Geoscience BC Report 2021-05

Geochemical and Indicator Mineral Data from a Regional Bulk Stream-Sediment Survey,

Boundary District, South-Central British Columbia

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1.0 Introduction

Government-funded, reconnaissance-scale regional stream sediment and water geochemical surveys (RGS) have been conducted in British Columbia (BC) since 1976 (Hickin and Plouffe, 2017; McCurdy et al., 2014). During this time, silt-sediment samples have been collected from more than 55 000 stream drainage sites throughout the province. The resulting RGS database has evolved into a comprehensive collection of field information plus accompanying multi-element analytical data. It continues to be recognized as an important resource for supporting mineral-exploration activities.

Although RGS coverage is extensive and the resulting database has great utility, there remain opportunities for improvement. Physical gaps in coverage include regions that have not been surveyed and, more notably, areas that have a limited density of existing sample sites. In these situations, the deficiencies relate to original survey parameters established by the Geological Survey of Canada (GSC) that specified reconnaissance-scale densities to be one sample site every 10 to 14 km^2 (Friske and Hornbrook, 1991). The targeting of first- and second-order drainages at this scale has sometimes resulted in only partial coverage of areas surveyed. In addition, analytical data derived from conventional silt samples collected at the outlet of drainage basins characterized by large catchment areas can be adversely affected by increases in sediment dilution and greater lithological variations that influence element dispersal and suppress geochemical signatures (Fletcher, 1997; Heberlein, 2013).

To examine how to resolve this inherent issue with the existing RGS database, a modified RGS sampling strategy that integrates the collection of bulk stream-sediment samples and derived mineralogical information, with multi-element data, was included as part of a new regional stream-sediment survey conducted in the Boundary District in south-central BC (Figure 1) in the summer of 2019.

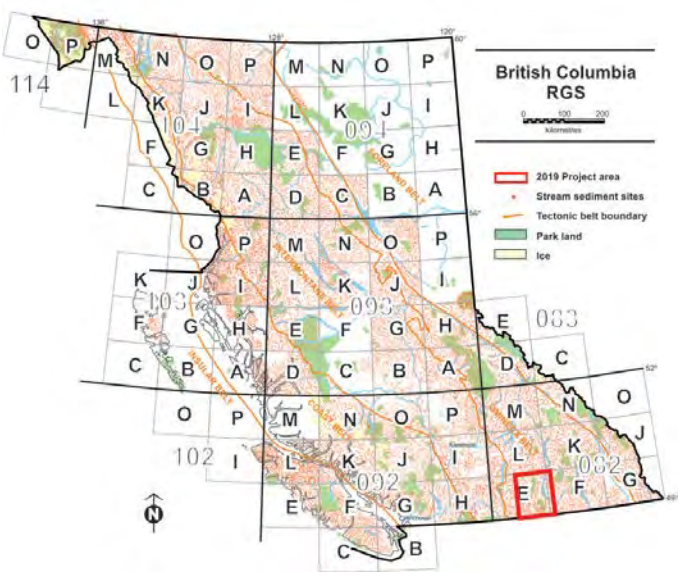

Figure 1. Location of the study area in the Boundary District, south-central BC, showing RGS stream sediment site coverage across the province.

The Boundary District in south-central British Columbia was selected for this study for the following reasons:

1) historical Au and Ag (plus Cu, Pb and Zn) mining camps hosted within a prospective geological setting continue to support active exploration;
2) synergy with other ongoing locally focused geoscience initiatives, including an extensive geological mapping and mineral-evaluation program (Hoy et al., 2020) funded by Geoscience BC;
3) the area offers good access to sample sites using established highway and forest-service-road infrastructure;
4) the mountainous terrain has a well-developed incised drainage network suitable for regional stream sediment geochemical surveys and is typical of many previously surveyed areas in BC; and
5) a previous government funded RGS program was completed in the area in 1976 and the sediment samples were later reanalyzed for additional elements by modern methods in 1991 and 2009.

Conducting a bulk-sediment sampling program in an area that was previously covered by a government-funded RGS program will demonstrate that this method can improve existing geochemical coverage; can add valuable mineralogical information to the existing RGS database; can enable relatively larger areas to be effectively assessed for mineral deposits; and is complementary to other exploration initiatives. In addition, this survey strategy targets considerably fewer sample sites, allowing for significant cost savings when compared to conventional infill methods that require greater sample-site densities and, more commonly, helicopter support.

This report presents the methods and resulting field and analytical data compiled as part of the 2019 field survey. The data summaries included in this package are not considered exhaustive. In order to accommodate more detailed assessments, raw digital data files are included as Microsoft® Excel (XLSX) files.

2.0 Regional Setting

2.1 Location and Physiography

Most sample sites are located in the east half of NTS map area 082E (Penticton) although some sites and associated drainage basins do extend into the west half of this sheet and into NTS map areas 082F (Nelson) and 082L (Vernon). The survey area covers approximately 10 000 km^2 of the Columbia Mountain physiographic region. The west edge of the survey area includes part of the Okanagan Highland and extends east through the Monashee Mountains, past Lower Arrow Lake and into the Selkirk Mountains (Holland, 1976). Mountain peaks up to 2000 m in elevation are common and are drained by the Kettle and Granby rivers and their numerous tributaries. Provincial highways 3, 6 and 33 provide access into the project area and a network of forest-service roads extend access to the sample site locations.

2.2 Geological Setting

Historical exploration for base and precious metals and mining in the Boundary District (particularly in the Greenwood, Franklin and Beaverdell camps) from the late 1890s to the early 1990s is well documented by Hoy et al., 2020. Exploration activities for a variety of deposit types, including epithermal gold, skarn and base and precious-metal vein deposits continues throughout the area, although most work is currently focused in the Greenwood camp.

A large part of the study area is underlain by poorly dated granitic and alkalic intrusive rocks (Hoy et al., 2020). Exploration of these rocks can potentially lead to the discovery of new base- and precious-metal mineralization that is controlled by north- and northwest-trending structures. These structures are commonly the loci for late, high-level granite and Coryell syenite intrusions within similar-age batholithic bodies. Other than in existing mineral camps, the presence of these stocks often remains unrecognized and they do not appear on regional federal or provincial bedrock geological maps. Structures can also localize regional tectonic highs that expose contacts of batholithic rocks and country rocks, as well as being a favourable environment for mineralization (Hoy et al., 2020).

