Geochemical Orientation Surveys in the Quesnel Terrane between Quesnel and Williams Lake, central British Columbia (NTS 093A, B, G)

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INTRODUCTION

Orientation surveys are an essential part of any large-scale geochemical program because they serve to establish optimum sampling and analytical techniques. Among variables that need to be determined by a soils orientation are the sample density, soil horizon, sample grain size or mineral fraction, and analytical method. Establishing geochemical background for each element, either by reference to literature values or by calculating statistics from the orientation survey data, is the first stage in defining an anomaly. Closely linked to establishing background is deciding on the combination of sample grain size, sample digestion technique and element detection method that will give the greatest anomaly contrast (signal to noise ratio) for all ore indicator and pathfinder elements.

Selective and sequential metal extractions have long been used in stream sediment and soil surveys to improve geochemical anomaly contrast. For example, Cameron et al. (2004) showed that selective extraction techniques, such as Enzyme Leach^{SM} and Mobile Metal Ion^{SM} analysis, are often able to better detect sulphide and other types of mineralization beneath thick surficial deposits by enhancing geochemical anomaly contrast. The factors that govern element transport and migration from source to site of accumulation must be appreciated for correctly interpreting the subtle but often distinct element patterns revealed in selective extraction data. Among the factors influencing element dispersion are lithogeochemistry, bedrock geology, surficial geology (including stratigraphy and material thickness), glacial erosion and transport of mineralization from a bedrock source, soil drainage, soil-forming processes, soil redox potential and soil pH.

Geochemical models can help estimate the influence of these variables on anomaly formation by visually demonstrating the relationships between a mineral deposit and its geochemical response in the near-surface environment. First proposed by Bradshaw (1975) for the Canadian Cordillera, conceptual geochemical models have most recently been adapted by Butt et al. (2005) in Australia to simplify the interpretion of complex survey data with visual three-dimensional diagrams. Lett and Bradshaw (2002) proposed developing an atlas of similar geochemical models supported by real analytical and field data from Cordilleran case histories. For example, Hoffman and Perkins (1990) developed a geochemical model for Au-Cu porphyry mineralization, from geology and lithogeochemical studies, to explain the results of multi-element soil surveys on the Cat Mountain deposit in central British Columbia. Their model proposed concentric lithogeochemical zones radiating from a W-Ag core into a Mo zone, a Au zone, a Cu-Co-Fe zone and, finally, a peripheral As-Al-V-Mn zone. Depending on the erosion level of the Cu-Au-mineralized bedrock, there was a lateral transition from the peripheral As-Al-V-Mn into a Pb-Zn zone.

Much of the current mineral exploration in British Columbia has focused on Quesnel Terrane rocks because of production from economic Cu-Au deposits such as Mount Polley. Although there have been few specific orientation studies to determine the near-surface geochemical expression of Cu-Au porphyry deposits, the results of recent orientation surveys over epithermal Au mineralization have been published by Cook and Dunn (2007). They demonstrated that the partial extraction of trace elements using Enzyme Leach and Mobile Metal Ion analysis from soil samples collected over the Tommy and Ted Au-mineralized epithermal vein near Vanderhoof, BC could improve geochemical contrast compared to results from more rigorous acid digestion. Many of the elements detected by the partial extraction used by Cook and Dunn (2007) were important pathfinders for base and precious metal mineralization. Hall (1998) described a number of the more recently developed partial extraction methods and assessed the analytical precision for geochemical pathfinders determined by these techniques. Not only is the analytical method (e.g., Enzyme Leach) important for enhancing contrast, but so too is the element suite that best characterizes mineralization. Improved geochemical techniques need to be developed for detecting more deeply buried mineral deposits, since much of central BC has an extensive cover of plateau basalts and glacially transported overburden. Here we report preliminary results of orientation geochemical studies over the Mouse Mountain (MINFILE 093G 003) and Shiko Lake (MINFILE 093A 058) porphyry Cu-Au mineral occurrences, as well as a target for possible Cu mineralization near Soda Creek. The locations of these three areas are shown in Figure 1.

SURVEY TECHNIQUES

Field Sampling

Samples from major soil horizons were taken down vertical profiles at specific intervals in the Mouse Mountain, Shiko Lake and Soda Creek areas. The profiles were

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located at stations along road and bush traverses that were generally orientated perpendicular to the regional ice-flow direction. Several sampling traverses up and down-ice of a mineralized zone (where known) were completed, although it was often not practical to carry out an extensive or regular sampling pattern. Where possible, the following samples were taken from:

- the decomposed humus (F-H) horizon, just beneath the surface vegetation litter;
- the upper B soil horizon, just beneath the eluviated (Ae) horizon (where visible);
- the lower B soil horizon close to the transition between the B and C soil horizons;
- a depth of 20 to 25 cm for Mobile Metal Ion analysis; and
- the C soil horizon glacial sediment (typically till).

Eighty-eight upper B-horizon, 84 lower B-horizon and 83 C-horizon samples were taken (including quality-control field duplicates). Median midpoint depths of the upper B, lower B and C-horizon samples were 16.0 cm (1st to 3rd quartile ranged from 13 to 18 cm), 26 cm (1st to 3rd quartile ranged from 24 to 26 cm) and 43 cm (1st to 3rd quartile ranged from 36 to 57 cm), respectively. Horizons were identified in the field using the Canadian Soil Classification Working Group (1998) nomenclature. However, distinction between 'upper' and 'lower' B horizon is often arbitrary because there is commonly only a subtle change in soil colour and texture within a given profile.

The samples were collected from hand-dug pits or from trenches excavated in road cuts. Profile sites were accurately located with a Garmin Map 60 hand-held GPS unit. Duplicate samples were taken at a frequency of one duplicate per twenty routine samples. Depth, soil texture, soil colour (Munsell Classification) and structure were described for each sample taken, with details on the percentage, size and shape of rock clasts and presence (or absence) of clast striations recorded. Still digital photographs were taken of each profile and a short video made to record details of the area surrounding the station. At the end of each day, the B-horizon pH was measured on a 1:1 (by volume) slurry of soil to distilled water with an Extech$^{®}$ Instruments Corporation P110 pH meter calibrated daily with pH 4 and 7 buffers. Multiple samples were collected from each horizon for use in different analytical methods. For example, B-horizon soil and litter samples for aqua regia digestion – inductively coupled plasma – mass spectrometry (ICP-MS) analysis were collected in Hubco Inc. polyester weave bags, and the C-horizon samples (glacial sediment) were collected in large PVC bags. Samples intended for Enzyme Leach^{SM}, Soil Gas Hydrocarbons^{SM} and Mobile Metal Ion^{SM} analysis were collected and double-bagged in sealed PVC Ziploc$^{®}$ bags. A number of sediment samples were also collected in Hubco bags from streams in the areas surveyed. A typical soil from the Mouse Mountain area is shown in Figure 2.

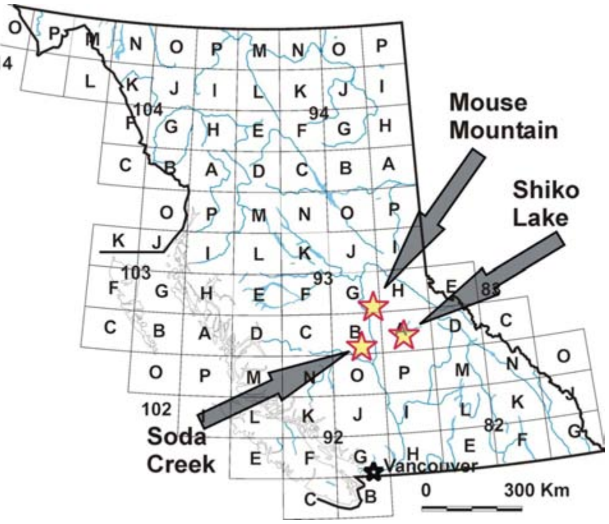

Figure 1. Location of the Mouse Mountain, Shiko Lake and Soda Creek survey areas, central British Columbia.

