Geochemistry Projects of the British Columbia Geological Survey

by R.E. Lett and J. Doyle

KEYWORDS: geochemistry, copper, gold, soils, databases, Spanish Mountain

INTRODUCTION

Geochemistry traditionally plays a significant role in British Columbia mineral exploration and in the past has been responsible for the discovery of several economically viable deposits. Drainage sediment, soil and rock surveys were among the geochemical techniques first used by mining companies and later by government agencies. Research by the Government of Canada and the need to identify new strategic mineral resources encouraged the federal and provincial governments to start a regional geochemical survey (RGS) over BC in 1976. This survey was a part of a National Geochemical Reconnaissance (NGR) program that now covers much of Canada. Regional stream sediment surveys were subsequently undertaken by the BC Geological Survey (BCGS) and most recently by Geoscience BC, an agency that has also carried out an ambitious program of reanalyzing archived drainage samples for new elements with aqua regia digestion followed by inductively coupled plasma-mass spectrometry (ICP-MS) and instrumental neutron activation analysis (Jackaman, 2008). BCGS geochemistry projects have changed in scope over time from the management of large regional data collections to more focus on research aimed at improving geochemical prospecting methods for minerals. In addition to research, there has also been an emphasis on updating geochemical databases with results from new surveys to make databases continuously useful to the mining community. This paper reports on geochemical research activities and related project work that has been carried out in the past year.

GEOCHEMICAL DATABASES

Regional Geochemical Survey Database

An atlas of contoured maps showing the spatial variation of As, Au, Cu, Co, Fe, Mn, Mo, Ni, Pb, U and Zn in stream sediment, lake sediment and moss-mat sediments was released in 2008 by Lett et al. (2008). The element values used to create the maps were captured from a Microsoft® Access database that contains location co-ordinates, field records and analyses for over 56 000 stream sediment, lake sediment and moss-mat sediment samples collected at an average density of one sample per 13 km^2. Updates of information from more detailed drainage and Geoscience BC regional surveys have produced a version of the database containing records for 59 633 sample sites. Stream sediment, lake sediment and moss-mat sediment sample coverage is shown on Figure 1. Geology codes are included in the most recent database by linking sample sites to the geological polygons of the BC digital geology map published by Massey et al. (2005). One advantage of including stratigraphic and rock-type codes for each sample in the database is that the element data can be easily used for calculating drainage sediment thresholds that more realistically reflect bedrock geology. Another tool for refining the interpretation of drainage sediment geochemistry is a digital catchment basin atlas, like the one created by Cui et al. (2009) for drainage sediment survey sites on Vancouver Island. The atlas has revived an earlier BCGS project by Sibbick (1994) who recalculated geochemical thresholds for drainage sediment samples taken on Vancouver Island based on the predominant rock type within the limits of the stream catchment basin.

Till Geochemical Database

Since 1991, the BCGS and the Geological Survey of Canada (GSC) have analyzed over 5000 drift samples collected across the province. Much of these geochemical data are available to the public in digital form. Ferbey (2008) summarized the spatial coverage of BCGS drift prospecting surveys and Jackaman (2007) compiled BCGS and GSC till geochemical survey data for parts of the BC interior affected by the mountain pine beetle infestation. Lett (2008) created a database of combined BCGS and GSC drift geochemical data from central BC and Vancouver Island with previously unpublished analyses of till samples collected around Mount Milligan (MINFILE 093N 191; MINFILE, 2008). Figure 2 shows the distribution of till sample sites and the outlines of the geochemical survey areas. The analytical methods used to produce the till sample data are instrumental neutron activation analysis (INAA), aqua regia digestion followed by inductively coupled plasma-emission spectroscopy (ICP-ES), ICP-ES with lithium metaborate fusion and loss on ignition (LOI). Not all of the samples have been analyzed by these four techniques. In the database, the till samples have been classified by bedrock geology at the sample site based on published BCGS geology maps (Massey et al., 2005) and also by surficial sediment type (e.g., lodgment till, melt-out till, colluvium) from the descriptions in the source publication for the geochemical data.

SPANISH MOUNTAIN PROJECT

A geochemical study of the Spanish Mountain Au-deposit rock was initiated in 2008 as a University of Victoria undergraduate thesis project (Figure 3). Gold mineralization at Spanish Mountain is unusual for BC in that the Au

This publication is also available, free of charge, as colour digital files in Adobe Acrobat® PDF format from the BC Ministry of Energy, Mines and Petroleum Resources website at http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/Fieldwork/Pages/default.aspx.

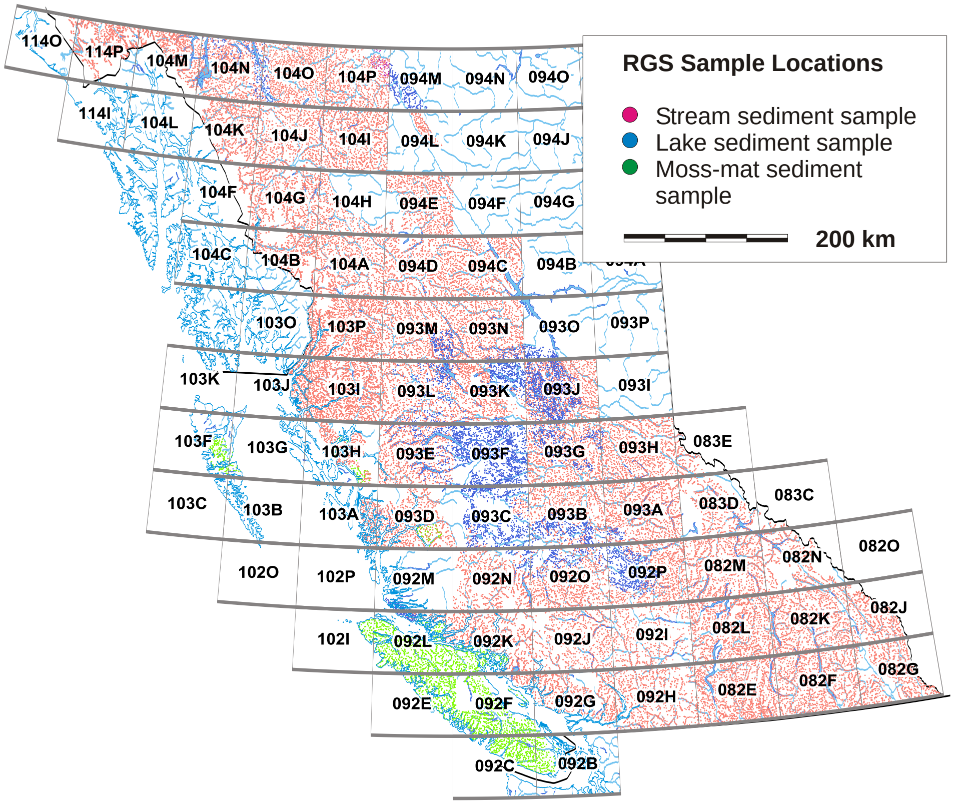

Figure 1. Regional Geochemical Survey stream sediment, lake sediment and moss-mat sediment sites in British Columbia.

