GEOCHEMICAL DISPERSION IN COMPLEX GLACIAL DRIFT AT THE MOUNT MILLIGAN COPPER-GOLD PORPHYRY DEPOSIT (93N/1E, 93O/4W)

(Fig. B1, No. 6)

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INTRODUCTION

Mining camps in glaciated areas evolve from initial discoveries of outcropping or subcropping mineral deposits and progress until all deposits detectable by surface or near surface exploration methods are located. Standard geological, geophysical and geochemical exploration techniques are often ineffective in regions of thick, complex glacial drift. However, depletion of known ore reserves and the extrapolation of favourable geology beneath drift-covered regions forces mineral exploration into these areas. Its success often depends on the utilization of drift-exploration methodologies which can interpret the three dimensional relationships between underlying bedrock, transported surficial deposits and soils formed during post-glacial weathering. Mineral exploration programs in eastern and central Canada, where areas of high mineral potential are blanketed by thick surficial deposits, have evolved a comparatively advanced drift-prospecting capability. Application of these techniques, devised for shield areas which underwent continental glaciation, may be inappropriate for exploration in British Columbia which has experienced predominantly alpine glaciation.

An integrated geochemistry and surficial geology program has been undertaken by the British Columbia Geological Survey Branch to develop drift-prospecting strategies appropriate for the province. This program will involve a number of case studies which will examine glacial and post-glacial processes which influence geochemical dispersion patterns.

The Mount Milligan alkaline copper-gold porphyry deposit was chosen for the inaugural study on the basis of several attributes. Intense exploration for this style of deposit is concentrated within the Quesnel trough, a region of extensive glacial drift cover. Also, the Mount Milligan deposits are concealed by complex surficial deposits comprising colluvial, morainal and glaciofluvial sediments of variable thickness.

During 1990, several features of geochemical dispersion at Mount Milligan were examined:

- Copper and gold concentrations outwash and till.
- Dispersion of copper and gold soils developed in outwash and till.
- Lateral and vertical dispersion of anomalous copper and gold in glaciofluvial sediments.
- Dispersion of gold in colluvial soils.

The term surficial deposit refers to oxidized or unoxidized colluvium, till and glaciofluvial outwash, whereas the terms soil and soil horizon refer to the upper layers of these surficial deposits which have undergone post-depositional weathering and soil formation.

This study has shown the importance of distinguishing surficial deposits and the recognition of weathering effects in the interpretation of geochemical trends. Mean background concentrations of copper and gold are predominantly influenced by the type of surficial deposit and soil horizon. Misidentification of sample media may mask true anomalies and highlight false anomalies.

PROPERTY OVERVIEW

LOCATION AND ACCESS

Mount Milligan is located at latitude 55°08′N, longitude 124°02′W (NTS map sheet 93N/01), approximately 150 kilometres northwest of Prince George in north-central British Columbia (Figure B-6-1). The property can be reached by truck along a series of active logging roads leading west from Windy Point on Highway 97.

LOCAL GEOLOGY AND MINERALIZATION

The Mount Milligan property is dominantly underlain by upper Triassic alkalic flows, pyroclastics and related sediments (Figure B-6-2). Recent regional mapping by Nelson *et al.* (1991) in the Mount Milligan area identifies the assemblage as the Witch Lake Formation within the Takla Group. Units comprise augite (±plagioclase) porphyry agglomerate, trachyte breccias and flows and bedded epiclastic sediments. Locally intruding this sequence are several monzonite bodies of early Jurassic age. Loci of mineralization at Mount Milligan are the MBX and Southern Star stocks composed of crowded plagioclase-porphyritic monzonite. The stratigraphy strikes northwest and dips at 30° to 60° to the northeast. The porphyry systems are spatially related to long-lived faults which controlled intrusive activity (Nelson *et al.*, 1991). The Great Eastern fault, immediately east of the

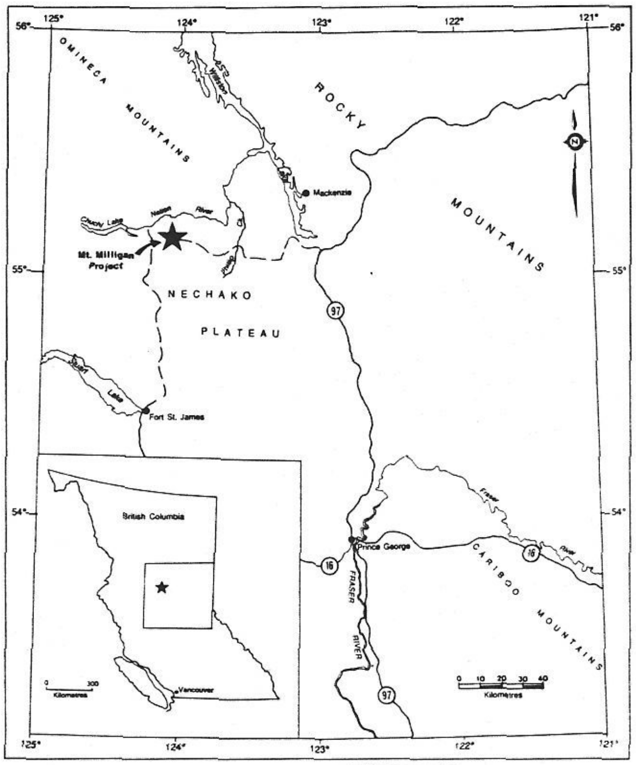


Figure B-6-1. Location of the Mount Milligan deposit.

porphyries, juxtaposes Takla Group rocks with Eocene continental sediments within an extensional basin.

Mineralization is centred on the porphyry intrusions and consists of disseminated and stockwork sulphides. Delong *et al.* used cluster analysis to demonstrate the significant association between mineralization (copper, gold; chalcopyrite, bornite and magnetite) and potassic alteration (biotite, K-feldspar) enveloping the stocks. Nelson *et al.*, postulated that much of the latite and trachyte units mapped in drill core are potassically altered andesite flows and derived sediments. Delong *et al.* statistically identified the assemblage of calcite, albite, epidote and pyrite associated with propylitic alteration which has developed peripheral to the potassic zone. A pyrite alteration halo measuring 3.0 kilometres by 4.5 kilometres, elongate about an east-west axis extends outwards from the deposits. Combined geological reserves of the two deposits are 400 million tonnes grading 0.48 gram per tonne gold and 0.20 per cent copper. Lesser deposits include high-grade gold-copper (arsenic, silver, lead, zinc and molybdenum) quartz veins in the Esker and Creek zones and an oxidized supergene cap of less than 10 million tonnes (D. Forster, personal communication, 1990) overlying the MBX stock. Within the supergene