Sample Preparation

The F-H, B and C-horizon samples were oven dried at 35 to 40ºC and prepared in the British Columbia Geological Survey laboratory, Victoria, BC before being sent for analysis at commercial laboratories. The F-H-horizon samples were milled. Part of the B-horizon sample and stream sediment samples were disaggregated and sieved to –80 mesh (<0.180 mm), whereas C-horizon (glacial sediment) samples were sieved to –230 mesh (<0.063 mm). The +2 mm size fraction of the glacial sediment was archived for later identification of clast lithology. Sieved or milled duplicate samples (generally from one of the field replicates) and standard reference materials were inserted into each batch of 20 samples before analysis. No preparation was carried

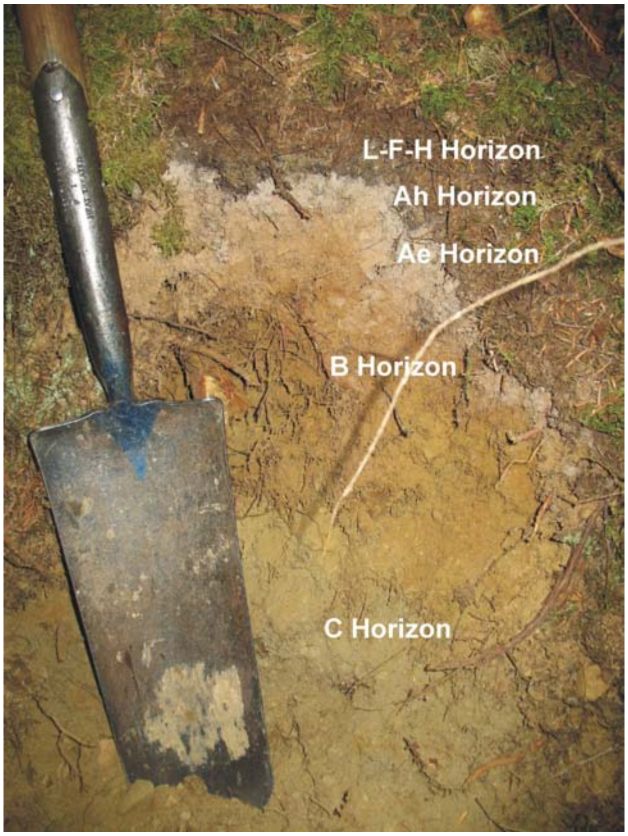

Figure 2. Profile showing Brunisolic soil developed on till, Mouse Mountain area.

TABLE 1. ELEMENTS DETERMINED BY AQUA REGIA – INDUCTIVELY COUPLED PLASMA – MASS SPECTROMETRY (AR-ICP), INSTRUMENTAL NEUTRON ACTIVATION ANALYSIS (INAA), MOBILE METAL ION ^{SM} (MMI) AND ENZYME LEACH^{SM} (EL) ANALYSIS, WITH INSTRUMENTAL DETECTION LIMITS. DETECTION LIMITS FOR ALL ELEMENTS BY EL AND MMI ARE IN PARTS PER BILLION (PPB); ELEMENTS DETERMINED BY AR-ICP AND INAA ARE IN PARTS PER MILLION (PPM). EL RESULTS FOR CL, HG, SC AND TI ARE SEMIQUANTITATIVE.

Element	AR-ICP (ppm)	INAA (ppm)	MMI (ppb)	EL (ppb)
Ag	0.002	5	1	0.2
Al	100		1	
As	0.1	0.5	10	1
Au	0.002	0.002	0.1	0.05
B	1			
Ba	0.5	50	10	1
Be				2
Bi	0.02		1	0.8
Br		0.5		5
Ca	100	10000	10	
Cd	0.01		1	0.2
Ce		3	5	0.1
Cl				2000
Co	0.1	1	5	1
Cr	0.5	5	100	20
Cs		1		0.1
Cu	0.01		10	3
Dy			1	0.1
Er			0.5	0.1
Eu		0.2	0.5	0.1
Fe	100	100	1	
Ga	0.2			1
Gd			1	0.1
Ge				0.5
Hf		1		0.1
Hg	0.005	1		1SQ
Ho				0.1
I				2
In				0.1
K	100			
Ir		0.005		
La	0.5	0.5	1	0.1
Li			5	2
Lu				0.1
Mg	100		1	
Mn	1			1
Mo	0.01	1	5	1
Na	100	100		
Nb			0.5	1
Nd		5	1	0.1
Ni	0.1	20	5	3
Os				1
P	10			
Pb	0.01		10	1
Pr			1	0.1
Pt			1	1
Pd			1	1
Rb		15	5	1
Re				0.01
Rh				
Ru				1
S	20			
Sb	0.02	0.1	1	0.1
Sc	0.1		5	100SQ
Se	0.1	3		5
Sm		0.1	1	0.1
Sn		200	1	0.8
Sr	0.5	50	10	1
Ta		0.5	1	0.1
Tb		0.5	1	0.1
Te	0.02		10	1
Th	0.1		0.5	0.1
Ti	10		3	100SQ
Tl	0.02		0.5	0.1
Tm				0.1
U	0.1	0.5	1	0.1
V	2			1
W	0.2	1	1	1
Y			5	0.5
Yb		0.5	1	0.1
Zn	0.1	50	20	10
Zr			5	1

out on the soil samples sent for Enzyme Leach, Soil Gas Hydrocarbons and Mobile Metal Ion analysis.

Sample Analysis

Analysis of samples is currently in progress by the following methods:

- **Aqua regia digestion – ICP-MS:** The <0.18 mm soil and <0.063 mm glacial sediment fractions have been analyzed for 37 elements, including Au and Cu, at Acme Analytical Laboratories, Vancouver, BC by aqua regia digestion (HNO_3-HCl-H_2O 1:1:1 by volume), followed by ICP-MS.
- **Instrumental neutron activation analysis (INAA):** The <0.180 mm soil and <0.063 mm glacial sediment fractions are being analyzed for 33 elements, including Au, at Activation Laboratories Limited, Ancaster, Ontario by INAA. This method involves irradiation of either a 5 or 20 g sample in a high-density neutron flux, followed by counting the gamma-ray emission from elements after a decay period.
- **Enzyme Leach^{SM} analysis:** This technique, developed by Activation Laboratories Limited, Ancaster, Ontario, detects small element variations in B-horizon soils over and around mineral deposits by selectively removing the amorphous manganese dioxide soil-particle coatings with hydrogen peroxide, thereby releasing trapped trace elements (Yeager et al., 1998).
- **Soil Gas Hydrocarbons (SGH)^{SM}:** Developed by Activation Laboratories Limited, Ancaster, Ontario, this is an extractive procedure for C5 to C17 organic compounds that have been absorbed on B-horizon soil samples. The procedure is designed to measure these compounds in the low parts per trillion (ppt) concentration range.
- **Mobile Metal Ion (MMI)^{SM} analysis:** This technique, developed by Mann et al. (1998), utilizes reagents containing strong ligands designed to extract metals such as Cu, Pb, Zn, Ni, Cd, Au, Ag, Co and Pd from soil samples.
- **Loss-on-ignition (LOI):** LOI of soil samples at 500ºC was determined on the <0.180 mm fraction of the B-horizon soil samples at Acme Analytical Limited, Vancouver, BC.