Considerable exploration effort in the Boundary district is focused on Eocene-age gold mineralization, including epithermal, skarn and intrusive-related deposits (Hoy et al., 2020). Basal Penticton Group rocks, notably the Marron Formation and overlying "Sanpoil volcanics", host epithermal gold mineralization in the Republic (Washington State) and Greenwood areas, and this favourable stratigraphic horizon is a viable exploration target farther north in the Boundary District.

A total of 774 metallic and industrial mineral occurrences are documented in the study area (BC Geological Survey, 2020) including one producing mine, the Lexington (NTS 082E/02; MINFILE 082ESE041), a porphyry Cu-Au deposit located in the Greenwood mining district. Additionally, there are 10 producers, 241 past producers, 19 developed prospects, 106 prospects, 395 showings and 2 anomalies dispersed throughout the district. Of the documented metallic mineral occurrences, 233 are coded as polymetallic veins, 106 as skarns, and 76 as quartz veins.

2.3 Previous Regional Geochemical Surveys

In 1976 and 1977, federal-provincial government funded reconnaissance-scale silt-sediment and water regional geochemical surveys were conducted in southern British Columbia under the direction of the GSC and the BC Department of Mines and Petroleum Resources (Christopher, 1977; Ballantyne et al., 1977). These were the first public surveys carried out in the Cordillera under the auspices of the Uranium Reconnaissance Program (URP). Within the current study area, more than 1000 conventional silt samples were collected at an average sample-site density of approximately 1 site every 8 km^2. First- and second-order drainages were targeted, although many larger drainages (>10 km^2) also were sampled. The silt-sediment samples weighed from 1 to 2 kg and consisted of recently deposited, fine-grained sediments collected from within the active stream channel.

Geochemical results by atomic absorption spectrometry (AAS) from the Penticton map area were released as GSC Open File 409 (1977). Excess minus 80 mesh (<177 um) fractions from these surveys were saved and stored at the GSC archive facility in Ottawa. In 1990, as part of a BC Geological Survey Branch (BCGSB) reanalysis initiative, the samples were recovered from storage and reanalyzed using

instrumental neutron activation analysis (INAA); (Matysek et al., 1991; Jackaman et al., 1992). In 2009, Geoscience BC funded the further reanalysis of these samples by inductively coupled plasma–mass spectrometry (ICP-MS) following modified aqua-regia digestion (Jackaman, 2010). The RGS geochemical maps provided in this report depict Au by INAA, and Ag, Cu, Pb and Zn by ICP-MS.

3.0 2019 Bulk-Sediment Survey Methods

Bulk-sediment sample collection, processing and analytical methods for the 2019 survey are based on methods developed for the GSC's National Geochemical Reconnaissance (NGR) program and Natural Resources Canada's (NRCan) Geo-mapping for Energy and Minerals (GEM) Program (McCurdy et al., 2013; McCurdy et al., 2014). Qualified laboratories were selected to conduct sample preparation and analysis. Following these guidelines ensure that portions of collected materials can be incorporated into existing GSC and BCGSB archives, and survey results can be included as part of the provincial and national geochemical databases.

3.1 Sample Collection

During the 2019 field program, 98 bulk-sediment samples, 103 conventional silt samples and 98 pebble samples were collected from 98 stream sites (Figure 2). Sampling was undertaken in late summer to facilitate access to channel bar sites. At each site, a 12–15 kg bulk stream-sediment sample was collected from a single 50–75 cm deep, hand-dug pit (Figure 3) located at the upstream end of mid-channel or side-channel bars or from mid-channel boulder traps (Figure 4). The material was obtained by wet-sieving coarse-grained sands and gravel using a plastic 10-mesh (2 mm) sieve and capturing the less than 10 mesh size grains in a 20 litre plastic pail lined with a polyethylene sample bag.

Figure 2. Sampling equipment used to collect stream-sediment samples, including bulk stream sediment collected into polyethylene sample bag plus silt-sediment and pebbles samples in synthetic cloth bags.

Figure 3. A representative bulk stream-sediment pit located on a mid-channel bar and sieving of sample material to capture the minus 10 mesh material in a 20 litre plastic bucket.

Figure 4. Examples of representative bulk -sediment sample sites located on a) the upstream end of a mid-channel bar, and b) a mid-channel boulder trap.

Conventional RGS silt-samples were also collected from the active stream channel at each site. Approximately 2 kg samples of fine-grained material were recovered and placed in a synthetic cloth bag. At a small number of sites, sufficient fined grained material was not available and moss-mat sediment samples were collected instead. A field duplicate pair of silt-samples, assigned sequential sample numbers, was collected within each block of 20 samples. In addition, 50 large pebbles (50mm) from the oversized material were collected during the field sieving process and placed in a synthetic cloth bag. Standard field observations, site photographs and location co-ordinates were recorded digitally.

4.0 Sample Analysis

4.1 Bulk Sediments – Preparation and Identification of Indicator Minerals

Overburden Drilling Management (ODM) Limited (Ottawa, ON) processed 98 bulk-sediment samples to prepare mineral concentrates (Figure 5). Gold grain concentrates (<2.0 mm), a specific gravity (SG) 2.8 to 3.2 mineral concentrate from the 0.25 to 2.0 mm fraction, and a SG > 3.2 concentrate were produced using a combination of gravity table and heavy liquids. Gold grains, sulphides and magmatic or metamorphosed massive sulphide indicator minerals (MMSIMs®) were visually identified and hand-picked from the concentrates (Averill, 2001).

