after hornblende phenocrysts (1-2%), and rare skeletal quartz phenocrysts (<<1%) in very fine-grained, heavily sericitized felsic groundmass.	Sericite, chlorite, epidote.
62486	Plutonic	Magnetite-hornblende diorite	Light grey, massive diorite with rare phenocrysts of plagioclase (up to 5x9 mm) and quartz (up to 6 mm) in medium-grained groundmass made up of euhedral to subhedral, weakly sericitized (±chloritized) plagioclase; subhedral, fresh to weakly chloritized and epidotized brown-green hornblende (6-7%); subhedral magnetite (1%); interstitial anhedral quartz (4-5%) and chlorite; and accessory apatite as euhedral inclusions in hornblende; rare angular to rounded mafic-ultramafic xenoliths (up to 15 cm along B-axis).	Epidote, chlorite, and sericite after primary minerals and along jointing.
62487	Volcanic-hydrothermal	Pyritic gossan in felsic tuff	Composite sample from a series of subvertical, subparallel, pyrite-rich oxidized gossans with abundant clay, sericite, chlorite, some epidote and quartz veinlets, and accessory sphalerite and titanite in a shear zone (~1.5 m wide; 130°N strike) within rusty-weathering, grey, intermediate to felsic lithic-crystal lapilli tuffs cut by dacitic dike; subhedral pyrite up to 5.6 x 6.0 mm.	Oxidation, clay in gossan
62488	Volcanic	Felsic ash tuff	Rusty-weathering, dark green, finely laminated to massive, cross-bedded, very fine-grained felsic ash tuff.	Sericite, oxidation, fine-grained hematite along bedding and fracture planes.
62489	Volcanic-hydrothermal	Mineralized felsic breccia	Subhedral to euhedral pyrite (up to 1 x 1 mm; 50-60%), commonly as inclusions in chalcopyrite; subhedral sphalerite (up to 1.6 x 3.0 mm; 7-10%); and anhedral chalcopyrite (up to 2.6 x 3.2 mm; ~5%) in well sericitized and silicified felsite.	Sericite, silicification.

Explanation of headings:

Sample ID	Unique ID for each data record.
Field ID	Unique field ID for each data record.
NTS	National Topographic System (NTS) 1:50,000 scale map underlying site.
Year	Year of sample collection.
Date	Day\month of sample collection.
Zone	Site location UTM zone.
UTM83 Easting	Site location UTM easting (NAD83).
UTM83 Northing	Site location UTM northing (NAD83).
Latitude	NAD83 latitude (decimal degrees).
Longitude	NAD83 longitude (decimal degrees).
Elevation	Site elevation (asl, metres).
Geology	Name of geologic unit after Monger (1970), Arthur et al. (1993), Monger and Journeay (1994), and Mahoney et al. (1995).
Map Unit	Geology map unit after Monger (1970), Arthur et al. (1993), Monger and Journeay (1994), and Mahoney et al. (1995).
Rock Class	General rock classification.
Rock Name	Petrographic name of rock.
Description	Petrographic description of sample.
Alteration	Description of alteration in sample.

Appendix 5. Portable XRF data for till (<0.063 mm fraction) and whole-rock samples.

Sample ID	Type[1]	Status[2]	Reading[3]	Cu (ppm)	2σ	Zn (ppm)	2σ	As (ppm)	2σ	Rb (ppm)	2σ	Sr (ppm)	2σ	Zr (ppm)	2σ	Mo (ppm)	2σ	Pb (ppm)	2σ
62446	Till		83	20	5	47	3	9.8	1.5	14.4	0.9	248	2	191	2	6.2	1.2	8.5	1.6
62447	Till		82	26	5	93	4	3.7	1.3	14.6	0.9	178	2	101	2	<2		10.0	1.5
62448	Till		81	53	5	111	4	8.7	1.5	13.8	0.9	182	2	106	2	<2		9.7	1.5
62450	Till		80	38	5	127	4	7.1	1.5	10.9	0.8	161	2	100	2	<2		14.4	1.6
62451	Till		79	12	4	82	4	11.5	1.5	15.8	0.9	109	2	98	2	<2		9.5	1.5
62452	Till	Field Dup1-1	78	27	5	71	4	7.0	1.4	16.9	0.9	139	2	109	2	2.7	1.0	9.3	1.5
62453	Till	Field Dup1-2	77	25	5	77	4	5.7	1.4	16.5	0.9	143	2	112	2	2.3	1.0	9.4	1.5
62454	Till	Dup1-1	76	30	5	68	4	12.4	1.6	18.1	1.0	247	2	120	2	<2		11.7	1.7
62455	Till	Dup1-2	75	28	5	68	4	12.3	1.6	17.9	1.0	247	2	124	2	<2		11.3	1.6
62457	Till		74	49	5	91	4	11.8	1.6	18.4	1.0	290	3	142	2	2.0	1.1	11.7	1.7
62458	Till		71	47	5	76	4	10.0	1.6	24.4	1.1	225	2	135	2	<2		11.0	1.7
62459	Till		70	39	5	65	4	7.8	1.5	20.6	1.0	226	2	116	2	<2		10.0	1.7
62460	Till	Field Dup2-1	69	60	5	107	4	10.1	1.6	21.2	1.0	212	2	121	2	<2		12.4	1.7
62461	Till	Field Dup2-2	68	51	5	86	4	11.1	1.6	21.0	1.0	213	2	129	2	<2		10.5	1.7
62462	Till	Dup2-1	67	19	5	53	3	5.9	1.4	18.2	1.0	206	2	139	2	<2		8.8	1.5
62463	Till		66	39	5	92	4	9.4	1.6	23.3	1.0	170	2	127	2	<2		12.3	1.7
62464	Till		65	44	5	169	5	11.7	1.6	15.2	0.9	157	2	89	2	<2		14.7	1.7
62465	Till		64	32	5	136	5	14.2	1.7	18.9	0.9	165	2	103	2	<2		14.7	1.8
62466	Till	Dup2-2	63	17	4	54	3	4.5	1.4	18.5	1.0	204	2	147	2	<2		9.6	1.6
62468	Till	Field Dup3-1	62	29	5	98	4	10.1	1.6	18.7	1.0	194	2	101	2	<2		12.5	1.7
62469	Till	Field Dup3-2	61	32	5	107	4	11.1	1.5	19.8	1.0	195	2	99	2	<2		9.3	1.6
62470	Till		60	80	5	264	6	10.0	1.6	15.7	0.9	144	2	97	2	<2		13.4	1.7
62471	Till		14	37	5	154	5	10.9	2.2	20.5	0.9	121	2	121	2	<2		48	3
62471	Till	Repeat	59	41	5	154	5	11.7	2.1	21.3	0.9	121	2	123	2	<2		46	2
62472	Till		48	55	5	100	4	7.5	1.5	14.0	0.8	163	2	105	2	<2		12.2	1.6
62473	Till		47	10	4	1011	11	24.2	2.1	17.7	0.9	106	2	97	2	<2		32	2
62474	Till		46	29	5	84	4	9.0	1.5	13.7	0.9	143	2	86	2	<2		8.5	1.5
62475	Till		19	711	12	1040	12	20.4	3.5	16.6	0.9	108	2	79	2	2.5	1.1	142	4
62475	Till	Repeat	40	720	12	1029	12	25.2	3.6	16.7	0.9	108	2	81	2	2.0	1.1	139	4
62478	Till		37	33	5	134	5	9.2	2.2	16.6	0.9	113	2	95	2	<2		54	3
62479	Rock		35	2754	51	51813	185	2396	44	19.2	3.8	2391	16	<15		74	4	3117	43
62480	Rock		33	7172	102	149903	396	2790	47	15.8	5.1	4041	27	<24		104	5	1148	34
62481	Rock		32	65	6	753	11	41.0	2.9	13.1	0.9	78.0	1.5	45	2	23	1	46	3

Appendix 5. Continued.

Sample ID	Type[1]	Status[2]	Reading[3]	Cu (ppm)	2σ	Zn (ppm)	2σ	As (ppm)	2σ	Rb (ppm)	2σ	Sr (ppm)	2σ	Zr (ppm)	2σ	Mo (ppm)	2σ	Pb (ppm)	2σ
62482	Rock		31	<8		28	2	<2		1.9	0.6	175	2	147	2	<2		7.0	1.2
62483	Rock		30	21	4	31	3	<2		1.9	0.6	254	2	114	2	<2		5.3	1.2
62484	Rock		29	<8		31	3	<2		2.5	0.6	203	2	71	2	<2		5.9	1.2
62485	Rock		28	<9		47	3	<2		14.6	0.8	153	2	92	2	<2		5.0	1.2
62486	Rock		27	8	5	42	4	5.5	1.6	2.9	0.8	612	4	41	2	<2		7.0	1.8
62487	Rock		26	<13		180	8	4.5	1.8	26.3	1.2	16.4	0.9	9.9	1.3	<3		4.3	2.4
62488	Rock		25	41	5	78	4	<3		7.1	0.7	97.3	1.5	84	2	<2		9.8	1.5
62489	Rock		23	44362	177	104439	245	493	17	33.8	2.2	29.7	2.3	<5		86	3	339	15
Relative difference (%) for <0.063 mm-fraction duplicate pairs:																			
Dup1 (%)				8		0.0		0.6		0.7		0.1		3.0		0.0		3.2	
Dup2 (%)				11		1.1		26		1.8		0.7		5.7		0.0		9.0	
Average (%)				**9.2**		**0.5**		**13**		**1.2**		**0.4**		**4.4**		**0.0**		**6.1**	
Relative difference (%) for sample-site duplicate pairs:																			
Field Dup1 (%)				5.6		7.9		20		2.2		3.0		2.4		17		1.2	
Field Dup2 (%)				15		22		9.9		0.9		0.2		6.7		1.9		16	
Field Dup3 (%)				11		9.4		9.5		5.6		0.6		2.1		0.6		29	
Average (%)				**11**		**13**		**13**		**2.9**		**1.3**		**3.7**		**6.5**		**15**	
CCRMP TILL-1 standard:																			
This study			10	54	5	91	4	16	2	44.2	1.4	291	3	496	3	3.0	1.4	22	2
Certified mean ±2SD (Lynch, 1996)				*47*	*8*	*98*	*20*	*18*	*2*	*44*	*12*	*291*	*20*	*502*	*116*	*2*	*2*	*22*	*6*
CCRMP TILL-2 standard:																			
This study			11	153	7	125	5	23	2	146	2	145	2	376	3	13.3	1.3	32	2
Certified mean ±2SD (Lynch, 1996)				*150*	*20*	*130*	*16*	*26*	*4*	*143*	*24*	*144*	*16*	*390*	*78*	*14*	*4*	*31*	*6*
CCRMP TILL-3 standard:																			
This study			12	16	4	57	3	75	3	55.8	1.4	292	3	201	2	<2		29	2
Certified mean ±2SD (Lynch, 1996)				*22*	*10*	*56*	*12*	*87*	*8*	*55*	*14*	*300*	*24*	*230*	*48*	*2*	*2*	*26*	*6*

Appendix 5. Continued.

Sample ID	Type[1]	Status[2]	Reading[3]	Cu (ppm)	2σ	Zn (ppm)	2σ	As (ppm)	2σ	Rb (ppm)	2σ	Sr (ppm)	2σ	Zr (ppm)	2σ	Mo (ppm)	2σ	Pb (ppm)	2σ
CCRMP TILL-4 standard:																			
This study			13	242	8	72	4	99	3	164	2	115	2	386	3	14.9	1.4	57	3
This study		Repeat 1	22	245	8	71	4	101	3	166	2	114	2	383	3	14.8	1.4	53	3
This study		Repeat 2	58	248	8	70	4	103	3	164	2	113	2	387	3	14.4	1.4	54	3
This study mean ±2SD (n = 3)				245	6	71	3	101	4	165	2	114	2	385	4	14.7	0.5	54	4
Certified mean ±2SD (Lynch, 1996)				*237*	*34*	*70*	*14*	*111*	*12*	*161*	*30*	*109*	*22*	*385*	*68*	*16*	*4*	*50*	*8*
SiO_2 blank			7	<7		19	2	<2		0.7	0.4	<0.8		<1		<2		6.8	1.0
SiO_2 blank repeat			51	<7		17	2	<2		0.7	0.4	<0.8		<1		<2		6.4	1.0

Footnotes:

Total concentrations were determined by a Thermo Scientific Niton FXL 950 energy-dispersive X-ray fluorescence (ED-XRF) spectrometer in hand-pressed, 32 mm-diameter sample pellets, made with a 4 µm-thick polypropylene bottom, using an automated sample spinner, 180 seconds total counting time, Compton internal standardization method, and external calibration of Rukhlov (2013) at the British Columbia Geological Survey.

[1] Sample medium: T**ill** = till matrix (<0.063 mm fraction); R**ock** = pulverized whole rock.

[2] Identifies duplicate sample pairs: **Field Dup** = duplicate bulk till samples collected from a single site; **Dup** = duplicate splits of <0.063 mm fraction; **Repeat** = repeat analysis of the same sample.

[3] Sequential analysis number.

2σ = two times absolute standard error or two times standard deviation (2SD) where indicated; **ppm** = parts per million.

Relative difference (%) = absolute(X1-X2)/((X1+X2)/2)*100, where X1 and X2 are duplicate results.

Appendix 6. 'Total' determinations for till (<0.063 mm fraction) and whole-rock samples.

Sample ID	Type[1]	Status[2]	SiO_2 (wt %)	Al_2O_3 (wt %)	Fe_2O_3t (wt %)	MgO (wt %)	CaO (wt %)	Na_2O (wt %)	K_2O (wt %)	TiO_2 (wt %)	P_2O_5 (wt %)	MnO (wt %)	Cr_2O_3 (wt %)	LOI (wt %)	Sum (wt %)	Total C (wt %)	Total S (wt %)
62445	Till	Dup1-1	70.96	12.39	4.85	1.39	2.29	3.35	0.90	0.59	0.13	0.10	0.004	2.9	99.85	0.02	<0.02
62446	Till		65.77	14.19	5.75	1.59	3.38	3.43	0.79	0.69	0.10	0.10	0.003	4.0	99.85	0.29	<0.02
62447	Till		70.17	13.20	4.36	1.90	2.18	3.48	1.05	0.60	0.12	0.09	0.003	2.7	99.86	0.03	0.07
62448	Till	Dup1-2	71.14	12.34	4.89	1.40	2.29	3.31	0.90	0.59	0.12	0.10	0.003	2.8	99.85	<0.02	<0.02
62450	Till		72.66	12.15	4.18	0.98	1.63	3.77	0.83	0.67	0.17	0.07	0.003	2.8	99.88	<0.02	<0.02
62451	Till		62.22	15.56	5.16	1.77	1.12	3.34	1.25	0.62	0.18	0.10	0.004	8.6	99.87	0.86	<0.02
62452	Till	Field Dup1-1	69.10	13.70	4.82	1.97	1.39	3.02	1.11	0.62	0.11	0.10	0.004	3.9	99.89	0.02	<0.02
62453	Till	Field Dup1-2	69.12	13.50	4.69	1.85	1.61	3.00	1.06	0.59	0.11	0.11	0.003	4.2	99.86	0.02	<0.02
62454	Till	Dup2-1	65.69	14.86	5.50	1.82	2.66	3.44	1.04	0.76	0.12	0.10	0.003	3.9	99.84	0.09	<0.02
62455	Till	Dup2-2	65.59	14.77	5.49	1.82	2.63	3.44	1.03	0.76	0.13	0.10	0.004	4.1	99.84	0.08	<0.02
62457	Till		63.81	15.65	5.79	1.93	2.77	3.18	1.02	0.78	0.11	0.10	0.003	4.7	99.82	0.09	<0.02
62458	Till		61.05	16.28	6.18	2.33	3.07	2.94	1.21	0.67	0.12	0.13	0.005	5.8	99.81	0.13	<0.02
62459	Till		59.66	16.54	6.29	2.27	3.50	2.99	1.07	0.67	0.10	0.13	0.003	6.6	99.81	0.38	<0.02
62460	Till	Field Dup2-1	61.81	16.33	6.13	2.26	2.66	2.88	1.15	0.69	0.13	0.13	0.003	5.6	99.82	0.19	<0.02
62461	Till	Field Dup2-2	61.63	16.44	6.12	2.23	2.69	2.89	1.12	0.68	0.09	0.12	0.003	5.8	99.81	0.18	<0.02
62462	Till	Dup3-1	68.73	13.47	5.06	1.82	3.04	3.16	1.07	0.63	0.12	0.10	0.003	2.7	99.85	<0.02	<0.02
62463	Till		61.21	16.99	6.02	1.95	2.04	2.52	1.15	0.72	0.07	0.14	0.004	7.0	99.82	0.17	<0.02
62464	Till		66.96	14.05	5.16	1.48	2.07	3.43	1.08	0.71	0.12	0.14	0.004	4.6	99.84	0.02	<0.02
62465	Till		64.97	14.59	5.97	2.01	2.02	3.22	1.18	0.70	0.13	0.12	0.003	4.9	99.82	0.25	<0.02
62466	Till	Dup3-2	68.68	13.43	5.05	1.81	3.03	3.18	1.07	0.63	0.11	0.10	0.003	2.8	99.86	0.02	<0.02
62468	Till	Field Dup3-1	64.39	15.48	5.65	1.88	2.09	3.03	1.10	0.70	0.17	0.10	0.003	5.2	99.84	0.05	<0.02
62469	Till	Field Dup3-2	63.87	15.59	5.68	1.92	2.09	2.99	1.11	0.70	0.13	0.11	0.003	5.6	99.82	0.06	<0.02
62470	Till		65.80	14.61	5.35	1.75	1.68	3.43	1.09	0.66	0.11	0.11	0.003	5.2	99.80	0.12	<0.02
62471	Till		61.26	16.49	5.10	1.95	1.35	2.49	1.30	0.63	0.18	0.09	0.004	9.0	99.86	0.38	<0.02
62472	Till		66.03	14.85	4.95	1.64	1.57	2.92	0.89	0.67	0.03	0.10	0.003	6.2	99.84	0.08	<0.02
62473	Till		67.16	13.89	3.96	2.03	1.42	3.76	1.28	0.74	0.14	0.10	0.004	5.3	99.76	0.31	<0.02
62474	Till		60.54	16.16	6.20	2.47	1.78	3.07	1.02	0.70	0.15	0.10	0.004	7.6	99.80	0.19	<0.02
62475	Till	Dup4-1	61.18	14.78	7.34	2.47	1.09	3.49	1.13	0.75	0.23	0.12	0.003	7.1	99.64	0.36	0.04
62476	Till	Dup4-2	61.32	14.87	7.36	2.50	1.09	3.52	1.15	0.76	0.25	0.12	0.004	6.7	99.63	0.36	0.04
62478	Till		60.95	16.28	5.68	2.48	1.37	3.14	1.16	0.71	0.21	0.11	0.003	7.7	99.84	0.56	<0.02
62479	Rock		36.23	0.98	14.12	0.06	0.02	0.02	0.23	0.02	0.01	0.06	0.014	9.3	61.05	<0.02	17.7
62480	Rock		2.33	0.51	22.02	0.03	0.02	<0.01	0.16	0.01	0.01	0.07	0.009	13.9	39.12	<0.02	29.0
62481	Rock		57.25	15.39	9.37	4.64	0.83	4.58	0.96	0.66	0.15	0.28	0.014	5.6	99.73	<0.02	4.42

Appendix 6. Continued.

