



## DETAILED GEOCHEMICAL EXPLORATION TECHNIQUES FOR BASE AND PRECIOUS METALS IN THE KOOTENAY TERRANE (82L/13, 82L/14, 82M/4, 82M/5, 92P/1)

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**KEYWORDS:** Kootenay Terrane, Geochemistry, Sulphide deposits, Pathfinder Elements, Soil, Till.

### INTRODUCTION

There is high potential for economic gold and polymetallic sulphide mineralization in the Cambrian to Mississippian rocks that form the Eagle Bay Assemblage within the Kootenay Terrane. These rocks presently host a number of gold-base metal sulphide deposits such as Homestake (MINFILE 82M025) and Samatosum (MINFILE 82M244). There are, however, a number of challenges to exploration for new deposits including the relatively small size of massive sulphide bodies, misleading electromagnetic response due to graphitic interbeds in sulphide-bearing host rocks, and limited bedrock exposure due to extensive drift cover. As part of an integrated project to better understand mineral potential of the Kootenay Terrane a regional stream water survey, detailed geochemical studies, regional till geochemical surveys, surficial mapping and mineral deposit studies have been undertaken between 1996 and 1998 by the Geological Survey Branch. The till geochemical surveys have covered NTS sheets 82M/4 and 82M/5 (Bobrowsky *et al.*, 1997), the western half of NTS sheets, 92P/1 and 8 (Paulen *et al.*, 1998) and parts of NTS P/9, 82M/3, 82L/13 and 82L/14 (Paulen *et al.*, 1999).

Stream sediment and basal till geochemistry successfully detected the larger massive-sulphide deposits such as Samatosum (Matysek *et al.*, 1991; Dixon-Warren 1998) because anomalous dispersal plumes for copper, cobalt, gold, lead and zinc in the till and copper dispersion patterns in drainage sediment are well developed. Till geochemical patterns can be a misleading indication of mineralization because there can be multiple bedrock sources for glacially transported materi-

al. Also, high pH conditions created by weathering of carbonate interbeds will inhibit the secondary geochemical dispersion of more mobile elements (e.g. zinc) in surface water, streams sediments and soil. Consequently, element patterns formed in soil over thick till may be small and more difficult to detect without a detailed sampling program. The identity of a sulphide mineral source can be better defined using pathfinder elements such as arsenic for gold and mercury or cadmium for copper-lead-zinc sulphides.

The objectives of the detailed geochemical studies described here are to:

- ♦ Discriminate between different sources of mineralized material reflected in the geochemistry of down-ice dispersal plumes.
- ♦ Compare the geochemical expression of different types of base and precious-metal mineralization in soil and underlying till to establish the most effective and economical follow-up geochemical technique (e.g. sampling strategy, analytical methods, ore indicator metals, mineralization pathfinder elements).
- ♦ Compare the effectiveness of different geochemical methods such as stream sediment, stream water, till and soil for detecting base and precious metal mineralization in the Kootenay Terrane.

As far as possible the detailed geochemical studies have been integrated with the regional till surveys and mineral deposit studies. Detailed geochemical studies in 1997 (Lett *et al.*, 1998) focused on the Cam-Gloria (MINFILE M266) gold-bismuth prospect and two base metal sulphide occurrences north-west of North Barriere Lake. Selenium and arsenic were identified as useful pathfinders for precious-base metal massive sulphide mineralization. High

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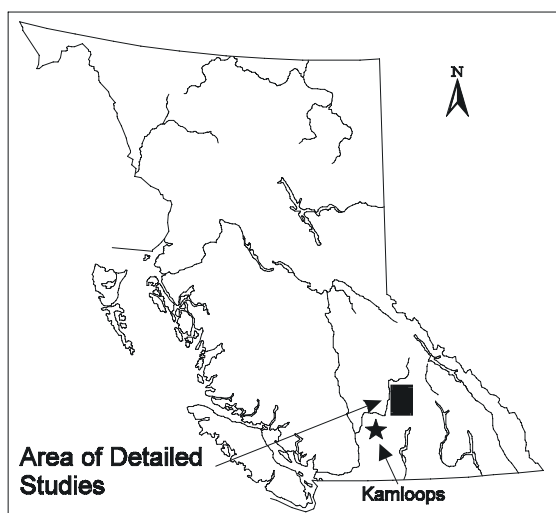


Figure 1. Location of detailed studies.

gold, bismuth, lead and arsenic in the till near Honeymoon Bay on Adams Lake originated from gold-sulphide mineralization in the Cam-Gloria quartz-vein.