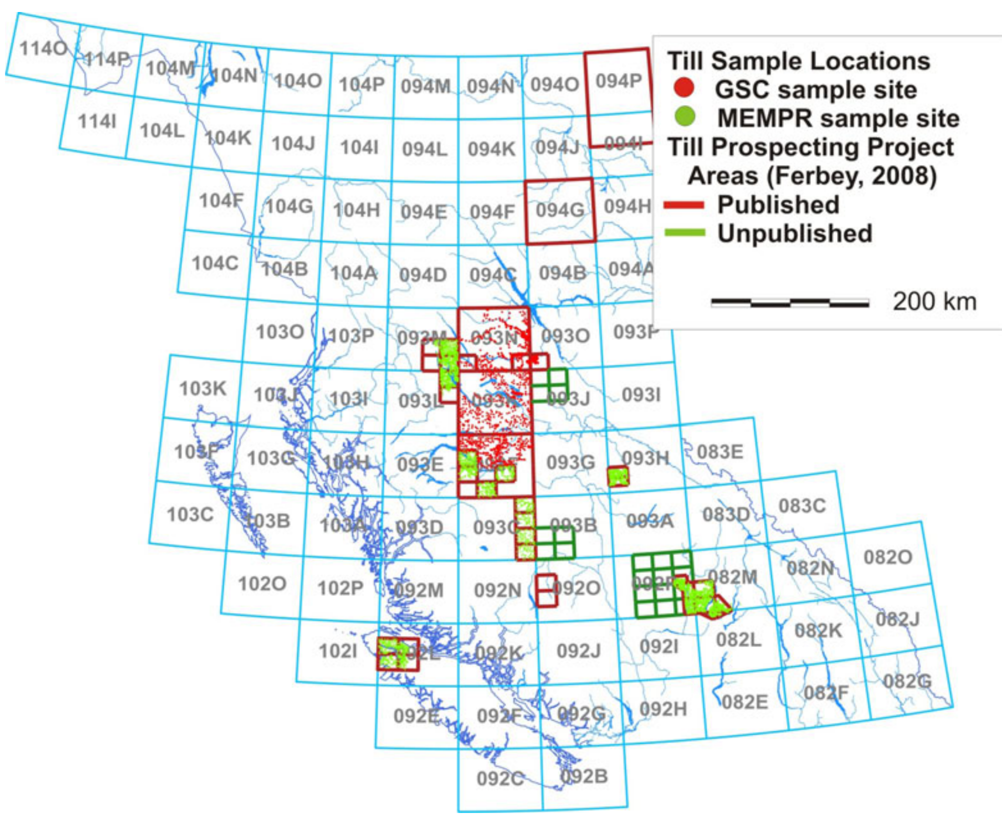

Figure 2. Outline of till prospecting survey areas (*from* Ferbey, 2008) and location of regional till sample sites, British Columbia. Abbreviations: GSC, Geological Survey of Canada; MEMPR, Ministry of Energy, Mines and Petroleum Resources.

is most closely associated with a black argillite unit within a metasedimentary facies of the Quesnel Terrane. The deposit may be orogenic or sedimentary-hosted Au based on a comparison to similar deposits in China, the United States and Russia (Large et al., 2007). At Spanish Mountain, there is extensive Fe-Mg carbonate and serecite alteration, varying Zn, Cu, Sb, Pb, As and Mg concentrations in the bedrock that is associated with the Au mineralization. Among questions that still remain unanswered are the relationship between the carbonate alteration and the Au mineralization. During the summer of 2008, bedrock and diamond-drillcore samples were collected for optical petrography, mineral identification by x-ray diffraction, major oxide, minor and trace-element analysis and laser ablation analysis. The geochemical analysis is largely complete and thin sections have been examined. Project details are documented in Paterson, Lett and Telmer (2009).

SOIL GEOCHEMICAL ORIENTATION STUDIES

Background

Preliminary results of detailed geochemical orientation surveys carried out over the Mouse Mountain and Shiko Lake mineral occurrences as well as the Soda Creek area were reported by Lett and Sandwith (2008; Figure 3). The surveys were carried out to establish the optimum soil sampling and analytical techniques to detect porphyry Cu-Au mineralization that is commonly covered by glacially transported overburden. Samples from the major soil horizons (F-H, B, C) were taken from vertical profiles along traverses crossing each area. The samples were analyzed for elements by several commercial selective extraction methods to determine which combination of soil horizon and analytical method would give the greatest anomaly contrast (signal to noise ratio) for ore indicator and pathfinder elements. Samples for preparation and analysis were taken from the decomposed humus (F-H) horizon just beneath the surface vegetation litter; the upper B-horizon soil just under the eluviated (Ae) horizon (where visible); the lower B-horizon soil close to the transition from the B- to C-horizon soil; and from the C-horizon soil. The C-horizon soil is glacial sediment that is most commonly a till. An additional sample at each profile was collected at a depth of 20–25 cm, independent of the horizon, for Mobile Metal Ion^{SM} (MMI) analysis. A typical soil profile is shown in Figure 4.

The methods used to study the soil geochemistry have been previously described by Lett and Sandwith (2008). Here is a brief summary of each analytical method:

Aqua regia digestion followed by ICP-MS analysis of the <0.18 mm fraction of the B-horizon soil sample and the <0.063 mm fraction of the C-horizon soil sample for 37 elements, including Au and Cu, at Acme Analytical Laboratories Ltd. (Vancouver, BC). F-H–horizon soil samples were milled before ICP-MS analysis.

INAA of the <0.18 mm fraction of the B-horizon soil sample and the <0.063 mm fraction of the C-horizon soil sample for 33 elements, including Au, at Activation Laboratories Ltd. (Ancaster, ON).

Enzyme Leach^{SM} and Bio Leach^{SM} analysis of the <0.18 mm fraction of the B-horizon soil sample for elements including Br and I. Bio Leach^{SM} is a proprietary

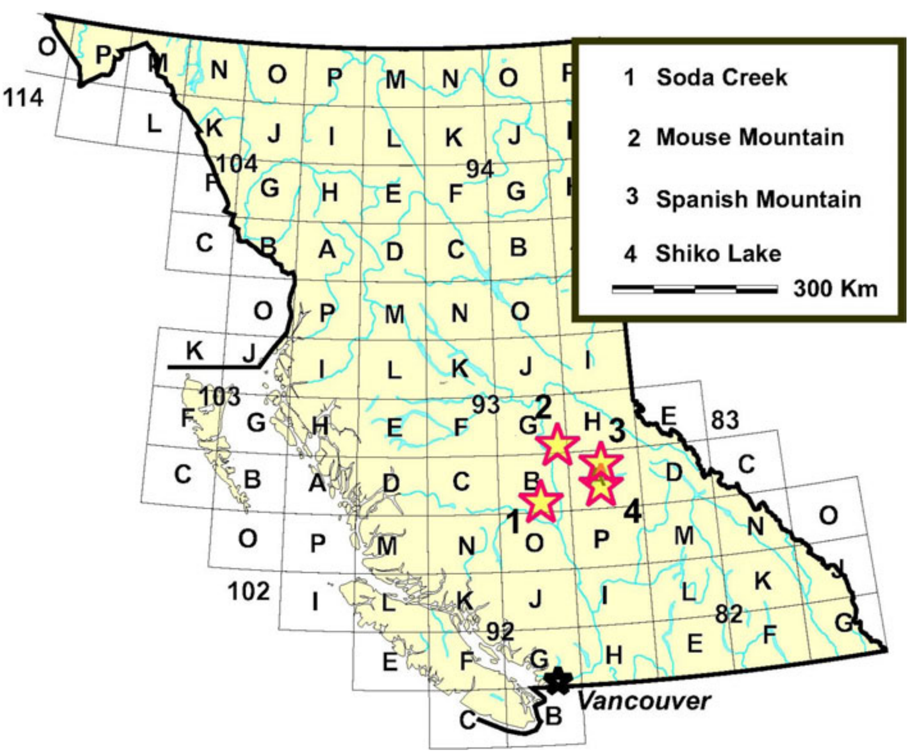

Figure 3. The location of the Spanish Mountain project area and geochemical orientation survey areas.

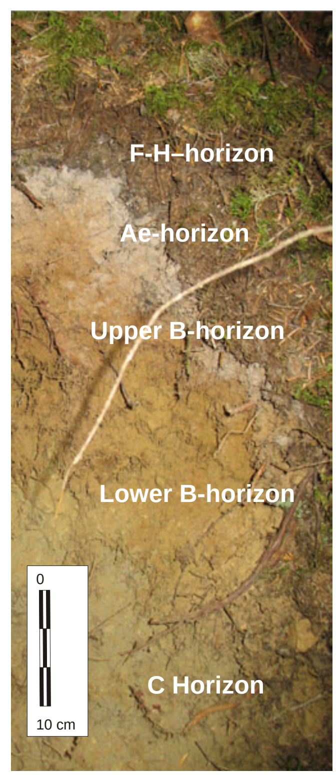

Figure 4. A typical soil profile from Mouse Mountain, British Columbia, with the horizons identified.

selective extraction developed by Activation Laboratories Ltd. that utilizes bacterial decomposition of mineral sulphides. The bacteria cell membranes rupture when organisms die leaving a diagnostic organic and inorganic geochemical signature. Bio Leach^{SM} dissolves the dead bacterial remnants in the surface soils and detects the geochemical signature of the sulphide minerals (E. Hoffman, pers comm, 2008).