Sample ID	Type[1]	Status[2]	SiO_2 (wt %)	Al_2O_3 (wt %)	Fe_2O_3t (wt %)	MgO (wt %)	CaO (wt %)	Na_2O (wt %)	K_2O (wt %)	TiO_2 (wt %)	P_2O_5 (wt %)	MnO (wt %)	Cr_2O_3 (wt %)	LOI (wt %)	Sum (wt %)	Total C (wt %)	Total S (wt %)
62482	Rock		75.21	12.32	2.13	0.83	2.85	4.78	0.13	0.43	0.08	0.05	0.020	1.1	99.94	<0.02	<0.02
62483	Rock		73.58	13.44	2.62	1.16	1.63	5.36	0.15	0.33	0.07	0.05	0.014	1.5	99.91	<0.02	<0.02
62484	Rock		74.24	12.35	2.90	1.74	2.62	4.27	0.11	0.3	0.07	0.06	0.013	1.3	99.93	<0.02	<0.02
62485	Rock		71.30	13.54	3.34	3.49	1.03	2.45	1.23	0.35	0.10	0.08	0.008	2.9	99.85	<0.02	<0.02
62486	Rock		56.68	16.58	7.29	1.53	12.6	1.07	0.08	0.97	0.30	0.20	0.014	2.6	99.86	<0.02	<0.02
62487	Rock		42.29	16.68	18.26	9.30	0.54	0.06	1.94	0.44	0.03	0.46	0.020	9.7	99.71	<0.02	4.84
62488	Rock		65.22	14.53	5.06	4.60	0.73	4.98	0.52	0.43	0.05	0.11	0.010	3.6	99.86	<0.02	0.04
62489	Rock		14.47	3.49	45.39	0.23	0.04	0.02	1.07	0.09	<0.01	0.02	0.026	25	89.88	0.03	37.2
Relative difference (%) for <0.063 mm-fraction duplicate pairs:																	
Dup1 (%)			0.25	0.40	0.82	0.72	0.00	1.20	0.00	0.00	8.00	0.00	28.6	3.5	0.00		0.0
Dup2 (%)			0.15	0.61	0.18	0.00	1.13	0.00	0.97	0.00	8.00	0.00	28.6	5.0	0.00	11.8	0.0
Dup3 (%)			0.07	0.30	0.20	0.55	0.33	0.63	0.00	0.00	8.70	0.00	0.0	3.6	0.01		0.0
Dup4 (%)			0.23	0.61	0.27	1.21	0.00	0.86	1.75	1.32	8.33	0.00	28.6	5.8	0.01	0.0	0.0
Average (%)			**0.2**	**0.5**	**0.4**	**0.6**	**0.4**	**0.7**	**0.7**	**0.3**	**8.3**	**0.0**	**21.4**	**4.5**	**0.0**		**0.0**
Relative difference (%) for sample-site duplicate pairs:																	
Field Dup1 (%)			0.03	1.47	2.73	6.28	14.67	0.66	4.61	4.96	0.00	9.52	28.6	7.4	0.03	0.0	0.0
Field Dup2 (%)			0.29	0.67	0.16	1.34	1.12	0.35	2.64	1.46	36.36	8.00	0.0	3.5	0.01	5.4	0.0
Field Dup3 (%)			0.81	0.71	0.53	2.11	0.00	1.33	0.90	0.00	26.67	9.52	0.0	7.4	0.02	18.2	0.0
Average (%)			**0.38**	**0.95**	**1.14**	**3.24**	**5.26**	**0.78**	**2.72**	**2.14**	**21.01**	**9.02**	**9.5**	**6.1**	**0.02**	**7.9**	**0.0**
CCRMP LKSD-1 standard:																	
This study			38.61	7.38	3.87	1.71	10.38	1.97	1.10	0.48	0.15	0.08	0.005	29.4	95.17	13.2	1.56
Certified (Lynch, 1990; 1999)			*40.10*	*7.80*	*4.11*	*1.73*	*10.80*	*2.00*	*1.14*	*0.53*	*0.16*	*0.09*	*0.005*	*29.9*			*1.57*
CCRMP TILL-2 standard:																	
This study			60.76	15.75	5.49	1.85	1.26	2.27	3.00	0.88	0.16	0.10	0.009	8.2	99.77	1.66	0.03
Certified (Lynch, 1996)			*60.80*	*16.00*	*5.39*	*1.83*	*1.27*	*2.19*	*3.07*	*0.88*	*0.17*	*0.10*	*0.011*	*8.1*			*<0.05*
USGS BCR-2 standard:																	
This study			53.77	13.49	13.74	3.66	7.12	3.12	1.80	2.27	0.31	0.20	0.003	0.2	99.67	<0.02	0.03
Certified (Wilson, 1997)			*54.10*	*13.50*	*13.80*	*3.59*	*7.12*	*3.16*	*1.79*	*2.26*	*0.35*	*0.20*	*0.003*				

Appendix 6. Continued.

Sample ID	Type[1]	Status[2]	SiO_2 (wt %)	Al_2O_3 (wt %)	Fe_2O_3t (wt %)	MgO (wt %)	CaO (wt %)	Na_2O (wt %)	K_2O (wt %)	TiO_2 (wt %)	P_2O_5 (wt %)	MnO (wt %)	Cr_2O_3 (wt %)	LOI (wt %)	Sum (wt %)	Total C (wt %)	Total S (wt %)
USGS RGM-1 standard:																	
This study			72.88	13.70	1.87	0.28	1.20	4.03	4.34	0.26	0.03	0.04	<0.002	1.2	99.88	<0.02	<0.02
Certified (Govindaraju, 1994)			*73.40*	*13.70*	*1.86*	*0.28*	*1.15*	*4.07*	*4.30*	*0.27*		*0.04*	*0.001*				
Laboratory quality controls:																	
62479 Rep																<0.02	17.9
62475 Rep			61.14	14.81	7.32	2.48	1.09	3.5	1.14	0.75	0.22	0.12	0.004	7.1	99.63		
62489 Rep			14.26	3.47	45.5	0.23	0.04	0.02	1.06	0.09	<0.01	0.02	0.026	25	89.74	0.02	38.1
GS311-1 Std																1.01	2.31
GS311-1 Std -Rep																0.99	2.46
GS910-4 Std																2.73	8.21
GS910-4 Std -Rep																2.68	8.32
GBM309-15 Std																0.19	28.1
GBM309-15 Std -Rep																0.18	27.7
SO-18 Std average (n=10)				14.09	7.66	3.39	6.33	3.65	2.14	0.69	0.81	0.40	0.56	1.90	99.73		
SO-18 Std RSD (%)				0.8	1.4	1.4	0.9	1.4	1.1	1.2	2.9	0.8	1.2	0.0	0.0		
Blank average (n=5)			<0.01	<0.01	<0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.002			<0.02	<0.02

Appendix 6. Continued.

Sample ID	Type[1]	Status[2]	Ba (ppm)	Be (ppm)	Ce (ppm)	Co (ppm)	Cs (ppm)	Dy (ppm)	Er (ppm)	Eu (ppm)	Ga (ppm)	Gd (ppm)	Hf (ppm)	Ho (ppm)	La (ppm)	Lu (ppm)	Nb (ppm)	Nd (ppm)	Ni (ppm)	Pr (ppm)	Rb (ppm)
62445	Till	Dup1-1	418	<1	27.1	8.2	0.9	3.84	2.46	0.97	12.0	3.81	2.7	0.84	12.2	0.39	4.7	14.4	<20	3.26	11.5
62446	Till		420	<1	24.7	7.6	0.6	4.32	2.59	1.02	13.1	4.03	4.4	0.96	11.2	0.40	4.2	16.3	<20	3.41	11.8
62447	Till		537	<1	22.3	5.9	0.8	3.30	2.44	0.97	12.0	3.52	3.2	0.75	10.7	0.32	4.0	14.5	<20	3.15	12.7
62448	Till	Dup1-2	425	<1	24.8	8.2	0.5	4.18	2.53	0.85	10.5	4.08	3.0	0.80	11.7	0.33	4.1	15.5	<20	3.34	11.3
62450	Till		409	<1	24.0	4.1	0.4	3.44	2.01	0.82	6.6	3.19	3.6	0.71	10.8	0.31	3.8	11.3	<20	2.74	9.6
62451	Till		464	2	28.8	7.3	1.0	3.14	2.05	0.90	11.7	3.28	2.9	0.67	9.4	0.37	3.6	11.5	<20	2.60	12.8
62452	Till	Field Dup1-1	427	<1	28.1	7.5	0.7	4.08	2.69	0.98	10.2	3.88	2.8	0.88	13.3	0.39	4.4	15.6	<20	3.72	13.5
62453	Till	Field Dup1-2	418	<1	28.0	7.5	1.0	3.90	2.42	1.04	10.5	4.39	3.6	0.91	13.3	0.45	4.3	15.0	<20	3.51	14.2
62454	Till	Dup2-1	517	<1	29.2	8.5	0.7	4.12	2.93	1.14	11.6	4.36	3.3	0.98	12.3	0.44	4.0	17.1	<20	3.66	15.6
62455	Till	Dup2-2	555	<1	29.0	7.8	0.8	4.14	2.88	1.07	11.7	4.29	3.6	0.91	13.4	0.41	4.4	17.3	<20	3.82	15.7
62457	Till		564	<1	30.9	12.3	1.0	4.19	2.81	1.15	11.8	4.35	4.0	0.95	13.4	0.41	3.6	15.7	<20	3.75	16.4
62458	Till		614	1	26.3	13.2	1.5	4.20	3.04	0.87	12.9	4.03	3.7	1.03	10.8	0.43	2.9	14.9	<20	3.24	21.7
62459	Till		633	<1	25.7	12.0	1.0	4.41	2.85	0.77	12.6	3.88	3.2	0.98	9.5	0.50	3.0	13.4	<20	3.00	16.9
62460	Till	Field Dup2-1	604	<1	24.9	11.9	1.5	3.87	2.94	1.06	12.0	3.95	3.5	0.92	11.3	0.40	2.9	14.4	<20	3.21	20.2
62461	Till	Field Dup2-2	626	<1	25.7	10.4	1.4	4.21	2.73	0.90	11.9	3.73	3.7	0.89	11.0	0.45	2.6	14.5	<20	3.25	18.6
62462	Till	Dup3-1	475	1	26.5	8.3	0.6	3.91	2.48	0.95	10.4	4.29	3.9	0.85	12.3	0.46	2.9	13.9	<20	3.26	15.6
62463	Till		630	1	36.2	12.8	1.3	4.04	2.47	0.97	13.4	3.75	3.8	0.91	12.4	0.39	3.3	14.8	<20	3.50	20.1
62464	Till		519	<1	31.0	9.0	1.0	3.98	2.40	1.15	9.1	4.57	3.0	0.87	12.5	0.39	3.4	16.4	<20	3.63	12.6
62465	Till		606	<1	35.3	8.9	0.8	4.00	2.80	0.97	10.1	3.70	2.7	0.84	12.1	0.40	3.3	14.3	<20	3.53	16.5
62466	Till	Dup3-2	451	1	24.9	7.6	0.7	3.74	2.42	0.89	10.0	3.83	3.8	0.78	12.0	0.40	3.4	13.0	<20	3.15	16.5
62468	Till	Field Dup3-1	523	<1	28.9	8.2	1.2	4.97	3.10	1.21	11.1	5.22	2.9	0.98	15.3	0.47	3.4	18.4	<20	4.23	17.4
62469	Till	Field Dup3-2	581	1	29.4	8.6	1.2	5.53	3.50	1.32	10.7	5.58	3.0	1.25	16.1	0.52	3.3	21.0	<20	4.70	17.0
62470	Till		720	<1	30.3	7.0	0.9	4.35	2.20	1.11	9.6	4.26	2.6	0.90	13.0	0.36	2.7	16.2	<20	3.77	13.7
62471	Till		486	<1	30.1	8.8	1.7	3.40	2.15	0.88	13.0	3.28	3.3	0.74	9.6	0.38	3.7	12.3	<20	2.85	18.4
62472	Till		558	<1	29.3	7.6	1.0	3.84	2.46	0.93	9.6	3.86	3.2	0.85	12.4	0.37	3.3	16.0	<20	3.52	12.5
62473	Till		380	<1	39.0	6.5	0.7	4.26	2.80	1.10	8.5	4.45	3.0	0.98	11.6	0.40	4.3	16.2	<20	3.69	16.2
62474	Till		741	<1	28.2	9.7	1.0	3.87	2.45	1.12	11.9	4.08	2.4	0.86	11.8	0.36	3.0	15.3	<20	3.44	12.4
62475	Till	Dup4-1	535	<1	24.0	9.5	0.5	3.82	2.47	1.17	10.0	4.08	2.6	0.77	8.4	0.38	2.6	12.9	<20	2.93	12.9
62476	Till	Dup4-2	566	<1	24.2	10.2	0.6	3.91	2.46	1.12	10.8	3.84	2.5	0.86	8.6	0.42	2.9	12.9	<20	3.07	13.6
62478	Till		474	3	33.3	9.6	1.2	4.19	2.45	0.97	11.3	3.73	3.0	0.81	11.1	0.42	3.1	13.9	<20	3.31	14.2
62479	Rock		>50000	<1	2.5	0.9	<0.1	<0.05	0.04	1.06	4.1	1.21	1.6	<0.02	4.1	0.02	0.4	0.6	29	0.20	3.7
62480	Rock		>50000	<1	2.6	1.0	<0.1	<0.05	<0.03	3.61	18.7	2.27	1.5	<0.02	5.7	0.03	0.2	0.3	<20	0.18	2.3
62481	Rock		344	2	16.6	18.6	0.3	3.77	2.02	0.95	15.7	2.95	1.8	0.75	5.7	0.30	3.3	11.7	<20	2.55	11.5

Appendix 6. Continued.

Sample ID	Type[1]	Status[2]	Ba (ppm)	Be (ppm)	Ce (ppm)	Co (ppm)	Cs (ppm)	Dy (ppm)	Er (ppm)	Eu (ppm)	Ga (ppm)	Gd (ppm)	Hf (ppm)	Ho (ppm)	La (ppm)	Lu (ppm)	Nb (ppm)	Nd (ppm)	Ni (ppm)	Pr (ppm)	Rb (ppm)
62482	Rock		79	<1	29.0	3.3	0.2	3.52	2.63	0.66	9.5	3.57	3.9	0.85	14.8	0.49	5.4	14.4	<20	3.58	1.6
62483	Rock		80	<1	26.6	3.8	0.1	3.26	2.35	0.84	12.3	3.34	3.3	0.72	13.3	0.38	3.6	14.1	<20	3.49	2.0
62484	Rock		75	1	17.5	4.7	<0.1	2.40	1.50	0.58	11.0	1.82	2.3	0.45	9.1	0.27	3.0	8.7	<20	2.09	1.3
62485	Rock		544	1	19.1	6.4	0.3	2.69	1.64	0.53	9.6	2.60	2.6	0.57	9.4	0.27	2.2	11.1	<20	2.44	13.6
62486	Rock		24	<1	19.9	10.3	<0.1	3.98	2.38	1.01	17.4	3.71	1.8	0.91	9.2	0.38	2.4	14.2	<20	2.98	1.4
62487	Rock		607	<1	30.6	27.8	2.4	2.41	1.67	1.08	23.4	2.99	1.0	0.47	14.5	0.20	0.6	17.7	<20	4.09	23.7
62488	Rock		236	<1	22.0	10.6	0.3	3.05	2.35	0.80	12.8	3.19	2.6	0.72	11.9	0.37	2.3	11.1	<20	2.65	7.2
62489	Rock		1577	1	13.4	5.9	0.2	0.48	0.43	0.43	13.8	0.60	0.6	0.13	10.3	0.08	0.7	3.9	35	1.22	13.5
Relative difference (%) for <0.063 mm-fraction duplicate pairs:																					
Dup1 (%)			1.7	0.0	8.9	0.0	57.1	8.5	2.8	13.2	13.3	6.8	10.5	4.9	4.2	16.7	13.6	7.4	0.0	2.4	1.8
Dup2 (%)			7.1	0.0	0.7	8.6	13.3	0.5	1.7	6.3	0.9	1.6	8.7	7.4	8.6	7.1	9.5	1.2	0.0	4.3	0.6
Dup3 (%)			5.2	0.0	6.2	8.8	15.4	4.4	2.4	6.5	3.9	11.3	2.6	8.6	2.5	14.0	15.9	6.7	0.0	3.4	5.6
Dup4 (%)			5.6	0.0	0.8	7.1	18.2	2.3	0.4	4.4	7.7	6.1	3.9	11.0	2.4	10.0	10.9	0.0	0.0	4.7	5.3
Average (%)			**4.9**	**0.0**	**4.2**	**6.1**	**26.0**	**3.9**	**1.8**	**7.6**	**6.5**	**6.5**	**6.4**	**8.0**	**4.4**	**11.9**	**12.5**	**3.8**	**0.0**	**3.7**	**3.3**
Relative difference (%) for sample-site duplicate pairs:																					
Field Dup1 (%)			2.1	0.0	0.4	0.0	35.3	4.5	10.6	5.9	2.9	12.3	25.0	3.4	0.0	14.3	2.3	3.9	0.0	5.8	5.1
Field Dup2 (%)			3.6	0.0	3.2	13.5	6.9	8.4	7.4	16.3	0.8	5.7	5.6	3.3	2.7	11.8	10.9	0.7	0.0	1.2	8.2
Field Dup3 (%)			10.5		1.7	4.8	0.0	10.7	12.1	8.7	3.7	6.7	3.4	24.2	5.1	10.1	3.0	13.2	0.0	10.5	2.3
Average (%)			**5.4**	**0.0**	**1.7**	**6.1**	**14.1**	**7.9**	**10.0**	**10.3**	**2.5**	**8.2**	**11.3**	**10.3**	**2.6**	**12.1**	**5.4**	**5.9**	**0.0**	**5.9**	**5.2**
CCRMP LKSD-1 standard:																					
This study			360	< 1	25	9.2	0.8	3.1	2.0	0.8	7.6	3.4	3.1	0.7	13	0.3	4.1	17	< 20	3.6	22
Certified (Lynch, 1990; 1999)			*430*	*1.1*	*27*	*11*	*1.5*	*3.4*		*0.9*	*10*	*3.6*	*3.6*	*1*	*16*	*0.4*	*7*	*16*	*16*		*24*
CCRMP TILL-2 standard:																					
This study			490	1	102	13	12	6.5	3.8	1.2	16	7.2	9.6	1.3	44	0.5	16	37	39	10.2	135
Certified (Lynch, 1996)			*540*	*4*	*98*	*15*	*12*		*3.7*	*1*			*11*		*44*	*0.6*	*20*	*36*	*32*		*143*
USGS BCR-2 standard:																					
This study			658	2	50	34	1.1	5.8	3.7	1.9	17	6.3	4.5	1.3	25	0.48	9.1	27	<20	6.3	42
Certified (Wilson, 1997)			*683*		*53*	*37*	*1.1*			*2*	*23*	*6.8*	*4.8*	*1.3*	*25*	*0.51*		*28*		*6.8*	*48*

Appendix 6. Continued.