Elements analyzed and detection limits for the aqua regia – ICP-MS, INAA, Enzyme Leach, and Mobile Metal Ion analytical methods are listed in Table 1.

SURVEY AREAS

Mouse Mountain

Soil profiles were sampled over part of the Mouse Mountain mineral occurrence (MINFILE 093G 003), a property located 10 km east of Quesnel, BC and currently being developed by Richfield Ventures Corp. Undulating topography around Mouse Mountain is typical of the Fraser River basin, where most of the surface below 1200 m is drift covered (Holland, 1976). Mouse Mountain, a prominent uneven rocky ridge rising to 1020 m, with a steeper northwest-facing slope and a gentler southeast-facing slope, could be interpreted as a roche moutonnée formed by regional ice flow from the southeast during the late Wisconsinan. Glaciers advanced into the region from both the Coast and Cariboo mountains, resulting in ice-flow events towards the north and northwest, respectively. These ice-flow events were followed by a later northwest advance from the Cariboo Mountains only. Tipper (1971) described north-trending glacial groves as a common glacial landform in the area east of Quesnel and suggested that these features could reflect erosion by one or more glacial advance(s) (or glaciations) across the region. The extent of the last glacial advance into the Mouse Mountain area is uncertain. Glacial sediments deposited on gentler hillsides are typically sandy till, whereas reworked till and colluvium occur on steeper slopes. During final stages of deglaciation, ice blocked the Fraser River and a large proglacial lake filled much of the Fraser River basin. Thick sand and clay units near Prince George are typical of sediments deposited in this lake. Near Mouse Mountain, however, an intermittent thin veneer of sand and gravel could be evidence of the reworking of the underlying till by proglacial lake water (Tipper, 1971).

Undisturbed soil formed on the better drained glacial sediments is mainly a humo-ferric Podzol that supports Douglas-fir, white spruce, lodgepole pine, trembling aspen and paper birch. These are species typical of the Douglas-fir – white spruce ecological subzone (Lord, 1982). Willow, alder and devils club grow densely along valley floors and in wetlands. The area around Mouse Mountain has been extensively logged and there is presently some damage to timber by the mountain pine beetle.

Regional geology of the Mouse Mountain area consists of Triassic arc-related volcanic and sedimentary rocks and Jurassic intrusive complexes (Panteleyev et al., 1996; Logan, 2008). Jonnes and Logan (2007) described the geology, Cu-Au mineralization and alteration of the Mouse Mountain mineral property in detail, so only a summary will be given here. There are three separate northwest-trending zones of pyrite, chalcopyrite, malachite and azurite mineralization within a carbonate-potassic-altered monzonite stock that has intruded Upper Triassic Nicola Group lapilli tuff. Siltstone and pyroxene basalt also crop out on the property. Soil samples were collected along traverses crossing the poorly exposed Rainbow mineralized zone in the northwestern part of the property. Where visible, Cu-Au mineralization at the Rainbow zone consists of disseminated and vein-hosted pyrite, chalcopyrite, malachite and azurite, with traces of fluorite, sphalerite and bornite within ankerite-fuchsite-altered monzonite. Up to 2500 ppm Cu and 100 ppb Au have been reported in rock samples from this zone (Jonnes and Logan, 2007).

Shiko Lake

The Shiko (Redgold) mineral occurrence (MINFILE 093A 058) is a property owned by R. Durfeld and is currently being developed by NovaGold Resources Inc. Detailed soil sampling on this property, located northwest of Shiko Lake, focused on a partly drift-covered, steep-sided ridge 2 km south of Mitchell Bay on Quesnel Lake. The northwest-trending ridge (1020 m) on which the property is situated is typical of the undulating Fraser Plateau to the west and is in contrast to the more rugged Quesnel Highlands (Holland, 1976). Glaciers advanced from the southeast into the region from the Cariboo Mountains, as suggested by rare striations and crescent-shaped rock gouges, with orientations between 280º and 300º (northwest), on ice-polished outcrop. Tipper (1971) described and interpreted various glacial landforms north and west of Quesnel Lake as evidence for two distinct glaciations during the Pleistocene. Given the proximity of Shiko Lake to the Cariboo Mountains, the glacial sediments occurring there are likely the product of the most recent Late Wisconsinan glacial advance (i.e., Fraser Glaciation) and subsequent deglaciation. A predominantly sandy till was deposited that, on steeper slopes, has been mobilized and reworked into colluvium. Sand and gravel deposited during deglaciation have accumulated to a considerable thickness on the floors of major valleys, such as the Horsefly River valley located south of Shiko Lake. Levson and Giles (1993) described an exposure north of Horsefly where a Late Wisconsinan diamicton and glaciofluvial sand and gravel overlie Au-bearing Miocene gravel.

Humo-ferric Podzolic and Brunisolic soils have developed on the better drained sandy till, whereas organic and Gleysolic soils are common in poorly drained depressions. Western red cedar, white spruce and Douglas-fir, lodgepole pine, common paper birch, black cottonwood and trembling aspen form the canopy. Willow, alder and devils club grow thickly in poorly drained areas. The ridge and surrounding area have been extensively logged.

An early Jurassic intrusive complex, which was emplaced in hornfelsed metasedimentary rocks, volcaniclastic rocks and massive plagioclase-pyroxene basalt, dominates the geology of the Shiko Lake property. The intrusive stock consists of an older biotite-pyroxene monzodiorite phase and younger potassium-feldspar syenite and alkaline-feldspar phases. The dominant phase near the centre of the stock is a medium to coarse-grained monzonite containing traces of magnetite, sphene and pyrite. Fine-grained, pink quartz syenite veins and dikes intrude the monzonite and form an intrusive breccia that has a matrix containing chalcopyrite and pyrite. At this mineral occurrence, chalcopyrite, bornite and gold occur in veins and as coarse disseminations, mainly in the youngest quartz syenite but also in the other intrusive phases. Fracture-controlled pervasive potassium alteration and epidote alteration of the volcaniclastic rocks is associated with the Cu mineralization. Earlier potassium and epidote alteration has been cut by late-stage calcite-filled veinlets (Logan and Mihalynuk, 2005). Soil profile sampling focused on the North, Northeast and East zones, where, in addition to recent diamond-drilling, a detailed overburden geochemical survey has been completed by NovaGold Resources Inc.

Soda Creek

Soil profiles were sampled near Soda Creek in an area west of the Fraser River (Fig 1). With gently undulating to flat topography at an elevation of 1000 m, this area has numerous lakes and poorly defined marshy streams. The land surface slopes steeply towards the Fraser River, reflecting erosion of the plateau basalt cover. Tipper (1972) interpreted a few drumlin-like landforms, visible on air photographs, as indicating a northward ice-flow event during the Late Wisconsinan Fraser Glaciation. Till, exposed in roadcuts, has a silty clay matrix and, in one section sampled, is carbonate rich. Soils are predominantly Brunisolic and organic, and support mainly white spruce, Douglas-fir and lodgepole pine.

The Eocene to Pleistocene Chilcotin Group plateau basalt, covering Permian to Triassic Cache Creek marine sedimentary and volcanic rocks, underlies the area surveyed. The thickness of the Chilcotin Group in the area around Coyote Lake is unknown, but Mihalynuk (2007) predicted that, close to the Fraser River valley, the thickness of these volcanic rocks may exceed 100 m.