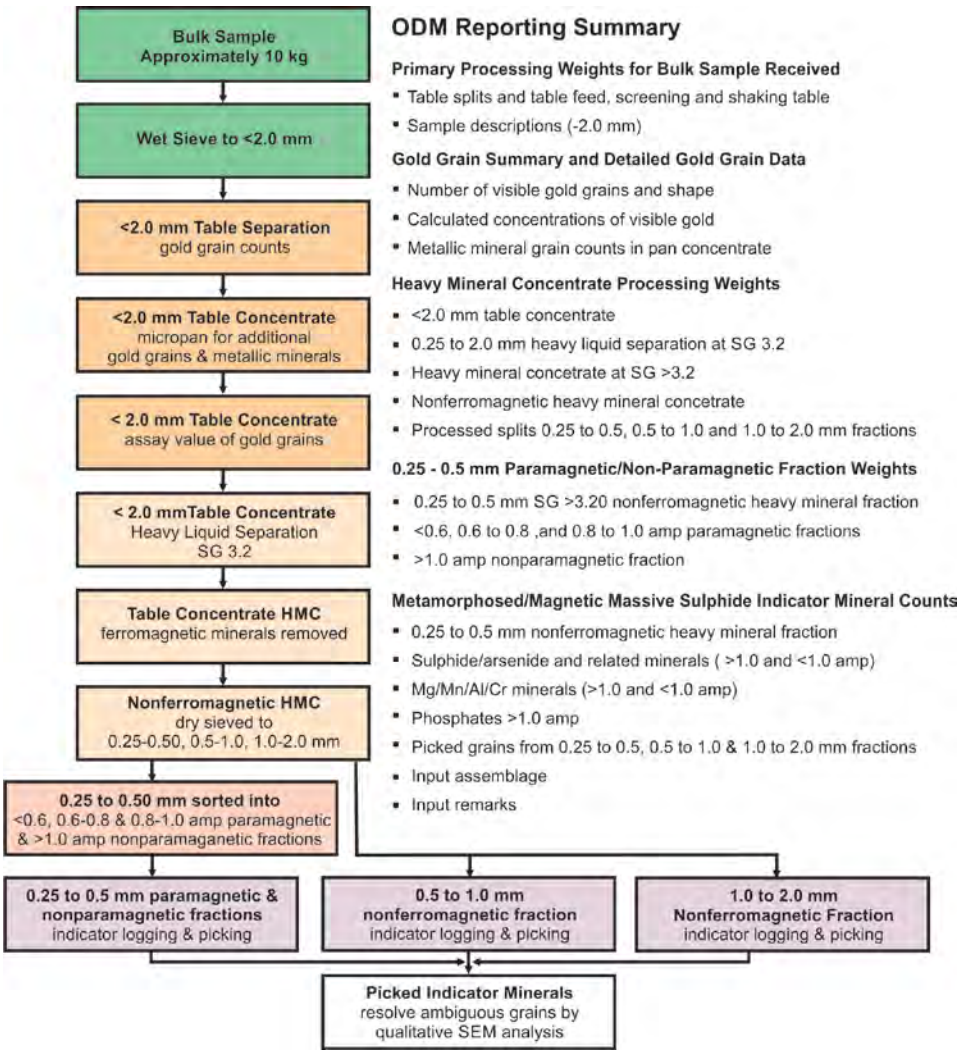

Figure 5. Flow diagram showing ODM's bulk-sediment sample preparation process and a listing of key headings from the lab's data reports.

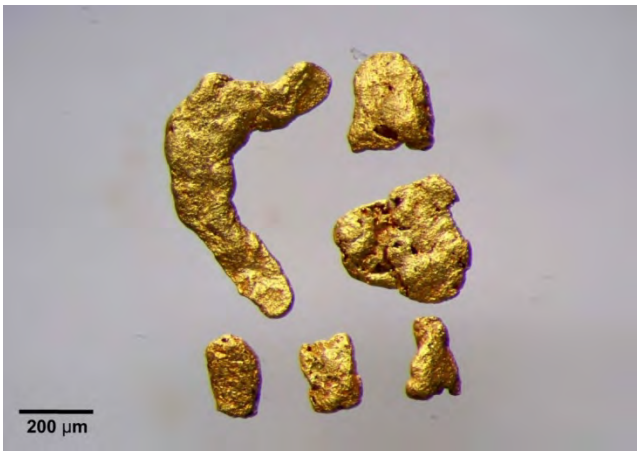

Figure 6. Photograph of selected gold grains recovered from bulk site ID 1059.

Gold grains observed in the <2.0 mm shaking table concentrate (Figure 6) were counted, measured and classified as to degree of wear which provides some indication of distance of detrital transport. Counts from 1 to a maximum of 32 gold grains were identified in 53 of the 98 processed bulk-sediment samples. Gold grains were not identified in 45 of the samples. A summary of the gold grains observed is provided in Table 1.

Pan concentrates derived from the <2.0 mm shaking table concentrates revealed metallic minerals in 86 of the 98 processed bulk-sediment samples. The type of metallic mineral identified and the total number of grains counted in the 86 samples are provided in Table 2.

Table 1. Total number and morphology of gold grains picked from 53 bulk-sediment samples.

Total Gold Grains	Pristine Gold Grains	Modified Gold Grains	Reshaped Gold Grains
277	51	39	187

Table 2. List of sulphide and oxide minerals recovered from pan concentrates and possible deposit types that may be associated with each metal.

Metallic Metal		Grains Picked	Possible Associated Deposit Types
Arsenopyrite	FeAsS	~60	Polymetallic veins Ag-Pb-Zn+/-Au; Epithermal Au
Galena	PbS	1	Volcanogenic and Sedex Pb-Zn-Ba; Polymetallic veins Ag-Pb-Zn+/-Au; Skarn
Molybdenite	MoS_2	5	Porphyry Mo; Skarn
Pyrite	FeS_2	~9583	Ubiquitous - most deposit types
Thorianite/uraninite	ThO_2 / UO_2	~330	Rare earth pegmatite deposit
Thoro-uraninite	UO_2	~100	Granite pegmatite

The <2.0 mm shaking table concentrate was reconstituted and then further refined in methylene iodide diluted with acetone to a SG of 3.2 to recover heavy minerals. Ferromagnetic minerals (mainly magnetite) were removed after the heavy liquid separation. The remaining nonferromagnetic concentrate was then cleaned with oxalic acid to remove limonite stains. After being dried, the concentrate was sieved into 0.25 to 0.50 mm, 0.5 to 1.0 mm and 1.0 to 2.0 mm size heavy mineral fractions. The 0.25 to 0.50 mm fraction was further sorted with a Carpco® drum magnetic separator into a <0.6, 0.6 to 0.8 and 0.8 to 1.0 amp paramagnetic heavy mineral fractions and a >1.0 amp nonparamagnetic heavy mineral fraction.

Indicator minerals were visually identified and picked from the 0.25 to 0.50 mm paramagnetic and nonparamagnetic heavy mineral fractions as well as from the 0.5 to 1.0 mm and 1.0 to 2.0 mm nonferromagnetic fractions. Scheelite was identified using short wave-ultraviolet light to identify the grains. Possible deposit types associated with the identified indicator minerals are listed in Table 3.