Detailed studies carried out in 1998 centered on the area shown in Figure 1. This paper provides a summary of detailed geochemical studies to date including new areas investigated in 1998. In addition, till and soil geochemical data from the area around the Samatosum, and Rea deposits are compared to show how pathfinder element signatures can distinguish between different types of gold-base metal sulphide deposits.

## GEOCHEMICAL SIGNATURES OF MINERALIZATION

Each mineral deposit type has a distinct primary trace element signature that, depending on the degree of weathering, may be closely reflected in till, soil or stream sediment geochemistry. These signature or pathfinder elements can be particularly useful in distinguishing between multiple sources of mineralized bedrock in glacial dispersal plumes. Minor and trace element associations typical of gold and base-metal sulphide deposits in the Kootenay terrane around Adams Lake (Nelson *et al.*, 1997; Höy, 1991, 1996, 1998, 1999; Schiarizza and Preto, 1987) are:

- ♦ Volcanogenic gold-copper-lead-zinc-sulphide and barite deposits hosted predominantly by felsic volcanic rocks of the Eagle Bay Assemblage. Examples of this type are

the Homestake (MINFILE 82M025), Rea Gold (MINFILE 82M191), Samatosum (MINFILE 82M244), Harper (MINFILE 82M060), and Scotch Creek (MINFILE 82LNW046). Pathfinder elements for this type of deposit are arsenic, barium, mercury, cadmium, selenium, tin, bismuth and potassium.

- ♦ Massive, volcanogenic copper-zinc sulphide deposits hosted predominantly by metasediments of the Eagle Bay Assemblage. The Mount Armour occurrence (MINFILE 92P050) is an example of this type of deposit. Pathfinder elements for this type of deposit are sodium, magnesium, cobalt, nickel and arsenic.
- ♦ Massive, volcanogenic copper-zinc sulphide deposits in mafic volcanic rocks. The Chu Chua deposit (MINFILE 92P140) hosted by mafic flows and tuffs of the Fennell Formation is an example of this type. Pathfinder elements for this type of deposit are cobalt, chromium and nickel.
- ♦ Massive, lead-zinc-silver sulphide deposits hosted by metasedimentary rocks of the Eagle Bay Assemblage. An example of this type is the Spar occurrence (MINFILE 82M017). Pathfinder elements for this type of deposit are potassium, barium and manganese.
- ♦ Disseminated copper-molybdenum sulphide deposits hosted by metavolcanic and metasedimentary rocks of the Eagle Bay Assemblage adjacent to Devonian orthogneiss. Examples of this type of deposit are Harper Creek (MINFILE 82M017) and the EBL prospect (MINFILE 82M017). Pathfinder elements for this type of deposit are potassium, magnesium, arsenic, antimony, cadmium, fluorine, bismuth, molybdenum and tungsten.
- ♦ Gold mineralized quartz veins in biotite quartz monzonite of the Cretaceous Baldy Batholith. An example, discovered by follow-up of the 1996 regional till geochemical survey is the Cam-Gloria prospect (MINFILE M266). Pathfinder elements for this type of mineralization are bismuth, lead, molybdenum, fluorine and tungsten.

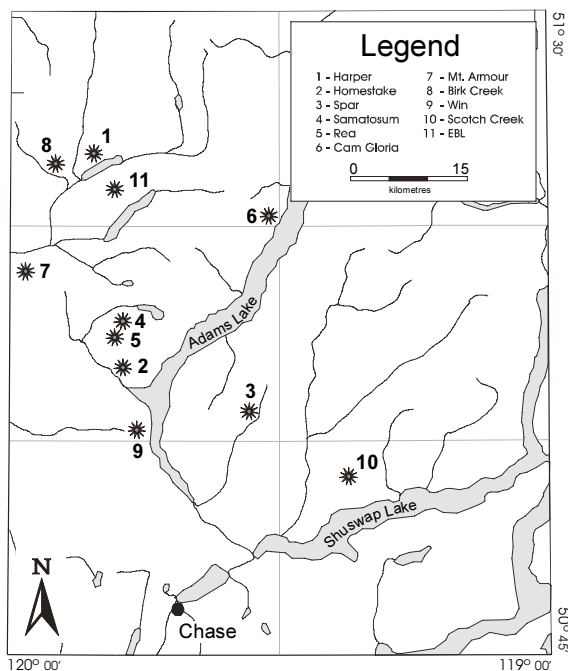


Figure 2. Location of orientation sites.