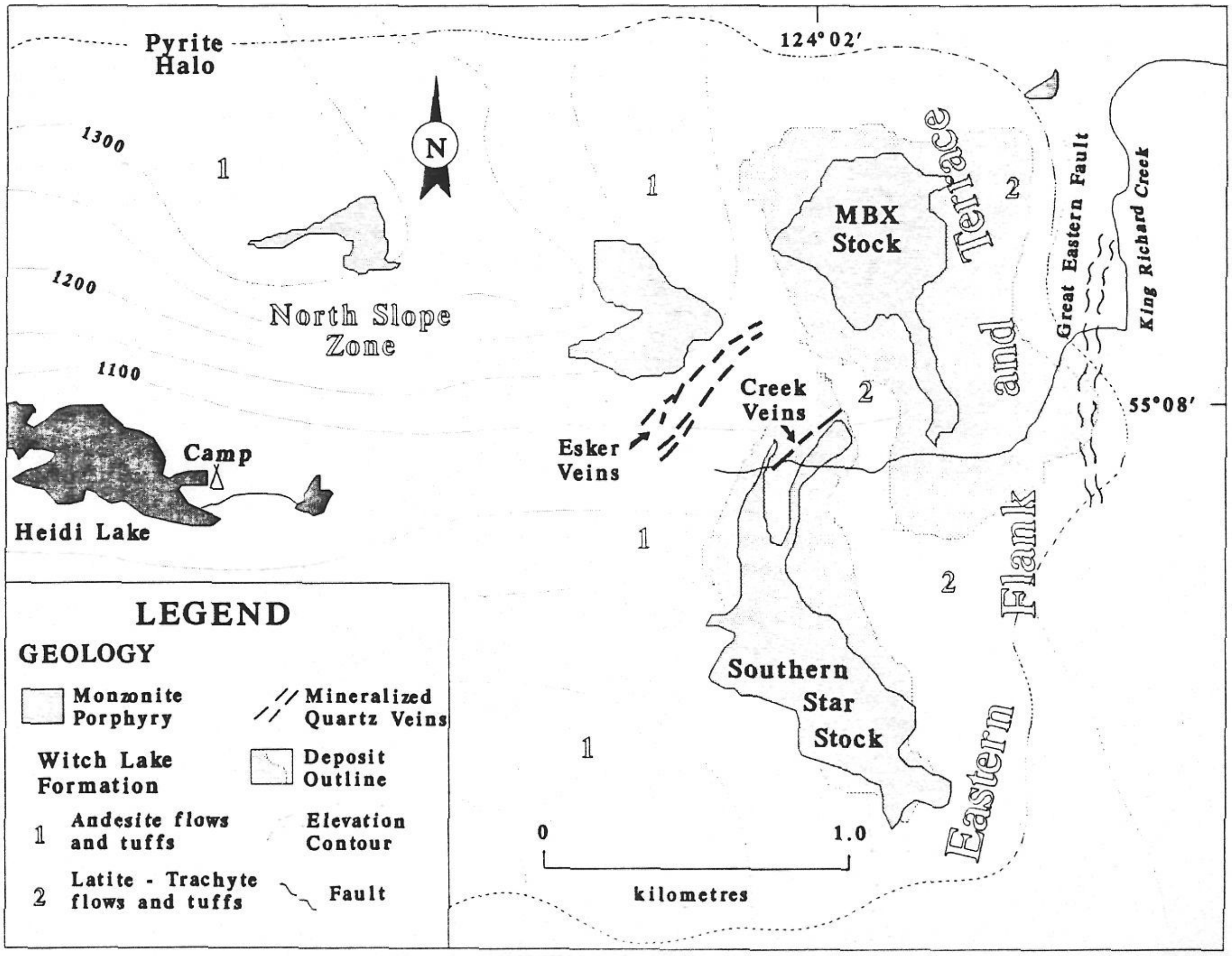


Figure B-6-2. Geology of the Mount Milligan area.

zone chalcopyrite, the dominant copper-bearing mineral, has been altered to chalcocite, djurleite, covellite, malachite, cuprite and native copper.

SURFICIAL GEOLOGY

The Mount Milligan area was glaciated during the last glacial episode. All glacial features observed in the study area are associated with this event. Ice-flow indicators such as drumlinoids and striae suggest a southwest to northeast direction of ice advance across the area. The surficial deposits, which may attain tens of metres in thickness, consist mainly of matrix-supported diamictons in the form of a till blanket, as well as glaciofluvial deposits of sand and gravel. The latter generally exhibit a southwest trend as defined by sinuous esker ridges; the dominant meltwater paleocurrent direction obtained from outwash sediments is to the northeast. Till veneer and colluvium deposits frequently mantle the steeper slopes of hills, whereas glaciofluvial sediments define broad gently rolling terraces. Isolated deposits of fine glaciolacustrine sand, silt and clay are found within several topographic depressions. Thickness of surficial deposits varies considerably, from less than 1 metre to in excess of 90 metres. Test pits and cut faces expose a complex stratigraphic sequence. A more complete discussion of Quaternary geology in the Mount Milligan area is given by Kerr and Bobrowsky (1991, this volume).

PHYSIOGRAPHY AND CLIMATE

The Mount Milligan property lies in the Nechako Plateau, a region of flat to gently rolling terrain. Local relief is provided by a northwest-trending ridge which rises 300 to 500 metres above the local plateau elevation of 1000 metres. Mount Milligan, with a summit elevation of 1508 metres lies at the northwestern end of the ridge. Drainage along the ridge is dendritic, becoming glacially disturbed on the surrounding plateaus where short meandering stream courses connect pothole lakes, ponds and swamps. The MBX and Southern Star stocks underlie a terrace on the eastern flank of the ridge. At this location the ridge and terrace are dissected by an east-west oriented valley occupied by Heidi Lake which drains to the west and King Richard Creek which drains to the east.

The region has a sub-boreal climate. Winters are long and cold, average daily temperature in January is -15 to -20°C. Summers are short and cool, July average daily temperature is less than 16°C. The area is moderately wet receiving between 500 to 1000 millimetres of precipitation annually. Predominant soil type of the region is a humo-ferric podzol (soil and horizon nomenclature based on the Canadian System of Soil Classification, *Agriculture Canada*, Queen's Printer, Canada) based which is characterized by a moderately thin (10-20 cm) organic-rich Ah horizon, a thin to absent leached Ae horizon, a moderately thick (20-40 cm) iron-enriched Bf horizon, a thin to moderately thick (10-30 cm) olive-brown Bm horizon, an oxidized C1 horizon in which pre-soil development textures and glacial structures are preserved and an unoxidized C2 horizon typically found at a depth greater than 2 metres (Epp and Kenk, 1983). Forest cover comprises hybrid Engelmann – white spruce and subalpine fir on hills whereas extensive areas of lodgepole pine cover plateaus.

EXPLORATION HISTORY

Initially explored in the 1970s as a porphyry copper prospect and subsequently dropped, the Mount Milligan property was acquired in the early 1980s as an alkaline copper-gold porphyry target based on the QR deposit model. Release of British Columbia regional geochemical survey data (BC RGS 11 - NTS 93N, Manson River) in 1984, confirmed the property's anomalous nature. King Richard Creek, draining the Mount Milligan property, recorded the second highest copper value (493 ppm) in the RGS 11 survey. Geochemical soil surveys from 1984 to 1986 defined broad copper-gold soil anomalies in colluvium on the North and South Slope zones east of Heidi Lake and small, linear copper-gold soil anomalies in moraine and glaciofluvial sediments on the eastern flank and terrace.

By 1990, follow-up geophysical surveys and extensive diamond drilling had defined the mineralized systems associated with the MBX and Southern Star stocks underlying the anomalies on the eastern flank and terrace. The association between soil anomalies developed in the complex, often thick surficial deposits and underlying mineralization was unclear. In addition, a bedrock source for the North Slope colluvium anomalies had not been defined.