4.2 Bulk Sediments – Aqua Regi/ICP-MS and INAA

Prior to processing to recover indicator minerals, a 500 g split was taken from each bulk-sediment sample and shipped to Bureau Veritas Commodities Laboratory (Vancouver, BC) where the samples were sieved to recover the minus 80 mesh (<177 um). The -80 mesh fraction was analyzed for minor and trace elements by ICP-MS following a modified aqua-regia digestion (65 elements) on a 0.5 g aliquot. Loss-on-ignition (LOI) was also determined on a 1.0 g aliquot. Total gold determinations plus 34 elements by INAA were provided by Maxxam Analytics (Mississauga, ON) on a 20 g aliquot. A complete listing of elements that were determined and their lower detection limits (RDL) is provided in Table 4.

4.3 Conventional Silt-Sediments – Aqua Regi/ICP-MS and INAA

Conventional silt-sediment samples were air dried and processed to recover the minus 80 mesh (<177 um) fraction. The 80 mesh fractions were analyzed by Bureau Veritas Commodities Laboratory (Vancouver, BC) for major, minor and trace elements by ICP-MS following modified aqua-regia digestion (65 elements) on a 0.5 g aliquot. Loss-on-ignition (LOI) was also determined on a 1.0 g aliquot. Total gold determinations plus 34 elements by INAA were provided by Maxxam Analytics (Mississauga, ON) on a 35 g aliquot.

4.4 Pebble Samples

Pebbles that averaged 50 mm in size were recovered from the sieved oversize fraction (>2 mm) at each bulk-sediment sample site and photographed to provide general information on common bedrock sources up-stream from each sample site (Figure 7). The photographs have been provided as part of this data compilation.

Table 3. Indicator minerals reported (trace amounts and greater) in bulk-stream sediment samples of the Boundary District and possible local deposit types that may be associated with each indicator mineral (modified from Averill, 2001).

Gold		**Possible Associated Deposit Types**
Prestine	Au	Gold quartz veins, Porphyry Cu +/- Mo +/- Au; skarn
Reshaped - modified	Au	Placer
Sulphide/Arsenide + Related Minerals		**Possible Associated Deposit Types**
Arsenopyrite	FeAsS	Polymetallic veins Ag-Pb-Zn+/-Au; Epithermal Au; orogenic veins
Barite	$BaSO_4$	Volcanogenic massive sulphide and SEDEX Pb-Zn-Ba
Chalcopyrite	Cu_3FeS_2	Porphyry Cu +/- Mo +/- Au; skarn; epithermal; VMS; SEDEX
Crocoite	$PbCrO_4$	Polymetallic veins Ag-Pb-Zn+/-Au
Fluorite	CaF_2	Greisen Sn-W-Mo-Au; epithermal
Goethite	$HFeO_2$	Oxidized porphyry Cu +/- Mo +/- Au; skarn; VMS/MS Cu-Ni; pyrite weathering
Malachite	$Cu_2CO_3(OH)_2$	Oxidized porphyry Cu +/- Mo +/- Au; skarn; VMS/MS Cu-Ni; Cu weathering
Molybdenite	MoS_2	Porphyry Mo; Skarn; black shales
Pyrite	FeS_2	Ubiquitous - most deposit types
Scheelite	$CaWO_4$	Skarn
Mg/Mn/Al/Cr Minerals		**Possible Associated Deposit Types**
Chromite	$Fe^{2+}Cr_2O_4$	Metamorphosed magmatic Cu-Ni massive sulphide
Cr-garnet	$Ca_3Cr_2(SiO_4)_3$	Porphyry Cu +/- Mo +/- Au; skarn
Fayalite	Fe_2SiO_4	Skarn; metamorphosed magmatic Cu-Ni massive sulphide; mafic igneous rock
Forsterite	Mg_2SiO_4	Skarn; metamorphosed magmatic Cu-Ni massive sulphide; ultramafic and mafic igneous rock
Green Cr-garnet	$Ca_3Cr_2(SiO_4)_3$	Porphyry Cu +/- Mo +/- Au; skarn
Green Cr-grossular	$Ca_3Al_2Si_3O_{12}$	Porphyry Cu +/- Mo +/- Au; skarn
Kyanite	Al_2SiO_5	Metamorphosed magmatic Cu-Ni massive sulphide; high pressure metamorphism
Low-Cr diopsdie	$Ca(MgCr)Si_2O_6$	Metamorphosed magmatic Cu-Ni massive sulphide
Mn-epidote	$Ca_2(Al,Fe,Mn)_3Si_3O_{12}(OH)$	Volcanogenic massive sulphide
Orthopyroxene	$[Mg,Fe]SiO_3$	Metamorphosed magmatic Cu-Ni massive sulphide; mafic igneous rocks
Red rutile	TiO_2	Metamorphosed magmatic Cu-Ni massive sulphide
Ruby corundum	Al_2O_3:Cr	Metamorphosed magmatic Cu-Ni massive sulphide
Sapphire corundum	Al_2O_3	Metamorphosed magmatic Cu-Ni massive sulphide
Sapphirine	$(Mg,Al)_8(Al,Si)_6O_{20}$	Metamorphosed magmatic Cu-Ni massive sulphide
Sillimanite	Al_2SiO_5	Metamorphosed magmatic Cu-Ni massive sulphide; high temperature metamorphic rocks
Spessartine	$Mn_2+3Al_2(SiO_4)_3$	Metamorphosed magmatic Cu-Ni massive sulphide
Spinel	$MgAl_2O_4$	Metamorphosed Cu–Zn–Pb–Au–Ag-VMS
Staurolite	$(Fe,Mg,Zn)_2Al_9(Si,Al)_4O_{22}(OH)_2$	Metamorphosed magmatic Cu-Ni massive sulphide
Tourmaline	$(Na,Ca)(Mg,Fe)_3Al_6(BO_3)_3(Si_6Oi_8)(OH)_4$	Greisen Sn-W-Mo-Au
Uvarovite	$Ca_3Cr_2Si_3O_{12}$	Metamorphosed magmatic Cu-Ni massive sulphides; skarn; orgenic Au
Phosphates		**Possible Associated Deposit Types**
Apatite	$Ca_5(PO_4)_3(F,Cl,OH)$	Porphyry Cu +/- Mo +/- Au
Monazite	$(Ce,La,Th)PO_4$	Rare earth pegmatite deposit

Table 4. Analytical methods, elements and their lower detection limits used for this survey. Abbreviations: ICP-MS, aqua regia digestion/inductively coupled plasma–mass spectrometry; INAA, instrumental neutron activation analysis; RDL, detection limit; ppm, parts per million; ppb, parts per billion; pct, percent.