## GEOCHEMICAL ORIENTATION SITES

Detailed geochemical orientation studies were conducted at eleven locations shown in Figure 2. The locations were selected to include the different types of gold and base metal sulphide mineralization and associated till geochemical dispersal trains. Mineralization, host rocks, surficial geology and types of sample collected at each site are summarized in Table 1.

## SAMPLING AND ANALYSIS

Soil and till samples were collected from road cuts or pits at intervals ranging from 20 to 200 metres depending on the size of the mineralized zone or the glacial dispersal plume. Soil and till samples (minus 63 micron fraction) and pulverised rock samples were analysed for over 50 elements including antimony, gold, arsenic, barium, bismuth, cadmium, cobalt, copper, gallium, lead, molybdenum, nickel, mercury, silver, selenium, thallium, tellurium and zinc by a combination of thermal neutron activation (INA), aqua regia digestion-inductively coupled plasma emission spectroscopy (ARICP) and aqua regia digestion-solvent extraction and ultrasonic nebulizer-inductively coupled plasma emission spectroscopy (UARICP). Selected soil and till samples were analysed for major oxides, loss on ignition, carbon, sulphur, barium, scandium, ni-

bium, nickel, strontium, yttrium and zirconium by lithium metaborate fusion-inductively coupled plasma emission spectroscopy and leco combustion. Detection limits for INA, ARICP and UARICP are compared in Table 2. Detection limits for major oxides (e.g. aluminium oxide), carbon and sulphur are typically 0.01 per cent and for barium, scandium, niobium, nickel, strontium, yttrium and zirconium typically 10 ppm. The rock, soil and till samples were prepared by Eco Tech, Laboratories, Kamloops. Neutron activation analyses were carried out by Actlabs, Ancaster, Ontario and the inductively coupled plasma emission analyses were carried out by ACME analytical laboratories, Vancouver.

Each geo-analytical method has certain advantages and limitations. Neutron activation is non-destructive to the sample and provides a "total" estimate of an element concentration. It cannot, however, measure ore-indicator elements such as lead and copper. These can be determined on a separate sample by an aqua regia digestion and inductively coupled plasma emission spectroscopy. An aqua regia digestion, while very effective for dissolving gold, carbonates and sulphides in a sample, cannot completely break down aluminosilicate, oxide and other refractory minerals such as barite. Consequently, element concentrations determined by ARICP are "partial" rather than "total". Aqua regia digestion followed by ultrasonic nebulizer inductively coupled plasma emission spectroscopy (UARICP) enables detection limits for certain elements such as silver, arsenic, bismuth, tellurium and thallium to be improved by an order of magnitude. High levels of copper and other base metals can, however, interfere and decrease the sensitivity of other elements determined by this method.

Reliable interpretation of geochemical data depends on separating real geochemical trends caused by geological changes from those variations due to sampling and/or analytical variations. These variations are typically measured by monitoring the quality of the data through routine analysis of reference standards and duplicate samples. The standards and duplicates are inserted into each batch of 20 prepared samples analysed to measure accuracy and precision. Each batch of 20 samples contains seventeen routine samples, a field duplicate sample