Sample ID	Type[1]	Status[2]	Ba (ppm)	Be (ppm)	Ce (ppm)	Co (ppm)	Cs (ppm)	Dy (ppm)	Er (ppm)	Eu (ppm)	Ga (ppm)	Gd (ppm)	Hf (ppm)	Ho (ppm)	La (ppm)	Lu (ppm)	Nb (ppm)	Nd (ppm)	Ni (ppm)	Pr (ppm)	Rb (ppm)
USGS RGM-1 standard:																					
This study			735	1	43	2	8.6	3.2	2.0	0.52	12	3.1	4.9	0.7	20	0.3	6.3	16	<20	4.6	132
Certified (Govindaraju, 1994)			*810*	*2.4*	*47*	*2*	*9.6*	*4.1*		*0.66*	*15*	*3.7*			*24*	*0.4*	*8.9*	*19*			*150*
Laboratory quality controls:																					
62479 Rep																					
62475 Rep			553	<1	23.6	8.6	0.4	4.03	2.31	1	9.1	3.75	2.3	0.75	8.6	0.33	2.8	12.9	<20	2.84	12.6
62489 Rep			1552	2	11.4	5.9	0.2	0.53	0.37	0.38	11.6	0.6	0.5	0.14	9	0.08	0.6	4	<20	1.18	12.5
GS311-1 Std																					
GS311-1 Std -Rep																					
GS910-4 Std																					
GS910-4 Std -Rep																					
GBM309-15 Std																					
GBM309-15 Std -Rep																					
SO-18 Std average (n= 10)			523	1.00	28	26	7.1	2.9	1.88	0.85	16.6	3.0	9.4	0.64	13.0	0.27	20	13.2	43	3.4	28
SO-18 Std RSD (%)			5.2	0.0	3.8	4.8	5.2	4.0	4.8	5.2	8.2	3.5	5.6	6.3	6.3	6.7	8.8	5.7	28.1	4.5	3.9
Blank average (n=5)			<1	<1	<0.1	<0.2	<0.1	<0.05	<0.03	<0.02	<0.5	<0.05	<0.1	<0.02	<0.1	<0.01	<0.1	<0.3	<20	<0.02	<0.1

Appendix 6. Continued.

Sample ID	Type[1]	Status[2]	Sc (ppm)	Sm (ppm)	Sn (ppm)	Sr (ppm)	Ta (ppm)	Tb (ppm)	Th (ppm)	Tm (ppm)	U (ppm)	V (ppm)	W (ppm)	Y (ppm)	Yb (ppm)	Zr (ppm)
62445	Till	Dup1-1	15	3.09	<1	182.0	0.3	0.60	1.6	0.35	0.8	79	0.5	21.1	2.70	117.8
62446	Till		18	3.66	1	233.2	0.3	0.66	2.0	0.45	1.0	131	0.6	24.1	2.82	168.3
62447	Till		15	3.15	<1	184.9	0.3	0.59	2.0	0.41	1.0	81	0.8	21.0	2.50	111.1
62448	Till	Dup1-2	15	3.51	<1	187.3	0.1	0.62	1.8	0.42	1.0	86	<0.5	21.2	2.44	114.4
62450	Till		15	2.83	<1	164.3	0.2	0.55	1.3	0.33	1.1	86	<0.5	19.3	2.44	112.5
62451	Till		15	2.37	<1	112.6	0.2	0.58	1.6	0.36	0.8	89	<0.5	18.8	2.36	107.2
62452	Till	Field Dup1-1	15	3.15	2	136.5	0.3	0.64	2.0	0.37	0.9	73	0.5	22.2	2.66	108.4
62453	Till	Field Dup1-2	15	3.55	<1	150.4	0.3	0.71	1.5	0.41	1.0	80	<0.5	26.0	2.67	118.5
62454	Till	Dup2-1	19	3.87	<1	249.0	0.2	0.71	2.0	0.46	1.3	110	<0.5	26.5	3.32	121.6
62455	Till	Dup2-2	19	3.97	1	248.5	0.2	0.76	2.1	0.44	0.9	108	0.7	25.1	2.96	129.5
62457	Till		20	3.84	<1	297.0	0.2	0.72	2.2	0.47	1.0	121	0.7	26.9	2.92	144.6
62458	Till		23	3.63	<1	221.6	0.3	0.66	2.2	0.45	1.3	136	0.9	25.6	3.12	140.1
62459	Till		25	3.32	<1	224.2	0.2	0.70	1.9	0.49	1.4	140	<0.5	25.0	3.38	121.5
62460	Till	Field Dup2-1	22	3.38	<1	222.8	0.1	0.68	2.3	0.44	1.3	130	0.7	23.4	2.87	126.9
62461	Till	Field Dup2-2	22	3.34	<1	210.7	0.2	0.68	2.1	0.44	1.2	127	0.6	23.2	2.90	126.2
62462	Till	Dup3-1	17	3.01	<1	216.8	0.2	0.63	2.0	0.43	1.0	105	0.8	25.4	3.07	140.9
62463	Till		21	3.3	<1	170.2	0.2	0.67	2.3	0.43	1.2	130	0.8	22.3	2.47	137.7
62464	Till		18	3.56	<1	161.7	0.2	0.68	1.3	0.39	0.9	103	<0.5	23.5	2.50	94.4
62465	Till		19	3.53	<1	166.0	0.2	0.66	2.1	0.39	1.0	114	0.7	20.0	2.62	103.8
62466	Till	Dup3-2	17	3.31	<1	208.3	0.3	0.58	1.6	0.40	0.7	107	0.7	23.6	2.67	147.4
62468	Till	Field Dup3-1	20	4.26	<1	197.1	0.3	0.85	2.0	0.42	1.2	111	<0.5	33.1	3.18	107.8
62469	Till	Field Dup3-2	20	5.06	<1	199.2	0.3	0.90	2.0	0.53	1.3	112	0.5	34.6	3.33	102.4
62470	Till		18	3.61	<1	146.4	0.2	0.70	1.4	0.39	0.8	105	<0.5	22.2	2.39	101.1
62471	Till		17	3.03	<1	124.5	0.3	0.54	2.0	0.33	0.8	96	<0.5	17.9	2.62	124.8
62472	Till		17	3.57	<1	163.4	0.4	0.66	1.9	0.38	0.8	101	<0.5	21.9	2.40	113.3
62473	Till		15	3.88	<1	114.8	0.3	0.81	1.6	0.44	0.9	73	<0.5	28.1	2.88	106.6
62474	Till		23	3.85	<1	153.1	0.2	0.69	1.2	0.38	0.7	136	<0.5	22.8	2.46	98.3
62475	Till	Dup4-1	25	3.93	<1	106.7	0.2	0.66	0.8	0.39	0.7	125	<0.5	18.5	2.35	86.9
62476	Till	Dup4-2	25	3.69	<1	113.4	0.2	0.68	1.3	0.42	0.7	133	<0.5	20.6	2.81	90.2
62478	Till		20	3.39	<1	115.6	0.3	0.67	1.1	0.39	1.0	116	<0.5	20.9	2.74	103.5
62479	Rock		<1	0.20	<1	2670.9	4.7	0.03	<0.2	0.01	4.4	44	0.8	1.2	0.12	7.9
62480	Rock		1	0.30	<1	4130.6	5.1	0.04	<0.2	0.02	1.7	37	0.8	1.4	0.17	3.1
62481	Rock		23	2.52	1	80.7	0.2	0.53	0.7	0.32	0.8	231	<0.5	19.7	1.76	63.6

Appendix 6. Continued.

Sample ID	Type[1]	Status[2]	Sc (ppm)	Sm (ppm)	Sn (ppm)	Sr (ppm)	Ta (ppm)	Tb (ppm)	Th (ppm)	Tm (ppm)	U (ppm)	V (ppm)	W (ppm)	Y (ppm)	Yb (ppm)	Zr (ppm)
62482	Rock		9	3.12	<1	193.7	0.3	0.60	2.3	0.42	1.1	38	<0.5	24.0	2.82	149.6
62483	Rock		7	3.12	<1	280.4	0.2	0.57	1.8	0.31	1.1	28	<0.5	20.6	2.42	127.0
62484	Rock		6	1.87	<1	228.1	0.3	0.34	1.7	0.23	0.7	40	0.5	14.8	1.67	93.5
62485	Rock		9	2.29	1	171.3	0.2	0.40	1.4	0.26	0.7	43	<0.5	15.5	1.99	101.5
62486	Rock		25	3.40	<1	703.5	<0.1	0.66	1.9	0.39	0.8	123	<0.5	22.2	2.55	47.8
62487	Rock		26	3.24	<1	16.9	<0.1	0.45	0.3	0.22	0.6	207	<0.5	13.4	1.19	30.6
62488	Rock		17	2.67	<1	110.2	0.1	0.55	1.3	0.34	0.8	102	<0.5	21.8	2.13	96.8
62489	Rock		4	0.64	<1	26.4	0.1	0.10	0.3	0.07	2.9	72	0.9	4.2	0.47	21.0
Relative difference (%) for <0.063 mm-fraction duplicate pairs:																
Dup1 (%)			0.0	12.7	0.0	2.9	100.0	3.3	11.8	18.2	22.2	8.5		0.5	10.1	2.9
Dup2 (%)			0.0	2.6		0.2	0.0	6.8	4.9	4.4	36.4	1.8		5.4	11.5	6.3
Dup3 (%)			0.0	9.5	0.0	4.0	40.0	8.3	22.2	7.2	35.3	1.9	13.3	7.3	13.9	4.5
Dup4 (%)			0.0	6.3	0.0	6.1	0.0	3.0	47.6	7.4	0.0	6.2	0.0	10.7	17.8	3.7
Average (%)			**0.0**	**7.8**	**0.0**	**3.3**	**35.0**	**5.3**	**21.6**	**9.3**	**23.5**	**4.6**	**6.7**	**6.0**	**13.3**	**4.4**
Relative difference (%) for sample-site duplicate pairs:																
Field Dup1 (%)			0.0	11.9		9.7	0.0	10.4	28.6	10.3	10.5	9.2		15.8	0.4	8.9
Field Dup2 (%)			0.0	1.2	0.0	5.6	66.7	0.0	9.1	0.0	8.0	2.3	15.4	0.9	1.0	0.6
Field Dup3 (%)			0.0	17.2	0.0	1.1	0.0	5.7	0.0	23.2	8.0	0.9		4.4	4.6	5.1
Average (%)			**0.0**	**10.1**	**0.0**	**5.4**	**22.2**	**5.4**	**12.6**	**11.1**	**8.8**	**4.1**	**15.4**	**7.0**	**2.0**	**4.9**
CCRMP LKSD-1 standard:																
This study			7	3.5	17	256	0.2	0.5	1.7	0.35	8.1	43	1.5	19	2.0	125
Certified (Lynch, 1990; 1999)			*9*	*4*	*16*	*250*	*0.3*	*0.6*	*2.2*	*0.35*	*9.7*	*50*	*<4*	*19*	*2*	*134*
CCRMP TILL-2 standard:																
This study			12	6.9	6	155	1.5	1.0	15.7	0.57	5.1	78	4.2	35	3.6	358
Certified (Lynch, 1996)			*12*	*7.4*		*144*	*1.9*	*1.2*	*18.4*		*5.7*	*77*	*5*	*40*	*3.7*	*390*
USGS BCR-2 standard:																
This study			32	5.8	2	328	0.6	1.04	5.3	0.53	1.40	396	<0.5	30	3.1	166
Certified (Wilson, 1997)			*33*	*6.7*		*346*		*1.07*	*6.2*	*0.54*	*1.69*	*416*		*37*	*3.5*	*188*

Appendix 6. Continued.

Sample ID	Type[1]	Status[2]	Sc (ppm)	Sm (ppm)	Sn (ppm)	Sr (ppm)	Ta (ppm)	Tb (ppm)	Th (ppm)	Tm (ppm)	U (ppm)	V (ppm)	W (ppm)	Y (ppm)	Yb (ppm)	Zr (ppm)
USGS RGM-1 standard:																
This study			4.0	3.4	3.0	97	0.80	0.54	13	0.32	5.1	12	1.7	18	2.3	192
Certified (Govindaraju, 1994)			*4.4*	*4.3*	*4.1*	*110*	*0.95*		*15*		*5.8*	*13*	*1.5*	*25*	*2.6*	*220*
Laboratory quality controls:																
62479 Rep																
62475 Rep			25	3.73	<1	107.2	0.3	0.66	1.1	0.35	0.7	132	0.7	19.7	2.6	85.5
62489 Rep			4	0.52	<1	24.3	<0.1	0.09	0.4	0.05	3	57	<0.5	3.4	0.35	21.5
GS311-1 Std																
GS311-1 Std -Rep																
GS910-4 Std																
GS910-4 Std -Rep																
GBM309-15 Std																
GBM309-15 Std -Rep																
SO-18 Std average (n=10)			24.1	2.9	15	419	6.7	0.51	10.0	0.28	15.8	187	14	31	1.8	302
SO-18 Std RSD (%)			2.4	5.0	6.5	4.1	4.3	3.7	7.3	7.1	3.7	6.5	8.8	5.0	6.8	5.3
Blank average (n=5)			<1	<0.05	<1	<0.5	<0.1	<0.01	<0.2	<0.01	<0.1	<8	<0.5	<0.1	<0.05	0.4

Footnotes:

Total carbon and sulphur were determined by LECO, loss-on-ignition (LOI) at 1000°C gravimetrically, and other analytes by lithium metaborate-tetraborate fusion with inductively coupled plasma atomic emission spectrometry (major and minor oxides) or inductively coupled plasma mass spectrometry (trace elements) finish at Acme Analytical Laboratories Ltd., Vancouver, British Columbia.

[1] Sample medium: **Till**=till matrix (<0.063 mm fraction); R**ock** = pulverized whole rock.

[2] Identifies duplicate sample pairs: **Field Dup** = duplicate bulk till samples collected from a single site; **Dup** = duplicate splits of <0.063 mm till fraction.

Fe_2O_3t = total iron as Fe_2O_3; **wt %** = weight per cent; **ppm** = parts per million; **RSD** = relative standard deviation (%).

Relative difference (%) = absolute(X1-X2)/((X1+X2)/2)*100, where X1 and X2 are duplicate results.

Appendix 7. Aqua regia extraction-ICP-MS data for till (<0.063 mm fraction) and whole-rock samples.

Sample ID	Type[1]	Status[2]	Ag (ppm)	As (ppm)	Au (ppb)	Bi (ppm)	Cd (ppm)	Cu (ppm)	Hg (ppm)	Mo (ppm)	Ni (ppm)	Pb (ppm)	Sb (ppm)	Se (ppm)	Tl (ppm)	Zn (ppm)
62445	Till	Dup1-1	<0.1	7.9	3.9	<0.1	0.4	59.3	0.20	1.3	4.3	4.0	0.2	<0.5	<0.1	93
62446	Till		<0.1	10.3	3.2	<0.1	<0.1	24.2	0.03	8.4	4.8	3.0	0.2	0.5	<0.1	28
62447	Till		<0.1	5.9	4.6	<0.1	0.2	29.2	0.13	2.1	4.7	3.1	0.2	<0.5	<0.1	76
62448	Till	Dup1-2	<0.1	7.7	3.2	<0.1	0.4	57.8	0.18	1.4	4.5	3.9	0.2	0.6	<0.1	92
62450	Till		<0.1	7.1	2.7	<0.1	0.4	42.8	0.12	1.1	3.5	8.5	0.3	<0.5	<0.1	99
62451	Till		<0.1	12.9	1.3	<0.1	<0.1	21.4	1.26	0.8	6.6	4.6	0.2	0.6	<0.1	70
62452	Till	Field Dup1-1	<0.1	7.2	1.2	0.1	<0.1	32.6	0.07	2.6	10.9	3.4	0.1	<0.5	<0.1	57
62453	Till	Field Dup1-2	<0.1	7.3	<0.5	0.1	0.1	28.5	0.07	2.1	5.7	3.0	0.1	0.5	<0.1	56
62454	Till	Dup2-1	<0.1	12.4	<0.5	0.1	<0.1	34.2	0.10	0.8	5.8	5.3	0.2	<0.5	<0.1	51
62455	Till	Dup2-2	<0.1	12.2	4.2	<0.1	<0.1	33.6	0.09	0.8	5.5	5.2	0.3	<0.5	<0.1	52
62457	Till		<0.1	11.1	6.1	<0.1	0.2	44.2	0.10	2.3	9.9	6.9	0.3	0.6	<0.1	74
62458	Till		<0.1	8.8	0.8	<0.1	<0.1	45.9	0.06	0.7	8.1	4.6	0.1	<0.5	<0.1	54
62459	Till		<0.1	9.0	3.3	<0.1	<0.1	41.1	0.06	0.8	5.3	3.9	0.1	<0.5	<0.1	49
62460	Till	Field Dup2-1	<0.1	10.3	1.8	<0.1	0.1	55.8	0.07	0.6	6.8	5.4	0.2	0.6	<0.1	75
62461	Till	Field Dup2-2	<0.1	11.2	3.7	<0.1	<0.1	48.8	0.06	0.6	7.0	5.1	0.2	<0.5	<0.1	67
62462	Till	Dup3-1	<0.1	4.8	<0.5	<0.1	<0.1	20.9	0.06	1.0	4.2	2.8	0.2	0.9	<0.1	35
62463	Till		<0.1	8.7	1.3	<0.1	0.2	40.2	0.08	0.9	8.0	6.7	0.2	<0.5	<0.1	68
62464	Till		<0.1	11.9	1.3	<0.1	0.4	41.7	0.23	0.7	5.1	8.8	0.2	<0.5	<0.1	123
62465	Till		<0.1	16.2	1.6	<0.1	0.2	39.8	0.20	0.9	7.0	9.2	0.3	<0.5	<0.1	112
62466	Till	Dup3-2	<0.1	5.3	<0.5	<0.1	<0.1	21.7	0.05	0.9	4.7	2.8	0.2	0.5	<0.1	37
62468	Till	Field Dup3-1	<0.1	10.7	<0.5	<0.1	0.1	33.4	0.12	0.5	7.1	6.3	0.2	<0.5	<0.1	71
62469	Till	Field Dup3-2	<0.1	11.3	<0.5	<0.1	0.1	31.6	0.21	0.7	7.0	5.4	0.2	0.5	<0.1	77
62470	Till		<0.1	10.0	77.2	<0.1	0.5	82.3	0.22	0.7	5.6	9.5	0.2	<0.5	<0.1	212
62471	Till		<0.1	12.7	21.6	<0.1	0.2	40.1	0.67	0.8	7.7	35.8	0.2	0.5	<0.1	124
62472	Till		<0.1	7.1	1.9	<0.1	<0.1	52.1	0.14	0.8	4.8	6.1	0.2	<0.5	<0.1	68
62473	Till		<0.1	26.9	<0.5	<0.1	0.8	21.0	0.07	0.8	14.3	26.1	0.2	<0.5	<0.1	842
62474	Till		<0.1	9.8	<0.5	<0.1	0.1	31.7	0.20	0.6	7.2	3.7	0.1	0.8	<0.1	70
62475	Till	Dup4-1	0.4	21.4	54.9	0.3	2.8	709.3	0.16	2.2	6.0	119	0.8	1.0	0.3	867
62476	Till	Dup4-2	0.4	22.3	54.4	0.3	2.7	725.8	0.19	2.4	6.0	123	0.8	0.9	0.3	877
62478	Till		<0.1	11.3	<0.5	<0.1	0.3	36.4	0.16	0.6	6.7	43.9	0.2	0.7	<0.1	109
62479	Rock		>100	3107.8	4325.0	0.7	155.8	2183.3	3.82	67.9	47.1	1650.1	200.2	2.4	320.9	>10000
62480	Rock		>100	3947.2	6204.8	1.4	467.7	5523.8	2.39	81.0	23.1	130.6	220.6	2.9	122.7	>10000

Appendix 7. Continued.