Lab	Method	Element		RDL	Unit
Bureau Veritas	ICP-MS	Molybdenum	Mo	0.01	ppm
Bureau Veritas	ICP-MS	Copper	Cu	0.01	ppm
Bureau Veritas	ICP-MS	Lead	Pb	0.01	ppm
Bureau Veritas	ICP-MS	Zinc	Zn	0.1	ppm
Bureau Veritas	ICP-MS	Silver	Ag	2	ppb
Bureau Veritas	ICP-MS	Nickel	Ni	0.1	ppm
Bureau Veritas	ICP-MS	Cobalt	Co	0.1	ppm
Bureau Veritas	ICP-MS	Manganese	Mn	1	ppm
Bureau Veritas	ICP-MS	Iron	Fe	0.01	pct
Bureau Veritas	ICP-MS	Arsenic	As	0.1	ppm
Bureau Veritas	ICP-MS	Uranium	U	0.1	ppm
Bureau Veritas	ICP-MS	Gold	Au	0.2	ppb
Bureau Veritas	ICP-MS	Thorium	Th	0.1	ppm
Bureau Veritas	ICP-MS	Strontium	Sr	0.5	ppm
Bureau Veritas	ICP-MS	Cadmium	Cd	0.01	ppm
Bureau Veritas	ICP-MS	Antimony	Sb	0.02	ppm
Bureau Veritas	ICP-MS	Bismuth	Bi	0.02	ppm
Bureau Veritas	ICP-MS	Vanadium	V	1	ppm
Bureau Veritas	ICP-MS	Calcium	Ca	0.01	pct
Bureau Veritas	ICP-MS	Phosphorus	P	0.001	pct
Bureau Veritas	ICP-MS	Lanthanum	La	0.5	ppm
Bureau Veritas	ICP-MS	Chromium	Cr	0.5	ppm
Bureau Veritas	ICP-MS	Magnesium	Mg	0.01	pct
Bureau Veritas	ICP-MS	Barium	Ba	0.5	ppm
Bureau Veritas	ICP-MS	Titanium	Ti	0.001	pct
Bureau Veritas	ICP-MS	Boron	B	20	ppm
Bureau Veritas	ICP-MS	Aluminum	Al	0.01	pct
Bureau Veritas	ICP-MS	Sodium	Na	0.001	pct
Bureau Veritas	ICP-MS	Potassium	K	0.01	pct
Bureau Veritas	ICP-MS	Tungsten	W	0.1	ppm
Bureau Veritas	ICP-MS	Scandium	Sc	0.1	ppm
Bureau Veritas	ICP-MS	Thallium	Tl	0.02	ppm
Bureau Veritas	ICP-MS	Sulphur	S	0.02	pct

Lab	Method	Element		RDL	Unit
Bureau Veritas	ICP-MS	Mercury	Hg	5	ppb
Bureau Veritas	ICP-MS	Selenium	Se	0.1	ppm
Bureau Veritas	ICP-MS	Tellurium	Te	0.02	ppm
Bureau Veritas	ICP-MS	Gallium	Ga	0.1	ppm
Bureau Veritas	ICP-MS	Cesiun	Cs	0.02	ppm
Bureau Veritas	ICP-MS	Germanium	Ge	0.1	ppm
Bureau Veritas	ICP-MS	Hafnium	Hf	0.02	ppm
Bureau Veritas	ICP-MS	Niobium	Nb	0.02	ppm
Bureau Veritas	ICP-MS	Rubidium	Rb	0.1	ppm
Bureau Veritas	ICP-MS	Tin	Sn	0.1	ppm
Bureau Veritas	ICP-MS	Tantalum	Ta	0.05	ppm
Bureau Veritas	ICP-MS	Zirconium	Zr	0.1	ppm
Bureau Veritas	ICP-MS	Yttrium	Y	0.01	ppm
Bureau Veritas	ICP-MS	Cerium	Ce	0.1	ppm
Bureau Veritas	ICP-MS	Indium	In	0.02	ppm
Bureau Veritas	ICP-MS	Rhenium	Re	1	ppb
Bureau Veritas	ICP-MS	Beryllium	Be	0.1	ppm
Bureau Veritas	ICP-MS	Lithium	Li	0.1	ppm
Bureau Veritas	ICP-MS	Praseodymium	Pr	0.02	ppm
Bureau Veritas	ICP-MS	Neodymium	Nd	0.02	ppm
Bureau Veritas	ICP-MS	Samarium	Sm	0.02	ppm
Bureau Veritas	ICP-MS	Europium	Eu	0.02	ppm
Bureau Veritas	ICP-MS	Gadolinium	Gd	0.02	ppm
Bureau Veritas	ICP-MS	Terbium	Tb	0.02	ppm
Bureau Veritas	ICP-MS	Dysprosium	Dy	0.02	ppm
Bureau Veritas	ICP-MS	Holmium	Ho	0.02	ppm
Bureau Veritas	ICP-MS	Erbium	Er	0.02	ppm
Bureau Veritas	ICP-MS	Thulium	Tm	0.02	ppm
Bureau Veritas	ICP-MS	Ytterbium	Yb	0.02	ppm
Bureau Veritas	ICP-MS	Lutetium	Lu	0.02	ppm
Bureau Veritas	ICP-MS	Palladium	Pd	10	ppb
Bureau Veritas	ICP-MS	Platinum	Pt	2	ppb
Bureau Veritas	GRAV	Loss on Ignition	LOI	0.1	pct