Table 1. Mineralization, geology and samples collected at each study site

Site	Mineralization	Host Rock	Surficial Geology	Samples
1. Harper	Massive pyrite, galena, pyrrhotite, chalcopyrite, sphalerite.	Eagle Bay Assemblage (EBA) phyllites and schist.	Lodgment till veneer derived from Eagle Bay and Baldy Batholith rocks.	Soil-till (69) Rock (10) Vegetation (15)
2. Homestake	Lenses containing barite, pyrite, tetrahedrite, galena, sphalerite, argentite with native silver and gold.	Eagle Bay Assemblage (EBA) quartz-talc-sericite schist; sericite-quartz-phyllite; sericite-chlorite-quartz phyllite.	Colluvium and rock.	Soil-till (16) Rock (2) Vegetation (10)
3. Spar	Banded and massive, pyrite, galena, pyrrhotite, chalcopyrite, sphalerite.	Eagle Bay Assemblage (EBG) siliceous and graphitic phyllites, limestone and greenschist.	Lodgment till blanket derived from Eagle Bay rocks.	Soil-till (25) Rock (5) Vegetation (5)
4. Samatosum	Coarse-grained tetrahedrite, sphalerite, galena, gold chalcopyrite associated with quartz veining.	Eagle Bay Assemblage (EBG) cherty sediment within sequence of mafic volcanics and turbidites.	Lodgment till blanket derived from Eagle Bay rocks, locally anthropogenic (mine site).	Soil-till (30) Rock (10)
5. Rea	Massive sulphide lenses of pyrite, sphalerite, galena, arsenopyrite, quartz, gold and barite.	Eagle Bay Assemblage (EBF) mafic tuff, chert, dark grey tuffaceous sediments.	Lodgment till blanket derived from Eagle Bay rocks, locally anthropogenic (mine site).	Soil-till (30)
6. Cam-Gloria	Pyrite, galena, chalcopyrite bismuth and gold in massive quartz veins.	Baldy Batholith biotite, quartz monzonite.	Ablation till derived from Baldy Batholith.	Soil-till (30) Rock (5)
7. Mount Armour	Massive lenses of pyrite, chalcopyrite, sphalerite.	Eagle Bay Assemblage (EBS) chert, argillite, conglomerate and limestone.	Lodgment till veneer derived from Eagle Bay and Fennel Formation rocks.	Soil-till (70) Rock (5)
8. Broken Ridge	Banded pyrite, chalcopyrite, sphalerite, galena.	Eagle Bay Assemblage (EBA) actinolite schist and gneiss.	Lodgment till veneer derived from Eagle Bay rocks. Colluvium on steeper slopes.	Soil-till (36) Rock (5)
9. Win	Minor disseminated pyrite, chalcopyrite, sphalerite, galena in quartz veins.	Eagle Bay Assemblage (EBA) mafic tuffs, graphitic argillite, and siltstone.	Lodgment till blanket derived from Eagle Bay rocks.	Soil-till (9)
10. Scotch Creek	Massive pyrrhotite, pyrite, galena, chalcopyrite, sphalerite.	Eagle Bay Assemblage (EBA) sericite-chlorite phyllite, graphitic argillite, marble, schist, and iron formation.	Lodgment till blanket derived from Eagle Bay rocks.	Soil-till (16)
11. EBL	Disseminated pyrrhotite, pyrite, chalcopyrite.	Eagle Bay Assemblage (EBQ) biotite-chlorite schist and limestone.	Lodgment till blanket derived from Eagle Bay rocks.	Soil-till (22) Rock (5)

Table 2. Detection limits for aqua regia digestion-inductively coupled plasma emission spectroscopy (ARICP), aqua regia digestion-solvent extraction and ultrasonic nebulizer-inductively coupled plasma emission spectroscopy (UARICP) and neutron activation (INA). nd = not detected by method

Element		ARICP	UARICP	INA
Aluminium	Al	0.01%	0.01%	nd
Antimony	Sb	2 ppm	0.2 ppm	0.1 ppm
Arsenic	As	2 ppm	0.5 ppm	0.5 ppm
Barium	Ba	1 ppm	1 ppm	50 ppm
Bismuth	Bi	2 ppm	0.1 ppm	nd
Boron	B	3 ppm	3 ppm	nd
Bromine	Br	nd	nd	0.5 ppm
Cadmium	Cd	0.2 ppm	10 ppb	nd
Calcium	Ca	0.01%	0.01%	1.00%
Cerium	Ce	nd	nd	3 ppm
Cesium	Cs	nd	nd	1 ppm
Chromium	Cr	1 ppm	1 ppm	5 ppm
Cobalt	Co	1 ppm	1 ppm	1 ppm
Copper	Cu	1 ppm	0.2 ppm	nd
Europium	Eu	nd	nd	0.2 ppm
Hafnium	Hf	nd	nd	1 ppm
Gallium	Ga	nd	0.5 ppm	nd
Gold	Au	2 ppm	100 ppb	2 ppb
Iron	Fe	0.01%	0.01%	0.01%
Lanthanum	La	1 ppm	1 ppm	0.5 ppm
Lead	Pb	3 ppm	0.3 ppm	nd
Lutetium	Lu	nd	nd	0.05 ppm
Magnesium	Mg	0.01%	0.01%	nd
Manganese	Mn	2 ppm	2 ppm	nd
Mercury	Hg	1 ppm	10 ppb	1 ppm
Molybdenum	Mo	1 ppm	0.1 ppm	1 ppm
Nickel	Ni	1 ppm	1 ppm	20 ppm
Neodmium	Nd	nd	nd	5 ppm
Phosphorus	P	10 ppm	10 ppm	nd
Potassium	K	0.01%	0.01%	nd
Samarium	Sm	nd	nd	0.1 ppm
Scandium	Sc	nd	nd	0.1 ppm
Selenium	Se	nd	0.4 ppm	3 ppm
Silver	Ag	0.3 ppm	30 ppb	5 ppm
Sodium	Na	0.01%	0.01%	0.01%
Strontium	Sr	1 ppm	1 ppm	500 ppm
Tantalum	Ta	nd	nd	0.5 ppm
Tellurium	Te	nd	0.2 ppm	nd
Terbium	Tb	nd	nd	0.5 ppm
Titanium	Ti	0.01%	0.01%	nd
Thallium	Tl	5 ppm	0.2 ppm	nd
Thorium	Th	2 ppm	2 ppm	0.2 ppm
Tungsten	W	2 ppm	2 ppm	1 ppm
Uranium	U	5 ppm	5 ppm	0.5 ppm
Vanadium	V	1 ppm	1 ppm	nd
Ytterbium	Y	nd	nd	0.2 ppm
Zinc	Zn	1 ppm	1 ppm	50 ppm