Soil Gas Hydrocarbons^{SM} (SGH) analysis for C5–C17 organic compounds that have been absorbed on B-horizon soil samples (Activation Laboratories Ltd.).

MMI analysis, a method described by Mann et al. (1998), of soil samples for metals including Cu, Pb, Zn, Ni, Cd, Au, Ag and Co with a proprietary selective extraction (SGS Minerals Services laboratory, Toronto, ON).

Loss on ignition (LOI) at 500°C of the <0.18 mm fraction of the B-horizon soil samples at Acme Analytical Laboratories Ltd.

Mineral grain identification, Au grain shape (reshaped, modified, pristine) and the number of Au grains in heavy mineral concentrates (specific gravity >3.3) recovered from C-horizon soil samples at Overburden Drilling Management (Nepean, ON).

Summary of Results

Lett and Sandwith (2008) concluded from an examination of the geochemical data generated mainly by aqua regia digestion–ICP-MS analysis of soil samples from the three orientation survey areas that anomalous Cu and Au with Ag, V and Co in the C- and lower B-horizon soil appeared to be geochemical pathfinders for porphyry Cu-Au mineralization. However, results suggested that the geochemistry of the shallow, upper B-horizon soil is less related to the underlying parent till geochemistry than the C-horizon soil is because of greater modification by various soil-forming and hydromorphic processes. Much of the geochemical data that was unavailable last year has now been assembled allowing a more complete analysis of the information but only the soil geochemical and Au mineral data from the Mouse Mountain and Shiko Lake mineral properties will be reviewed in this paper. A more detailed project report analyzing all of the data will be published in 2009 as a BCGS GeoFile.

Sixty-three elements, loss on ignition and soil pH have been determined by aqua regia digestion–ICP-MS, INAA, MMI, Enzyme Leach^{SM} and Bio Leach^{SM}. Detection limits for each element by each method are summarized in Table 1. However, only Ag, As, Au, Ba, Co, Cr, La, Mo, Ni, Sb, Sr, U and Zn have been measured by all of the methods and in the case of Cu and Pb there are no INAA results. Bromine and I determined by Enzyme Leach^{SM} and Bio Leach^{SM} are of particular interest since halogens can migrate relatively easily through thick overburden and cover rock and may be pathfinders for deeply buried, metallic and hydrocarbon deposits. Kendrick et al. (2001) discuss the implication of Br:Cl and I:Cl ratios in fluid inclusions to identifying the source of Cu-porphyry mineralizing fluids. Williams and Gunn (2002) speculate that the presence of elevated halogens in Enzyme Leach^{SM} solutions from soil samples collected over Au deposits may reflect the presence of oxidation haloes over deeply buried epithermal Au mineralization. Dunn et al. (2007) studied the variation of

Table 1. Elements determined by aqua regia digestion followed by inductively coupled plasma-mass spectrometry (ICP-MS) analysis, instrumental neutron activation analysis (INAA), Enzyme Leach^{SM}, Bio Leach^{SM} and Mobile Metal Ion^{SM} (MMI) analyses with instrumental detection limits. The **-** indicates that an element was not determined or that all values were below the instrumental detection limit.

Element	ICP-MS (ppm)	INAA (ppm)	MMI^{SM} (ppb)	Enzyme Leach^{SM} (ppb)	Bio Leach^{SM} (ppb)
Ag	2 ppb	5 ppb	1	0.2	0.2
Al	100	-	1	-	-
As	0.1	0.5	10	1	0.5
Au	2 ppb	2 ppb	0.1	0.05	0.05
Ba	0.5	50	10	1	1
Be	-	-	-	2	0.07
Bi	0.02	-	1	0.8	0.1
Br	-	0.5	-	5	5
Ca	100	10000	10	-	-
Cd	0.01	-	1	0.2	0.05
Ce	-	3	5	0.1	0.02
Cl	-	-	-	2	-
Co	0.1	1	5	1	0.1
Cr	0.5	5	100	20	2
Cs	-	1	-	0.1	0.01
Cu	0.01	-	10	3	0.5
Dy	-	-	1	0.1	0.01
Er	-	-	0.5	0.1	0.01
Eu	-	0.2	0.5	0.1	0.01
Fe	100	100	1	-	-
Ga	0.2	-	-	1	0.1
Gd	-	-	1	0.1	0.03
Ge	-	-	-	0.5	0.05
Hf	-	1	-	0.1	0.04
Hg	5 ppb	1 ppb	-	1	0.05
Ho	-	-	-	0.1	0.01
I	-	-	-	2	1
In	-	-	-	0.1	0.1
La	0.5	0.5	1	0.1	0.01
Li	-	-	5	2	0.2
Lu	-	-	-	0.1	0.01
Mg	100	-	1	-	-
Mn	1	-	-	1	0.1
Mo	0.01	1	5	1	2
Nb	-	-	0.5	1	0.2
Nd	-	5	1	0.1	0.03
Ni	0.1	20	5	3	0.2
Pb	0.01	-	10	1	0.1
Pr	-	-	1	0.1	0.01
Pt	-	-	1	1	0.5
Pd	-	-	1	1	0.5
Rb	-	15	5	1	0.1
Ru	-	-	-	1	0.05
Sb	0.02	0.1	1	0.1	0.2
Sc	0.1	0.1	5	100	0.5
Se	0.1	3	-	5	1
Sm	-	0.1	1	0.1	0.03
Sn	-	200	1	0.8	-
Sr	0.5	50	10	1	0.1
Ta	-	0.5	1	0.1	0.01
Tb	-	0.5	1	0.1	0.01
Te	0.02	-	10	1	1
Th	0.1	-	0.5	0.1	0.02
Ti	10	-	3	100	-
Tl	0.02	-	0.5	0.1	0.2
Tm	-	-	-	0.1	0.01
U	0.1	0.5	1	0.1	0.01
V	2	-	-	1	1
W	0.2	1	1	1	0.01
Y	-	-	5	0.5	0.02
Yb	-	0.5	1	0.1	0.02
Zn	0.1	50	20	10	2
Zr	-	-	5	1	0.5

F, Cl, Br and I in soil and vegetation over three mineral properties in central BC. At the Mount Polley porphyry Cu mine, they found that I was the most effective halogen pathfinder for the concealed Cu-Au mineralization. The authors concluded that while further research into methods for halogen analysis in geochemical samples was needed, these elements proved effective tracers for buried mineralization. They also concluded that the halogen signatures varied depending on the style of the mineralization.

Tables 2, 3, 4 and 5 show the mean, median, 95th percentile and maximum value statistics calculated from Au, Ag, Cu and Co soil geochemical data for Mouse Mountain and Shiko Lake. These elements are selected because they are among common geochemical pathfinders for Cu-Au porphyry mineralization. The geochemical data for each area is divided into subsets representing F-H–, upper B-, lower B- and C-horizons. There are no MMI, Enzyme Leach^SM and Bio Leach^SM statistics for the F-H– and C-horizons because these selective extractions were only applied to the B-horizon. Mean and percentile values reveal that almost all of the elements are higher in the Shiko Lake data subset compared to the Mouse Mountain data subset and they are all higher in the C-horizon. For example, the mean and 95th percentile Cu values at Shiko Lake increase from the F-H–horizon through the upper B to the lower B to reach a maximum in the C-horizon (Table 4). Geochemical anomaly contrast (the ratio of the maximum element value to the 95th percentile value) for elements measured in selective extractions is generally greater than the contrast for elements determined by aqua regia digestion–ICP-MS. However, contrast is element dependent and extraction dependent. For example, the MMI Au contrast in Shiko Lake soil samples is 6 as compared to 1.3 for Bio Leach^SM Au whereas the Bio Leach^SM Cu contrast is 13 as compared to 5 for MMI Cu (Tables 2, 4). One wetland sample from Shiko Lake has been excluded from the statistical analysis because the high Cu and Co contents in the organic-rich material are not typical of the well-drained soil chemistry. Unlike Au, Ag is highest in the F-H–horizon and generally decreases with depth through the B- into the C-horizon. Bio Leach^SM Ag contrast in both areas is greater than MMI Ag contrast and ICP-MS Ag contrast (Table 3). Cobalt soil chemistry is similar to Cu in that the highest values are in the C-horizon and the lowest in the F-H–horizon. Cobalt contrast is similar in both areas for all methods.