Sample ID	Type[1]	Status[2]	Ag (ppm)	As (ppm)	Au (ppb)	Bi (ppm)	Cd (ppm)	Cu (ppm)	Hg (ppm)	Mo (ppm)	Ni (ppm)	Pb (ppm)	Sb (ppm)	Se (ppm)	Tl (ppm)	Zn (ppm)
62481	Rock		1.7	50.7	73.4	9.6	2.2	68.5	0.06	28.9	12.0	53.5	6.4	1.6	1.9	705
62482	Rock		<0.1	<0.5	1.1	<0.1	<0.1	3.3	<0.01	0.1	3.0	0.3	<0.1	<0.5	<0.1	9
62483	Rock		<0.1	1.8	1.6	<0.1	<0.1	26.6	<0.01	<0.1	1.5	0.4	<0.1	<0.5	<0.1	18
62484	Rock		<0.1	<0.5	0.9	<0.1	<0.1	0.9	<0.01	0.1	2.2	0.3	<0.1	<0.5	<0.1	16
62485	Rock		<0.1	<0.5	<0.5	<0.1	<0.1	1.0	<0.01	<0.1	1.2	0.1	<0.1	<0.5	<0.1	32
62486	Rock		<0.1	2.1	<0.5	<0.1	<0.1	4.7	<0.01	0.2	2.3	1.0	<0.1	<0.5	<0.1	41
62487	Rock		0.2	1.9	2.4	0.9	<0.1	9.8	<0.01	1.0	8.4	4.2	<0.1	3.9	<0.1	208
62488	Rock		0.3	3.0	5.0	<0.1	<0.1	48.1	<0.01	<0.1	12.0	5.6	<0.1	<0.5	<0.1	74
62489	Rock		79.3	509.1	726.6	16.7	234.2	>10000	1.69	69.8	21.2	295.7	46.8	5.4	23.2	>10000
Relative difference (%) for <0.063 mm-fraction duplicate pairs:																
Dup1 (%)			0.0	2.6	19.7	0.0	0.0	2.6	10.5	7.4	4.5	2.5	0.0		0.0	1.1
Dup2 (%)			0.0	1.6			0.0	1.8	10.5	0.0	5.3	1.9	40.0	0.0	0.0	1.9
Dup3 (%)			0.0	9.9	0.0	0.0	0.0	3.8	18.2	10.5	11.2	0.0	0.0	57.1	0.0	5.6
Dup4 (%)			0.0	4.1	0.9	0.0	3.6	2.3	17.1	8.7	0.0	3.3	0.0	10.5	0.0	1.1
Average (%)			**0.0**	**4.6**	**6.9**	**0.0**	**0.9**	**2.6**	**14.1**	**6.7**	**5.3**	**1.9**	**10.0**	**22.6**	**0.0**	**2.4**
Relative difference (%) for sample-site duplicate pairs:																
Field Dup1 (%)			0.0	1.4		0.0		13.4	0.0	21.3	62.7	12.5	0.0		0.0	1.8
Field Dup2 (%)			0.0	8.4	69.1	0.0		13.4	15.4	0.0	2.9	5.7	0.0		0.0	11.3
Field Dup3 (%)			0.0	5.5	0.0	0.0	0.0	5.5	54.5	33.3	1.4	15.4	0.0		0.0	8.1
Average (%)			**0.0**	**5.1**	**34.5**	**0.0**	**0.0**	**10.8**	**23.3**	**18.2**	**22.3**	**11.2**	**0.0**		**0.0**	**7.0**
CCRMP LKSD-1 standard:																
This study			0.6	34	4	0.8	1.4	44	0.12	9.7	13	72	0.5	1.1	0.2	304
Certified (Lynch, 1990; 1999)			*0.6*	*30*	*5*		*1.2*	*44*	*0.11*	*12*	*12*	*83*	*1.2*			*335*
CCRMP TILL-2 standard:																
This study			0.2	24	<0.5	4.5	0.3	144	0.060	12	30	20	0.3	<0.5	0.3	101
Certified (Lynch, 1996)			*0.2*	*22*	*2*	*4*	*0.3*	*149*	*0.074*	*13*	*30*	*21*	*0.8*			*116*
USGS BCR-2 standard:																
This study			<0.1	<0.5	<0.5	<0.1	0.2	20	<0.01	265	7.3	2.6	0.2	0.8	<0.1	71
Certified (Wilson, 1997)								*19*		*248*		*11*				*127*

Appendix 7. Continued.

Sample ID	Type[1]	Status[2]	Ag (ppm)	As (ppm)	Au (ppb)	Bi (ppm)	Cd (ppm)	Cu (ppm)	Hg (ppm)	Mo (ppm)	Ni (ppm)	Pb (ppm)	Sb (ppm)	Se (ppm)	Tl (ppm)	Zn (ppm)
USGS RGM-1 standard:																
This study			<0.1	<0.5	<0.5	<0.1	<0.1	2.1	0.04	0.1	0.9	4.6	0.5	<0.5	<0.1	2
Certified (Govindaraju, 1994)			*0.11*	*3*				*12*		*2.3*		*24*	*1.3*			*32*
Laboratory quality controls:																
62476 Rep			0.3	21.6	62.4	0.3	2.5	721.8	0.15	2.4	6.7	118	0.8	1.1	0.3	861
62489 Rep			79.1	522.8	852.6	17.3	227.4	>10000	1.68	68	21.7	281.6	51	6.3	22.6	>10000
DS10 Std			2.2	44.3	56.5	9.9	2.2	151.9	0.28	14.1	74.7	130.7	7	2.4	5.1	349
DS10 Std -Rep			1.7	41.2	44.9	11.5	2.2	153.3	0.3	11.3	64.7	157.2	7.6	2.5	4.5	342
OREAS45EA Std			0.2	9.9	61.6	0.2	<0.1	686.6	<0.01	1.4	377.2	12	0.2	0.9	<0.1	29
OREAS45EA Std -Rep			0.3	7.6	57.3	0.3	<0.1	646.4	0.02	1.3	353	16.5	0.3	0.6	<0.1	28
Blank 1			<0.1	<0.5	<0.5	<0.1	<0.1	<0.1	<0.01	<0.1	<0.1	<0.1	<0.1	<0.5	<0.1	<1
Blank 2			<0.1	<0.5	<0.5	<0.1	<0.1	0.2	<0.01	<0.1	<0.1	<0.1	<0.1	<0.5	<0.1	3

Footnotes:

Concentrations were determined using 0.5 g per sample at Acme Analytical Laboratories Ltd., Vancouver, British Columbia.

[1] Sample medium: **Till** = till matrix (<0.063 mm fraction); **Rock** = pulverized whole rock.

[2] Identifies duplicate sample pairs: **Field Dup** = duplicate bulk till samples collected from a single site; **Dup** = duplicate splits of <0.063 mm till fraction.

Units: **PPB -** parts per billion, **PPM -** parts per million.

Relative difference (%) = absolute(X1-X2)/((X1+X2)/2)*100, where X1 and X2 are duplicate results.

Appendix 8. INAA data for till (<0.063 mm fraction) and whole-rock samples.

Sample ID	Type[1]	Status[2]	Ag (ppm)	As (ppm)	Au (ppb)	Ba (ppm)	Br (ppm)	Ca (wt %)	Ce (ppm)	Co (ppm)	Cr (ppm)	Cs (ppm)	Eu (ppm)	Fe (wt %)	Hf (ppm)	Hg (ppm)	Ir (ppb)	La (ppm)
62445	Till	Dup1-1	<5	17.4	<2	250	<0.5	<1	33	13	42	<1	1.0	3.68	3	<1	<5	12.1
62446	Till		<5	14.1	<2	490	11.7	<1	29	9	43	<1	0.9	4.16	8	<1	<5	12.1
62447	Till		<5	12.9	<2	360	<0.5	<1	29	<1	<5	<1	0.4	3.22	4	<1	<5	11.7
62448	Till	Dup1-2	<5	11.2	<2	380	<0.5	<1	63	11	28	<1	0.7	3.39	4	<1	<5	12.2
62450	Till		<5	14.0	<2	<50	<0.5	<1	31	<1	37	<1	0.8	3.14	5	<1	<5	10.7
62451	Till		<5	19.2	<2	<50	10.6	<1	33	<1	27	<1	0.8	3.71	5	<1	<5	10.1
62452	Till	Field Dup1-1	<5	10.7	<2	410	<0.5	<1	37	7	28	<1	<0.2	3.29	5	<1	<5	15.0
62453	Till	Field Dup1-2	<5	9.2	<2	<50	<0.5	<1	90	10	53	<1	<0.2	3.29	4	<1	<5	14.9
62454	Till	Dup2-1	<5	21.7	<2	<50	<0.5	<1	44	10	26	<1	0.8	3.77	5	<1	<5	14.5
62455	Till	Dup2-2	<5	17.7	<2	<50	<0.5	<1	29	10	16	<1	0.9	3.60	4	<1	<5	13.7
62457	Till		<5	15.4	<2	760	<0.5	<1	32	16	52	6	2.2	3.67	6	<1	<5	13.5
62458	Till		<5	9.9	<2	440	<0.5	<1	22	16	29	<1	1.1	4.27	6	<1	<5	11.4
62459	Till		<5	8.7	<2	620	22.3	<1	24	13	44	<1	0.9	4.38	5	<1	<5	12.9
62460	Till	Field Dup2-1	<5	15.6	<2	760	<0.5	<1	25	16	38	<1	1.5	4.17	5	<1	<5	13.4
62461	Till	Field Dup2-2	<5	15.0	<2	630	<0.5	<1	25	9	26	<1	<0.2	3.89	4	<1	<5	13.5
62462	Till	Dup3-1	<5	9.3	<2	<50	<0.5	<1	22	13	20	<1	<0.2	3.42	4	<1	<5	13.9
62463	Till		<5	14.7	<2	720	<0.5	<1	27	16	40	<1	0.8	4.19	5	<1	<5	11.7
62464	Till		<5	17.8	<2	630	<0.5	<1	21	9	34	<1	1.3	3.60	4	<1	<5	12.6
62465	Till		<5	18.4	<2	410	8.6	<1	35	14	50	<1	0.9	3.94	3	<1	<5	11.1
62466	Till	Dup3-2	<5	10.6	<2	600	<0.5	<1	18	11	<5	<1	0.8	3.63	6	<1	<5	12.0
62468	Till	Field Dup3-1	<5	14.9	<2	<50	<0.5	<1	27	13	27	<1	0.6	3.95	<1	<1	<5	19.4
62469	Till	Field Dup3-2	<5	17.3	<2	710	<0.5	<1	23	16	30	<1	1.5	3.99	7	<1	<5	20.6
62470	Till		<5	20.4	<2	690	<0.5	<1	25	<1	20	<1	0.6	3.93	4	<1	<5	15.6
62471	Till		<5	13.6	23	<50	17.5	<1	20	15	30	<1	0.9	3.39	4	<1	<5	11.2
62472	Till		<5	13.4	<2	680	<0.5	<1	21	12	18	2	0.9	3.31	5	<1	<5	14.0
62473	Till		<5	27.0	<2	<50	9.5	<1	32	11	50	<1	0.8	2.76	4	<1	<5	13.8
62474	Till		<5	12.8	<2	540	8.6	<1	18	15	42	<1	0.9	4.25	5	<1	<5	13.0
62475	Till	Dup4-1	<5	20.7	57	500	20.4	<1	18	14	27	<1	0.6	4.79	4	<1	<5	10.9
62476	Till	Dup4-2	<5	21.5	69	870	17.2	<1	29	17	36	<1	0.4	5.22	4	<1	<5	11.1
62478	Till		<5	15.4	<2	510	11.7	<1	32	14	21	<1	1.4	3.36	4	<1	<5	11.6
62479	Rock		189	2500	3220	132000	<0.5	<1	<3	<1	108	<1	<0.2	9.46	<1	<1	<5	3.1
62480	Rock		201	3050	4500	194000	<0.5	<1	<3	<1	<5	<1	<0.2	14.4	<1	<1	<5	3.4

Appendix 8. Continued.

Sample ID	Type[1]	Status[2]	Ag (ppm)	As (ppm)	Au (ppb)	Ba (ppm)	Br (ppm)	Ca (wt %)	Ce (ppm)	Co (ppm)	Cr (ppm)	Cs (ppm)	Eu (ppm)	Fe (wt %)	Hf (ppm)	Hg (ppm)	Ir (ppb)	La (ppm)
62481	Rock		<5	55.9	157	<50	<0.5	<1	15	30	68	<1	<0.2	6.43	<1	<1	<5	6.0
62482	Rock		<5	5.5	<2	<50	<0.5	<1	23	<1	128	<1	<0.2	1.74	5	<1	<5	13.5
62483	Rock		<5	10.7	<2	<50	<0.5	<1	19	<1	93	<1	<0.2	1.87	4	<1	<5	13.2
62484	Rock		<5	<0.5	<2	<50	<0.5	<1	14	<1	109	<1	0.3	2.12	2	<1	<5	9.4
62485	Rock		<5	3.5	<2	480	<0.5	<1	13	<1	54	3	<0.2	2.43	3	<1	<5	9.0
62486	Rock		<5	11	<2	<50	<0.5	6	16	14	92	<1	0.7	5.04	2	<1	<5	9.6
62487	Rock		<5	2.9	<2	440	<0.5	<1	21	28	133	2	1.1	12.3	<1	<1	<5	14.8
62488	Rock		<5	6.1	<2	<50	<0.5	<1	16	13	75	<1	<0.2	3.64	5	<1	<5	14.6
62489	Rock		75	511	835	1280	<0.5	<1	<3	8	122	<1	<0.2	30.2	<1	<1	<5	9.5
Relative difference (%) for <0.063 mm-fraction duplicate pairs:																		
Dup1 (%)			0.0	43.4	0.0	41.3	0.0	0.0	62.5	16.7	40.0	0.0	35.3	8.2	28.6	0.0	0.0	0.8
Dup2 (%)			0.0	20.3	0.0	0.0	0.0	0.0	41.1	0.0	47.6	0.0	11.8	4.6	22.2	0.0	0.0	5.7
Dup3 (%)			0.0	13.1	0.0	169.2	0.0	0.0	20.0	16.7	120.0	0.0	120.0	6.0	40.0	0.0	0.0	14.7
Dup4 (%)			0.0	3.8	19.0	54.0	17.0	0.0	46.8	19.4	28.6	0.0	40.0	8.6	0.0	0.0	0.0	1.8
Average (%)			**0.0**	**20.1**	**4.8**	**66.1**	**4.3**	**0.0**	**42.6**	**13.2**	**59.0**	**0.0**	**51.8**	**6.8**	**22.7**	**0.0**	**0.0**	**5.7**
Relative difference (%) for sample-site duplicate pairs:																		
Field Dup1 (%)			0.0	15.1	0.0	156.5	0.0	0.0	83.5	35.3	61.7	0.0	0.0	0.0	22.2	0.0	0.0	0.7
Field Dup2 (%)			0.0	3.9	0.0	18.7	0.0	0.0	0.0	56.0	37.5	0.0	152.9	6.9	22.2	0.0	0.0	0.7
Field Dup3 (%)			0.0	14.9	0.0	173.7	0.0	0.0	16.0	20.7	10.5	0.0	85.7	1.0	150.0	0.0	0.0	6.0
Average (%)			**0.0**	**11.3**	**0.0**	**116.3**	**0.0**	**0.0**	**33.2**	**37.3**	**36.6**	**0.0**	**79.6**	**2.7**	**64.8**	**0.0**	**0.0**	**2.5**
CCRMP LKSD-1 standard:																		
This study			<5	35	<2	<50	16	7.0	22	13	17	<1	0.7	2.9	4.0	<1	<5	14
Certified (Lynch, 1990; 1999)			*0.6*	*40*	*5*	*430*	*11*	*7.7*	*27*	*11*	*31*	*1.5*	*0.9*	*2.8*	*3.6*	*0.1*		*16*
CCRMP TILL-2 standard:																		
This study			<5	29	<2	400	17.2	<1	64	18	70	15	0.9	3.7	9	<1	<5	49
Certified (Lynch, 1996)			*0.2*	*26*	*2*	*540*	*12.2*	*0.9*	*98*	*15*	*74*	*12*	*1.0*	*3.8*	*11*	*0.074*		*44*
USGS BCR-2 standard:																		
This study			<5	<0.5	<2	730	<0.5	4.0	38	38	30	<1	1.4	9.1	6.0	<1	<5	22
Certified (Wilson, 1997)						*683*		*5.1*	*53*	*37*	*18*	*1.1*	*2.0*	*9.7*	*4.8*			*25*

Appendix 8. Continued.