PRELIMINARY RESULTS

Threshold Values

Mean, median, quartile and percentiles calculated from aqua regia digestion – ICP-MS analyses of 158 upper B and lower B-horizon samples are listed in Table 2. Soil Cu and Au results have been contoured with Manifold GIS software to create sections across the surveyed areas using median and quartile values for contour intervals. Quartiles, as opposed to percentiles, have been used because they are a more robust statistic when the data are suspected to contain several populations. For example, upper B, lower B and C-horizon geochemistry can be expected to represent separate data populations and, ideally, different anomaly thresholds should be calculated for each horizon. The difference between upper B and lower B-horizon geochemistry is demonstrated using the T statistic, which compares the means of the datasets for each element in the two horizons. The T statistic is calculated from the pooled variance and the means from element values for 79 upper B and 79 lower B-horizon samples (Davis, 1973). Table 3 lists the T

TABLE 2. STATISTICS FOR ELEMENTS DETERMINED BY AQUA REGIA – ICP-MS ANALYSIS IN 158 B-HORIZON SAMPLES. THE UPPER FENCE VALUE HAS BEEN CALCULATED BY MULTIPLYING THE DIFFERENCE BETWEEN THE 3RD AND 1ST QUARTILES BY 1.5.

Element	Units	Median	1st quartile	3rd quartile	Upper fence	Maxi-mum	Mean	95th percentile	98th percentile	99th percentile
Ag	ppb	73	46.5	129	252.75	580	99.29	228.2	376.2	470.84
Al	%	1.605	1.28	2.33	3.905	3.83	01.79	3.016	3.3086	3.4358
As	ppm	4.4	2.225	6.1	11.9125	13.2	04.45	9.33	10.93	12.288
Au	ppb	1.2	0.225	3.275	7.85	239.1	07.68	28.69	99.394	142.054
Ba	ppm	77.8	63.425	93.275	138.05	304.2	83.66	131.775	203.498	245.51
Bi	ppm	0.09	0.07	0.12	0.195	0.26	00.10	0.17	0.1986	0.2143
Ca	%	0.315	0.24	0.4	0.64	0.88	00.33	0.613	0.713	0.7686
Cd	ppm	0.125	0.08	0.19	0.355	0.69	00.15	0.38	0.4672	0.6045
Co	ppm	12.8	9.425	18.6	32.3625	34.4	14.27	27.115	30.79	32.188
Cr	ppm	47.2	37.225	63.3	102.4125	128.8	53.10	92.98	104.534	119.167
Cu	ppm	29.255	20.105	43.35	78.2175	482.95	48.82	157.9815	246.3706	276.7893
Fe	%	3.06	2.4325	3.8975	6.095	6.79	03.18	4.8365	5.1216	5.9732
Ga	ppm	5	4	6.7	10.75	13	05.45	9.115	10.23	11.229
Hg	ppb	30	17	40.75	76.375	176	33.39	71.75	125.72	130.29
K	%	0.07	0.05	0.11	0.2	0.4	00.09	0.2215	0.2586	0.333
La	ppm	8.3	6.6	10.9	17.35	21.3	09.10	15	17.93	18.931
LOI	%	6.4	4.5	8.5	14.5	22.5	06.72	10.675	13.994	16.648
Mg	%	0.585	0.44	0.81	1.365	1.94	00.65	1.2215	1.303	1.4216
Mn	ppm	294	223.5	375	602.25	2504	333.07	579.75	811.84	936.73
Mo	ppm	0.59	0.4325	0.74	1.20125	6.09	00.74	1.741	2.8504	3.6046
Na	%	0.008	0.006	0.014	0.026	0.035	00.01	0.028	0.029	0.03229
Ni	ppm	32.5	24.75	53.925	97.6875	205	42.80	97.615	116.268	122.919
P	%	0.0685	0.047	0.10125	0.182625	0.235	00.08	0.1616	0.185	0.22001
Pb	ppm	4.685	4.035	5.875	8.635	15.35	05.22	9.576	10.6248	11.5679
S	%	0.01	-0.01	0.01	0.04	0.05	00.00	0.02	0.03	0.0343
Sb	ppm	0.195	0.1425	0.39	0.76125	0.76	00.26	0.5315	0.6072	0.7001
Sc	ppm	3.2	2.7	4.2	6.45	11.9	04.07	10.015	11.272	11.615
Se	ppm	0.3	0.2	0.4	0.7	1.7	00.29	0.6	0.872	0.9
Sr	ppm	24.2	18.125	29.675	47	87.6	25.89	44.305	65.984	70.367
Te	ppm	0.02	-0.02	0.03	0.105	0.14	00.01	0.06	0.1086	0.13
Th	ppm	2	1.4	2.6	4.4	5.6	02.19	4.2	4.572	4.843
Ti	%	0.083	0.065	0.1155	0.19125	0.637	00.10	0.1777	0.28906	0.44421
Tl	ppm	0.06	0.05	0.0775	0.11875	0.19	00.06	0.1	0.11	0.1329
U	ppm	0.4	0.3	0.4	0.55	1.6	00.39	0.6	0.6	1.5
V	ppm	61	49	71	104	155	61.91	98.45	122.16	130.58
W	ppm	-0.1	-0.1	0.1	0.4	0.7	-00.03	0.2	0.286	0.3
Zn	ppm	72	56.325	85.675	129.7	160.4	73.53	117.655	139.336	151.49

statistic at the 90% confidence level, together with the upper B and lower B means for each element. At the 90% confidence level, for a sample size of 79, a T statistic greater than 2 indicates that there is a significant difference between population means. Most elements (including Cu and Au) do have a T statistic that is greater than 2, although Mo, Ag, Pb and Mn have T statistics less than 2, so there may be no significant difference between their means. An interpretation of these results might be that, although the difference between the population means for upper B and lower B elements is small, there is a significant difference in the soil chemistry for many of the elements. This difference could be the result of different soil-forming processes active in the two horizons and also the presence or absence of metals introduced from mineralized bedrock. Care is needed when collecting samples from soil profiles to avoid the misleading geochemical trends that are introduced by mixing sample populations (e.g., different sample media from different sample depths).

TABLE 3. T STATISTICS FOR ELEMENTS DETERMINED BY AQUA REGIA – ICP-MS ANALYSIS IN UPPER AND LOWER B-HORIZON SAMPLES. DATA FROM ALL SAMPLE AREAS WERE USED TO CALCULATE THE STATISTICS REPRESENTED HERE.