METHODS

SAMPLE COLLECTION

SURFICIAL DEPOSIT AND SOIL HORIZON COMPARISONS

One-kilogram B and C-horizon soil samples were collected from 26 test pits ranging from 2 to 5 metres in depth, in the area underlain by the MBX and Southern Star stocks (Figure B-6-3). Mean depth for B-horizon soil samples was 30 centimetres, individual depths ranged from 20 to 60 centimetres, C horizon soil samples varied from 50 to 210 centimetres and averaged 115 centimetres in depth. Field duplicate samples were collected at six of the sites. Samples of mineralized float and bedrock were collected where available. Site observations were recorded regarding: soil type and horizon, depth of sampling, texture of sample, type of overburden, site physiography, nature and abundance of float, nature and abundance of barren and mineralized float and any abnormalities within the overburden such as ferromanga-

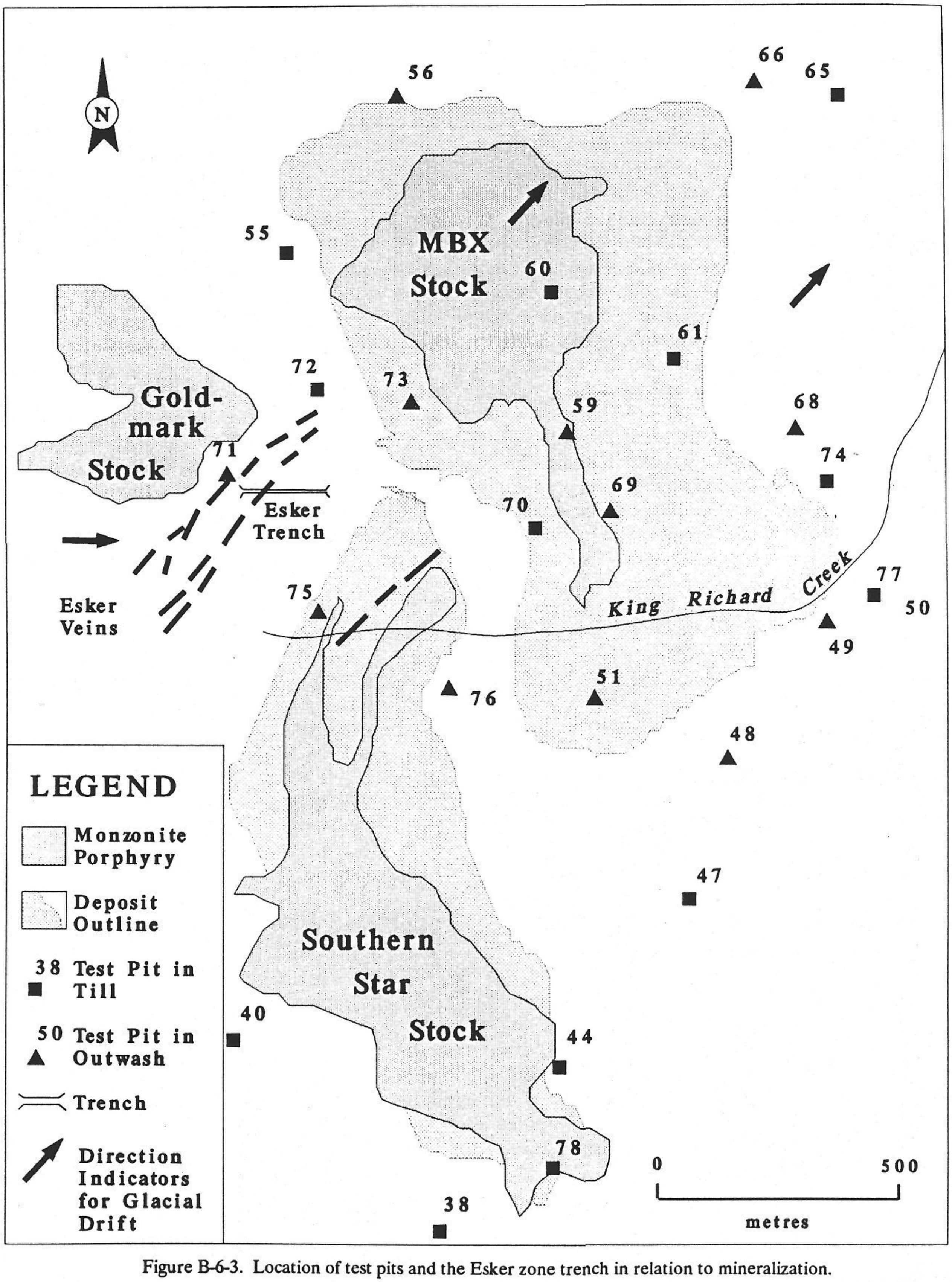


Figure B-6-3. Location of test pits and the Esker zone trench in relation to mineralization.

neous concretions. Photographs and sketches were made of sampled profiles.

DISPERSION IN GLACIOFLUVIAL SEDIMENTS

Profile sampling was conducted along a 160-metre trench intersecting mineralized veins in the Esker zone. Bulk 10-kilogram B-horizon soil samples and routine 1-kilogram C-horizon soil samples were collected at 50-centimetre intervals down profile. Eight profiles spaced 10 to 20 metres apart were sampled with each profile yielding from two to six samples. Rock-chip samples (1 kilogram) of underlying bedrock were collected where possible. Photographs, sketches and site observations were recorded for each profile.

DISPERSION IN COLLUVIAL SOILS

Seven sites were sampled for bulk B-horizon soil, C-horizon soil and bedrock-chip samples (were possible). Research centred on grid location 115+00N, 93+50E where a 19000 ppb (0.55 oz/t) gold anomaly was reported by the original soil sampling program conducted by the property owners. A pair of field duplicate samples, spaced 5 metres apart, was collected at this site.

SAMPLE PROCESSING

All samples were sent to ACME Analytical in Vancouver for processing and analysis. B and C-horizon soil samples were dry sieved to -80 mesh ASTM (-177 μm). In addition, C-horizon soils were dry sieved to -40 + 80 mesh (-420 + 177 μm). Chip samples of float and bedrock were crushed and pulverized to -100 mesh (-150 μm).

B-horizon bulk samples were divided into two splits, one split from each sample was dry sieved to coarse (-40 + 80 mesh) and fine (-80 mesh) size fractions. Magnetic and nonmagnetic heavy liquid concentrates were produced from the -80 mesh fraction of the remaining split using bromoform (specific gravity = 2.96 g/cm^3). Pan concentrates were produced from coarse reject material.

SAMPLE ANALYSIS

Subsamples (0.5 gram) of all size fractions of soil and pulverized rock were subjected to aqua regia digestion (3 millilitres of 3-1-2 $HCl:HNO_3:H_2O$ at 95°C for 1 hour then diluted to 10 millilitres with water). Sample solutions were then analysed by inductively coupled plasma emission spectrometry (ICP-ES) for determination of a suite of 29 elements (Al, Sb, As, Ba, Bi, B, Cd, Ca, Cr, Co, Cu, Fe, La, Pb, Mg, Mn, Mo, Ni, P, K, Ag, Na, Sr, Th, Ti, W, U, V and Zn). Results are quantitative for base metals and silver (0.1 to 2 ppm detection limits), semi-quantitative for siderophile and lithophile elements (1 ppm to 100 ppm detection limits) and qualitative for refractory elements such as boron, chromium and tungsten (1 ppm detection limits). Gold content was measured using 10-gram soil subsamples (-80 mesh) and 30-gram rock-chip subsamples (-100 mesh) by fire assay flux digestion followed by ICP-ES determination. Reported detection limit by this method is 1 ppb.