Table 3. Analytical precision at the 95 per cent confidence limit for elements by ICP and INA. ne = not estimated.

Element		ICP (%)	INA (%)
Aluminium	Al	10.20	ne
Antimony	Sb	14.00	ne
Arsenic	As	26.10	6.20
Barium	Ba	18.80	29.00
Bismuth	Bi	90.20	ne
Bromine	Br	ne	ne
Cadmium	Cd	29.00	ne
Calcium	Ca	14.20	26.00
Cerium	Ce	ne	11.20
Cesium	Cs	ne	34.60
Chromium	Cr	9.00	10.10
Cobalt	Co	10.20	7.80
Copper	Cu	8.20	ne
Europium	Eu	12.80	ne
Hafnium	Hf	ne	29.20
Gallium	Ga	13.20	ne
Gold	Au	ne	100.00
Iron	Fe	11.40	5.60
Lanthanum	La	ne	9.30
Lead	Pb	9.60	ne
Lutetium	Lu	ne	14.80
Magnesium	Mg	16.00	ne
Manganese	Mn	6.60	ne
Mercury	Hg	22.80	ne
Molybdenum	Mo	25.40	ne
Nickel	Ni	12.60	ne
Neodmium	Nd	ne	21.00
Phosphorus	P	5.40	ne
Potassium	K	11.20	ne
Samarium	Sm	ne	10.60
Scandium	Sc	ne	7.60
Silver	Ag	16.00	ne
Sodium	Na	71.00	8.10
Strontium	Sr	ne	ne
Tantalum	Ta	ne	ne
Tellurium	Te	ne	ne
Terbium	Tb	ne	ne
Titanium	Ti	12.20	ne
Thallium	Tl	25.80	ne
Thorium	Th	48.80	16.00
Tungsten	W	ne	ne
Uranium	U	ne	43.00
Vanadium	V	6.40	ne
Ytterbium	Y	ne	15.00
Zinc	Zn	5.10	18.00

collected adjacent to one of the routine samples, a blind duplicate sample split from one of the 17 routine samples prior to analysis and a control reference standard containing material of known element concentrations (either Canada Centre for Mineral and Energy Technology certified standard or a Geological Survey Branch 'prepared' bulk soil). The locations of blind duplicate and control reference samples are selected prior to sampling, whereas field duplicate sites are chosen randomly during field-work. The analytical precision (at the 95 per

cent confidence limit) for elements determined by ARICP, UARICP and INA from fourteen replicate analyses of a Geological Survey Branch reference standard is shown in Table 3. The precision for some elements (e.g. boron) has not been calculated because all values are below detection limit. Also, low precision indicated by a high value in Table 3 does not necessarily mean that the analysis of a particular element is unreliable because the concentration of that element in the standard can be close to or below detection limit.