Element	Units	Upper B horizon mean	Lower B horizon mean	T statistic
Ag	ppb	103.76	99.29	2.03
Al	%	1.68	1.79	6.56
As	ppm	4.01	4.45	6.27
Au	ppb	5.01	7.68	3.96
Ba	ppm	86.52	83.66	3.17
Bi	ppm	0.10	0.10	0.12
Ca	%	0.31	0.33	5.81
Cd	ppm	0.17	0.15	5.53
Co	ppm	12.77	14.27	9.70
Cr	ppm	48.89	53.10	7.89
Cu	ppm	40.61	48.82	5.43
Fe	%	2.97	3.18	8.73
Ga	ppm	5.32	5.45	2.82
Hg	ppb	32.33	33.39	1.65
K	%	0.09	0.09	4.29
La	ppm	8.46	9.10	7.67
LOI	%	7.05	6.72	4.55
Mg	%	0.57	0.65	11.67
Mn	ppm	336.13	333.07	0.54
Mo	ppm	0.71	0.74	1.49
Na	%	0.01	0.01	3.49
Ni	ppm	35.73	42.80	10.59
P	%	0.08	0.08	0.78
Pb	ppm	5.20	5.22	0.36
S	%	0.00	0.00	2.25
Sb	ppm	0.25	0.26	4.43
Sc	ppm	3.54	4.07	8.82
Se	ppm	0.27	0.29	4.89
Sr	ppm	24.17	25.89	5.96
Te	ppm	0.01	0.01	1.57
Th	ppm	1.96	2.19	9.42
Ti	%	0.09	0.10	3.20
Tl	ppm	0.06	0.06	5.60
U	ppm	0.36	0.39	6.70
V	ppm	58.76	61.91	6.05
W	ppm	-0.03	-0.03	0.19
Zn	ppm	78.12	73.53	7.61

Element Associations

Correlation matrices were calculated from element data for upper B, lower B and C-horizon samples from the Mouse Mountain and Shiko Lake areas, to examine variations of element association between soil horizons. The Soda Creek area was excluded because there is no confirmed source of metal for any geochemical variations in the soil. Strong (less than +0.70 coefficient) element correlations are revealed between Cu, Co, Fe, Au, W and Se in the C horizon (53 samples); between Cu, Ag, Fe, Au, W and Se in the lower B horizon (53 samples); and between Cu, V, Al, Sc and Ga in the upper B horizon (58 samples). The element associations show that there has been only slight modification of the parent glacial sediment (till) geochemistry into the lower part of the soil profile, but more redistribution of elements due to soil-forming processes in the upper part of the soil.

Mouse Mountain Results

Soil profiles were sampled at 11 stations along traverses north and south of Highway 26. Figure 3 shows the location of profiles across the Mouse Mountain Rainbow mineralized zone. The variation of Cu and Au in the soil over the Rainbow zone is displayed as contoured sections in Figures 4 and 5. Copper values generally increase with depth from the B to the C horizon, and the highest values are in the C horizon towards the east end of the traverse. Increased Cu in the soil from the B to the C horizon may partly reflect a higher metal content in the <0.063 mm fraction of the glacial sediment compared to that in the <0.180 mm fraction in B-horizon soil. At profile 7, there is a C-horizon Cu anomaly (up to 123 ppm) with elevated Ag, V and Hg, and up to 16 ppb Au. The B-horizon pH tends to increase from the upper B to the lower B, with most values being above pH 6. Towards the east end of the traverse, however, where Cu and Au are higher the soil, pH is lower than at profile 6.

Figure 6 shows the locations of eight vertical profiles along logging roads south of Highway 26, an area underlain by geology similar to that at Mouse Mountain. The aim of sampling this area was to compare soil geochemistry with a region remote from Mouse Mountain and that is thought to be unmineralized. Figure 7 shows that the highest Cu (89.9 ppm) in the C horizon at profile 40 is associated with elevated V and Co and the lowest B-horizon pH values (5.47) measured along the traverse. While there are background levels of Cu in profile 39 to the west, the Hg content of the C horizon reaches 482 ppb. Gold values in the soil west of profile 40 are below 5 ppb. However, to the east in profile 44, the Au content of the lower B horizon increases to 24 ppb (Fig 8). Lower values were detected in the underlying C horizon. The higher Au and Cu in profiles could reflect an undetected Cu-Au-mineralized source to the south of the traverse.

Shiko Lake

Figure 9 shows the locations of 30 vertical profiles on the Shiko Lake property, where soil samples were taken. The Cu and Au geochemistry for only five of these profiles will be described here because they show element variations parallel to the regional ice-flow direction (i.e., in the down-ice direction). In addition to the analytical results generated by this study, there is a large database of bedrock, overburden and soil geochemical results generated by NovaGold Resources exploration work on and around the property. Although these company data will be used in conjunction with new analyses from this study when they are available, they will only be used at this time to identify apparent element associations in bedrock and till, and to corroborate the trends observed in selected soil profiles. For example, an element correlation matrix from data for 486 company analyses of overburden samples collected greater than 1 m below the surface reveals an association (coefficient greater than +0.45) between Cu, V and Co, and between Ag, Cd and Pb.

Figure 10 shows Cu variation in soil between profiles 56 and 59. The highest Cu recorded is 1096 ppm in the C horizon of profile 60 at the southeastern end of the traverse. In this profile, Cu values increase from 155 ppm in the upper B horizon to 1096 ppm in the C horizon. A com-

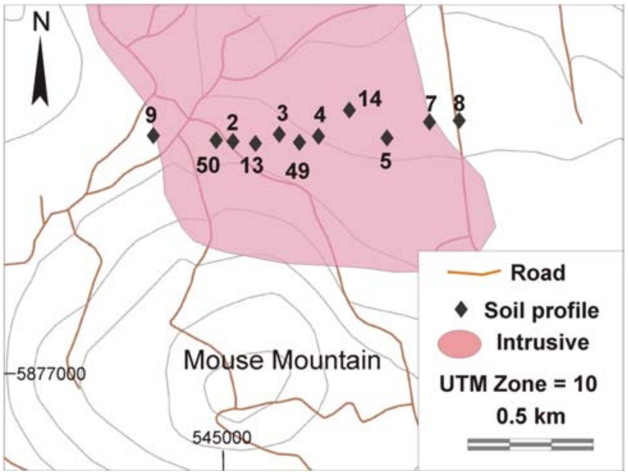

Figure 3. Soil profile locations over the Rainbow zone, Mouse Mountain (geology *after* Jonnes and Logan, 2007).

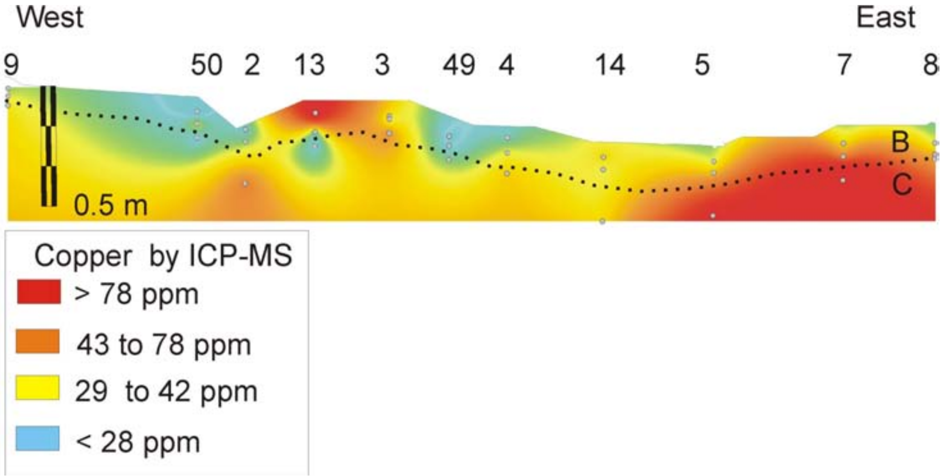

Figure 4. Contoured Cu in soil over the Rainbow zone, Mouse Mountain.