A two-sample t-test can be applied to determine if there is a statistical difference at the 0.05 significance level between population means. Population means were determined for samples representing the major soil horizons; samples were analyzed by aqua regia digestion–ICP-MS and INAA. An analysis of variance (F-test) is applied

Table 2. Mean, median, 95^th percentile, maximum values for Au determined by several different analytical methods (aqua regia digestion followed by inductively coupled plasma-mass spectrometry [ICP-MS], Mobile Metal Ion^SM [MMI], Enzyme Leach^SM and Bio Leach^SM). Statistics have been calculated from the analyses of 27 Mouse Mountain and 29 Shiko Lake samples.

Soil Horizon		Mouse Mountain				Shiko Lake			
		ICP-MS	MMI^SM	Enzyme Leach^SM	Bio Leach^SM	ICP-MS	MMI^SM	Enzyme Leach^SM	Bio Leach^SM
		Au (ppb)	Au (ppb)	Au (ppb)	Au (ppb)	Au (ppb)	Au (ppb)	Au (ppb)	Au (ppb)
F-H	Mean	6.3	-	-	-	5.0	-	-	-
F-H	Median	0.3	-	-	-	0.3	-	-	-
F-H	95%ile	8.7	-	-	-	0.8	-	-	-
F-H	Max	117.0	-	-	-	143.0	-	-	-
Upper B	Mean	1.8	-	0.03	0.03	13.3	-	0.03	0.07
Upper B	Median	1.1	-	0.03	0.03	2.9	-	0.03	0.03
Upper B	95%ile	4.6	-	0.09	0.03	49.0	-	0.06	0.20
Upper B	Max	12.9	-	0.10	0.05	138.7	-	0.14	0.48
Lower B	Mean	3.5	0.2	0.04	0.03	24.0	1.60	0.03	0.08
Lower B	Median	2.0	0.2	0.03	0.03	3.6	0.60	0.03	0.03
Lower B	95%ile	13.3	0.6	0.10	0.03	128.6	3.26	0.05	0.21
Lower B	Max	24.0	0.7	0.13	0.03	239.1	20.10	0.10	0.27
C	Mean	3.1	-	-	-	33.5	-	-	-
C	Median	2.6	-	-	-	5.9	-	-	-
C	95%ile	5.7	-	-	-	166.2	-	-	-
C	Max	6.8	-	-	-	283.5	-	-	-
C	Number	21.0	-	-	-	32.0	-	-	-

Table 3. Mean, median, 95^th percentile, maximum values for Ag determined by several different analytical methods (aqua regia digestion followed by inductively coupled plasma-mass spectrometry [ICP-MS], Mobile Metal Ion^SM [MMI], Enzyme Leach^SM and Bio Leach^SM). Statistics have been calculated from the analyses of 27 Mouse Mountain and 29 Shiko Lake samples.

Soil Horizon		Mouse Mountain				Shiko Lake			
		ICP-MS	MMI^SM	Enzyme Leach^SM	Bio Leach^SM	ICP-MS	MMI^SM	Enzyme Leach^SM	Bio Leach^SM
		Ag (ppb)	Ag (ppb)	Ag (ppb)	Ag (ppb)	Ag (ppb)	Ag (ppb)	Ag (ppb)	Ag (ppb)
F-H	Mean	234.0	-	-	-	305	-	-	-
F-H	Median	187	-	-	-	205	-	-	-
F-H	95%ile	498	-	-	-	855	-	-	-
F-H	Max	665	-	-	-	1200	-	-	-
Upper B	Mean	114	-	0.10	0.12	163	-	0.1	0.1
Upper B	Median	74	-	0.10	0.10	141	-	0.1	0.1
Upper B	95%ile	271	-	0.10	0.10	388	-	0.1	0.1
Upper B	Max	578	-	0.10	0.60	700	-	0.1	0.1
Lower B	Mean	68	16.3	0.10	0.12	174	32.6	0.1	0.1
Lower B	Median	68	13.0	0.10	0.10	128	28.0	0.1	0.1
Lower B	95%ile	132	31.0	0.10	0.21	461	68.6	0.1	0.3
Lower B	Max	171	41.0	0.10	0.40	696	74.0	0.1	1.0
C	Mean	68	-	-	-	112	-	-	-
C	Median	53	-	-	-	85	-	-	-
C	95%ile	155	-	-	-	272	-	-	-
C	Max	211	-	-	-	614	-	-	-
C	Number	21	-	-	-	32	-	-	-

Table 4. Mean, median, 95th percentile, maximum values for Cu determined by several different analytical methods (aqua regia digestion followed by inductively coupled plasma-mass spectrometry [ICP-MS], Mobile Metal Ion^{SM} [MMI], Enzyme Leach^{SM} and Bio Leach^{SM}). Statistics have been calculated from the analyses of 27 Mouse Mountain and 29 Shiko Lake samples.

Soil Horizon		Mouse Mountain				Shiko Lake			
		ICP-MS	MMI^{SM}	Enzyme Leach^{SM}	Bio Leach^{SM}	ICP-MS	MMI^{SM}	Enzyme Leach^{SM}	Bio Leach^{SM}
		Cu (ppm)	Cu (ppb)	Cu (ppb)	Cu (ppb)	Cu (ppb)	Cu (ppb)	Cu (ppb)	Cu (ppb)
F-H	Mean	12.6	-	-	-	32.7	-	-	-
F-H	Median	10.9	-	-	-	13.8	-	-	-
F-H	95%ile	24.4	-	-	-	168.7	-	-	-
F-H	Max	29.7	-	-	-	212.0	-	-	-
Upper B	Mean	26.1	-	23.8	341.0	124.6	-	74.0	593.7
Upper B	Median	23.6	-	23.0	348.0	49.6	-	28.5	426.0
Upper B	95%ile	34.5	-	41.0	565.0	329.3	-	249.8	1135.8
Upper B	Max	92.3	-	41.0	680.0	1327.2	-	988.0	2780.0
Lower B	Mean	27.5	377.7	30.9	414.9	105.0	1142.0	46.0	748.0
Lower B	Median	27.0	385.0	28.0	445.0	57.3	660.0	25.0	524.0
Lower B	95%ile	39.9	547.5	52.6	569.6	280.0	1333.0	176.0	222.0
Lower B	Max	49.5	750.0	61.0	595.0	483.0	6070.0	205.0	2830.0
C	Mean	48.8	-	-	-	175.1	-	-	-
C	Median	40.4	-	-	-	84.4	-	-	-
C	95%ile	89.9	-	-	-	631.1	-	-	-
C	Max	123.5	-	-	-	1096.4	-	-	-

Table 5. Mean, median, 95th percentile, maximum values for Co determined by several different analytical methods (aqua regia digestion followed by inductively coupled plasma-mass spectrometry [ICP-MS], Mobile Metal Ion^{SM} [MMI], Enzyme Leach^{SM} and Bio Leach^{SM}). Statistics have been calculated from the analyses of 27 Mouse Mountain and 29 Shiko Lake samples.

Soil Horizon		Mouse Mountain				Shiko Lake			
		ICP-MS	MMI^{SM}	Enzyme Leach^{SM}	Bio Leach^{SM}	ICP-MS	MMI^{SM}	Enzyme Leach^{SM}	Bio Leach^{SM}
		Co (ppm)	Co (ppb)	Co (ppb)	Co (ppb)	Co (ppb)	Co (ppb)	Co (ppb)	Co (ppb)
F-H	Mean	3.9	-	-	-	5.3	-	-	-
F-H	Median	3.2	-	-	-	3.7	-	-	-
F-H	95%ile	10.2	-	-	-	13.4	-	-	-
F-H	Max	11.2	-	-	-	13.8	-	-	-
Upper B	Mean	9.1	-	19.4	69.1	18.0	-	41.0	73.5
Upper B	Median	8.9	-	13.0	65.9	15.7	-	28.5	49.2
Upper B	95%ile	11.7	-	46	113	25.5	-	68	171.4
Upper B	Max	24.3	-	47	126	77.8	-	276	291
Lower B	Mean	9.2	59.3	21.1	74.2	17.8	72.4	35.5	75.0
Lower B	Median	9.6	43.5	16.5	67.7	17.3	49.5	30.0	61.2
Lower B	95%ile	11.1	158.2	42.6	129.7	27.4	150.2	83.4	218
Lower B	Max	11.9	179	51	155	33.1	175	93	245
C	Mean	11.6	-	-	-	19.6	-	-	-
C	Median	11.2	-	-	-	15.5	-	-	-
C	95%ile	18.4	-	-	-	40.9	-	-	-
C	Max	20	-	-	-	63.5	-	-	-