Some pan and heavy liquid concentrates from bulk B-horizon samples were examined under a binocular microscope to recover gold grains for examination and photography using the scanning electron microscope (SEM) at The University of British Columbia in Vancouver. Samples were selected based on gold content determined by fire assay ICP-ES.

RESULTS

GEOCHEMICAL COMPARISON OF SURFICIAL DEPOSITS

Locations of the 26 test pits for this comparison are presented in Figure B-6-3. Thirteen of the profiles are in glaciofluvial outwash, the remaining sites are in till. Most of the Southern Star deposit is blanketed by matrix supported till which increases in thickness towards King Richard Creek. Conversely, the MBX deposit is covered primarily by outwash of variable thickness which contains isolated exposures of the underlying till and bedrock. Outwash texture ranges from coarse cobbles in a sandy matrix to well-sorted, stratified sands. Soil profiles developed in both parent materials are dominantly humo-ferric podzols. Angular fragments of local mineralized bedrock were evident in varying amounts in both the till and outwash units. Ferro-manganous concretions were noted within the C horizon in several pits close to the MBX stock, generally in close association with abundant mineralized float.

Table B-6-1 lists the pH, copper content and gold content by soil horizon and overburden type within the test pits. Mean copper concentrations of B and C-horizon samples in till-derived soil exceed two times the average concentration found in the corresponding horizons for soil derived from outwash. F-tests indicate a significant (95% confidence limit) difference in mean copper concentrations in soils developed over till, relative to soils formed in outwash (Table B-6-2a).

Mean gold concentrations demonstrate a similar geochemical distinction between surficial deposit types. B horizons in till-derived soils have mean gold contents 2.7 times higher than outwash-derived B-horizon soils. After excluding test pit 71 (C horizon concentration of 733 ppb) which significantly biases statistical calculations, C-horizon gold concentrations in till-derived soils average 2.3 times higher then C-horizon concentrations in outwash-derived soils.

GEOCHEMICAL COMPARISON OF SOIL HORIZONS

Overall, soil pH values are slightly acidic, ranging from a pH of 4.9 to 6.4. Mean B-horizon pH levels are lower than C-horizon pH levels for both till and outwash-

TABLE B-6-1
pH, COPPER AND GOLD CONCENTRATIONS IN SOIL PROFILES OVERLYING THE MBX AND SOUTHERN STAR ZONES

Outwash								Till							
Test Pit	Samp #	Soil Hor.	Depth (m)	Zone	pH	Cu (ppm)	Au (ppb)	Test Pit	Samp #	Soil Hor.	Depth (m)	Zone	pH	Cu (ppm)	Au (ppb)
71	905001	Bf	0.30	MBX	5.1	75	19	72	905004	Bf	0.30	MBX	5.5	71	29
71	905002	C	0.70	MBX	5.6	495	733	72	905005	C	1.20	MBX	5.7	715	85
56	905011	Bf	0.20	MBX	5.0	42	39	55	905008	Bf	0.20	MBX	5.3	165	40
56	905012	C	0.60	MBX	5.8	114	52	55	905009	C	1.20	MBX	5.2	99	37
66	905017	Bf	0.35	MBX	5.6	55	46	65	905014	Bf	0.30	MBX	5.4	137	507
66	905018	C	1.00	MBX	5.8	143	57	65	905015	C	0.70	MBX	5.7	511	134
59	905024	Bf	0.25	MBX	5.3	61	77	61	905021	Bf	0.30	MBX	5.4	129	12
59	905026	C	0.90	MBX	5.7	228	78	61	905022	C	0.50	MBX	5.6	172	19
73	905032	Bf	0.30	MBX	5.5	59	55	60	905030	Bf	0.50	MBX	5.1	258	41
73	905034	C	0.70	MBX	5.7	161	20	60	905031	C	0.95	MBX	5.9	1094	90
69	905042	Bf	0.30	MBX	5.0	93	16	70	905040	Bf	0.35	MBX	5.3	332	103
69	905043	C	1.50	MBX	5.4	241	23	70	905041	C	0.60	MBX	5.5	1229	73
68	905046	Bf	0.25	MBX	4.9	57	205	74	905049	Bf	0.30	MBX	5.0	31	28
68	905047	C	1.00	MBX	5.5	126	14	74	905050	C	2.00	MBX	5.4	58	8
75	905052	Bf	0.40	S.S	5.0	152	12	77	905072	Bm	0.30	S.S	5.7	123	285
75	905054	C	1.20	S.S	5.7	93	23	77	905074	C	2.00	S.S	6.3	327	57
76	905058	Bm	0.30	S.S	5.2	66	10	47	905079	Bm	0.60	S.S	5.8	168	69
76	905059	C	1.60	S.S	5.5	140	22	47	905080	C	1.20	S.S	5.9	183	65
51	905062	Bf	0.40	S.S	5.2	42	5	44	905081	Bh	0.50	S.S	5.8	193	115
51	905063	C	0.80	S.S	5.4	79	13	44	905085	C	1.00	S.S	5.2	386	109
49	905066	Bf	0.25	S.S	5.0	26	18	78	905087	Bm	0.30	S.S	6.4	60	47
49	905067	C	2.10	S.S	5.5	46	35	78	905088	C	0.60	S.S	5.9	95	114
50	905069	Bf	0.30	S.S	5.1	37	4	38	905091	Bm	0.45	S.S	5.7	67	55
50	905070	C	0.70	S.S	5.6	64	11	38	905092	C	1.60	S.S	6.1	147	27
48	905076	Bf	0.30	S.S	5.1	47	4	40	905093	Bf	0.30	S.S	5.8	70	17
48	905077	C	1.90	S.S	5.9	76	15	40	905095	C	1.80	S.S	5.9	380	50
Mean - B horizon:					5.2	62	39	Mean - B horizon:					5.6	139	104
Std dev - B horizon:					0.2	32	55	Std dev - B horizon:					0.4	86	141
Mean - C horizon:					5.6	154	84	Mean - C horizon:					5.7	415	67
Std dev - C horizon:					0.2	118	196	Std dev - C horizon:					0.3	382	39

derived soils. Mean copper concentrations show a strong difference between the B and C soil horizons in both types of overburden. Mean copper concentrations in the C horizon average 2.5 to 3.0 times higher relative to the B horizon for soils derived from outwash and tills respectively. At test pit 72 which demonstrates the greatest contrast, copper increases by an order of magnitude between the B (71 ppm) and C (715 ppm) horizons. Results of F-tests (Table B-6-2a) clearly indicate that B and C soil horizons contain significantly different copper concentrations at the 95 per cent confidence level in both till and outwash.

An analysis of variance (Table B-6-2b) which examines within-site variability (B versus C horizon) relative to between-site variability (B horizon at site 1 versus B horizon at site 2) was conducted using copper concentrations. F-ratios for both till and outwash-derived soils exceed the critical F-value at the 95 per cent confidence limit, indicating that differences between soil horizons are greater than differences between sites.

A comparison of gold concentrations between soil horizons demonstrates an erratic pattern. Significant differences, measured by a 100 per cent difference in concentration between horizons, are noted at 10 of 19 anomalous sites (average gold concentration between horizons is >25 ppb). These ten sites are evenly split with five reporting higher B-horizon gold concentrations and five having higher concentrations in the C horizon.