### GEOCHEMICAL EXPRESSION OF THE SAMATOSUM AND REA DEPOSITS

Bedrock, soil and till geochemical data produced from the 1997 detailed sampling program in the area south east from the Samatosum and Rea deposits serves to illustrate how pathfinder elements can distinguish between different sources of mineralized bedrock. Surficial and bedrock geology of the area between Johnson Creek and Adams Lake are shown in Figure 3. Geology of the area around the Samatosum and Rea deposits comprises a northwest trending, northeast dipping sequence of mafic volcanics, mixed cherty argillites, black distal turbidites, minor amounts of felsic volcanics and recrystallized limestone. The Samatosum deposit occurs in cherty mixed sediments close to the contact between greenstone to the northeast and metasediments to the south-west. Mineralization at Samatosum consists of coarse-grained tetrahedrite, sphalerite, galena and chalcopyrite associated with quartz veining whereas at Rea the mineralization is dominated by fine grained arsenopyrite, pyrite, sphalerite, galena, quartz and barite.

Terrain mapping (Dixon-Warren, 1998) has identified that the surficial sediment in the area between Johnson Creek and Adams Lake is predominantly a single, locally derived, basal till deposited by ice that moved from the north or northwest to southeast. The distribution of gold, arsenic, silver, copper, cadmium, lead and zinc in basal till samples collected during the 1996 regional survey (Dixon-Warren, 1998) reveals high element concentrations forming ribbon-shaped plumes down-ice from the Samatosum and Rea deposits. These plumes trend parallel to the

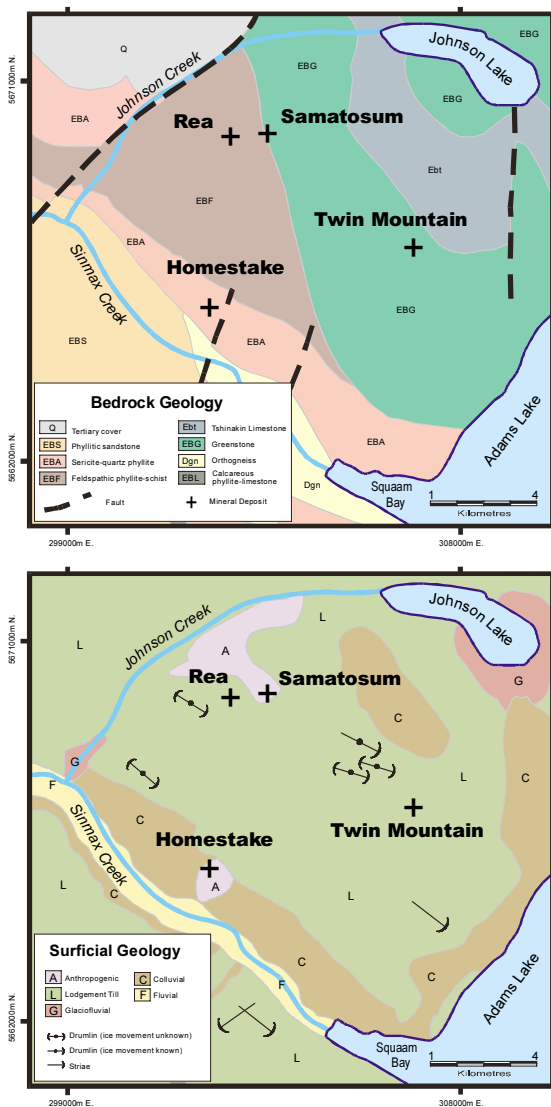


Figure 3. Bedrock Geology (from Schiarizza and Preto, 1987) and Surficial Geology (from Dixon-Warren, 1998).

direction of ice flow or form isolated clusters of values. Regionally, there is a moderate correlation between arsenic and gold in the till and maximum concentrations occur near known mineral occurrences. Down-ice from the Samatosum deposit till-clast plumes extend up to 5 kilometres in length whereas the gold-arsenic geochemical dispersal train can be detected up to 10 kilometres.

Examination of element data for 33 till samples collected in 1997 along profiles crossing the down-ice dispersal plume confirms a moderate statistical correlation (+0.7 coefficient) between gold and arsenic and a much stronger correlation (> +0.80 coefficient) between: cadmium-zinc-thallium-tellurium (sphalerite), copper-cobalt-iron (sulphides), magnesium-nickel-cobalt-

chromium-vanadium (mafic bedrock), mercury-antimony-silver (sulphides) and barium-molybdenum-selenium (barite-sulphides).