before the t-test to determine if the data for each horizon has an equal or unequal variance. Once this is determined, the appropriate t-test is used to test the null hypothesis (H_0) that there is no significant difference between sample means (Davis, 1973). Figure 5 summarizes the results of the t-test applied to element (Au, Ag, As, Br, Co, Cu, Cr, Hg, Fe, Mn, Mo, Ni, Pb, V, Zn) data for the F-H–horizon compared to element data for the upper B-horizon; element data for the upper B-horizon compared to element data for the lower B-horizon; and element data for the lower B-horizon compared to the element data for the C-horizon. In both areas, there is a significant difference (at the 0.05 significance level) between population means for most elements, except Au, in the F-H–horizon tested against the upper B-horizon. There is no significant difference for upper B-horizon elements compared to lower B-horizon elements, except for Ag and Zn at Mouse Mountain. However, lower B-horizon elements compared to the C-horizon elements reveal that As, Cu, Cr, Fe, Mn, Ni and V are significantly different for Mouse Mountain samples and Ag, As, Mn, Pb and Zn are significantly different for Shiko Lake samples. The between-horizon element differences for Mouse Mountain compared to Shiko Lake most likely reflect the varying effect of local topography, drainage and climate on soil chemistry. For example, Rose et al. (1979) show that the depth to a Cu-enriched B-horizon soil on the slope of a hill is greater than that on a ridge crest due to increased soil development on the hillside.

A t-test also determined if there were significant differences in the population means of Au, As, Br, Cu, I, Mo, Mn, Pb, V and Zn extracted by Enzyme Leach^{SM} and Bio Leach^{SM} from upper B-horizon soils compared to lower B-horizon soils in both areas (Figure 5). For the elements determined by Enzyme Leach^{SM}, only Zn is significantly different for the upper B- and lower B-horizon soil samples from Shiko Lake but for the elements determined by Bio Leach^{SM} there is a significant difference for Mn, Br and I at Shiko Lake and Zn at both sites. Figure 6 summarizes the results of the t-test for elements extracted by MMI compared to those extracted by Bio Leach^{SM} from lower B-horizon soil samples. The figure shows that As, Ba and Mo are significantly different at Mouse Mountain and Au, Ba and Pb significantly different at Shiko Lake.

At the Shiko Lake property, several traverses were undertaken by Lett and Sandwith (2008) and Petsel (2006) with soil and soil-overburden samples taken at numerous sites (Figure 7). The bedrock geology at Shiko Lake consists of an early Jurassic intrusive complex emplaced in hornfelsed metasedimentary rocks, volcaniclastic rocks and massive plagioclase-pyroxene basalt. The intrusive stock consists of an older biotite-pyroxene monzodiorite phase and younger potassium-feldspar syenite and alkali-feldspar syenite phases. Near the centre of the stock is medium- to coarse-grained monzonite containing traces of magnetite and sphene. Pyrite and fine-grained, pink,

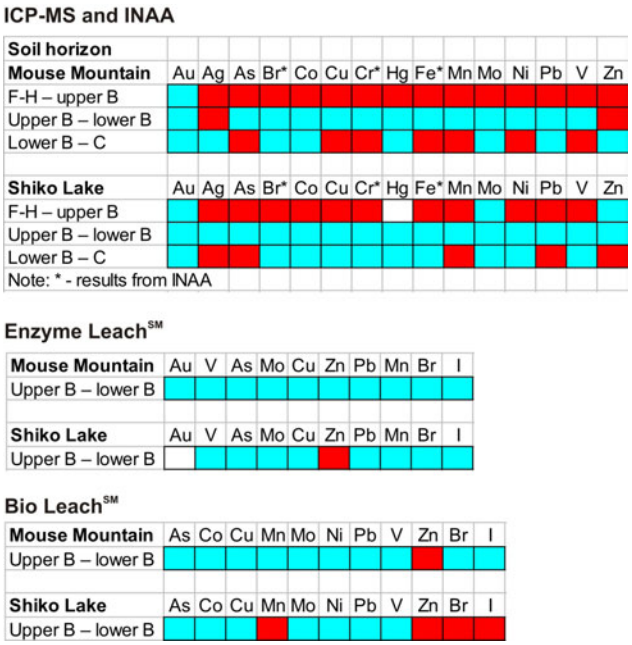

Figure 5. Summary of a t-test for the population means of selected elements measured by aqua regia digestion followed by inductively coupled plasma-mass spectrometry (ICP-MS) and instrumental neutron activation analysis (INAA). Comparisons were made between the F-H–horizon and the upper B-horizon, the upper B- and lower B-horizon and the lower B-horizon and the C-horizon. Also shown are results of a t-test for elements measured by Enzyme Leach^{SM} and Bio Leach^{SM} analysis. Comparisons were made between the upper B-horizon and the lower B-horizon for the two areas. A red square indicates a significant difference at the 0.05 significance level between the means. A blue square indicates no difference. A blank square indicates that there were insufficient values above detection limits for a test to be applied.

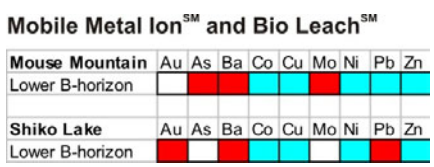

Figure 6. Summary of a t-test for the population means of selected elements in the lower B-horizon. Two different analyses were compared: Mobile Metal Ion^{SM} (MMI) and Bio Leach^{SM}. A red square indicates a difference at the 0.05 significance level between the means. A blue square indicates no difference. A blank square indicates that there were insufficient values above detection limits for a test to be applied.

quartz-syenite veins and dikes intrude the monzonite forming an intrusive breccia. Chalcopyrite occurs in the matrix of the breccia with bornite and gold in veins or as coarse disseminations, mainly in the youngest quartz syenite. Pervasive, fracture-controlled, potassium alteration and epidote alteration of the volcaniclastic rocks is associated with the Cu mineralization. Potassium and epidote alteration is cut by late-stage, calcite-filled veinlets (Logan and Mihalynuk, 2005). Bedrock is largely covered by sandy till deposited by a northwest ice advance. On the steeper slopes, the till has been mobilized and reworked into colluvium. 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.

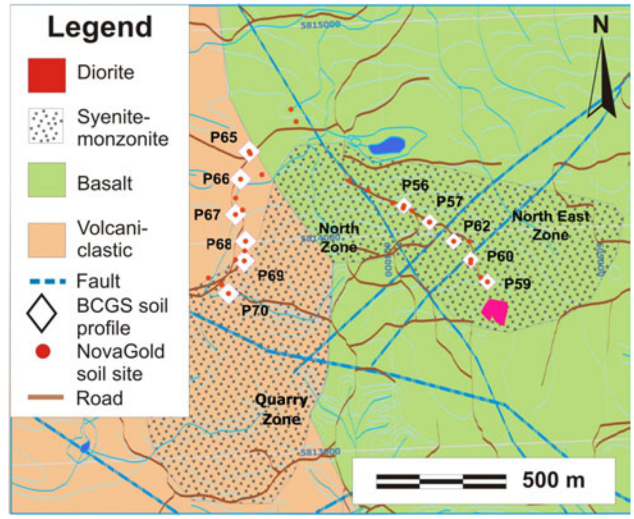

Figure 7. The main mineral zones of the Shiko Lake property (*after* Petsel, 2006) with soil-overburden sampling sites (Petsel, 2006) and soil profile sites (Lett and Sandwith, 2008).