DISPERSION OF COPPER AND GOLD IN GLACIOFLUVIAL SEDIMENTS

A series of high-grade copper-gold (arsenic, silver, lead, zinc, molybdenum) quartz veins hosted by Witch Lake Formation volcanics comprise the Esker zone. The veins, which trend 050° and dip 70° northwest, lie approximately 500 metres southeast of the MBX stock. Profile sampling was conducted along a previously excavated 160-metre trench which intersects the Esker zone. The trench lies 20 metres south of line 91N and extends from 122+30E to 123+90E. Mineralized bedrock is exposed sporadically from 122+50E to 123+15E.

Surficial cover, shown schematically in Figure B-6-4, comprises outwash varying in depth from 0.5 to 2.5 metres (maximum depth of trenching). Orientation of the trench parallels the local paleocurrent direction of 090°. Sediment textures vary from clast-supported coarse cobbles in a sandy matrix to well-sorted stratified sands. B-horizon development in the dominantly humo-ferric podzols ranges from 30 to 70 centimetres in depth and is underlain by an oxidized C horizon (C1). Unoxidized C horizons (C2) were noted in the bottom of three pits at an average depth exceeding 2.0 metres and as a perched layer at a depth of 1.0 to 1.5 metres in test pit 95.

Copper and gold concentrations in mineralized bedrock samples range from 97 to 1471 ppm and 41 to 107 ppb respectively. Large, angular, mineralized clasts were noted in all profiles. Abundance of mineralized clasts varies from 50 per cent near bedrock to 5 per cent in distal profiles. Iron and manganese cementation of the outwash is found close (< 5 metres) to bedrock and is conformable to bedding within the drift.

Table B-6-3 presents the results of reduced major axis regression analysis comparing -40+80 mesh and -80 mesh fractions of B and C soil horizon samples from the Esker trench. Concentrations of most elements are significantly higher (95% confidence limit) in the -80 mesh fraction. Significant (95% confidence limit) correlations are noted between the two size fractions for all elements except gold.

Table B-6-4 compares concentrations for copper, iron, manangese, gold and pH between horizons and size fractions. Considerable increases in concentration with depth are noted for these elements, with the effect generally greater in the -80 mesh fraction.

This trend is most pronounced for copper (Figure B-6-5). Excluding test pit 91, which contains subcroping mineralized bedrock, mean concentration of copper in the Bf horizon (sampled at an average depth of 25 cm) is 57 ppm (standard deviation of 13 ppm). In the upper C1-horizon samples (collected at an average depth of 55 cm), copper increases to an average concentration of 179 ppm (standard deviation of 97 ppm). Greatest variability occurs in profiles close to bedrock (test pits 90 to 95) where copper concentrations generally increase four-fold between the B and upper C horizon and attain maximum concentrations at the base of the pits.

Laterally, copper concentrations diminish with distance. Test pit 98, located 55 metres down paleocurrent from mineralized bedrock, has a maximum concentration of 134 ppm. Background for glaciofluvial sediments, based on test pits 48 to 51, is 66 ppm (standard deviation of 15 ppm). Contouring sample concentrations (Figure B-6-5), using arbitrarily chosen levels of 100 and 300 ppm, defines two lobes of moderately enriched copper in sediment extending down paleocurrent from mineralized bedrock. The upper-most lobe is not evident in surface (B horizon) samples.

Figure B-6-6 presents vertical and lateral variability for gold concentrations in soils. Moderately enhanced concentrations (>15 ppb) are noted near bedrock with good correlation between bedrock and surrounding overburden concentrations. A plume of gold-enriched material (>100 ppb) is seen extending towards the surface and down paleocurrent from test pit 95 to test pit 98. Background for glaciofluvial sediments, as determined from test pits 48 to 51, is 7.8 ppb (standard deviation of 6.5 ppb). The anomalous plume is present within the B-horizon. Heavy mineral concentration of the B horizon bulk soil sample from test pit 90 produced several coarse (>50 microns) gold grains. One equant gold grain recovered

TABLE B-6-2a
RESULTS OF F-TESTS ON CU CONCENTRATIONS OF B AND C HORIZON SOILS

Outwash

B horizon variance:	1022.7	Degrees of Freedom: 12
C horizon variance:	13947.6	Degrees of Freedom: 12

Till

B horizon variance:	7389.1	Degrees of Freedom: 12
C horizon variance:	145618.6	Degrees of Freedom: 12

F-ratios

($F_{crit(0.05,12,12)}$: 2.69)

	B Horizon	C horizon
Till vs. Outwash	7.22	10.44
	Till	Outwash
B Horizon vs. C Horizon	19.71	13.64

TABLE B-6-2b
ANALYSIS OF VARIANCE ON B AND C HORIZON CU CONTENTS

Outwash

Source	Sum of Squares	DF	Mean-Square	F-ratio	$F_{crit(0.05,12,12)}$
Between	1022.8	12	85.2	23.3	2.69
Within	23852.8	12	1987.7		

Till

Source	Sum of Squares	DF	Mean-Square	F-ratio	$F_{crit(0.05,12,12)}$
Between	7389.1	12	615.8	14.2	2.69
Within	105133.4	12	8761.1		