The spatial distribution of gold, lead, barium and mercury in the till samples (Figure 4) reveals dispersal plumes extending down-ice from the Samatosum and Rea deposits. Gold values fall sharply immediately southeast of the Samatosum deposit and then increase to a maximum concentration at 1.8 kilometres down-ice. The variation of lead, arsenic, antimony, cobalt, copper, chromium, silver and zinc along the down-ice profile is similar to gold and the fluctuation of values most likely reflects the influence of bedrock topography and till thickness on the dispersal of elements (Yeow, 1998). These elements are typical of those associated with the Samatosum mineralization. In contrast to the till geochemical signature of the Samatosum deposit, higher barium and mercury values occur with gold and arsenic down-ice from the Rea deposit. This element association most likely reflects the different mineralogy of the Rea mineralization. The full extent of the down-ice dispersal plumes from Samatosum and Rea is difficult to determine, however, due to the wide distribution of sample locations. As a result, the cluster of high gold, copper, mercury, barium and silver in the till about 5 kilometres southeast from the Samatosum deposit may reflect local dispersal of mineralized material from the Twin Mountain galena-sphalerite-chalcopyrite-barite occurrence.

A comparison between metals in the B-soil horizon and till is illustrated by gold and arsenic in Figure 5. While both elements can be detected in the B-soil horizon concentrations in soil are lower and there is a much weaker expression of the Rea mineralization compared to that in the till. Other elements (e.g. mercury, lead, zinc) also show smaller patterns in the soil. This difference can be explained by the expression of mineralized bedrock at different locations along an idealized dispersal plume (Figure 6). Close to the bedrock source a long, thin geochemical signature can be expected in the till whereas at a greater distance down-ice from the source the patterns detected will be smaller because of dilution. Secondary dispersion of more mobile elements (e.g. copper and zinc) can further distort and displace the soil geochemical anomaly away from the till dispersal plume.

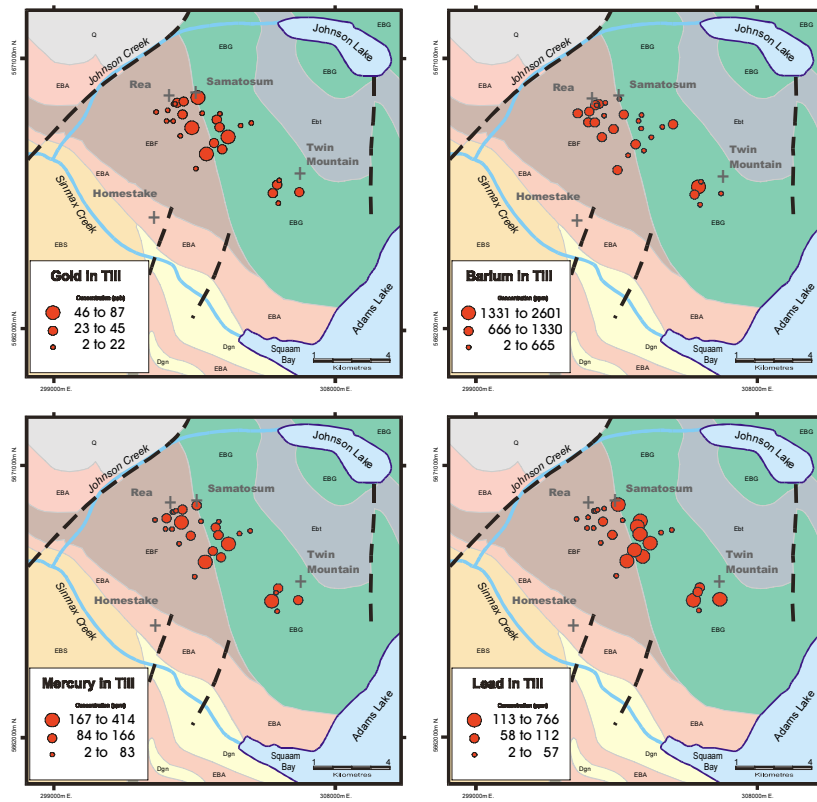


Figure 4. Gold, lead, barium and mercury in till samples.