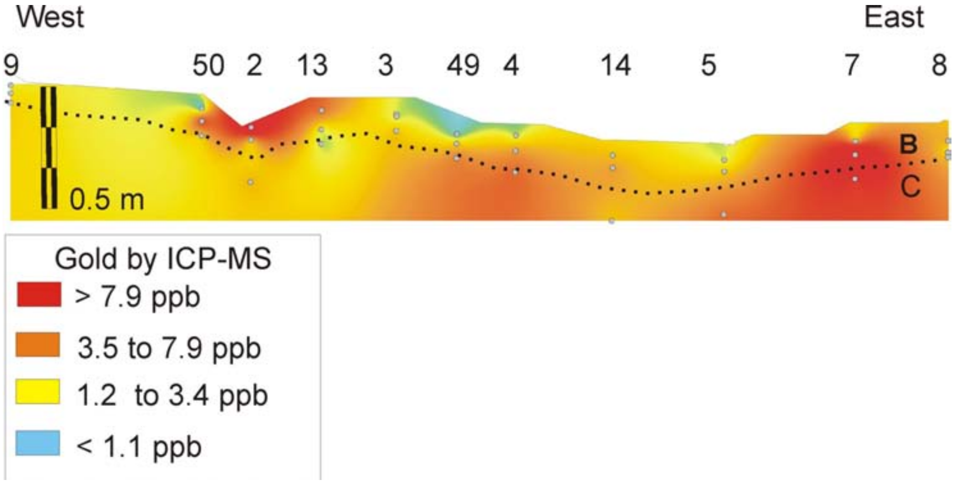

Figure 5. Contoured Au in soil over the Rainbow zone, Mouse Mountain.

pany overburden sample (S-28-18-6), taken near profile 60, contained 487 Cu and 69 ppb Au at 1 m depth. Both lower B and C-horizon samples at profile 60 also have elevated Ag, Co, V and W, with up to 244.8 ppb Au in the C horizon. Element concentrations fall sharply from profile 60 to 62, and Cu values are typically below 120 ppm for soil sampled northwest of profile 62. Gold values, shown in Figure 11, are more variable along the traverse and reach a maximum 156 ppb in the lower B horizon at profile 56. This maximum Au value corresponds to the highest Cu content in the soil.

Soda Creek

Soil samples were taken from vertical profiles located at intervals of about 1 km along two traverses that paralleled forestry access roads east and north of Yorston and Coyote lakes (Fig 12). Soil profiles were sampled to determine if the source of a government regional geochemical survey (RGS) Cu-Ni anomaly in stream sediments collected from Coyote Creek (Jackaman, 2001) could be detected. Copper content in the original stream sediment sam-

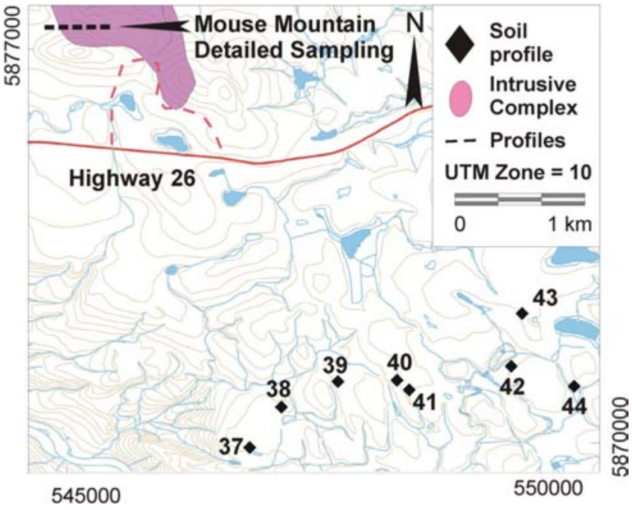

Figure 6. Locations of soil profiles in the area south of Highway 26.

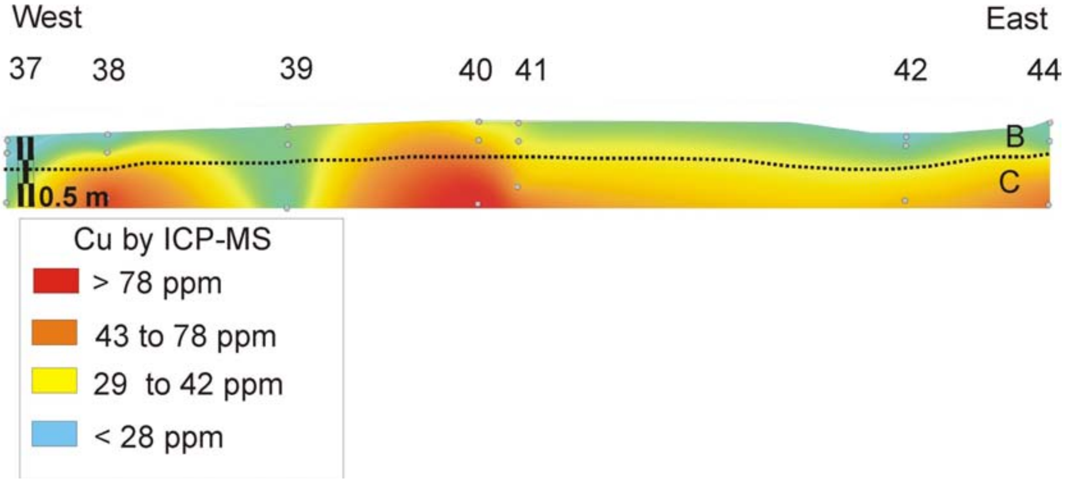

Figure 7. Contoured Cu in soil from profiles south of Mouse Mountain.

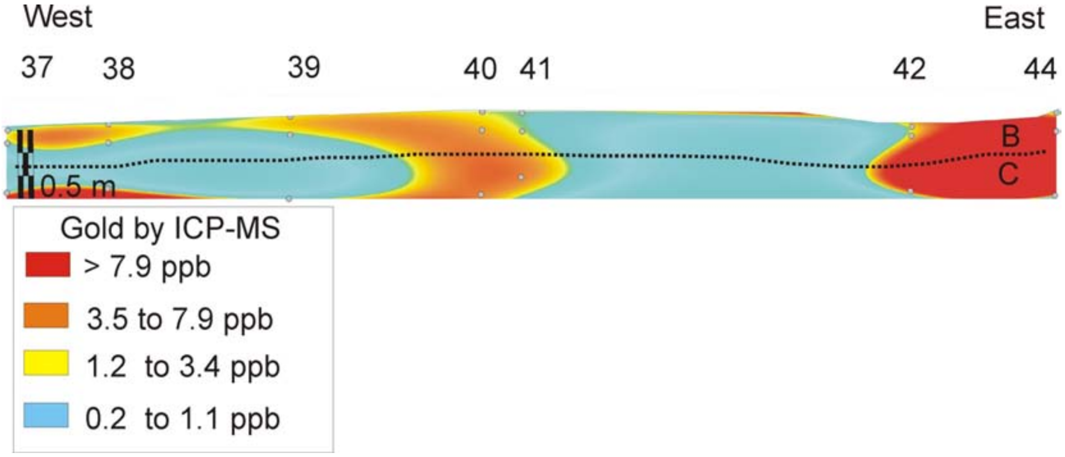

Figure 8. Contoured Au in soil from profiles south of Mouse Mountain.

ple (93B805009) was 164 ppm and the Ni content was 190 ppm. A stream sediment sample collected as part of this study from roughly the same stream site and analyzed by a similar method (<0.180 mm size fraction and aqua regia digestion – ICP-MS) contained 33.4 ppm Cu and 72.6 ppm Ni. Although the sediment has only background Cu values, it still has anomalous Ni as defined by Jackaman (2001) for the NTS 93B regional survey 95th percentile. Part of the geochemical variation between the two samples may be due to the high organic content of the sediment and the stagnant character of the stream. Weathered vesicular basalt boulders lined the stream reach that was sampled, and weathering of these boulders could contribute some of the Cu and Ni to the sediment. Soil profile sampling was also aimed at detecting a possible northwest mineral-rich trend revealed by contoured RGS Cu values. This trend extends beneath the plateau basalts from Quesnel Terrane rocks in the east.