Lab	Method	Element		RDL	Unit
Maxxam	INAA	Antimony	Sb	0.1	ppm
Maxxam	INAA	Arsenic	As	0.5	ppm
Maxxam	INAA	Barium	Ba	50	ppm
Maxxam	INAA	Bromine	Br	0.5	ppm
Maxxam	INAA	Cadnium	Cd	5	ppm
Maxxam	INAA	Cerium	Ce	5	ppm
Maxxam	INAA	Cesium	Cs	0.5	ppm
Maxxam	INAA	Chromium	Cr	20	ppm
Maxxam	INAA	Cobalt	Co	5	ppm
Maxxam	INAA	Europium	Eu	1	ppm
Maxxam	INAA	Gold	Au	0.002	ppm
Maxxam	INAA	Hafnium	Hf	1	ppm
Maxxam	INAA	Iridium	Ir	0.05	ppm
Maxxam	INAA	Iron	Fe	2000	ppm
Maxxam	INAA	Lanthanum	La	2	ppm
Maxxam	INAA	Lutetium	Lu	0.2	ppm
Maxxam	INAA	Molybdenum	Mo	1	ppm
Maxxam	INAA	Nickel	Ni	10	ppm

Lab	Method	Element		RDL	Unit
Maxxam	INAA	Rubidium	Rb	5	ppm
Maxxam	INAA	Samarium	Sm	0.1	ppm
Maxxam	INAA	Scandium	Sc	0.2	ppm
Maxxam	INAA	Selenium	Se	5	ppm
Maxxam	INAA	Silver	Ag	2	ppm
Maxxam	INAA	Sodium	Na	200	ppm
Maxxam	INAA	Tantalum	Ta	0.5	ppm
Maxxam	INAA	Tellurium	Te	10	ppm
Maxxam	INAA	Terbium	Tb	0.5	ppm
Maxxam	INAA	Thorium	Th	0.2	ppm
Maxxam	INAA	Tin	Sn	100	ppm
Maxxam	INAA	Titanium	Ti	500	ppm
Maxxam	INAA	Tungsten	W	1	ppm
Maxxam	INAA	Uranium	U	0.2	ppm
Maxxam	INAA	Ytterbium	Yb	2	ppm
Maxxam	INAA	Zinc	Zn	100	ppm
Maxxam	INAA	Zirconium	Zr	200	ppm
Maxxam	INAA	Weight	Wt	0.01	g

Figure 7. Pebbles collected from sieved oversize fraction, bulk site ID 1054.

4.5 Quality Control

ODM maintains strict protocols related to material processing and mineral indicator logging. Their mineral separation quality control is visible at shaking table, heavy liquid, magnetic, electromagnetic concentration stages as well as during final indicator mineral logging. Heavy mineral recovery tests are routinely conducted on all shaking tables. Customized shaker tables eliminate indicator mineral carryover; blank samples are inserted and processed between projects and after anomalous samples. Sieves are systematically cleaned after each concentrate. All sample fractions and sub-fractions obtained during processing are weighed and tallied to identify potential sample mix-ups. Any conflicting weight imbalances are assessed and immediately reported. Unusual mineral grains or other suspect particles observed during gold micro-panning or indicator mineral logging are immediately resolved by scanning electron microscope (SEM) analysis. Additional quality control samples (i.e. field duplicates) were not included as part of ODM's bulk sediment processing and mineral indicator logging.

Quality control for routine silt-sediment analytical determinations was monitored by the commercial laboratory using their in-house procedures as well as established NGR protocols (Friske and Hornbrook, 1991) that include the addition of field duplicates, analytical duplicates and reference standards. For every 17 routine samples, one field duplicate (taken at a randomly selected sample site), one analytical duplicate (a sample split during the preparation process), and one reference standard was included to make a block of 20 samples. For this data-set a total of 5-field duplicate pairs, 6-blind duplicate pairs and 6 reference standards where included in the analytical work. Blind duplicate splits and standards were inserted by the lab during sample processing. Standards included a commonly used BCGSB stream sediment standard called REDDOG and a Canadian Certified Reference Materials Project stream sediment standard called STSD-1. Duplicate samples determine sampling and analytical variability and reference standards measure the accuracy and precision of the analytical results.

A review of the results determined the reported analytical information is complete and of a reasonable quality. This review included the calculation of the average coefficient of variation (CV_{AVR}) using a

formula proposed by Abzalov (2008). This value provides an estimate of sampling precision using analytical results reported for the silt-sediment field duplicate data and can range from 0%, when duplicate sample pairs have equal concentrations, to an upper value above 141.21% when duplicate results exhibit maximum differences. Table 5 lists the CV_{AVR} values for each element in the five field-duplicate sample pairs analysed by aqua regia/ICP-MS and INAA. For sediments, values below 15% indicate good data quality, values between 15 and 30% acceptable quality and over 30% marginal to poor quality.

A complete listing of quality control data has been provided in Digital_Data_File_7_Quality_Control.XLSX and original lab certificates of analysis (PDF format) have been included as part of this data package.

Table 5. CV_{AVR} values for each element in the five silt-sediment field-duplicate sample pairs analysed by aqua regia/ICP-MS and INAA. Green indicates good precision, yellow acceptable precision and red, marginal to poor precision.