Sample ID	Type[1]	Status[2]	Ag (ppm)	As (ppm)	Au (ppb)	Ba (ppm)	Br (ppm)	Ca (wt %)	Ce (ppm)	Co (ppm)	Cr (ppm)	Cs (ppm)	Eu (ppm)	Fe (wt %)	Hf (ppm)	Hg (ppm)	Ir (ppb)	La (ppm)
USGS RGM-1 standard:																		
This study			<5	<0.5	<2	960	<0.5	<1	25	<1	<5	13	<0.2	1.2	7	<1	<5	26
Certified (Govindaraju, 1994)			*0.11*	*3*		*810*	*1.3*	*0.8*	*47*	*2*	*3.7*	*9.6*	*0.7*	*1.3*				*24*
Laboratory quality controls:																		
GXR-1 std			31	428	3330	730	<0.5	<1	17	9.0	14	<1	0.6	24.7	<1	<1		7.7
GXR-1 std-certified			31	427	3300	750	0.5	0.96	17	8.2	12	3	0.69	23.6	0.96	3.9		7.5
CZN-3 std																		
CZN-3 std-certified																		
MP-1b std				>10000				<1						8.01				
MP-1b std-certified				23000				2.47						8.19				
DMMAS 116 std				1520	1690	1200			29	41	64			3.26				15.8
DMMAS 116 std-certified				1560	1610	1190			30	41	77			3.12				15.9
Method Blank			<5	<0.5	<2	<50	<0.5	<1	<3	<1	<5	<1	<0.2	<0.01	<1	<1	<5	<0.5

Appendix 8. Continued.

Sample ID	Type[1]	Status[2]	Lu (ppm)	Mo (ppm)	Na (wt %)	Nd (ppm)	Ni (ppm)	Rb (ppm)	Sb (ppm)	Sc (ppm)	Se (ppm)	Sm (ppm)	Sn (wt %)	Sr (wt %)	Ta (ppm)	Tb (ppm)	Th (ppm)	U (ppm)
62445	Till	Dup1-1	0.39	<1	2.44	<5	<20	<15	1.3	14.2	<3	3.6	<0.02	<0.05	<0.5	<0.5	1.8	<0.5
62446	Till		0.47	8	2.54	<5	<20	<15	1.4	16.6	<3	3.7	<0.02	<0.05	<0.5	<0.5	1.9	<0.5
62447	Till		0.30	<1	2.63	16	<20	<15	0.9	13.9	<3	3.2	<0.02	<0.05	<0.5	<0.5	2.1	<0.5
62448	Till	Dup1-2	0.46	<1	2.45	11	<20	<15	0.8	13.9	<3	3.1	<0.02	<0.05	<0.5	<0.5	2.6	4.6
62450	Till		0.46	<1	2.77	<5	<20	103	0.7	13.5	<3	2.9	<0.02	<0.05	<0.5	<0.5	1.5	4.3
62451	Till		0.34	<1	2.45	25	<20	<15	2.2	13.5	<3	2.9	<0.02	<0.05	<0.5	<0.5	<0.2	<0.5
62452	Till	Field Dup1-1	0.51	<1	2.20	28	<20	<15	<0.1	14.2	<3	3.9	<0.02	<0.05	<0.5	<0.5	1.4	<0.5
62453	Till	Field Dup1-2	0.55	<1	2.19	15	<20	<15	0.5	14.0	<3	3.6	<0.02	<0.05	<0.5	<0.5	3.2	4.3
62454	Till	Dup2-1	0.43	<1	2.56	21	<20	<15	1.3	17.5	<3	4.4	<0.02	<0.05	<0.5	<0.5	2.3	<0.5
62455	Till	Dup2-2	0.41	<1	2.52	35	<20	<15	1.3	17.6	<3	4.1	<0.02	<0.05	<0.5	<0.5	4.0	<0.5
62457	Till		0.61	<1	2.30	16	<20	<15	2.7	18.0	<3	4.1	<0.02	<0.05	<0.5	<0.5	3.8	<0.5
62458	Till		0.47	<1	2.08	<5	<20	<15	1.3	19.9	<3	3.8	<0.02	<0.05	<0.5	<0.5	3.4	<0.5
62459	Till		0.49	<1	2.09	<5	<20	<15	1.2	22.8	<3	3.6	<0.02	<0.05	<0.5	<0.5	3.4	<0.5
62460	Till	Field Dup2-1	0.51	<1	2.04	<5	<20	<15	1.6	19.4	<3	3.7	<0.02	<0.05	<0.5	<0.5	3.9	<0.5
62461	Till	Field Dup2-2	0.51	<1	2.06	18	<20	<15	1.6	19.7	<3	3.8	<0.02	<0.05	<0.5	<0.5	3.5	<0.5
62462	Till	Dup3-1	0.47	<1	2.21	20	<20	<15	1.2	15.0	<3	3.5	<0.02	<0.05	<0.5	<0.5	2.1	<0.5
62463	Till		0.59	<1	1.73	18	<20	<15	0.9	18.7	<3	3.3	<0.02	<0.05	<0.5	<0.5	1.9	<0.5
62464	Till		0.38	<1	2.46	<5	<20	<15	1.4	16.3	<3	4.1	<0.02	<0.05	<0.5	<0.5	<0.2	<0.5
62465	Till		0.38	<1	2.31	<5	<20	<15	1.4	17.0	<3	3.8	<0.02	<0.05	<0.5	<0.5	6.4	<0.5
62466	Till	Dup3-2	0.43	<1	2.31	<5	<20	68	0.9	15.5	<3	3.6	<0.02	<0.05	<0.5	<0.5	2.6	<0.5
62468	Till	Field Dup3-1	0.50	<1	2.14	<5	<20	<15	2.1	18.1	<3	4.8	<0.02	<0.05	<0.5	<0.5	2.1	<0.5
62469	Till	Field Dup3-2	0.46	<1	2.07	39	<20	<15	2.3	17.9	<3	4.9	<0.02	<0.05	<0.5	<0.5	3.6	1.3
62470	Till		0.38	<1	2.37	<5	<20	<15	2.1	15.9	<3	4.1	<0.02	<0.05	<0.5	<0.5	<0.2	<0.5
62471	Till		0.38	<1	1.76	<5	<20	<15	0.5	14.9	<3	3.2	<0.02	<0.05	<0.5	<0.5	1.5	<0.5
62472	Till		0.47	<1	2.07	<5	<20	<15	2.0	14.9	<3	3.6	<0.02	<0.05	<0.5	<0.5	1.3	<0.5
62473	Till		0.41	<1	2.59	9	<20	<15	0.9	13.1	<3	4.1	<0.02	<0.05	<0.5	<0.5	<0.2	<0.5
62474	Till		0.53	<1	2.16	<5	<20	<15	1.3	20.4	<3	3.6	<0.02	<0.05	<0.5	<0.5	1.8	2.3
62475	Till	Dup4-1	0.34	<1	2.46	24	<20	<15	2.6	22.0	<3	4.0	<0.02	<0.05	<0.5	<0.5	1.2	<0.5
62476	Till	Dup4-2	0.43	<1	2.47	<5	<20	<15	2.3	21.9	<3	4.0	<0.02	<0.05	<0.5	<0.5	2.3	<0.5
62478	Till		0.34	22	2.23	<5	<20	<15	1.2	17.5	<3	3.5	<0.02	<0.05	<0.5	<0.5	2.3	<0.5
62479	Rock		<0.05	47	0.03	<5	<20	<15	225	0.6	<3	0.3	<0.02	<0.05	<0.5	<0.5	<0.2	<0.5
62480	Rock		<0.05	49	0.02	<5	<20	<15	199	0.4	<3	<0.1	<0.02	<0.05	<0.5	<0.5	<0.2	<0.5

Appendix 8. Continued.

Sample ID	Type[1]	Status[2]	Lu (ppm)	Mo (ppm)	Na (wt %)	Nd (ppm)	Ni (ppm)	Rb (ppm)	Sb (ppm)	Sc (ppm)	Se (ppm)	Sm (ppm)	Sn (wt %)	Sr (wt %)	Ta (ppm)	Tb (ppm)	Th (ppm)	U (ppm)
62481	Rock		0.31	23	3.23	<5	<20	<15	14.6	21	<3	2.6	<0.02	<0.05	<0.5	<0.5	<0.2	<0.5
62482	Rock		0.55	<1	3.36	19	<20	<15	<0.1	8.7	<3	3.2	<0.02	<0.05	<0.5	<0.5	2.2	<0.5
62483	Rock		0.38	<1	3.82	<5	<20	<15	<0.1	6.8	<3	3.0	<0.02	<0.05	<0.5	<0.5	2.2	<0.5
62484	Rock		0.41	<1	3.00	<5	<20	<15	0.3	5.5	<3	1.7	<0.02	<0.05	<0.5	<0.5	1.2	<0.5
62485	Rock		0.42	<1	1.74	<5	<20	55	<0.1	7.9	<3	2.2	<0.02	<0.05	<0.5	<0.5	<0.2	<0.5
62486	Rock		0.11	<1	0.78	<5	<20	<15	1.5	22	<3	3.0	<0.02	<0.05	<0.5	<0.5	1.4	2.8
62487	Rock		0.24	<1	0.05	27	<20	<15	<0.1	23	<3	3.3	<0.02	<0.05	<0.5	<0.5	<0.2	<0.5
62488	Rock		0.38	<1	3.55	<5	<20	<15	<0.1	15.2	<3	2.5	<0.02	<0.05	<0.5	<0.5	1.5	<0.5
62489	Rock		<0.05	66	0.02	<5	<20	<15	126	3.4	<3	0.5	<0.02	<0.05	<0.5	<0.5	<0.2	<0.5
Relative difference (%) for <0.063 mm-fraction duplicate pairs:																		
Dup1 (%)			16.5	0.0	0.4	75.0	0.0	0.0	47.6	2.1	0.0	14.9	0.0	0.0	0.0	0.0	36.4	160.8
Dup2 (%)			4.8	0.0	1.6	50.0	0.0	0.0	0.0	0.6	0.0	7.1	0.0	0.0	0.0	0.0	54.0	0.0
Dup3 (%)			8.9	0.0	4.4	120.0	0.0	127.7	28.6	3.3	0.0	2.8	0.0	0.0	0.0	0.0	21.3	0.0
Dup4 (%)			23.4	0.0	0.4	131.0	0.0	0.0	12.2	0.5	0.0	0.0	0.0	0.0	0.0	0.0	62.9	0.0
Average (%)			**13.4**	**0.0**	**1.7**	**94.0**	**0.0**	**31.9**	**22.1**	**1.6**	**0.0**	**6.2**	**0.0**	**0.0**	**0.0**	**0.0**	**43.6**	**40.2**
Relative difference (%) for sample-site duplicate pairs:																		
Field Dup1 (%)			7.5	0.0	0.5	60.5	0.0	0.0	133.3	1.4	0.0	8.0	0.0	0.0	0.0	0.0	78.3	158.3
Field Dup2 (%)			0.0	0.0	1.0	113.0	0.0	0.0	0.0	1.5	0.0	2.7	0.0	0.0	0.0	0.0	10.8	0.0
Field Dup3 (%)			8.3	0.0	3.3	154.5	0.0	0.0	9.1	1.1	0.0	2.1	0.0	0.0	0.0	0.0	52.6	88.9
Average (%)			**5.3**	**0.0**	**1.6**	**109.4**	**0.0**	**0.0**	**47.5**	**1.4**	**0.0**	**4.2**	**0.0**	**0.0**	**0.0**	**0.0**	**47.2**	**82.4**
CCRMP LKSD-1 standard:																		
This study			0.3	4	1.50	13	<20	<15	1.0	7	<3	3.4	<0.02	<0.05	<0.5	<0.5	3.5	11.3
Certified (Lynch, 1990; 1999)			*0.4*	*10*	*1.48*	*16*	*16*	*24*	*1.2*	*9*		*4*	*0.0016*	*0.025*	*0.3*	*0.6*	*2.2*	*9.7*
CCRMP TILL-2 standard:																		
This study			0.6	<1	1.58	19	<20	107	1.3	11	<3	6.9	<0.02	<0.05	<0.5	<0.5	17.3	6.5
Certified (Lynch, 1996)			*0.6*	*14*	*1.62*	*36*	*32*	*143*	*0.8*	*12*		*7.4*		*0.0144*	*1.9*	*1.2*	*18.4*	*5.7*
USGS BCR-2 standard:																		
This study			0.35	219	2.20	27	<20	<15	<0.1	28	<3	5.9	<0.02	<0.05	<0.5	<0.5	5.5	<0.5
Certified (Wilson, 1997)			*0.51*	*248*	*2.34*	*28*		*48*		*33*		*6.7*		*0.0346*		*1.1*	*6.2*	*1.69*

Appendix 8. Continued.

Sample ID Type[1] Status[2]	Lu (ppm)	Mo (ppm)	Na (wt %)	Nd (ppm)	Ni (ppm)	Rb (ppm)	Sb (ppm)	Sc (ppm)	Se (ppm)	Sm (ppm)	Sn (wt %)	Sr (wt %)	Ta (ppm)	Tb (ppm)	Th (ppm)	U (ppm)
USGS RGM-1 standard:																
This study	0.7	<1	2.76	21	<20	244	1.7	3.9	<3	3.4	<0.02	<0.05	<0.5	<0.5	11.2	6.0
Certified (Govindaraju, 1994)	*0.4*	*2.3*	*3.02*	*19*		*150*	*1.3*	*4.4*		*4.3*	*0.00041*	*0.011*	*0.95*		*15*	*5.8*
Laboratory quality controls:																
GXR-1 std	0.27	19	0.06	<5	<20	<15	122	1.6	17	2.7	<0.02	<0.05	<0.5	<0.5	2.5	34.8
GXR-1 std-certified	0.28	18	0.052	18	41	14	122	1.58	16.6	2.7	0.0054	0.0275	0.175	0.83	2.44	34.9
CZN-3 std																
CZN-3 std-certified																
MP-1b std		279					57.2				1.61					
MP-1b std-certified		285					54				1.61					
DMMAS 116 std			2.02				6.8	6		2.1						12.9
DMMAS 116 std-certified			1.98				6.8	6.3		2.4						11.2
Method Blank	<0.05	<1	<0.01	<5	<20	<15	<0.1	<0.1	<3	<0.1	<0.02	<0.05	<0.5	<0.5	<0.2	<0.5

Appendix 8. Continued.

Sample ID	Type[1]	Status[2]	W (ppm)	Yb (ppm)	Zn (ppm)	Mass (g)
62445	Till	Dup1-1	<1	2.2	<50	1.04
62446	Till		<1	3.2	<50	1.24
62447	Till		<1	2.5	190	1.03
62448	Till	Dup1-2	<1	2.5	230	1.17
62450	Till		<1	2.3	<50	1.32
62451	Till		<1	3.1	<50	1.10
62452	Till	Field Dup1-1	<1	2.9	<50	1.05
62453	Till	Field Dup1-2	<1	2.7	<50	1.04
62454	Till	Dup2-1	<1	3.3	<50	1.14
62455	Till	Dup2-2	<1	3.0	<50	1.30
62457	Till		<1	2.9	<50	1.03
62458	Till		<1	3.0	<50	1.08
62459	Till		<1	3.8	280	1.04
62460	Till	Field Dup2-1	<1	2.7	<50	1.03
62461	Till	Field Dup2-2	<1	3.3	<50	1.06
62462	Till	Dup3-1	<1	2.7	<50	1.18
62463	Till		<1	2.6	<50	1.14
62464	Till		<1	3.3	<50	1.05
62465	Till		<1	2.6	<50	1.14
62466	Till	Dup3-2	<1	2.4	<50	1.20
62468	Till	Field Dup3-1	<1	2.8	<50	1.01
62469	Till	Field Dup3-2	<1	3.4	<50	1.05
62470	Till		<1	2.6	450	1.05
62471	Till		<1	2.5	<50	1.06
62472	Till		<1	2.9	<50	1.17
62473	Till		<1	2.6	760	1.10
62474	Till		<1	2.2	<50	1.10
62475	Till	Dup4-1	<1	2.6	980	1.10
62476	Till	Dup4-2	<1	2.6	1140	1.04
62478	Till		<1	3.2	<50	1.10
62479	Rock		<1	<0.2	38400	1.56
62480	Rock		<1	<0.2	92100	1.56

Appendix 8. Continued.

Sample ID	Type[1]	Status[2]	W (ppm)	Yb (ppm)	Zn (ppm)	Mass (g)
62481	Rock		<1	2.2	680	1.28
62482	Rock		<1	3.3	<50	1.13
62483	Rock		<1	2.6	<50	1.06
62484	Rock		<1	1.5	<50	1.19
62485	Rock		<1	1.9	<50	1.07
62486	Rock		<1	2.3	<50	1.30
62487	Rock		<1	1.3	120	1.27
62488	Rock		<1	2.1	<50	1.33
62489	Rock		<1	<0.2	66100	1.16
Relative difference (%) for <0.063 mm-fraction duplicate pairs:						
Dup1 (%)			0.0	12.8	128.6	
Dup2 (%)			0.0	9.5	0.0	
Dup3 (%)			0.0	11.8	0.0	
Dup4 (%)			0.0	0.0	15.1	
Average (%)			**0.0**	**8.5**	**35.9**	
Relative difference (%) for sample-site duplicate pairs:						
Field Dup1 (%)			0.0	7.1	0.0	
Field Dup2 (%)			0.0	20.0	0.0	
Field Dup3 (%)			0.0	19.4	0.0	
Average (%)			**0.0**	**15.5**	**0.0**	
CCRMP LKSD-1 standard:						
This study			<1	1.5	300	1.04
Certified (Lynch, 1990; 1999)			*<4*	*2*	*331*	
CCRMP TILL-2 standard:						
This study			<1	2.8	<50	1.11
Certified (Lynch, 1996)			*5*	*3.7*	*130*	
USGS BCR-2 standard:						
This study			<1	3.0	<50	1.51
Certified (Wilson, 1997)				*3.5*	*127*	

Appendix 8. Continued.

Sample ID	Type[1]	Status[2]	W (ppm)	Yb (ppm)	Zn (ppm)	Mass (g)
USGS RGM-1 standard:						
This study			<1	2.2	<50	1.05
Certified (Govindaraju, 1994)			*1.5*	*2.6*	*32*	
Laboratory quality controls:						
GXR-1 std			162	1.9	750	
GXR-1 std-certified			164	1.9	760	
CZN-3 std					>100000	
CZN-3 std-certified					509000	
MP-1b std			1120		>100000	
MP-1b std-certified			1100		166700	
DMMAS 116 std						
DMMAS 116 std-certified						
Method Blank			<1	<0.2	<50	

Footnotes:

Instrumental neutron activation analyses (INAA) were performed at Activation Laboratories Ltd., Ancaster, Ontario.