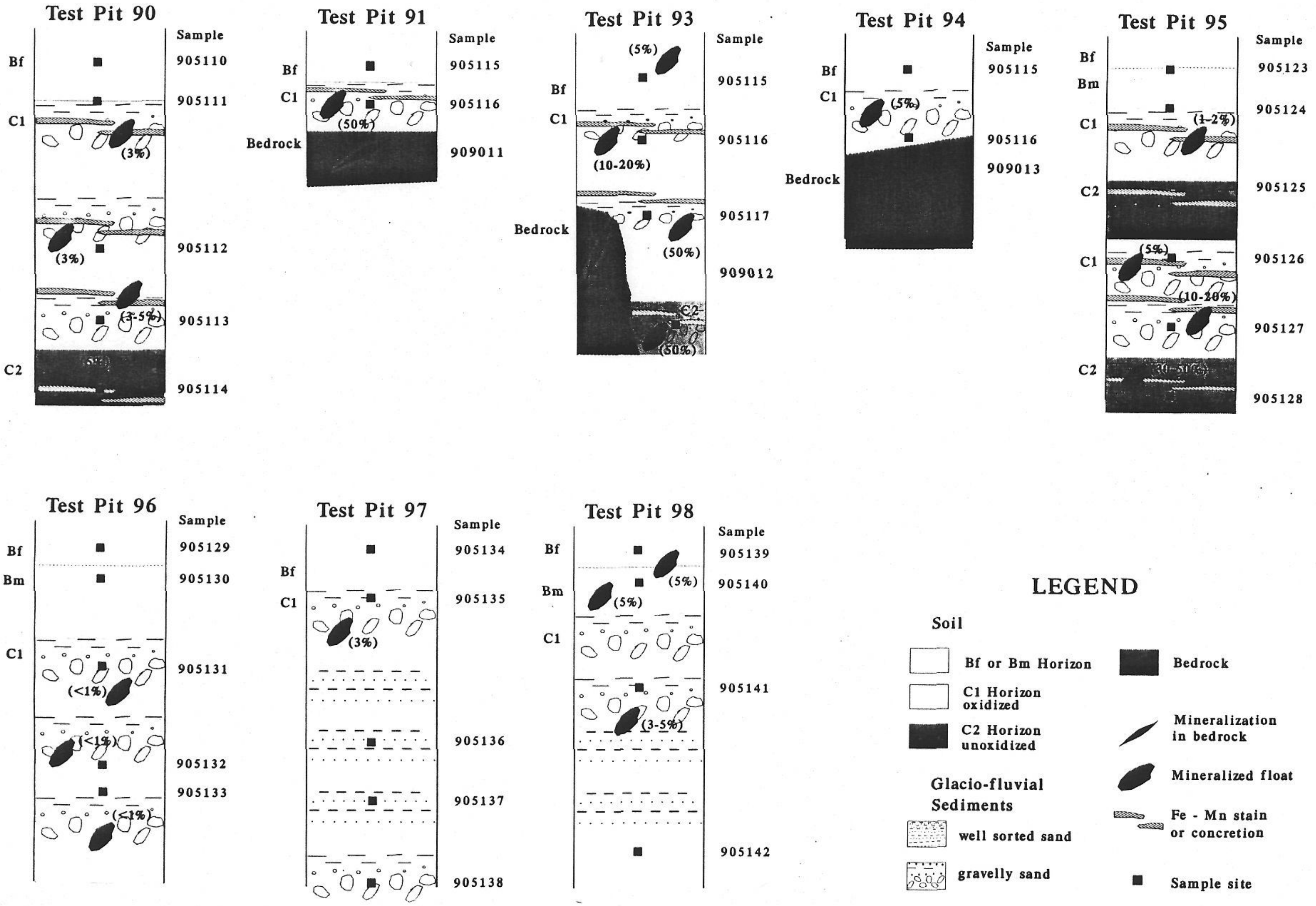


Figure B-6-4. Schematic representation of overburden profiles at the Esker zone trench.

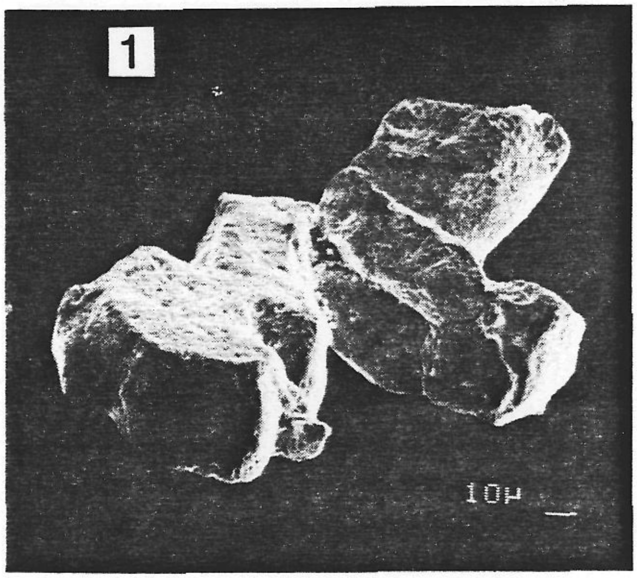
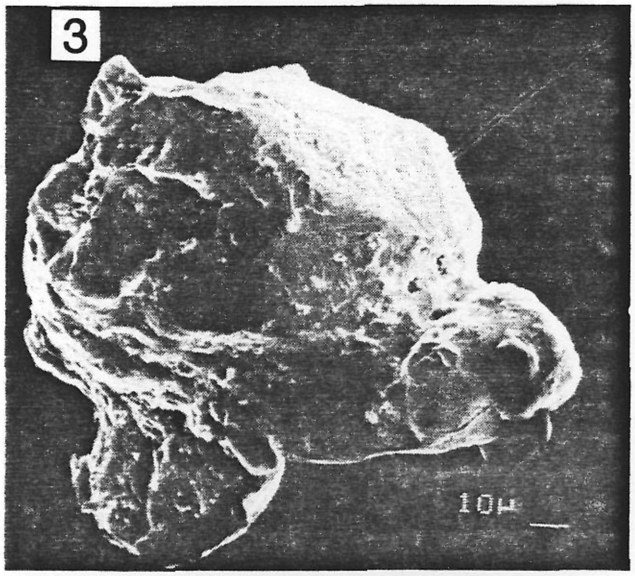
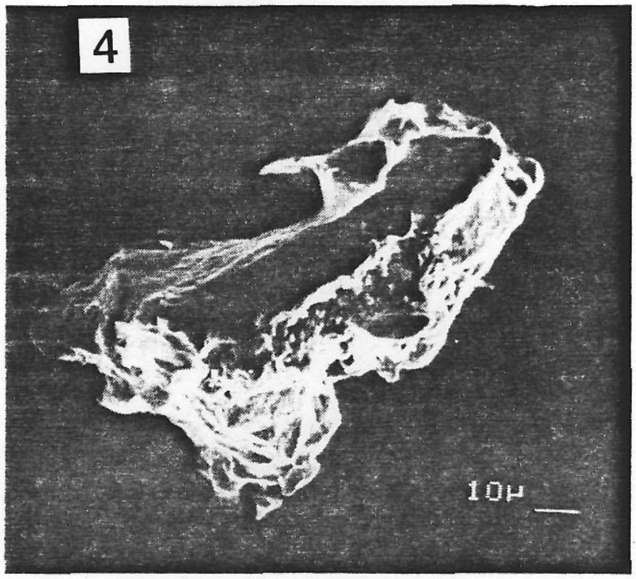
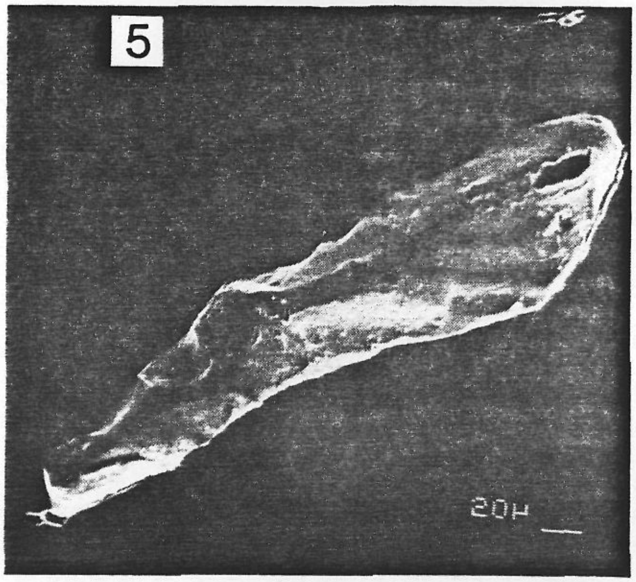


Plate B-6-1. Equant gold grain recovered from the Esker zone trench.







Plates B-6-3, B-6-4, B-6-5. Gold grains recovered from the North Slope site.

Plate B-6-2. Site of 19 000 ppb (0.54 oz/ton) gold soil anomaly on North Slope. Note the veneer (15-30 cm) of colluvium overlying bedrock. Cursory field panning of duplicate samples produced numerous visible grains.