Element	Unit	Method	CV_{AVR} (%)
B	ppm	ICP-MS	0.00
S	pct	ICP-MS	0.00
Te	ppm	ICP-MS	0.00
Ge	ppm	ICP-MS	0.00
Re	ppm	ICP-MS	0.00
Ta	ppm	ICP-MS	0.00
Pd	ppb	ICP-MS	0.00
Pt	ppb	ICP-MS	0.00
Ca	pct	ICP-MS	2.12
Fe	pct	ICP-MS	5.32
Cr	ppm	ICP-MS	5.77
Lu	ppm	ICP-MS	5.83
Er	ppm	ICP-MS	5.97
Ho	ppm	ICP-MS	6.05
Sr	ppm	ICP-MS	6.13
V	ppm	ICP-MS	6.16
Eu	ppm	ICP-MS	6.23
Y	ppm	ICP-MS	6.27
Dy	ppm	ICP-MS	7.33
Tb	ppm	ICP-MS	7.91
Ga	ppm	ICP-MS	7.93
Sm	ppm	ICP-MS	8.07
Sc	ppm	ICP-MS	8.64
Tm	ppm	ICP-MS	8.72
Mn	ppm	ICP-MS	8.78
Yb	ppm	ICP-MS	8.84
Pb	ppm	ICP-MS	8.98
P	pct	ICP-MS	9.28
Cs	ppm	ICP-MS	9.97
Ti	pct	ICP-MS	9.98
La	ppm	ICP-MS	10.00
Zr	ppm	ICP-MS	10.04
Al	pct	ICP-MS	10.09
Pr	ppm	ICP-MS	10.60
Ni	ppm	ICP-MS	10.70
Gd	ppm	ICP-MS	10.76
Ce	ppm	ICP-MS	10.89
Nd	ppm	ICP-MS	10.91
Ba	ppm	ICP-MS	11.14
Zn	ppm	ICP-MS	11.15
Cd	ppm	ICP-MS	11.63
Mo	ppm	ICP-MS	11.63
Ag	ppb	ICP-MS	11.89
Co	ppm	ICP-MS	12.58
Tl	ppm	ICP-MS	12.73
Sn	ppm	ICP-MS	12.78
Rb	ppm	ICP-MS	13.03
Na	pct	ICP-MS	13.50
Hf	ppm	ICP-MS	13.55
Cu	ppm	ICP-MS	14.44
Nb	ppm	ICP-MS	14.47
As	ppm	ICP-MS	15.33
K	pct	ICP-MS	15.92
Sb	ppm	ICP-MS	16.22
Mg	pct	ICP-MS	16.46
Hg	ppb	ICP-MS	16.92
Li	ppm	ICP-MS	17.04
U	ppm	ICP-MS	19.27
In	ppm	ICP-MS	21.08
Th	ppm	ICP-MS	29.85
W	ppm	ICP-MS	31.25
Be	ppm	ICP-MS	32.37
Se	ppm	ICP-MS	43.12
Bi	ppm	ICP-MS	50.52
Au	ppb	ICP-MS	81.46
Cd	ppm	INAA	0.00
Ir	ppm	INAA	0.00
Se	ppm	INAA	0.00
Te	ppm	INAA	0.00
Sn	ppm	INAA	0.00
Na	ppm	INAA	1.54
Sc	ppm	INAA	3.58
Zr	ppm	INAA	3.83
Ba	ppm	INAA	4.87
Rb	ppm	INAA	4.97
Fe	ppm	INAA	6.33
Co	ppm	INAA	8.50
Cs	ppm	INAA	10.29
Ti	ppm	INAA	10.37
Sb	ppm	INAA	11.45
Ta	ppm	INAA	11.81
Hf	ppm	INAA	12.37
U	ppm	INAA	12.81
Lu	ppm	INAA	14.29
Sm	ppm	INAA	14.99
La	ppm	INAA	15.13
Yb	ppm	INAA	15.54
As	ppm	INAA	16.17
Ce	ppm	INAA	16.59
Br	ppm	INAA	17.10
Tb	ppm	INAA	17.69
Th	ppm	INAA	18.17
Zn	ppm	INAA	26.33
W	ppm	INAA	30.63
Mo	ppm	INAA	36.51
Cr	ppm	INAA	38.98
Au	ppb	INAA	49.44
Eu	ppm	INAA	52.96
Ni	ppm	INAA	56.29

5.0 Data Presentation

Information presented in this report includes field information as well as trace element and mineralogical results from bulk-stream sediment samples collected during the 2019 regional geochemical survey conducted in the Boundary District.

Previously published RGS data, mineral occurrence data and bedrock mapping have been integrated into the data set and are included in accompanying digital data files and thematic maps.

5.1 Digital Data Files

Resulting field and raw unprocessed analytical information reported by the commercial laboratories have been provided in Microsoft® Excel (XLSX) tables and are described as follows:

1. *Bulk-sediment sample site field data (Digital_Data_File_1_Field_Data.xlsx)*

   This file includes location coordinates; descriptions of sample material collected; specific details on the character of the sample site and surrounding area; and size of drainage basin area upstream from each bulk-sediment sample site.

   The file includes data for a total of 98 bulk-sediment sample sites and corresponding drainage basins. The digital drainage basin outlines were acquired from Province of BC Freshwater Atlas (2011) and were modified to position the basin outlet at the location of the bulk-sediment sample sites. Sixty-six of the basins are identified as primary basins since they have no spatial relationship with other sampled basins. Thirty-two basins are identified as tributary basins or basins that are nested with other sampled basins. For nested basins, areal coverage and perimeter is measured to up-stream bulk-sediment samples sites. The relationship between primary and tributary basins is noted in the table.

   The minimum sized drainage basin is 7.1 km^2 (site ID 1097) and the maximum is 410.5 km^2 (site ID 1102). Mean catchment area is 67.7 km^2 and the median area is 48.8 km^2. The total area covered by the 98 sampled drainage basins is 6633 km^2.

2. *Bulk-sediment gold counts and mineralogy data (Digital_Data_File_2_Mineralogy_Data.xlsx)*

   This file includes data report by ODM and includes primary sample processing weights and description; gold grain summary and detailed gold grain data; heavy mineral concentration processing weights, paramagnetic and non-paramagnetic fraction weights; and metamorphosed and magmatic massive sulphide indicator mineral (MMSIM) counts.

3. *Silt-sediment trace metal data (Digital Data_File_3_Trace_Metal_Data.xlsx)*

   This file includes data reported by Bureau Veritas and Maaxam Labs and includes aqua regia/ICP-MS and INAA results from the -80 mesh silt-sediment samples and aqua regia/ICP-MS and INAA results from -80 mesh bulk-sediment samples collected during the 2019 field program.

4. *Historical RGS data (Digital_Data_File_4_RGS_Data.xlsx)*

   This file includes original field and analytical data compiled from previous URP, NGR and RGS programs and reanalysis initiatives by Han and Rukhlov (2017) carried out in the study area prior to 2019. A total of 1783 RGS samples are located in and adjacent to the study area. A total of 705 of these samples are located within 95 of the bulk-sediment drainage basins. Only 3 basins did not contain previously sampled RGS sites. Previous RGS samples are presented in a separate table that lists each RGS site that is located in the 2019 bulk-sediment drainage basin. The number of RGS sites in each bulk-sediment drainage basin ranges from 0 to 30.

5. *BCGS mineral occurrences (Digital_Data_File_5_MINFILE_Data.xlsx)*

   Known mineral occurrences listed in the BC Geological Survey mineral deposits database (2019) are provided. This file includes a listing of 774 mineral occurrences located in and adjacent to the study area. A total of 243 of these deposits are located in drainage basins upstream from bulk-sediment sites. Forty-one drainage basins recorded from 1 to 22 contained occurrences. Fifty-four drainage basins contain no occurrences. The most common occurrence type recorded are polymetallic Ag-Pb-Zn+/-Au veins (N = 65).