[1] Sample medium: **Till** = till matrix (<0.063 mm fraction); **Rock** = pulverized whole rock.

[2] Identifies duplicate sample pairs: **Field Dup** = duplicate bulk till samples collected from a single site; **Dup** = duplicate splits of <0.063 mm till fraction.

Units: **Mass (g)** = mass of sample in grams; **wt %** = weight per cent; **ppm** = parts per million; **ppb** = parts per billion.

Relative difference (%) = absolute(X1-X2)/((X1+X2)/2)*100, where X1 and X2 are duplicate results.

Appendix 9. Lead isotopic data for till (<0.063 mm fraction) and whole-rock samples.

Sample ID	Type[1]	Status[2]	^{204}Pb(CPS) Quad	^{206}Pb(CPS) Quad	^{207}Pb(CPS) Quad	^{208}Pb(CPS) Quad	^{208}Pb/^{204}Pb Quad	^{208}Pb/^{204}Pb HR	^{208}Pb/^{204}Pb MC	2σ MC
62445	Till	Dup1-1	538	10820	9282	21546	40.06	38.47		
62446	Till		437	8274	6966	17007	38.93	38.18	38.3285	0.0030
62447	Till		475	9196	7688	18328	38.60	38.64		
62448	Till	Dup1-2	583	10925	9221	23740	40.73	38.31		
62450	Till		1551	28027	25056	60669	39.12	38.60		
62451	Till		625	11441	9574	23730	37.99	38.12		
62452	Till	Field Dup1-1	423	7795	6561	16396	38.75	38.79		
62453	Till	Field Dup1-2	384	6668	5720	13913	36.26	38.25		
62454	Till	Dup2-1	807	14515	12173	29163	36.15	39.04	38.3087	0.0020
62455	Till	Dup2-2	791	14128	12016	29133	36.83	38.98	38.2793	0.0027
62457	Till		1132	19604	17124	42213	37.29	39.90		
62458	Till		642	12207	10024	24160	37.65	39.39		
62459	Till		579	10547	8719	21119	36.49	38.01	38.3149	0.0018
62460	Till	Field Dup2-1	830	15071	13432	30717	36.99	37.55		
62461	Till	Field Dup2-2	705	13310	11083	27406	38.90	38.79		
62462	Till	Dup3-1	383	7314	6062	14864	38.86	38.13	38.3324	0.0022
62463	Till		869	16050	13175	32173	37.01	38.24		
62464	Till		1374	26228	22505	56415	41.06	38.55		
62465	Till		1386	24871	21398	54266	39.16	38.43		
62466	Till	Dup3-2	377	7338	5949	14621	38.78	37.84		
62468	Till	Field Dup3-1	986	17586	14669	35758	36.26	38.17	38.2033	0.0034
62469	Till	Field Dup3-2	793	15041	12425	30800	38.84	37.27		
62470	Till		1525	28687	24350	58563	38.41	38.41	38.0516	0.0029
62471	Till		5900	107242	92412	223636	37.91	38.31		
62472	Till		1121	20331	16586	41039	36.62	38.00	38.1001	0.0025
62473	Till		4704	85996	72404	177753	37.79	38.06	37.9524	0.0037
62474	Till		613	10945	9218	22458	36.62	38.19	38.1150	0.0019
62475	Till	Dup4-1	16879	304462	259295	618570	36.65	38.24	37.9245	0.0017
62476	Till	Dup4-2	16769	311786	267096	635787	37.91	38.67		
62478	Till		5599	105449	88357	218792	39.08	38.69		
62479	Rock		324449	5561011	4762216	11870589	36.59	38.30	37.8887	0.0021
62480	Rock		53615	979378	828218	1893442	35.32	38.51		

Appendix 9. Continued.

Sample ID	Type[1]	Status[2]	^{204}Pb(CPS) Quad	^{206}Pb(CPS) Quad	^{207}Pb(CPS) Quad	^{208}Pb(CPS) Quad	^{208}Pb/^{204}Pb Quad	^{208}Pb/^{204}Pb HR	^{208}Pb/^{204}Pb MC	2σ MC
62481	Rock		4359	79807	68508	163036	37.40	38.01		
62482	Rock		76	1307	1104	2810	37.18	37.87		
62483	Rock		63	1192	1033	2537	40.06	38.01		
62484	Rock		39	744	642	1530	38.74	36.78		
62485	Rock		30	548	488	1123	36.83	39.89		
62486	Rock		78	1669	1387	3194	41.03	37.94	38.9817	0.0026
62487	Rock		254	4613	3911	9570	37.63	37.94		
62488	Rock		822	15187	12694	31739	38.61	39.16		
62489	Rock		41823	760308	644781	1582484	37.84	39.01	37.9074	0.0023
Relative difference (%) for <0.063 mm-fraction duplicate pairs:										
Dup1 (%)			8.0	1.0	0.7	9.7	1.7	0.4		
Dup2 (%)			2.0	2.7	1.3	0.1	1.9	0.2	0.08	
Dup3 (%)			1.4	0.3	1.9	1.7	0.2	0.8		
Dup4 (%)			0.7	2.4	3.0	2.7	3.4	1.1		
Average (%)			**3.0**	**1.6**	**1.7**	**3.5**	**1.8**	**0.6**		
Relative difference (%) for sample-site duplicate pairs:										
Field Dup1 (%)			9.7	15.6	13.7	16.4	6.7	1.4		
Field Dup2 (%)			16.4	12.4	19.2	11.4	5.0	3.2		
Field Dup3 (%)			21.7	15.6	16.6	14.9	6.9	2.4		
Average (%)			**16.0**	**14.5**	**16.5**	**14.2**	**6.2**	**2.3**		
CCRMP LKSD-1 standard:										
Leachate - this study			13435	253183	215790	498595	37.11	38.72		
Bulk dissolution (±2SD; Chauvel et al., 2011)									38.030	0.012
CCRMP TILL-2 standard:										
Leachate - this study			2847	55940	45229	112507	39.52	38.72		
USGS BCR-2 standard:										
Leachate - this study			501	9872	8528	20441	40.84	38.73	38.4333	0.0028
Leachate-1 (Weis et al., 2006)									38.4955	0.0020
Leachate-3 (Weis et al., 2006)									38.7996	0.0024
Residue-1 (Weis et al., 2006)									38.8256	0.0019
Residue-3 (Weis et al., 2006)									38.5279	0.0025
Bulk dissolution (weighted average, n=11, ±95% conf; Weis et al., 2006)									38.7210	0.0137

Appendix 9. Continued.

Sample ID Type[1] Status[2]	^{204}Pb(CPS) Quad	^{206}Pb(CPS) Quad	^{207}Pb(CPS) Quad	^{208}Pb(CPS) Quad	^{208}Pb/^{204}Pb Quad	^{208}Pb/^{204}Pb HR	^{208}Pb/^{204}Pb MC	2σ MC
GSJ JB-3 standard:								
Leachate - this study							37.9050	0.0017
Residue - this study							38.2529	0.0023
Bulk dissolution (Kimura et al., 2006)							38.224	0.004
USGS RGM-1 standard:								
Leachate - this study	963	17833	14832	36042	37.45	38.21	38.6053	0.0022
Bulk dissolution (weighted average, n=5, ±95% conf; Weis et al., 2006)							38.6853	0.0266
Laboratory quality controls:								
62452 Replicate	421	7793	6363	15488	36.77			
62487 Replicate	269	4896	4164	10177	37.86			
DS10 std	22976	439223	360184	867223	37.74			
DS10 std Replicate	22767	438894	368434	871704	38.29			
NBS981-1Y std	4081	71813	64676	152920	37.47			
NBS981-1Y std Replicate	3972	66694	61033	140949	35.49			
Average relative difference (%)	**2.4**	**3.4**	**4.3**	**5.1**	**3.2**			
NBS983-1Y std	814	280718	31738	31552	38.76			
NBS983-1Y std Replicate	106	256296	18393	4261	40.13			
NBS983 relative difference (%)	**154**	**9.1**	**53**	**152**	**3.5**			
Blank 1	20	160	114	253	12.94			
Blank 2	127	1988	2002	5691	44.87			
BCR-2 std						38.40		
BCR-2 std Duplicate						38.39		
62462						37.86		
62462 Duplicate						38.39		
62489						39.08		
62489 Duplicate						38.93		
Average relative difference (%)						**0.6**		
PCIGR Kil93 std							38.0647	0.0030
PCIGR Kil93 std Replicate run							38.0696	0.0021
62446 Replicate run							38.3304	0.0030
62467 Replicate run							38.6047	0.0030
62489 Duplicate							37.9104	0.0015
Average relative difference (%)							**0.007**	

Appendix 9. Continued.

Sample ID	Type[1]	Status[2]	^{204}Pb(CPS) Quad	^{206}Pb(CPS) Quad	^{207}Pb(CPS) Quad	^{208}Pb(CPS) Quad	^{208}Pb/^{204}Pb Quad	^{208}Pb/^{204}Pb HR	^{208}Pb/^{204}Pb MC	2σ MC
Mean measured values for NBS981 standard analyzed with the samples:										
June-05-2014 (±2SD; n=13)									36.6983	0.0053
June-06-2014 (±2SD; n=15)									36.7032	0.0052
July-04-2014 (±2SD; n=12)									36.7154	0.0033
Weighted average ±95% confidence-level uncertainty									**36.709**	**0.023**
Values used for offline normalization by standard-sample bracketing method:										
NBS981 (±2σ uncertainty; Galer and Abouchami, 1998)									36.7219	0.0044

Appendix 9. Continued.

Sample ID	^{207}Pb/^{204}Pb Quad	^{207}Pb/^{204}Pb HR	^{207}Pb/^{204}Pb MC	2σ MC	^{206}Pb/^{204}Pb Quad	^{206}Pb/^{204}Pb HR	^{206}Pb/^{204}Pb MC	2σ MC
62445	17.26	15.69			20.12	18.74		
62446	15.95	15.49	15.5833	0.0009	18.94	18.69	18.7018	0.0009
62447	16.19	15.79			19.37	18.92		
62448	15.82	15.46			18.74	18.55		
62450	16.16	15.66			18.07	18.59		
62451	15.33	15.52			18.32	18.63		
62452	15.51	15.83			18.42	18.92		
62453	14.90	15.63			17.38	18.78		
62454	15.09	15.68	15.5840	0.0008	17.99	18.75	18.6757	0.0009
62455	15.19	15.63	15.5811	0.0011	17.86	18.72	18.6385	0.0010
62457	15.13	15.82			17.32	19.05		
62458	15.62	15.86			19.02	19.10		
62459	15.07	15.53	15.5805	0.0009	18.22	18.71	18.7332	0.0009
62460	16.18	15.45			18.15	18.49		
62461	15.73	15.55			18.89	18.74		
62462	15.85	15.54	15.5830	0.0008	19.12	18.62	18.7040	0.0009
62463	15.16	15.58			18.46	18.56		
62464	16.38	15.57			19.09	18.64		
62465	15.44	15.66			17.95	18.62		
62466	15.78	15.37			19.46	18.63		
62468	14.88	15.63	15.5697	0.0013	17.83	18.63	18.5897	0.0014

Appendix 9. Continued.

Sample ID	$^{207}Pb/^{204}Pb$ Quad	$^{207}Pb/^{204}Pb$ HR	$^{207}Pb/^{204}Pb$ MC	2σ MC	$^{206}Pb/^{204}Pb$ Quad	$^{206}Pb/^{204}Pb$ HR	$^{206}Pb/^{204}Pb$ MC	2σ MC
62469	15.67	15.38			18.97	18.54		
62470	15.97	15.53	15.5492	0.0011	18.82	18.44	18.4541	0.0009
62471	15.66	15.63			18.18	18.40		
62472	14.80	15.62	15.5576	0.0012	18.14	18.54	18.5115	0.0009
62473	15.39	15.59	15.5361	0.0009	18.28	18.49	18.3553	0.0008
62474	15.03	15.56	15.5566	0.0006	17.85	18.57	18.5415	0.0007
62475	15.36	15.36	15.5328	0.0008	18.04	18.31	18.3283	0.0008
62476	15.93	15.67			18.59	18.53		
62478	15.78	15.63			18.83	18.37		
62479	14.68	15.47	15.5311	0.0008	17.14	18.23	18.3038	0.0010
62480	15.45	15.52			18.27	18.33		
62481	15.71	15.58			18.31	18.46		
62482	14.61	15.65			17.29	19.09		
62483	16.30	15.71			18.82	18.83		
62484	16.25	15.13			18.84	18.53		
62485	16.01	16.18			17.98	20.01		
62486	17.82	15.40	15.6183	0.0010	21.45	19.56	19.6702	0.0011
62487	15.38	15.49			18.14	18.53		
62488	15.44	15.74			18.47	18.70		
62489	15.42	15.62	15.5330	0.0009	18.18	18.50	18.3206	0.0009
Relative difference (%) for <0.063 mm-fraction duplicate pairs:								
Dup1 (%)	8.7	1.5			7.1	1.0		
Dup2 (%)	0.7	0.3	0.02		0.7	0.2	0.2	
Dup3 (%)	0.4	1.1			1.8	0.1		
Dup4 (%)	3.6	2.0			3.0	1.2		
Average (%)	**3.4**	**1.2**			**3.1**	**0.6**		
Relative difference (%) for sample-site duplicate pairs:								
Field Dup1 (%)	4.0	1.3			5.8	0.7		
Field Dup2 (%)	2.8	0.6			4.0	1.3		
Field Dup3 (%)	5.2	1.6			6.2	0.5		
Average (%)	**4.0**	**1.2**			**5.3**	**0.9**		
CCRMP LKSD-1 standard:								
Leachate - this study	16.06	15.70			18.84	18.45		
Bulk dissolution (±2SD; Chauvel et al., 2011)			15.609	0.004			18.357	0.005

Appendix 9. Continued.

Sample ID	$^{207}Pb/^{204}Pb$ Quad	$^{207}Pb/^{204}Pb$ HR	$^{207}Pb/^{204}Pb$ MC	2σ MC	$^{206}Pb/^{204}Pb$ Quad	$^{206}Pb/^{204}Pb$ HR	$^{206}Pb/^{204}Pb$ MC	2σ MC
CCRMP TILL-2 standard:								
Leachate - this study	15.89	15.70			19.65	19.13		
USGS BCR-2 standard:								
Leachate - this study	17.04	15.67	15.6259	0.0008	19.72	18.73	18.6121	0.0008
Leachate-1 (Weis et al., 2006)			15.6209	0.0007			18.6473	0.0009
Leachate-3 (Weis et al., 2006)			15.6146	0.0007			18.7951	0.0006
Residue-1 (Weis et al., 2006)			15.6241	0.0006			18.8007	0.0007
Residue-3 (Weis et al., 2006)			15.6265	0.0009			18.6646	0.0010
Bulk dissolution (weighted average, n=11, ±95% conf; Weis et al., 2006)			15.6249	0.0005			18.7516	0.0061
GSJ JB-3 standard:								
Leachate - this study			15.5326	0.0006			18.3191	0.0006
Residue - this study			15.5354	0.0011			18.2952	0.0009
Bulk dissolution (Kimura et al., 2006)			15.532	0.004			18.289	0.003
USGS RGM-1 standard:								
Leachate - this study	15.41	15.61	15.6638	0.0009	18.53	18.93	18.9530	0.0009
Bulk dissolution (weighted average, n=5, ±95% conf; Weis et al., 2006)			15.6347	0.0087			19.0002	0.0054
Laboratory quality controls:								
62452 Replicate	15.11				18.50			
62487 Replicate	15.49				18.21			
DS10 std	15.68				19.12			
DS10 std Replicate	16.18				19.28			
NBS981-1Y std	15.85				17.60			
NBS981-1Y std Replicate	15.37				16.79			
Average relative difference (%)	**2.4**				**1.6**			
NBS983-1Y std	39.0				345			
NBS983-1Y std Replicate	173				2414			
NBS983 relative difference (%)	**127**				**150**			
Blank 1	5.83				8.17			
Blank 2	15.78				15.68			
BCR-2 std		15.77				18.76		
BCR-2 std Duplicate		15.84				18.91		
62462		15.45				18.46		
62462 Duplicate		15.63				18.78		

Appendix 9. Continued.

Sample ID	$^{207}Pb/^{204}Pb$ Quad	$^{207}Pb/^{204}Pb$ HR	$^{207}Pb/^{204}Pb$ MC	2σ MC	$^{206}Pb/^{204}Pb$ Quad	$^{206}Pb/^{204}Pb$ HR	$^{206}Pb/^{204}Pb$ MC	2σ MC
62489		15.66				18.53		
62489 Duplicate		15.57				18.46		
Average relative difference (%)		**0.7**				**1.0**		
PCIGR Kil93 std			15.4729	0.0010			18.4066	0.0014
PCIGR Kil93 std Replicate run			15.4750	0.0008			18.4098	0.0009
62446 Replicate run			15.5830	0.0008			18.7022	0.0006
62467 Replicate run			15.6638	0.0010			18.9534	0.0008
62489 Duplicate			15.5343	0.0006			18.3222	0.0006
Average relative difference (%)			**0.006**				**0.008**	
Mean measured values for NBS981 standard analyzed with the samples:								
June-05-2014 (±2SD; n=13)			15.4899	0.0018			16.9358	0.0016
June-06-2014 (±2SD; n=15)			15.4922	0.0016			16.9386	0.0023
July-04-2014 (±2SD; n=12)			15.4973	0.0013			16.9411	0.0013
Weighted average ±95% confidence-level uncertainty			**15.494**	**0.010**			**16.939**	**0.007**
Values used for offline normalization by standard-sample bracketing method:								
NBS981 (±2σ uncertainty; Galer and Abouchami, 1998)			15.4963	0.0016			16.9405	0.0015

Appendix 9. Continued.

Sample ID	$^{208}Pb/^{206}Pb$ Quad	$^{208}Pb/^{206}Pb$ HR	$^{208}Pb/^{206}Pb$ MC	2σ MC	$^{207}Pb/^{206}Pb$ Quad	$^{207}Pb/^{206}Pb$ HR	$^{207}Pb/^{206}Pb$ MC	2σ MC
62445	1.99	2.05			0.858	0.837		
62446	2.06	2.04	2.04943	0.00005	0.842	0.829	0.833416	0.000012
62447	1.99	2.04			0.836	0.835		
62448	2.17	2.06			0.844	0.833		
62450	2.16	2.08			0.894	0.843		
62451	2.07	2.05			0.837	0.833		
62452	2.10	2.05			0.842	0.836		
62453	2.09	2.04			0.858	0.833		
62454	2.01	2.08	2.05125	0.00004	0.839	0.836	0.834655	0.000012
62455	2.06	2.08	2.05379	0.00004	0.851	0.835	0.836128	0.000014
62457	2.15	2.09			0.873	0.830		
62458	1.98	2.06			0.821	0.830		
62459	2.00	2.03	2.04529	0.00004	0.827	0.830	0.831871	0.000015
62460	2.04	2.03			0.891	0.836		

Appendix 9. Continued.