At Shiko Lake, samples were collected at the sites along a 1 km traverse located west of the North Zone (Figure 7). Profiles were created by combining the soil analyses from sites P65 to P70, sampled by Lett and Sandwith (2008), with data reported by Petsel (2006). Petsel submitted overburden samples for fire assay, atomic absorption and aqua regia digestion followed by ICP-ES analyses. Figure 8a shows the results for Cu concentrations determined by aqua regia digestion–ICP-MS. There is a marked Cu anomaly in the C-horizon, it occurs over an interval of 400 m between P65 to P68 reaching a peak value of 405 ppm Cu. The Cu anomaly contrast is greatest for the C-horizon and least for the F-H–horizon. The Cu peak in the C-horizon also has a distinctive asymmetric shape with a steep south-facing slope and a gentler north-facing slope. The Cu profile in the C-horizon has a similar shape and anomaly contrast to the MMI, Enzyme Leach^{SM} and Bio Leach^{SM} Cu profiles from the lower B-horizon (Figure 8b). Bio Leach^{SM} I and Br profiles (Figure 8c) resemble Cu profiles although values for P68 are missing so the sharp peak is absent and the contrast is smaller than the contrast for Cu in the C-horizon. The halogen peak is displaced to the north of the MMI, Enzyme Leach^{SM} and Bio Leach^{SM} peaks.

Samples from the same traverse were analyzed for Au by aqua regia digestion–ICP-MS. The Au profile for the C-horizon (Figure 9a) reveals an anomaly resembling the Cu profile for the C-horizon (Figure 8a) but with a more symmetrical shape. Again, the Au contrast in the C-horizon is larger than the Au contrast in the B-horizon (no Au was detected in the F-H–horizon soil samples). The larger Au anomaly contrast in the C-horizon may, in part, reflect a higher Au content in the <0.063 mm fraction of the sample compared to the <0.18 mm fraction of the B-horizon soil sample due to less dilution by sand-sized material. Also shown in Figure 9a are the total number of Au grains and pristine Au grains found in the heavy mineral concentrates from the C-horizon samples from sites P65 to P70. A nearby bedrock source for the Cu-Au mineralization would explain the high number of pristine (unweathered) Au grains along with a geochemical Au anomaly in the <0.063 mm fraction of the C-horizon. Figure 9b shows that for the MMI analysis there is a high contrast Au anomaly in

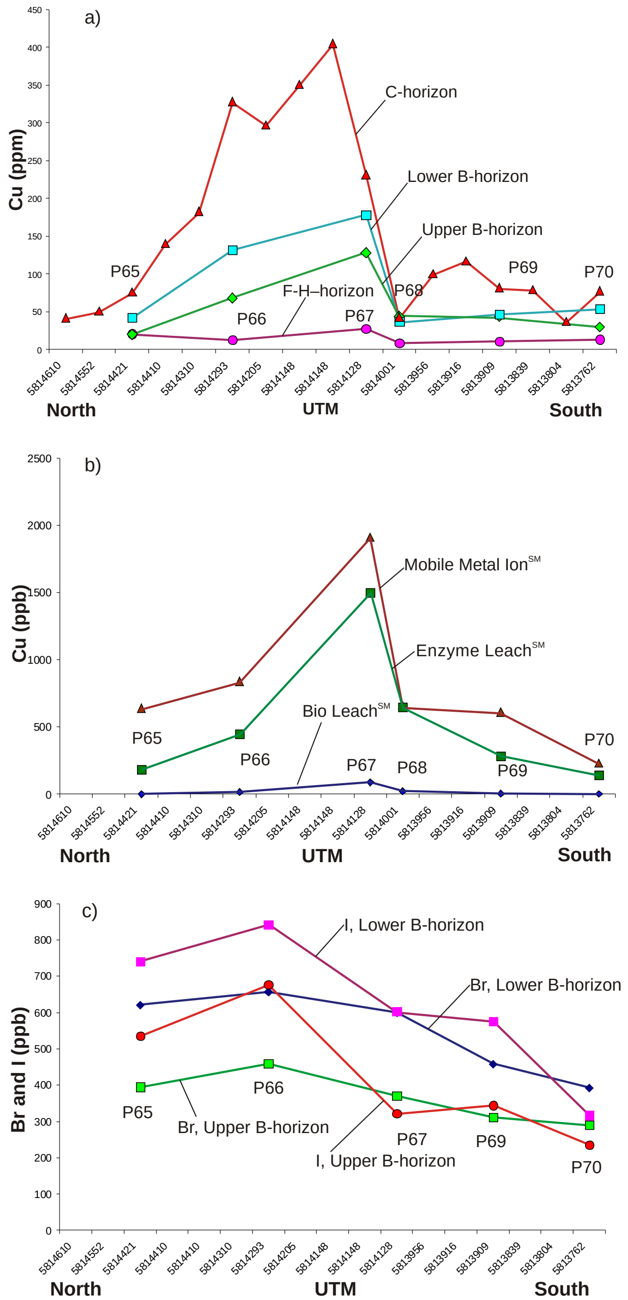

Figure 8. Copper profiles along a traverse west of the North Zone, Shiko Lake: **a**) aqua regia digestion followed by inductively coupled plasma-mass spectrometry (ICP-MS) analysis for Cu in the F-H–, upper B-, lower B- and C-horizons; **b**) Mobile Metal Ion^{SM} (MMI), Enzyme Leach^{SM} and Bio Leach^{SM} analyses for Cu in the lower B-horizon; **c**) Bio Leach^{SM} analysis for Br and I in the upper B- and lower B-horizons.

the lower B-horizon with a peak at P66 but there is almost no corresponding increase in Au in either the Enzyme Leach^{SM} or Bio Leach^{SM} analyses over the same interval. The large MMI Au anomaly at P66 corresponds to the C-horizon sample with the greatest number of total and pristine Au grains counted in a heavy mineral concentrate. A smaller MMI Au peak at P69 has a corresponding total and pristine Au grain anomaly but only background levels of

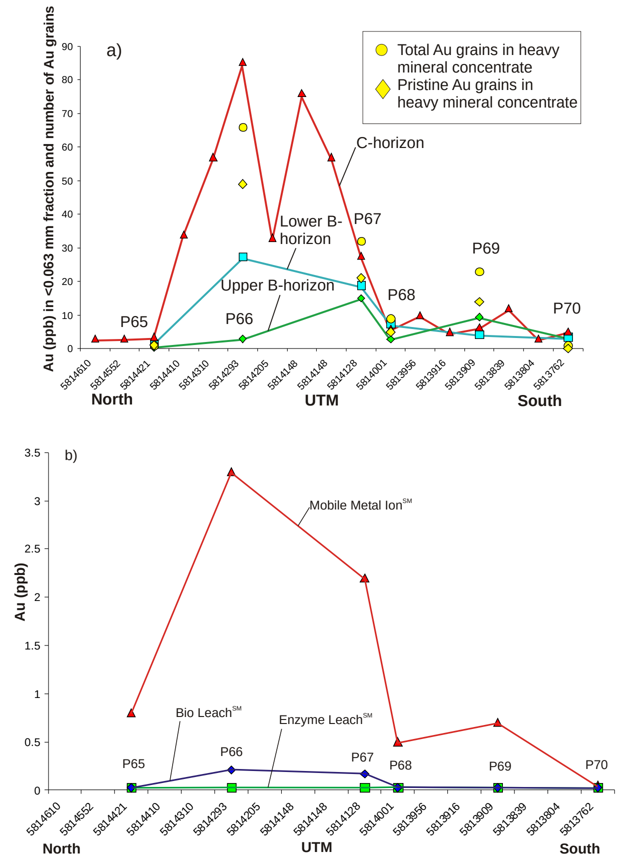

Figure 9. Gold profiles along a traverse west of the North Zone, Shiko Lake: **a**) aqua regia digestion followed by inductively coupled plasma-mass spectrometry (ICP-MS) analysis for Au in the F-H–, upper B-, lower B- and C-horizons; **b**) Mobile Metal Ion^{SM} (MMI), Enzyme Leach^{SM} and Bio Leach^{SM} analyses for Au in the lower B-horizon.

Au in the <0.063 mm fraction of the C-horizon sample. Figure 10a shows that the concentration of Co in the soil, determined by aqua regia digestion–ICP-MS, is similar to Cu although the C-horizon Co contrast is smaller and the anomaly shape more symmetrical between P68 and P70 than for Cu in the C-horizon. Selective extraction profiles (Figure 10b) show that the MMI Co and Bio Leach^{SM} Co anomaly peaks at P68 are displaced to the south of the C-horizon Co peak. The MMI Co contrast is smaller than the Bio Leach^{SM} Co contrast although the anomalies have a similar pattern.