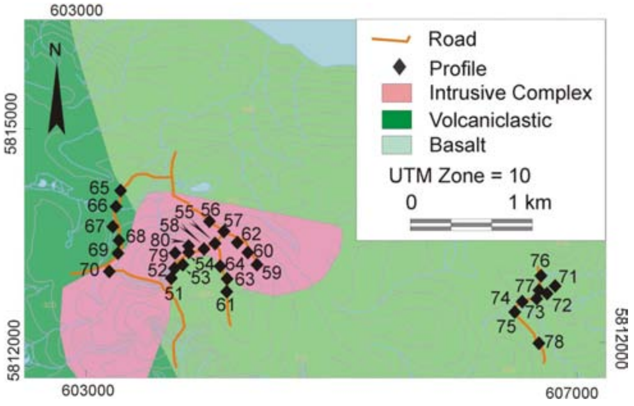

Figure 9. Soil profile locations over the Shiko Lake property (geology *after* Massey et al., 2005).

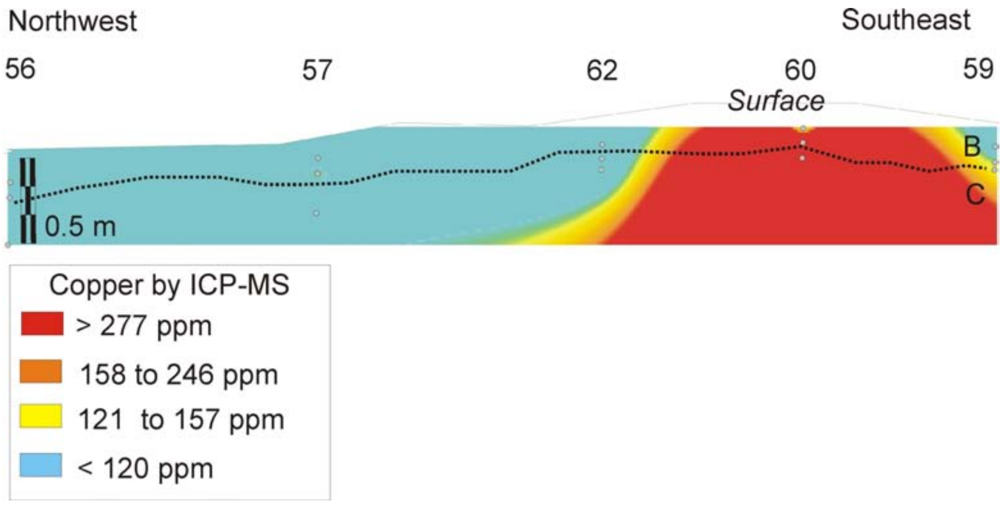

Figure 10. Contoured Cu in soil between profiles 56 and 59, Shiko Lake.

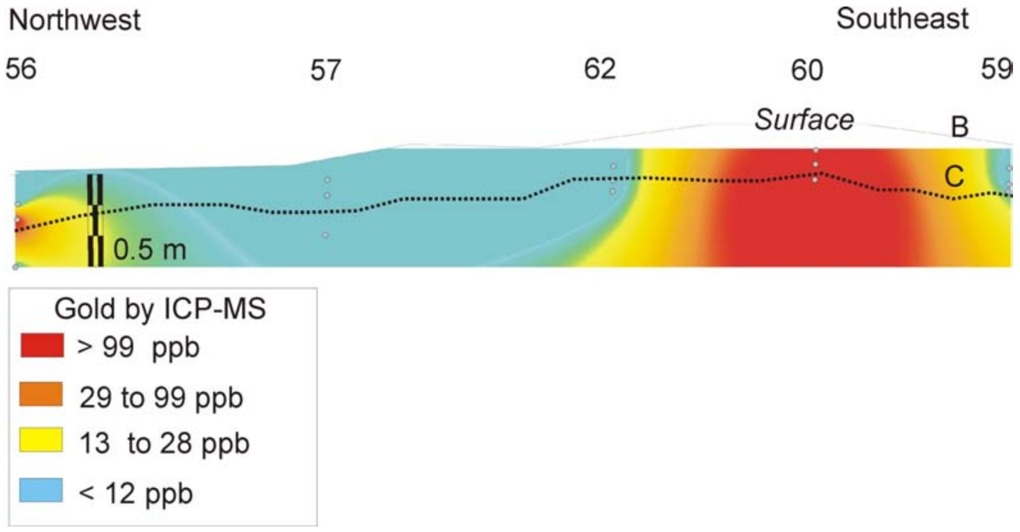

Figure 11. Contoured Au in soil from between profiles 56 and 59, Shiko Lake.

Figures 13 and 14 show contoured soil Cu and Ni along the north-south traverse. Copper is relatively uniform along the traverse and the highest value (50.1 ppm) occurs in the C horizon at profile 20. There is more variation in Ni, however, and values reach 124.9 ppm in the lower B horizon at profile 23. The anomalous Ni is associated with elevated Cr, Fe and Mg, suggesting that the source for these metals may be ultramafic rock incorporated in the till from a source area to the south. Soil pH values range from 5.26 in the upper B horizon to 7.11 in the lower B, and there is no obvious relationship between Ni and Cu chemistry and soil pH. There are no significant changes in Cu and Ni values in soil along the east-west traverse (profiles 10–19 in Fig 11), although the highest Ni value from this study (102.7 ppm) occurs in the C horizon at profile 19. Most Ca values in soil (from either traverse) are below 0.5%, but elevated Ca (2.81%) in the C horizon at profile 11 corresponds to a strong soil reaction with dilute (10%) hydrochloric acid. This Ca-rich C horizon could be till derived from Cache Creek Group rocks to the south.

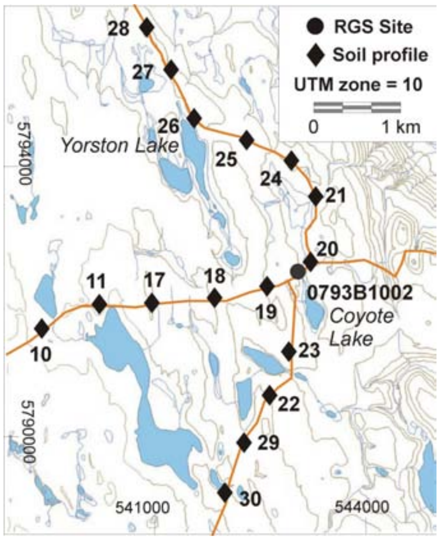

Figure 12. Profile locations in the Yorston and Coyote lakes (Soda Creek) area. Abbreviation: RGS, regional geochemical survey.