6. *Bedrock geology (Digital_Data_File_6_Bedrock_Geology_Data.xlsx)*

   The geological unit and calculated percentage coverage of the unit (Hoy, 2019; Cui et al., 2017) underlying each bulk-sediment drainage basin is provided. Only one basin (ID 1086) was determined to be underlain by a single geological unit. The average number of geological units contained by bulk-sediment drainage basins is five and the maximum number of geological units intersected is 12 (ID 1059). Coryell intrusions as mapped by Hoy (2019) were intersected by 52 drainage basins.

5.2 Thematic Maps

Maps generated from the digital data include a sample location map; combined proportional symbol and gridded image maps for selected RGS elements; and combined proportional symbol and colour coded drainage basins for selected indicator minerals. Previously released RGS data are presented as published and 2019 ODM results are presented as reported by the lab.

The underlying base map digital elevation data is from Natural Resources Canada (2015).

The thematic maps included in this report are as follows:

Map 1: Sample site locations

An overview map that includes the location of 2019 bulk-sediment sample sites and the drainage areas that flow into each site; previous RGS silt sample sites; known mineral occurrences; and general topographic features.

Maps 2 to 6: Au, Ag, Cu, Pb and Zn in RGS silt-sediments

Gridded image maps were created from previously published RGS data using an inverse distance weighting method. Colour depicted on the gridded images and proportional symbol size reflects data ranges that are based on percentiles calculated from the original data. 2019 bulk-sediment sample sites, drainage basin areas, mineral occurrences and general topographic features are included for reference.

Map 7: Picked gold grains and grain morphology

Colour coded drainage basins upstream from the bulk-sediment sites correspond to the number of gold grains identified in the <2.0 mm fraction. Pie chart symbols located at each bulk-sediment sample site summarizes the morphology of the gold grains (i.e. pristine, modified or reshaped).

Map 8: Metallic minerals in pan concentrates

Colour coded drainage basins upstream from the bulk-sediment sites correspond to the presence of metallic mineral grains identified in the <2.0 mm fraction of the table concentrate.

Maps 9 and 10: Dominant minerals in the 0.25 to 0.5 mm heavy mineral fraction

To provide indication of the general origin of the bulk-sediment, ODM's report summarizes the major background heavy minerals in the 0.25 to 0.5 mm S.G. > 3.2 heavy mineral fraction. This input assemblage lists in order of prominence, minerals comprising ≥ 15 percent of the 0.25 to 0.5 mm paramagnetic (<0.8 amp) heavy mineral fraction followed by minerals comprising ≥ 15 percent of the corresponding 0.25 to 0.5 mm nonparamagnetic (>1.0 amp) heavy mineral fraction. For example, the input assemblage hornblende-augite/titanite-diopside reported for bulk sample ID 1006 shows that hornblende exceeds augite in the paramagnetic heavy mineral fraction and titanite exceeds diopside in the nonparamagnetic heavy mineral fraction.

Using colour coded drainage basins upstream from each bulk-sediment site, Map 7 represents the first or most dominant mineral listed in the paramagnetic input assemblage and Map 8 represents the first or most dominant mineral listed in the nonparamagnetic input assemblage.

Map 11 Goethite in heavy mineral concentrates

Colour coded drainage basins upstream from the bulk-sediment sites correspond to the recorded percentage of goethite calculated in the 0.25 to 0.5 mm nonferromagnetic heavy mineral fraction (<1.0 amp).

Maps 12 to 16 Chalcopyrite, scheelite, spinel, red rutile, low-Cr diopside in heavy mineral concentrates

Colour coded drainage basins upstream from the bulk-sediment sites correspond to the recorded number of mineral grains identified in the 0.25 to 0.5, 0.5 to 1.0 and 1.0 to 2.0 mm nonferromagnetic heavy mineral fractions (<1.0 amp).

6.0 Survey Summary

Indicator minerals derived from bulk stream sediments collected at the outlets of large drainage basins can effectively detect the presence of potential mineral occurrences at far greater distances upstream than conventional silt sampling (McClenaghan, 2005). Based on this assertion, the collection of bulk-sediment samples at a density of one site per 100 km^2 or greater is routinely used as part of current GSC reconnaissance stream sediment surveys and has been successful in detecting a variety of ore-deposit types elsewhere in Canada (Berman et al., 2018; McCurdy et al., 2016).

Extending the length of detectable mineral-dispersal trains allows for the use of significantly fewer, but strategically located stream bulk -sediment sample sites. Processing bulk -sediment material captures gold and sulphide mineral grains, plus potential oxide- and silicate -mineral indicators. The abundance of these indicator minerals and their morphological characteristics provides information about potential economic mineralization associated with precious and base -metal deposits that may exist upstream from a bulk-sediment sample site located at the drainage basin outlet.

In BC, indicator-mineral methods are commonly included as part of regional till surveys but are not yet fully integrated into regional stream silt-sediment programs. Incorporating bulk stream-sediment sampling into government-funded RGS programs is starting to be recognized for effectively maintaining strict design requirements and program objectives while reducing overall collection costs. Targeting considerably fewer sample sites, allowing for significant cost savings when compared to conventional infill methods that require greater sample-site densities and, more commonly, helicopter support. There are numerous opportunities to apply this survey technique in BC, including regions where RGS programs have not been previously conducted and areas where nominal sample-site densities may have undervalued mineral assessments or inadvertently misrepresented geochemical results.

The Boundary District bulk-sediment study was conducted to demonstrate the application of this method in the ongoing development of the BC RGS database. The survey provided new geochemical information including the abundance of gold grains, pan concentrate sulphides plus metamorphosed and magmatic massive sulphide indicator minerals. Results suggest detection and interpretation of mineral dispersal has been enhanced and the overall geochemical coverage of the region has been improved. In addition, the data appears to be coincidental with existing RGS geochemical patterns, the location of known mineral occurrences and the local bedrock geology. It is hoped that detailed follow-up activities that combine the new data with other geoscience information will assist in the identification of new exploration targets. Applying this cost effective method when conducting new surveys and in-fill sampling initiatives, will further the utility of the existing RGS database as an exploration tool for the discovery of hidden mineralization.

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