The characteristic down-ice asymmetric shape of the C-horizon Cu anomaly, the abundance of pristine Au grains in the heavy mineral concentrate, Br and I patterns, and the MMI Au contrast suggest a Cu-Au mineral source nearby to the anomaly peak. Although ice flowed from southeast to northwest regionally, the local ice flow could have been deflected by the ridge between the North and Quarry zones so that till may have been deposited by a more north to south ice flow. The source of mineralized rock detected by the geochemistry could therefore be close to the contact between intrusive and volcaniclastic rocks (i.e., near P68 and P69). A nearby diamond-drill hole (SH91-18) intersected fine-grained, moderately hornfelsed siltstone with >5% disseminated pyrite. The drill log records an overburden thickness of 4.6 m (Petsel, 2006).

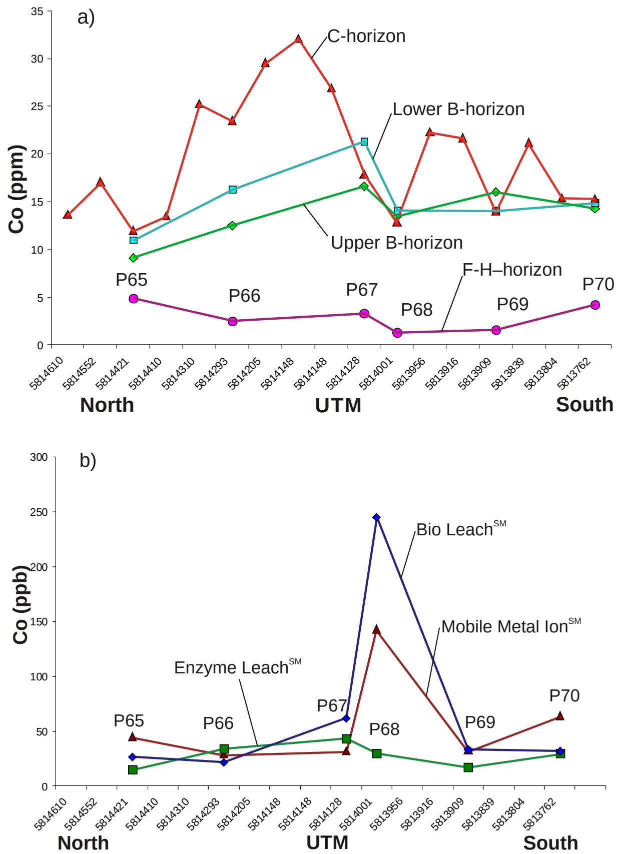

Figure 10. Cobalt profiles along a traverse west of the North Zone, Shiko Lake: **a**) aqua regia digestion followed by inductively coupled plasma-mass spectrometry (ICP-MS) analysis for Co in the F-H–, upper B-, lower B- and C-horizons; **b**) Mobile Metal Ion^{SM} (MMI), Enzyme Leach^{SM} and Bio Leach^{SM} analyses for Co in the lower B-horizon.

A second traverse at Shiko Lake extends more than 500 m across the North East mineralized zone. Figure 11a shows Cu concentrations in the F-H–, upper B-, lower B- and C-horizons using data from Lett and Sandwith (2008) combined with the soil-overburden geochemistry reported by Petsel (2006). Copper values were determined by aqua regia digestion–ICP-MS analysis and the pattern is similar to the pattern along the North Zone traverse (Figures 8a, 11a). The Cu in the C-horizon shows the greatest anomaly contrast compared to other horizons and there is an asymmetric Cu peak at P60. Bio Leach^{SM} Cu contrast is greater than the MMI Cu contrast and Enzyme Leach^{SM} Cu contrast at P60, but there is a secondary MMI Cu anomaly at P56 (Figure 11b). The highest Bio Leach^{SM} Br and I values (Figure 11c) occur in the lower B-horizon at P62 suggesting a possible bedrock source for the Cu and Au. The Au pattern in the C-horizon is similar to Cu and there is a sharp Au peak at P60, which is also the site of the greatest number of total and pristine Au grains in the C-horizon heavy mineral concentrate (Figure 12a). A second Au peak at P56 in the lower B-horizon but not the C-horizon has a corresponding marked MMI geochemical anomaly (Figure 12b). The asymmetric shape of the Au and Cu peaks suggests the source to be mineralized material in till, which has been deposited by ice flowing from north to south. Since this is at variance to the regional ice-flow direction, a likely explanation is that there are several sources of Au shown by the multiple peaks along the profile.

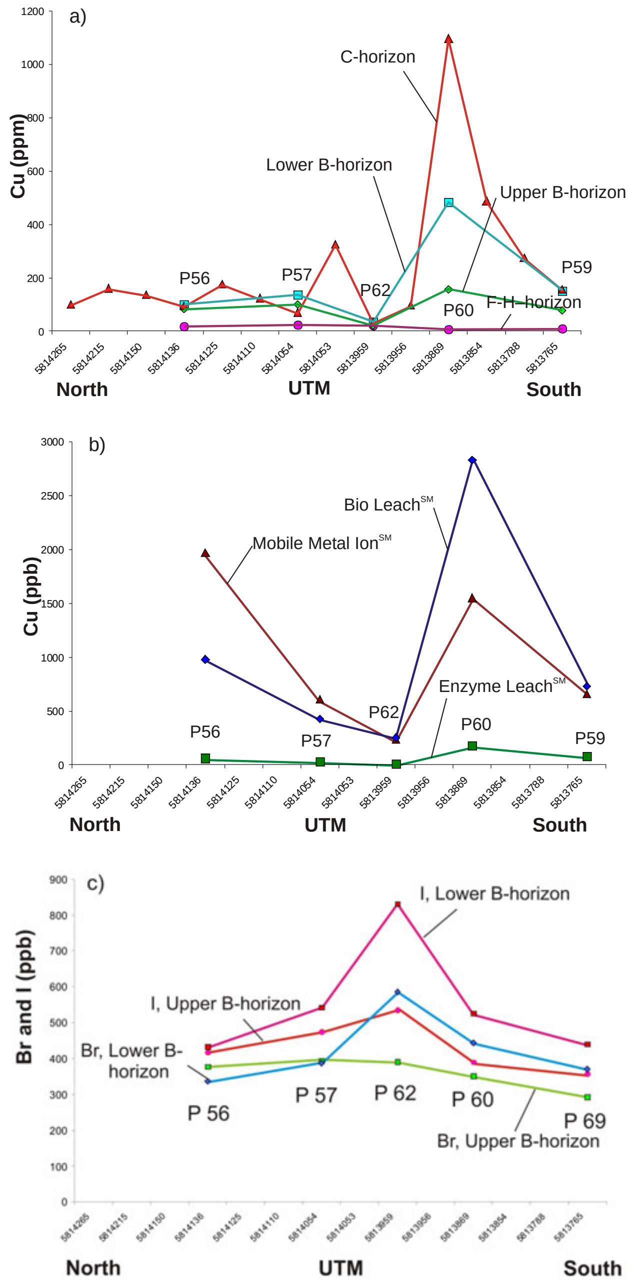

Figure 11. Copper profiles along a traverse across the North East Zone, Shiko Lake: **a**) aqua regia digestion followed by inductively coupled plasma-mass spectrometry (ICP-MS) analysis for Cu in the F-H–, upper B-, lower B- and C-horizons; **b**) Mobile Metal Ion^{SM} (MMI), Enzyme Leach^{SM} and Bio Leach^{SM} analyses for Cu in the lower B-horizon; **c**) Bio Leach^{SM} analysis for Br and I in the upper B- and lower B-horizons.

CONCLUSIONS

Regional geochemical survey and regional till survey databases have been updated with new information including spatial links of sample locations to bedrock geology.