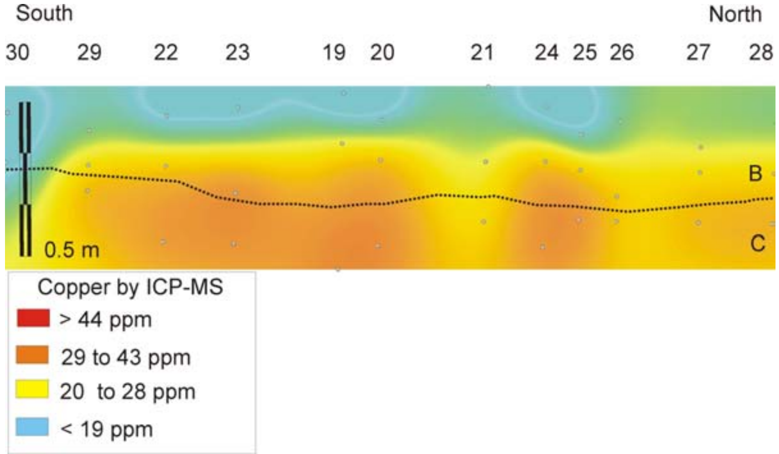

Figure 13. Contoured Cu in soil along a north-south traverse, Yorston and Coyote lakes (Soda Creek) area.

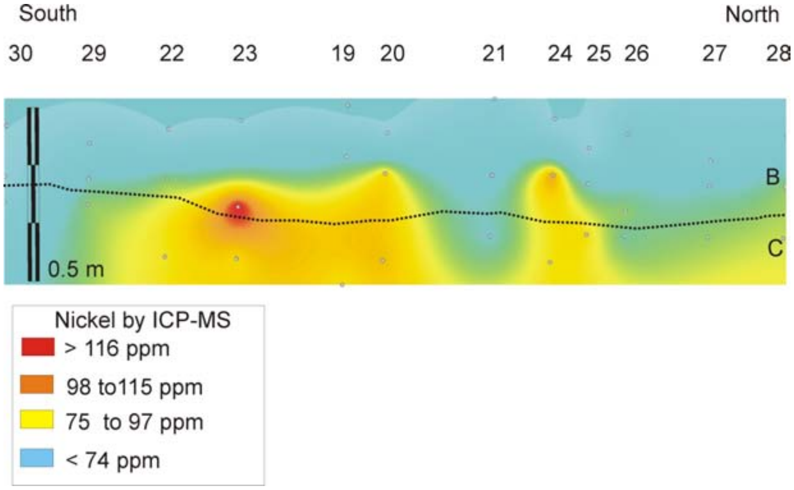

Figure 14. Contoured Ni in soil along a north-south traverse, Yorston and Coyote lakes (Soda Creek) area.

DISCUSSION

There will only be a preliminary discussion of geochemical results in this paper because various analyses (e.g., Enzyme Leach^{SM}, Soil Gas Hydrolysis^{SM} and Mobile Metal Ion^{SM}) are still pending, and these additional data are necessary for a full interpretation of the soil geochemistry within the areas studied. An association of Cu and Au with Ag, V±W and ±Co in the lower B and C horizons at Mouse Mountain and Shiko Lake most likely reflects detrital transport in till of material from mineralized bedrock. At Mouse Mountain, the regional ice flow is from the south and, at Shiko Lake, it is from the southeast. Although sampling at Mouse Mountain has not been sufficient to define the extent of a till dispersal train, the soil sampling at Shiko Lake, coupled with an examination of results from a company till program, suggest that dispersal trains are relatively short and perhaps less than 0.5 km. Levson (2001) reported a displacement distance of less than 100 m for near-surface geochemical anomalies in areas where the till thickness was less than 1 m, whereas the anomalies in thicker till could be displaced more than 500 m from their bedrock source. Given the regional ice-flow direction, the Cu-Au-V-Co anomaly in the C horizon south of Mouse Mountain is intriguing because it suggests a presently unknown mineral source to the south in Nicola Group rocks. Near Yorston and Coyote lakes, west of Soda Creek, the anomalous Ni values in soil are most likely caused by ultramafic rock entrained in the till and transported from the Cache Creek Group to the south.

A provisional model is proposed here for the transport of elements from bedrock into soil based on the geochemical patterns revealed in the soil profiles. The lower B horizon is a product of the underlying C horizon (till), so the geochemistry of the lower B horizon is most closely related to this lowermost horizon. Redistribution of elements in the upper B horizon by soil-forming processes explains the geochemical difference between the upper and lower B horizons. The upper B horizon is the part of the soil profile where adsorption of elements to secondary minerals (e.g., Fe and Mn oxides) is most active. Hence, reagents that selectively remove metal bound to oxide and other minerals will be most effective for enhancing anomaly contrast and for detecting subtle geochemical changes caused by the presence of mineralized material. Superimposed on the soil chemistry (that is related to dispersal of metals in till) may be a secondary signature of near-vertical migration of volatile elements such as halogens or halogen-metal complexes (Cook and Dunn, 2007). Figure 15 is a provisional model showing the relationship between these various element dispersion pathways. In the model, Cu, Ag, Au, W, V, Co, Se and Hg from porphyry-style mineralization beneath till contribute to a detrital dispersal train down-ice from the source of mineralized material. The vertical projection of mineralized subcrop onto the till layer is shown with the expected trace of volatile components migrating upward from bedrock. Both of the patterns are reflected in the lower B-horizon layer, but the soil anomaly related to till geochemistry in the upper B horizon is more dispersed and larger. The model has not attempted to predict different element patterns that might be expected in soil due the varying mobility in response to changing soil pH.

CONCLUSIONS

- Anomalous Cu and Au with Ag, V±W and ±Co in the C and lower B horizons appears to reflect bedrock Cu-Au mineralization.
- Differences between lower and upper B-horizon soil chemistry have implications for soil sampling during routine geochemical surveys. The lower B horizon (generally more than 20 cm below the surface litter horizon) is more effective for detecting mineralized bedrock dispersed in till, as it is the derivative of this lowermost horizon. The shallow upper B horizon, however, is most commonly sampled, even though metal concentrations in this horizon are less related to those in underlying till (first derivative of bedrock), since they are more the result of various soil-forming and hydromorphic processes. The lower B and C horizons and till are preferred for routine soil surveys, provided that the genesis of the parent glacial material can be interpreted with confidence (including transport direction), and colour and texture variations down soil profiles can be recognized in the field.
- A provisional model for element dispersion from Au-Cu porphyry mineralization into soil presented here distinguishes between geochemical anomalies that could form by ice-transported material (i.e., detrital transport) and elements that may have migrated as volatile compounds. Further sample analyses for elements and organic compounds will focus on confirming this model. Results of this research will be published as a British Columbia Geological Survey GeoFile in 2008.

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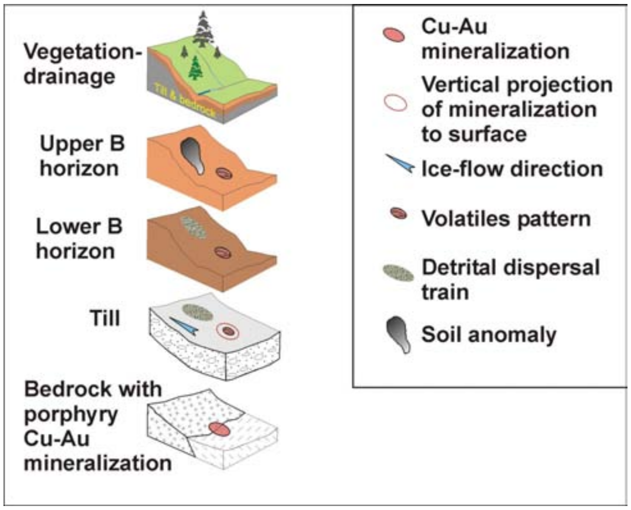

Figure 15. Provisional model for the transport of elements from mineralized bedrock into soil.

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