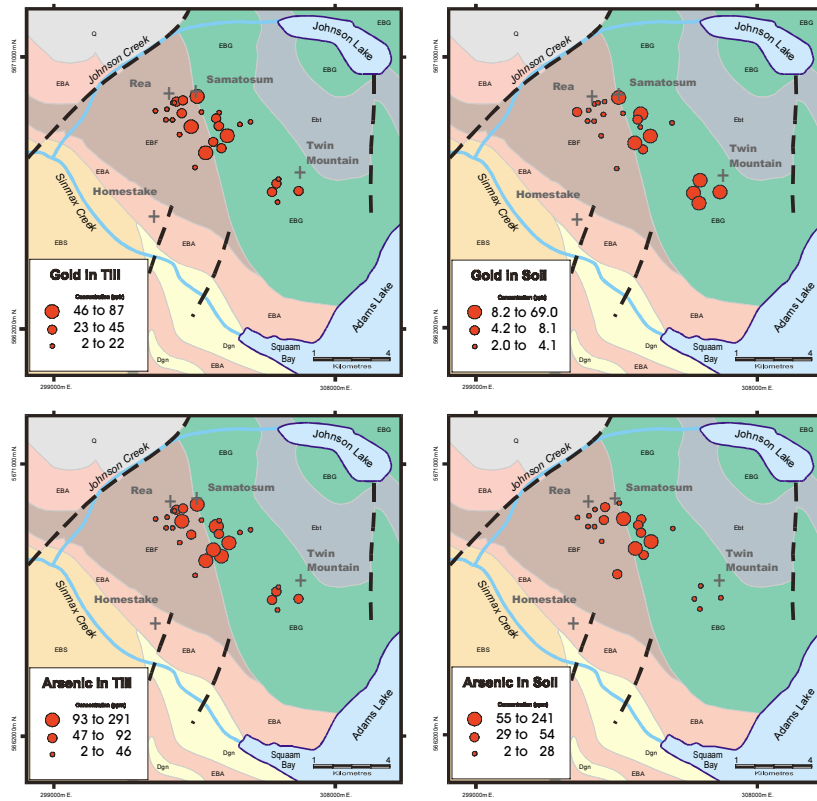


Figure 5. Comparison of gold and arsenic distribution in till and B-soil horizon samples.



# Ice Flow

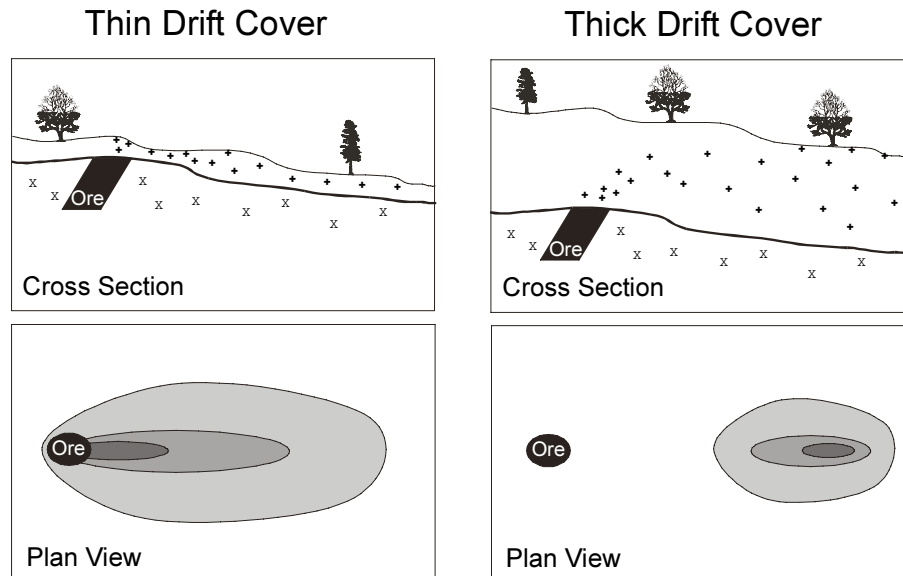


Figure 6. Geochemical signatures for mineralized bedrock in till.

## CONCLUSIONS

Detailed geochemical till, soil and rock sampling has been completed at eleven locations in an area of the Kootenay Terrane, including the Samatosum gold-base metal sulphide deposit. The aim of the studies has been to improve geochemical exploration methods for base and precious metals in the Kootenay Terrane. Detailed sampling east of the Samatosum-Rea deposits has confirmed down-ice geochemical dispersal plumes for gold, arsenic, silver, copper, cadmium, lead and zinc originally identified by a regional till survey. The detailed sampling also revealed that higher barium appears to be a pathfinder for the Rea mineralization. Soil geochemical patterns are smaller than those for corresponding elements in till due to dilution of mineralized material in the dispersal plume down-ice from the bedrock source.

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