Sample ID	$^{208}Pb/^{206}Pb$ Quad	$^{208}Pb/^{206}Pb$ HR	$^{208}Pb/^{206}Pb$ MC	2σ MC	$^{207}Pb/^{206}Pb$ Quad	$^{207}Pb/^{206}Pb$ HR	$^{207}Pb/^{206}Pb$ MC	2σ MC
62461	2.06	2.07			0.833	0.830		
62462	2.03	2.05	2.04944	0.00003	0.829	0.834	0.833331	0.000012
62463	2.00	2.06			0.821	0.840		
62464	2.15	2.07			0.858	0.835		
62465	2.18	2.06			0.860	0.841		
62466	1.99	2.03			0.811	0.825		
62468	2.03	2.05	2.05511	0.00006	0.834	0.839	0.837693	0.000039
62469	2.05	2.01			0.826	0.830		
62470	2.04	2.08	2.06202	0.00004	0.849	0.842	0.842796	0.000013
62471	2.09	2.08			0.862	0.849		
62472	2.02	2.05	2.05824	0.00004	0.816	0.842	0.840631	0.000014
62473	2.07	2.06	2.06766	0.00004	0.842	0.843	0.846612	0.000012
62474	2.05	2.06	2.05566	0.00004	0.842	0.838	0.839212	0.000013
62475	2.03	2.09	2.06919	0.00004	0.852	0.839	0.847666	0.000014
62476	2.04	2.09			0.857	0.846		
62478	2.07	2.11			0.838	0.851		
62479	2.13	2.10	2.06994	0.00004	0.856	0.849	0.848706	0.000013
62480	1.93	2.10			0.846	0.847		
62481	2.04	2.06			0.858	0.844		
62482	2.15	1.98			0.845	0.820		
62483	2.13	2.02			0.866	0.834		
62484	2.06	1.99			0.862	0.817		
62485	2.05	1.99			0.891	0.808		
62486	1.91	1.94	1.98177	0.00005	0.831	0.787	0.794208	0.000012
62487	2.07	2.05			0.848	0.836		
62488	2.09	2.09			0.836	0.842		
62489	2.08	2.11	2.06909	0.00004	0.848	0.845	0.848037	0.000012
Relative difference (%) for <0.063 mm-fraction duplicate pairs:								
Dup1 (%)	8.7	0.5			1.6	0.5		
Dup2 (%)	2.6	0.0	0.1		1.4	0.1	0.2	
Dup3 (%)	2.0	1.0			2.2	1.1		
Dup4 (%)	0.4	0.0			0.6	0.8		
Average (%)	**3.4**	**0.4**			**1.5**	**0.6**		

Appendix 9. Continued.

Sample ID	$^{208}Pb/^{206}Pb$ Quad	$^{208}Pb/^{206}Pb$ HR	$^{208}Pb/^{206}Pb$ MC	2σ MC	$^{207}Pb/^{206}Pb$ Quad	$^{207}Pb/^{206}Pb$ HR	$^{207}Pb/^{206}Pb$ MC	2σ MC
Relative difference (%) for sample-site duplicate pairs:								
Field Dup1 (%)	0.8	0.5			1.9	0.4		
Field Dup2 (%)	1.0	2.0			6.8	0.7		
Field Dup3 (%)	0.7	2.0			1.0	1.1		
Average (%)	**0.8**	**1.5**			**3.2**	**0.7**		
CCRMP LKSD-1 standard:								
Leachate - this study	1.97	2.10			0.852	0.851		
Bulk dissolution (Chauvel et al., 2011)			2.072				0.8503	
CCRMP TILL-2 standard:								
Leachate - this study	2.01	2.02			0.809	0.821		
USGS BCR-2 standard:								
Leachate - this study	2.07	2.07	2.06513	0.00004	0.864	0.837	0.839722	0.000031
Leachate-1 (Weis et al., 2006)			2.06440				0.837703	
Leachate-3 (Weis et al., 2006)			2.06435				0.830780	
Residue-1 (Weis et al., 2006)			2.06511				0.831038	
Residue-3 (Weis et al., 2006)			2.06422				0.837227	
Bulk dissolution (average, n=11; Weis et al., 2006)			2.06495				0.833262	
GSJ JB-3 standard:								
Leachate - this study			2.06913	0.00004			0.848060	0.000014
Residue - this study			2.09087	0.00004			0.849348	0.000012
Bulk dissolution (Kimura et al., 2006)			2.09000				0.849254	
USGS RGM-1 standard:								
Leachate - this study	2.02	2.02	2.03693	0.00004	0.832	0.825	0.826654	0.000015
Bulk dissolution (average, n=5; Weis et al., 2006)			2.03605				0.822873	
Laboratory quality controls:								
62452 Replicate	1.99				0.817			
62487 Replicate	2.08				0.851			
DS10 std	1.97				0.820			
DS10 std Replicate	1.99				0.839			
NBS981-1Y std	2.13				0.901			
NBS981-1Y std Replicate	2.11				0.915			
Average (n=4) relative difference (%)	**1.8**				**1.8**			

Appendix 9. Continued.

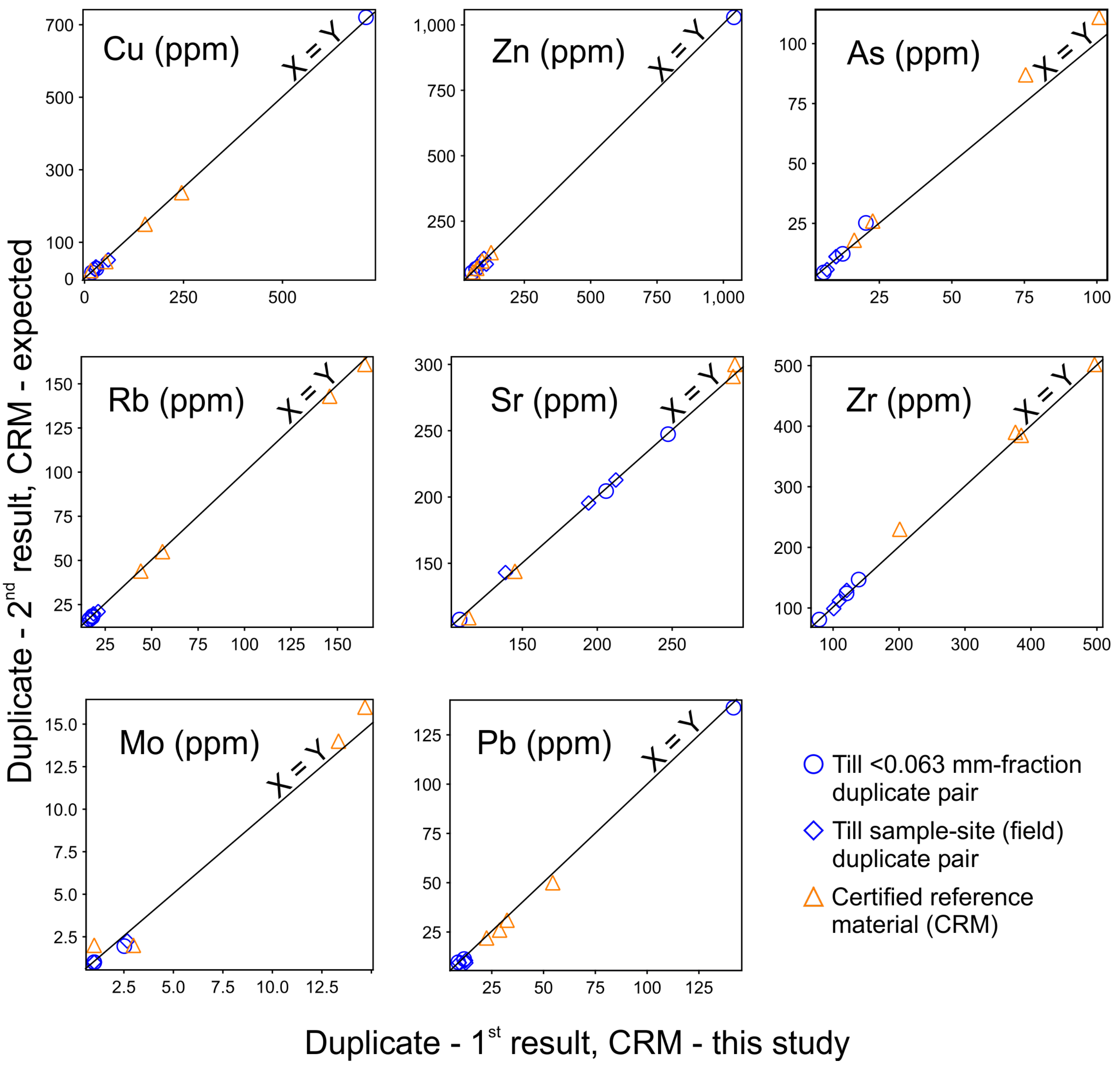
Sample ID	$^{208}Pb/^{206}Pb$ Quad	$^{208}Pb/^{206}Pb$ HR	$^{208}Pb/^{206}Pb$ MC	2σ MC	$^{207}Pb/^{206}Pb$ Quad	$^{207}Pb/^{206}Pb$ HR	$^{207}Pb/^{206}Pb$ MC	2σ MC
NBS983-1Y std	0.11				0.113			
NBS983-1Y std Replicate	0.02				0.072			
NBS983 relative difference (%)	**148**				**45**			
Blank 1	1.58				0.714			
Blank 2	2.86				1.007			
BCR-2 std		2.05				0.841		
BCR-2 std Duplicate		2.03				0.838		
62462		2.05				0.837		
62462 Duplicate		2.04				0.832		
62489		2.11				0.845		
62489 Duplicate		2.11				0.844		
Average (n=3) relative difference (%)		**0.4**				**0.4**		
PCIGR Kil93 std			2.06799	0.00005			0.840792	0.000017
PCIGR Kil93 std Replicate run			2.06788	0.00004			0.840754	0.000013
62446 Replicate run			2.04951	0.00005			0.833425	0.000012
62467 Replicate run			2.03688	0.00005			0.826626	0.000024
62489 Duplicate			2.06907	0.00003			0.848023	0.000012
Average (n=4) relative difference (%)			**0.003**				**0.003**	
Mean measured values for NBS981 standard analyzed with the samples:								
June-05-2014 (±2SD; n=13)			2.16690	0.00028			0.914635	0.000086
June-06-2014 (±2SD; n=15)			2.16684	0.00035			0.914607	0.000117
July-04-2014 (±2SD; n=12)			2.16724	0.00010			0.914774	0.000030
Weighted average ±95% confidence-level uncertainty			**2.16718**	**0.00041**			**0.91475**	**0.00016**

Footnotes:
Samples (0.3-0.5 g) were leached with 6-10 mL of 2.5N HCl at room temperature for ~2 hours and the leachates were analyzed for Pb isotopes by different methods:
Quad = counts per second (CPS) and atomic Pb isotopic ratios corrected for interferences but not for instrumental mass bias, measured on a Perkin Elmer Nexion quadrupole inductively-coupled plasma mass spectrometer (ICP-MS) directly in diluted bulk leachate solution at Acme Analytical Laboratories Ltd., Vancouver, B.C.; **HR** = atomic Pb isotopic ratios corrected for interferences and normalized to a Pb isotopic standard, measured on a Thermo Finnigan ELEMENT 2 high-resolution, double focusing magnetic sector field ICP-MS (HR-ICP-MS) directly in diluted bulk leachate+HNO_3 solution at Activation Laboratories Ltd., Ancaster, Ontario; **MC** = atomic Pb isotopic ratios corrected online for isobaric interference from ^{204}Hg and for the instrumental mass bias using $^{205}Tl/^{203}Tl$ ratio, measured on a Nu Plasma multi-collector ICP-MS (MC-ICP-MS) in solution after Pb purification by ion-exchange column separation at the Pacific Centre for Isotopic and Geochemical Research (PCIGR) at the University of British Columbia (Weis et al., 2006). The Pb isotopic ratios measured by MC-ICP-MS were further normalized to the NIST SRM 981 triple-spike values of Galer and Abouchami (1998) offline using standard-sample bracketing method (Albarède and Beard, 2004).

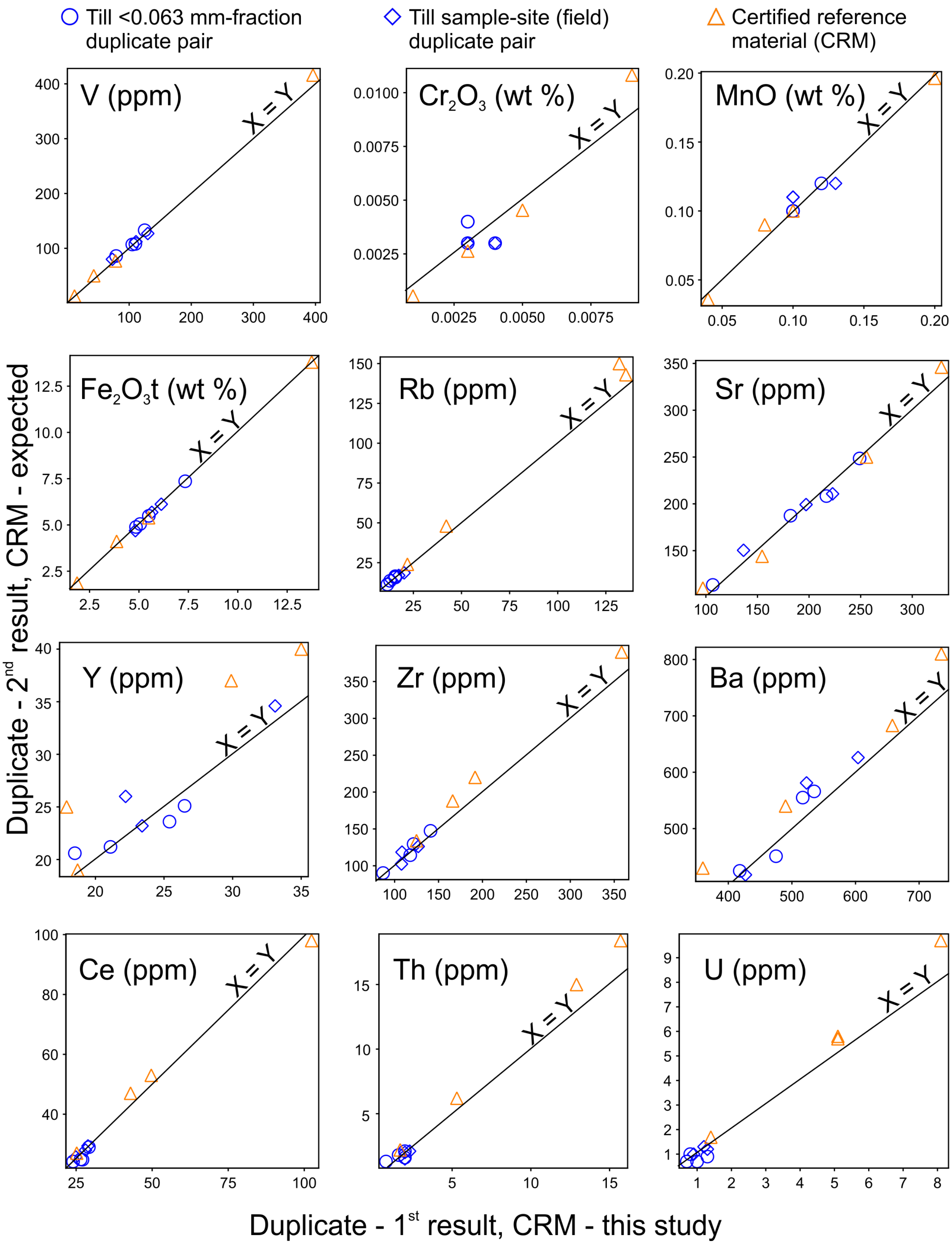
2σ is two times absolute standard error or 95% confidence-level absolute error, two times standard deviation (2SD), or 2σ uncertainty where indicated.
[1] Sample medium: **Till** = till matrix (<0.063 mm fraction); **Rock** = pulverized whole rock.

[2] Identifies duplicate sample pairs: **Field Dup** = duplicate bulk till samples collected from a single site; **Dup** = duplicate splits of <0.063 mm till fraction.
Relative difference (%) = absolute(X1-X2)/((X1+X2)/2)*100, where X1 and X2 are duplicate results.