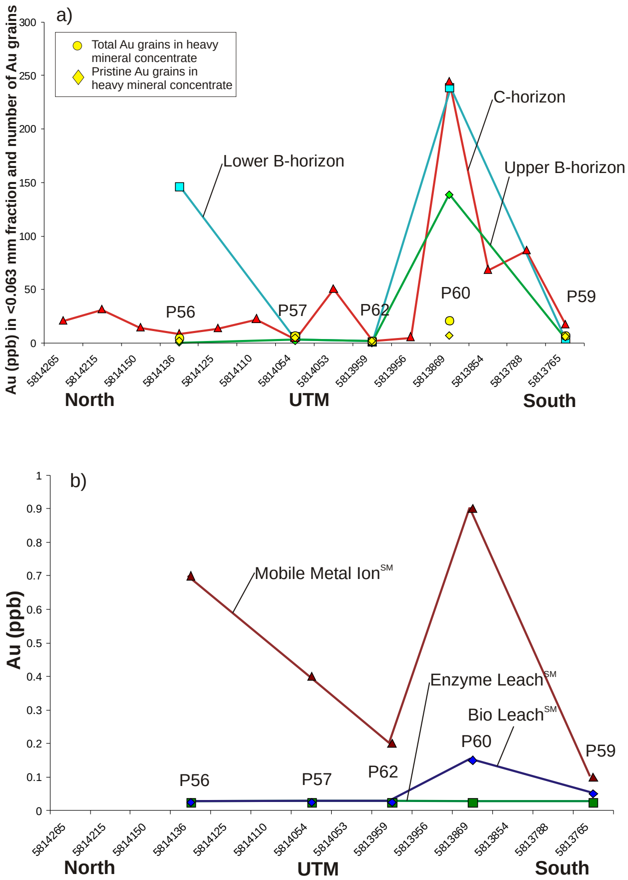

Figure 12. Gold profiles along a traverse across the North East Zone, Shiko Lake: **a**) aqua regia digestion followed by inductively coupled plasma-mass spectrometry (ICP-MS) analysis for Au in the F-H–, upper B-, lower B- and C-horizons; **b**) Mobile Metal Ion^{SM} (MMI), Enzyme Leach^{SM} and Bio Leach^{SM} analyses for Au in the lower B-horizon.

Aqua regia digestion–ICP-MS analyses of soil samples from traverses over the Mouse Mountain and Shiko Lake porphyry Cu-Au mineral deposits show that Cu and Au anomaly contrast is greater for the C-horizon compared to the F-H– and B-horizons.

At Shiko Lake, the asymmetric shape of the Cu anomaly in the C-horizon soil and the large number of pristine Au grains in the C-horizon heavy mineral concentrates suggest a nearby mineral source for the soil anomalies. However, local ice-flow direction may be different from the regional direction due to deflection by local bedrock topography and hence the azimuth vector from the bedrock source cannot be determined precisely.

There is very little variation in the element anomalies determined by Enzyme Leach^{SM} compared to anomalies determined by other methods. Bio Leach^{SM} analysis revealed higher contrast Cu and Co anomalies than the anomalies from MMI analysis. However, for Au the MMI has higher anomaly contrast than the other selective extractions.

In general, Bio Leach^{SM} Br and I show similar geochemical patterns to metals although the anomaly peaks appear displaced from the metal peaks.

ACKNOWLEDGMENTS

Advice from Peter Bernier, President, Richfield Ventures Corp., on the Mouse Mountain property is very much appreciated and Scott Petsel, NovaGold Resources Inc., and Rudi Durfeld are sincerely thanked for providing information and advice about the Shiko Lake property. The Geological Survey of Canada generously funded much of the sample preparation and analysis. A constructive review of this paper by Philippe Erdmer is very much appreciated by the authors.

REFERENCES

Cui, Y., Eckstrand, H. and Lett, R.E. (2009): Regional geochemical survey: delineation of catchment basins for sample sites in British Columbia; *in* Geological Fieldwork 2008, *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 2009-1, pages 231–238.

Davis, J.C. (1973): Statistics and data analysis in geology; *John Wiley and Sons*, New York, 550 pages.

Dunn, C.E., Cook, S.J. and Hall, G.E.M. (2007): Halogens in surface exploration geochemistry: evaluation and development of methods for detecting buried mineral deposits; *Geoscience BC*, Report 2007-10, 62 pages.

Ferbey, T. (2008): Regional to property-scale drift prospecting surveys in British Columbia; *BC Ministry of Energy, Mines and Petroleum Resources*, GeoFile 2008-12.

Jackaman, W. (2007): Mountain pine beetle infestation area (parts of NTS 082, 092, 093), central British Columbia: Regional Geochemical Data Repository Project; *in* Geological Fieldwork 2006, *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 2007-1 and *Geoscience BC*, Report 2007-1, pages 307–310.

Jackaman, W. (2008): Quest Project sample reanalysis digital data release; *Geoscience BC*, Report 2008-3.

Jackaman, W. and Balfour, J.S. (2008): QUEST Project geochemistry: field surveys and data reanalysis, central British Columbia (parts of NTS 093A, B, G, H, J, K, N, O); *in* Geoscience BC Summary of Activities, *Geoscience BC*, Report 2008-1, pages 7–10.

Jackaman, W., Balfour, J.S. and Reichheld, S.A. (2009): QUEST-West Project geochemistry: field survey and data reanalysis, central British Columbia (parts of NTS 093E, F, J, K, L, M, N); *in* Geoscience BC Summary of Activities 2008, *Geoscience BC*, Report 2009-1, pages 7–14.

Kendrick, M.A., Burgess, R., Pattrick, R.A.D. and Turner, G. (2001): Fluid inclusion noble gas and halogen evidence on the origin of Cu-porphyry mineralizing fluids; *Geochimica et Cosmochimica Acta*, Volume 65, Number 16, pages 2651–2668.

Large, R.R., Maslennikov, V.V. and Robert, F. (2007): Multistage sedimentary and metamorphic origin of pyrite, gold in the Giant Sukhoi Log deposit, Lena Gold Province, Russia; *Economic Geology*, Volume 102, pages 1233–1267.

Lett, R.E. (2008): Till geochemical open file; *BC Ministry of Energy, Mines and Petroleum Resources*, GeoFile 2008-13.

Lett, R.E., Man, E.C. and Mihalynuk, M.G. (2008): Towards a drainage geochemical atlas of British Columbia; *in* Geological Fieldwork 2007, *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 2008-1, pages 61–68.

Lett, R.E. and Sandwith, Z. (2008): Geochemical orientation surveys in the Quesnel Terrane between Quesnel and Williams Lake, central British Columbia (NTS 093A, B, G); *in* Geological Fieldwork 2007, *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 2008-1, pages 49–60.

Logan, J.M. and Mihalynuk, M.G. (2005): Regional geology and setting of the Cariboo, Bell, Springer and Northeast porphyry Cu-Au zones at Mount Polley, south-central British Columbia; *in* Geological Fieldwork 2004, *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 2005-1, pages 249–270.

Mann, A.W., Birrell, R.D., Mann, A.T., Humphreys, D.B. and Perdix, T. (1998): Application of mobile metal ion technique to routine geochemical exploration; *Journal of Geochemical Exploration*, Special Issue on Selective Extractions, Hall, G.E.M and Bonham-Carter, G.F., Editors, Volume 61, pages 87–102.

Massey, N.W.D., MacIntyre, D.G., Desjardins, P.J. and Cooney, R.T. (2005): Digital geology map of British Columbia; *BC Ministry of Energy, Mines and Petroleum Resources*, GeoFile 2005-1.

MINFILE (2008): MINFILE BC mineral deposits database; *BC Ministry of Energy, Mines and Petroleum Resources*, URL <http://www.empr.gov.bc.ca/Mining/Geoscience/MINFILE/Pages/default.aspx> [December 16, 2008].

Paterson, K., Lett, R.E. and Telmer, K. (2009): Lithogeochemistry of the Spanish Mountain gold deposit, east-central British Columbia (NTS 093A/11W); *in* Geological Fieldwork 2008, *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 2009-1, pages 163–168.

Petsel, S.A. (2006): Rock and soil sampling survey assessment report on the Shiko Lake property; *BC Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 2866, 182 pages.

Rose, A.W., Hawkes, H.E. and Webb, J.S. (1979): Geochemistry in mineral exploration; *Academic Press*, London, 657 pages.

Sibbick, S.J. (1994): Preliminary report on the application of catchment basin analysis to regional geochemical survey data, northern Vancouver Island (92L/3, 4, 5 and 6); *in* Geological Fieldwork 1993, *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 1994-1, pages 111–118.

Williams, T.M. and Gunn, A.G. (2002): Application of Enzyme Leach^{SM} soil analysis for epithermal gold exploration in the Andes of Ecuador; *Applied Geochemistry*, Volume 17, pages 367–385.