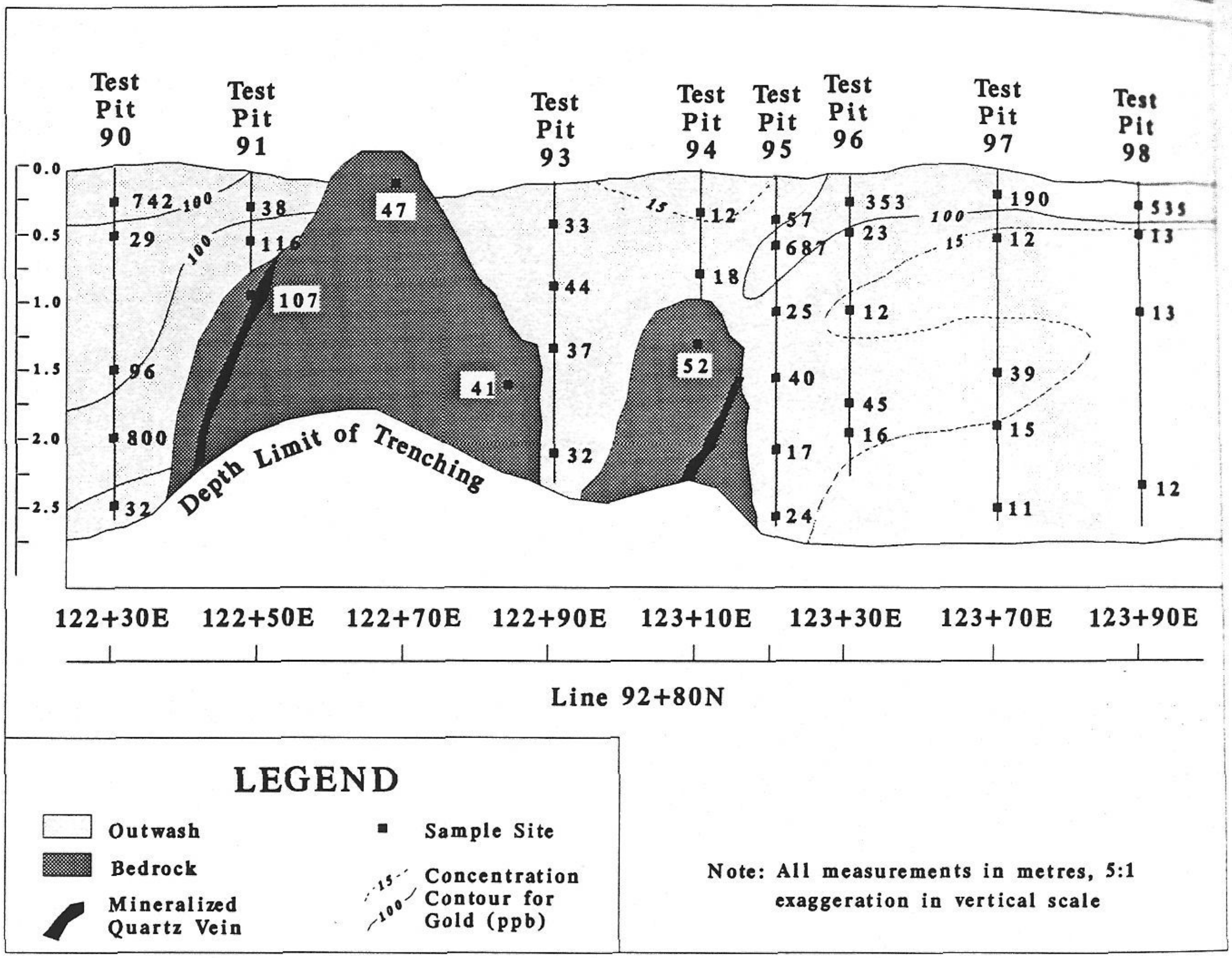


Figure B-6-5. Vertical and horizontal variations in copper concentration along the Esker zone trench.

(Plate B-6-1) has well-defined crystal faces which have been pitted.

DISPERSION OF GOLD IN COLLUVIUM

A broad, coherent region of elevated gold (> 30 ppb) and copper (> 100 ppm) concentrations in complex overburden covering the north wall of the Heidi Lake valley, approximately 1300 metres west of the MBX intrusion, is locally known as the North Slope zone (Plate B-6-2). Underlying lithology consists of andesite flows intruded by minor dikes and plugs of monzonite porphyry. Surficial deposits vary from a colluvium veneer (< 1.0 metre thick) on the steep (> 30°) middle slopes to a morainal blanket (> 1.0 metre thick) on the gentle uppermost slopes. Site 93N, 115 + 50E, in the original soil survey, contained strongly anomalous gold (19 000 ppb) in thin colluvium (Plate B-6-2). Subsequent bedrock sampling by the owners could not locate a conclusive source.

Sampling of the overburden and nearby bedrock at site 93N, 115 + 50E (Table B-6-5 and Figure B-6-7) essentially reproduced original results, although absolute concentrations of gold are considerably lower. Colluvium at this site is strongly anomalous, containing 3074 ppb gold as detected in the -80 mesh fraction of a 1-kilogram sample. Bedrock immediately down-slope (93N, 115 + 44E) gave only moderately enhanced levels (66 ppb mean concentration). Analysis of various size and density fractions from a 10-kilogram bulk B horizon sample collected at the strongly anomalous site gave remarkably consistent gold contents of 2860 ppb (-80 mesh size fraction), 3736 ppb (-270 mesh size fraction) and 2128 ppb (+ 270 mesh size fraction, < 2.96 g/cm^3 density fraction). The coarse size fraction (+ 80 mesh) contained less gold (875 ppb).

Samples from surrounding sites gave lower concentrations, although all samples exceeded 100 ppb gold and 175 ppm copper. Nearly identical values for copper and highly consistent values for gold are noted in coarse to fine size fraction comparisons at these sites. Profile samples from sites 93 + 50N, 114 + 50E and 93N, 115 + 55E show increasing copper concentration with depth.

Binocular microscope scanning of heavy mineral (magnetic and nonmagnetic) and pan concentrates produced surprisingly few gold grains. A maximum of four

TABLE B-6-3
REDUCED MAJOR AXIS REGRESSION ANALYSIS COMPARING FINE AND COARSE FRACTION CONCENTRATIONS FOR VARIOUS ELEMENTS

Slope of Element	Intercept of Regression	Correlation Regression	95% Confidence Coefficient	95% Confidence Limits on Slope		Limits on Intercept	
				Lower	Upper	Lower	Upper
Copper	0.857	0.176	0.9767	0.822	0.884	0.098	0.255
Zinc	0.859	-0.050	0.9828	0.833	0.884	-1.394	1.293
Manganese	0.771	40.868	0.9714	0.741	0.800	25.692	56.054
Iron	0.795	-0.004	0.9306	0.746	0.844	-0.225	0.217
Arsenic	0.666	-0.156	0.7757	0.580	0.752	-1.486	1.173
Vanadium	0.900	0.690	0.8614	0.816	0.984	-8.569	9.949
Calcium	0.962	0.111	0.9086	0.892	1.032	0.080	0.143
Aluminium	0.759	0.038	0.9548	0.722	0.796	-0.039	0.115
Gold	-0.726	2.969	-0.2057	nil		nil	

Notes: Regression equations are of the form $Y = sX + i$; where Y is the Y axis value (element concentration in +80 mesh fraction subsample) and X is the X axis value (element concentration in -80 mesh subsample), i is the Intercept of Regression and s is the Slope of Regression. A Slope of Regression value < 1.0 indicates higher concentrations in the -80 mesh fraction. Critical Correlation Cofficient (r) for 43 paired samples at the .95 confidence limit is 0.264.

gold grains larger than 50 microns were recovered per bulk sample. Ubiquitous limonitic coatings and numerous relict pyrite grains were noted. SEM examination of gold grains revealed pristine crystals (classification after DiLabio, 1990) having smooth surfaces and no evidence of curled thin edges (Plates B-6-3 to B-6-5).