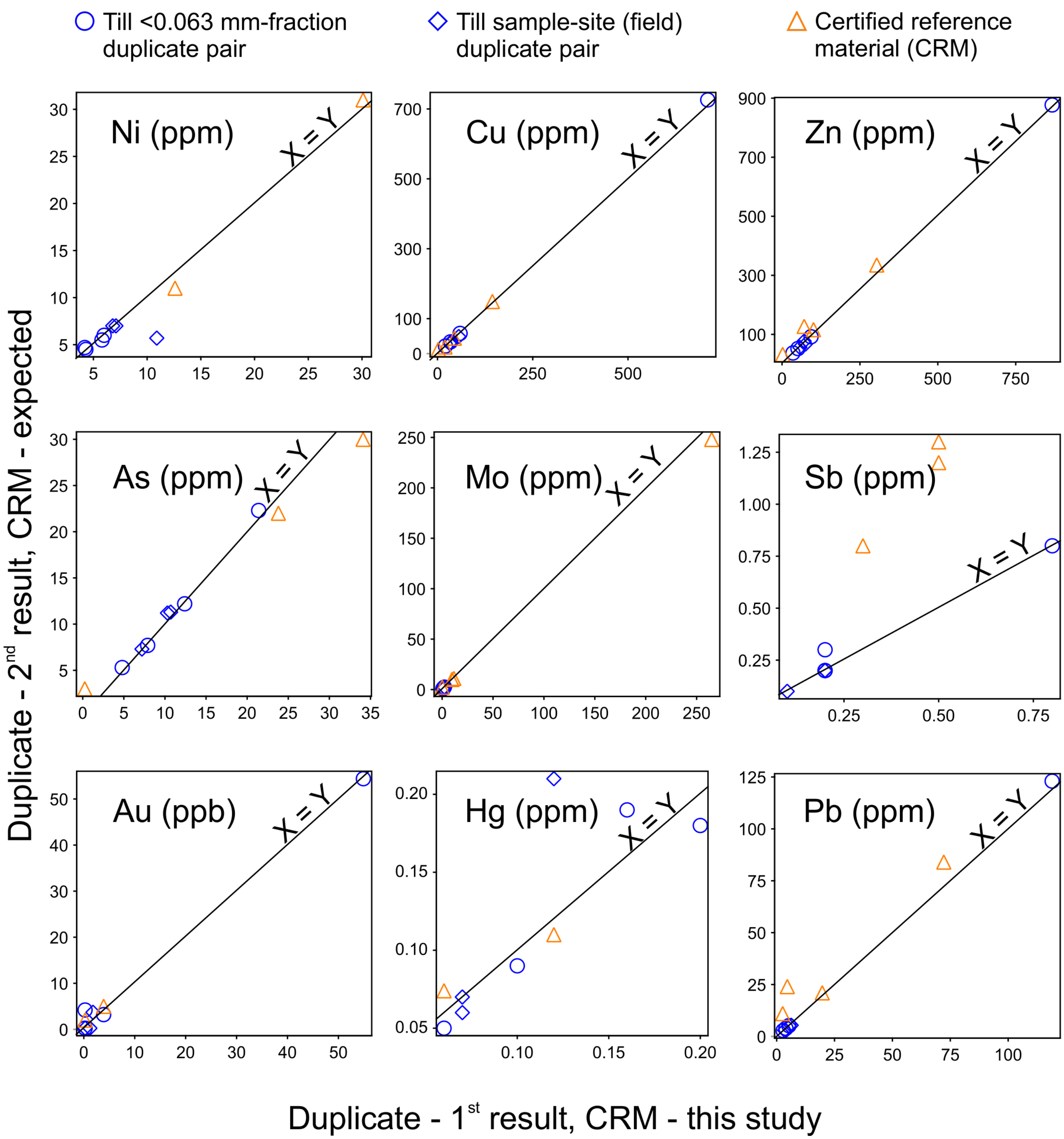
Appendix 10. Scatterplots of till field duplicates, till <0.063 mm-fraction duplicates, and certified reference materials for selected elements by portable XRF.



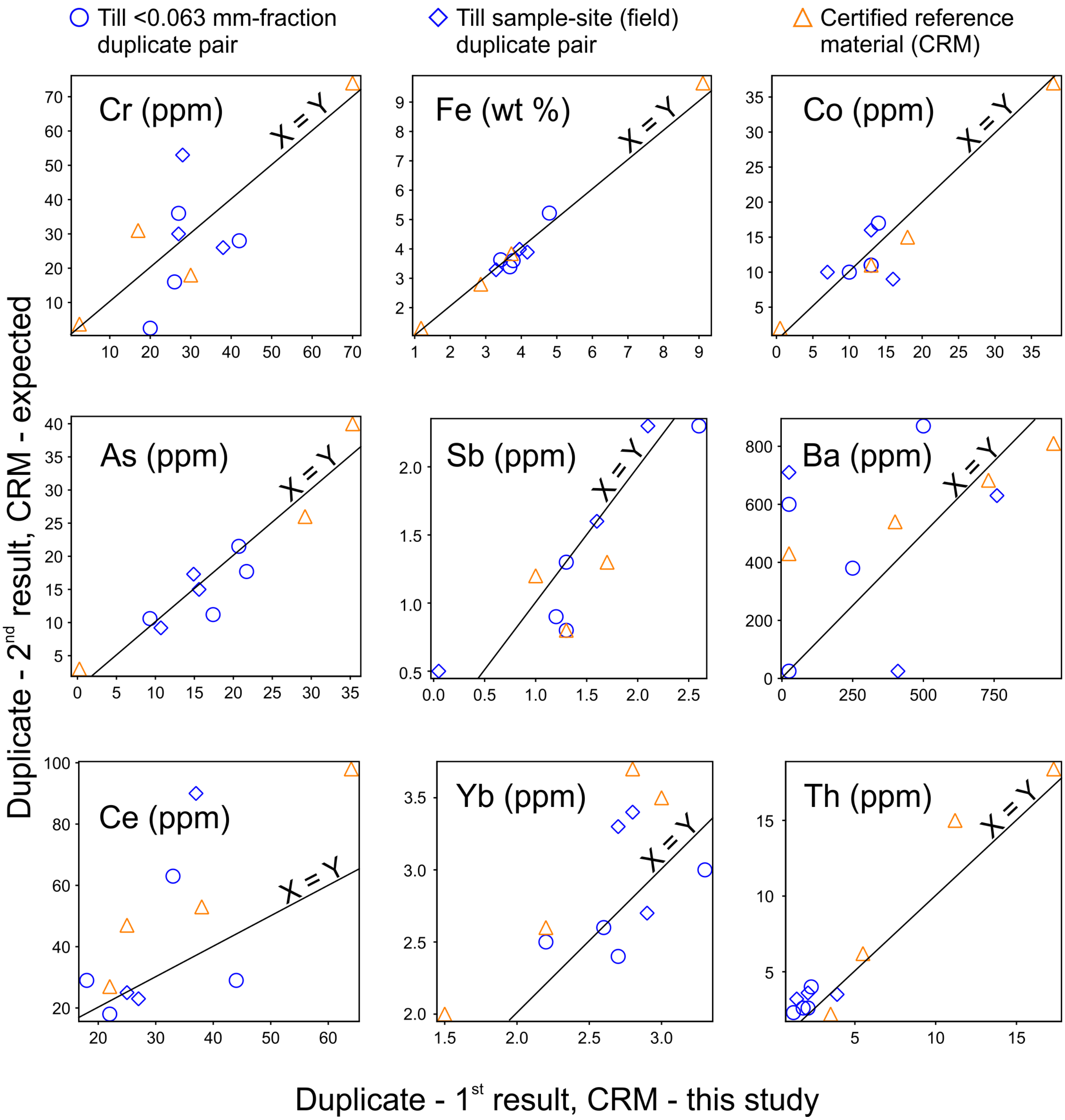
Appendix 11. Scatterplots of till field duplicates, till <0.063 mm-fraction duplicates, and certified reference materials for selected elements by lithium metaborate-tetraborate fusion with ICP-ES (major and minor oxides) and ICP-MS (trace elements) finish.

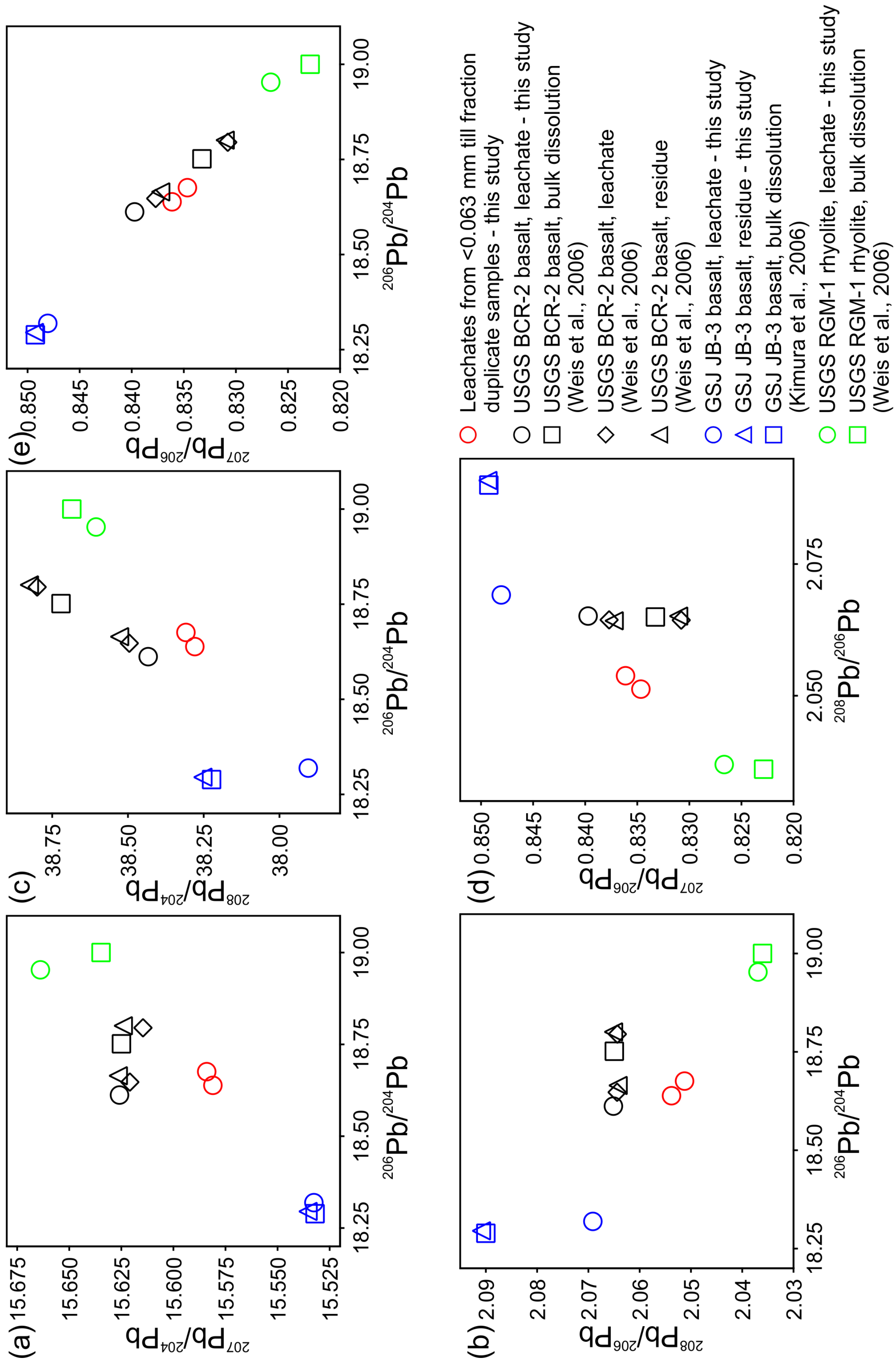


Appendix 12. Scatterplots of till field duplicates, till <0.063 mm-fraction duplicates, and certified reference materials for selected elements by aqua regia extraction with ICP-MS finish.

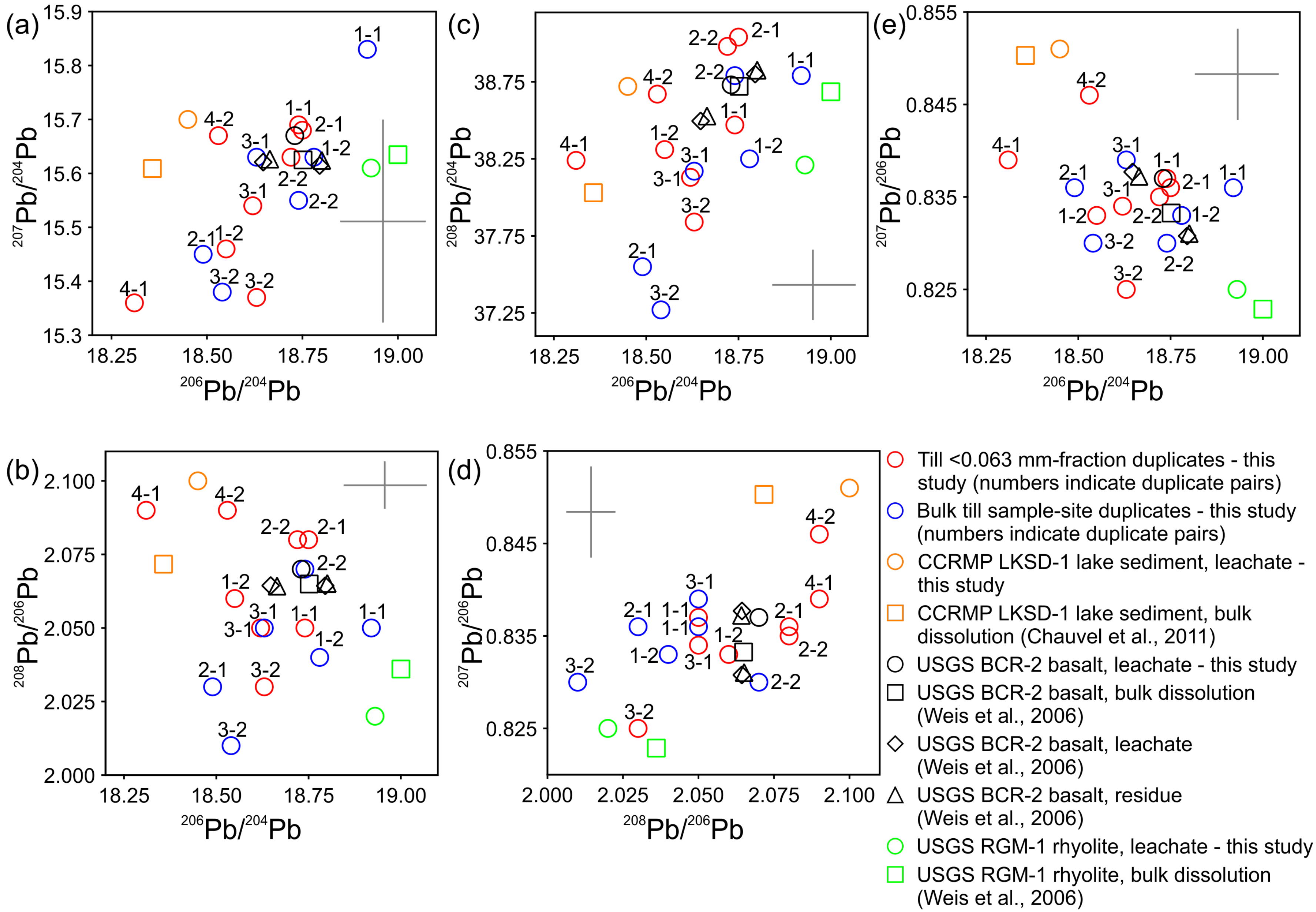


Appendix 13. Scatterplots of till field duplicates, till <0.063 mm-fraction duplicates, and certified reference materials for selected elements by INAA.

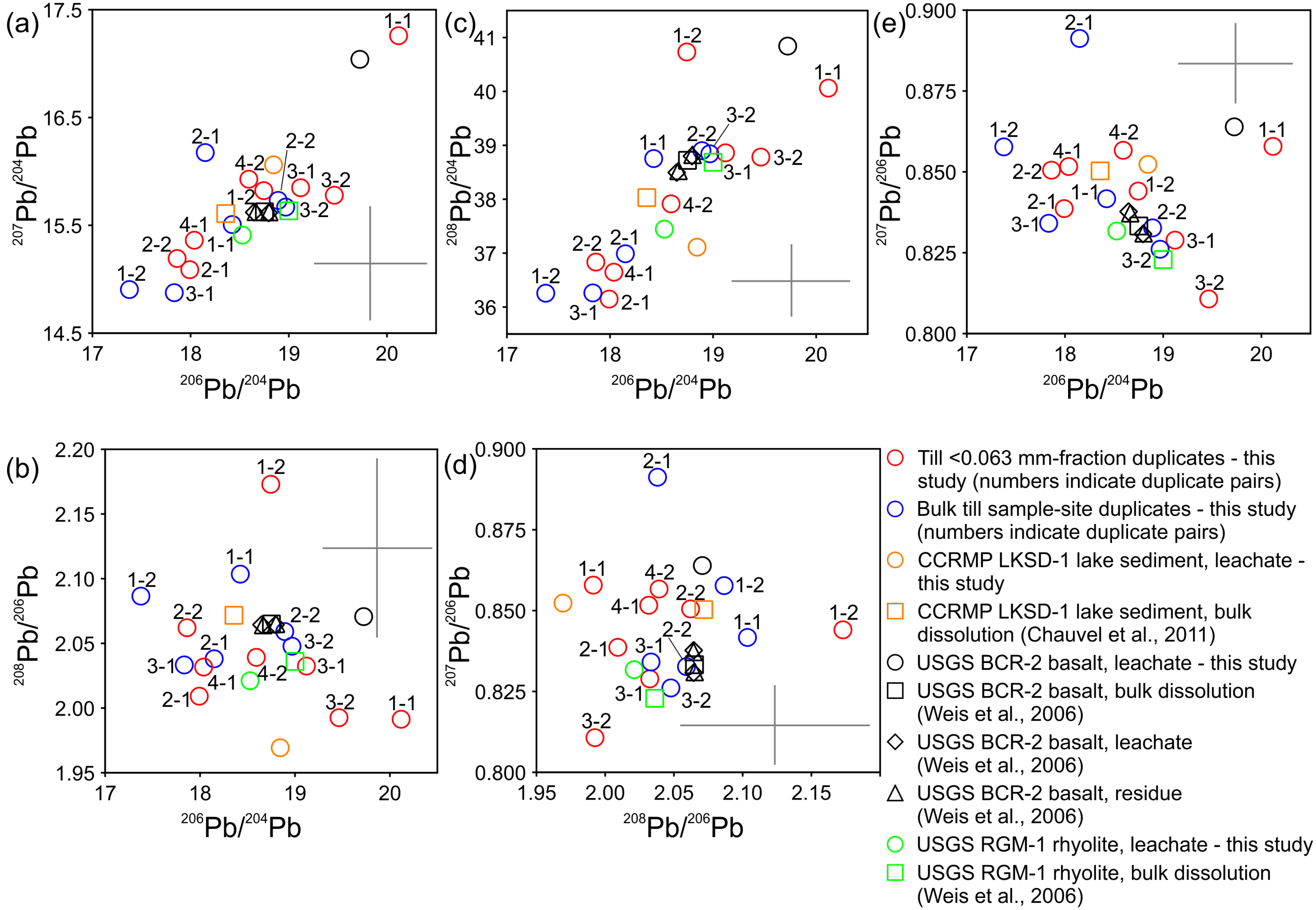




Appendix 14. Pb-Pb isotopic plots showing MC-ICP-MS results for leachates from Chehalis valley till <0.063 mm-fraction duplicates and for leachate-residue from rock standards. Uncertainties are smaller than the size of the symbols. Literature leachate-residue and bulk-dissolution analyses for the standards are shown for comparison.



Appendix 15. Pb-Pb isotopic plots showing HR-ICP-MS results for leachates from Chehalis valley till field duplicates, till <0.063 mm-fraction duplicates, and geological standards. Uncertainty bars show average relative difference based on till <0.063 mm-fraction duplicates. Literature leachate-residue and bulk-dissolution analyses for the standards are shown for comparison.



Appendix 16. Pb-Pb isotopic plots showing quadrupole ICP-MS results for leachates from Chehalis valley till field duplicates, till <0.063 mm-fraction duplicates, and geological standards. Uncertainty bars show average relative difference based on till <0.063 mm-fraction duplicates. Literature leachate-residue and bulk-dissolution analyses for the standards are shown for comparison.

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