DISCUSSION

VARIATIONS IN COPPER AND GOLD CONCENTRATIONS RELATED TO SURFICIAL DEPOSITS

The significantly higher mean copper and gold concentrations of till-derived soils relative to outwash-derived soils probably reflects the genesis of the two forms of drift. Outwash, in general, originates from a larger source area than till and will contain a greater proportion of sediment derived from nonlocal, barren sources. Till units overlying the property have a more local origin and contain a higher proportion of local, anomalous bedrock. However, observations of abundant mineralized float in the trench on the Esker zone and other test pits indicate that anomalous outwash can develop by incorporating local mineralized bedrock or by reworking mineralized drift of local derivation.

VARIATIONS IN COPPER CONCENTRATIONS RELATED TO WEATHERING

Significantly higher copper concentrations within the C horizon relative to the B horizon appear to be the result of weathering and soil-forming processes acting upon sulphides ubiquitous to the various types of glacial drift. Depleted copper concentrations in till, outwash and colluvium B-horizon soil samples at Mount Milligan indicates a common process affecting the surficial materials during soil formation. Evidence for sulphide weathering and hydromorphic remobilization is suggested by:

(a) an extensive pyrite halo in bedrock which encompasses the study area,
(b) relict pyrite grains in panned bulk samples,
(c) limonitic coatings on all mineral grains,
(d) low pH levels in most soils which increase in value with depth,
(e) uniformly lower copper contents in upper B soil horizons,
(f) the development of iron-manganese concretions close to mineralized bedrock and float.

Features c, d, e and f are readily explained by the oxidation of sulphides, particularity pyrite and chalcopyrite, in the upper soil horizons. In a simplified reaction (Levinson, 1974):

$$4FeS_2 + 15O_2 + 10H_2O -> 4FeO(OH) + 8H_2SO_4.$$

Pyrite in the presence of oxygen and water decomposes to form limonite and sulphuric acid. With sufficient decomposition of pyrite and other sulphides, together with naturally occurring humic and carbonic acids, the buffering capacity of the soil (if any) is exceeded such that soil pH drops below the point of hydrolysis of Fe^{+2} (5.5), promoting the mobility of iron as free ions in surface

TABLE B-6-4
ELEMENT CONCENTRATIONS IN VARIOUS SOIL HORIZONS AND SIZE FRACTIONS - ESKER ZONE TRENCH

Test Pit	Sample #	Soil Hor.	Depth (m)	pH	Copper		Iron		Manganese		Gold	
					-80	+80	-80	+80	-80	+80	-80	+80
90	905110	Bf	0.25	5.4	52	61	3.83	4.02	271	357	742	12
	905111	C1	0.50	5.6	165	106	6.02	5.16	467	411	29	-
	905112	C1	1.50	5.6	274	144	5.37	5.19	642	466	96	-
	905113	C1	2.00	5.7	593	352	4.78	5.04	711	628	800	-
	905114	C2	2.50	5.8	1185	817	4.81	4.64	1666	1283	32	-
91	905115	Bf	0.25	6.1	1172	841	5.65	5.04	590	574	38	15
	905116	C1	0.50	5.7	1401	679	6.95	5.18	669	582	116	-
93	905117	Bf	0.30	5.6	87	93	4.13	4.18	213	306	33	13
	905118	C1	0.75	5.7	306	169	6.33	4.52	508	450	44	-
	905119	C1	1.20	5.6	625	310	5.94	5.51	624	465	37	-
	905120	C2	2.00	5.7	513	392	4.47	4.37	667	643	32	-
94	905121	Bf	0.30	5.5	65	62	3.99	3.96	224	325	12	7
	905122	C1	0.75	5.3	323	219	6.22	4.01	341	333	18	-
95	905123	Bf	0.30	5.6	55	54	3.90	3.52	232	314	57	24
	905124	C1	0.50	5.5	84	53	4.94	3.04	437	377	687	-
	905125	C1	1.00	5.5	191	102	5.12	4.13	578	411	25	-
	905126	C2	1.50	5.5	184	114	5.59	3.82	524	417	40	-
	905127	C1	2.00	5.6	544	281	5.01	4.23	740	543	17	-
	905128	C2	2.50	5.7	623	457	4.06	3.56	841	677	24	-
96	905129	Bf	0.20	5.6	48	47	3.94	3.50	213	313	353	15
	905130	Bm	0.40	5.5	104	95	4.00	3.17	287	285	23	-
	905131	C1	1.00	5.4	145	86	4.43	4.34	514	418	12	-
	905132	C1	1.70	5.7	74	57	4.66	3.05	527	401	45	-
	905133	C1	1.90	5.8	208	117	5.08	3.66	654	476	16	-
97	905134	Bf	0.20	6.0	48	53	4.62	3.22	235	303	190	155
	905135	C1	0.50	5.4	96	75	4.47	3.63	305	321	12	-
	905136	C1	1.50	5.7	62	53	6.18	2.84	428	360	39	-
	905137	C1	1.90	6.0	74	64	6.35	3.52	560	467	15	-
	905138	C1	2.50	7.5	122	63	5.15	3.69	753	481	11	-
98	905139	Bf	0.20	6.1	49	44	5.05	3.26	313	315	535	16
	905140	C1	0.40	5.7	104	80	4.47	4.28	342	362	13	-
	905141	C1	1.00	5.6	134	87	4.10	3.50	445	398	13	-
	905142	C1	2.30	6.1	72	63	5.12	3.27	533	436	12	-

Notes: *-80 = -80 mesh size fraction; +80 = -40 to +80 mesh size fraction*

TABLE B-6-5
ANALYTICAL RESULTS FOR COPPER AND GOLD FROM NORTH SLOPE ZONE SAMPLES

Grid Location	**Soil Hor.**	**pH**	**Depth (m)**	**Routine 1-kg Soil Sample**		
				Cu+80	**Cu-80**	**Au-80**
92+50N 115+00E	Bf	5.4	0.30	418	400	107
	C1	6.0	1.20	838	1023	158
93N 115+00E	Bf	5.8	0.30	267	257	741
93N 115+44E	Bf	5.1	0.25	434	423	679
	Rock 1				281	72
	Rock 2				456	30
	Rock 3				442	96
93N 115+50E	Bf	5.1	0.25	504	430	3074
93N 115+55E	Bf	5.0	0.25	381	344	140
	C1	5.4	1.80	880	854	100

Grid Location	**Soil Hor.**	**pH**	**Depth (m)**	**Bulk 10-kg Soil Sample**					
				Cu+80	**Cu-80**	**Au+80**	**Au-80**	**Au-270**	**Au+270**
93N 115+50E	Bf	5.1	0.25	882	741	895	2860	3736	2128
93N 115+47E	Bf		0.25	470	417	161	277		
93N 115+55E	Bf	5.0	0.25	488	480	94	131		
93N 115+02E	Bf		0.50	177	184	226	290		

Notes: Rock 1 = sample of altered andesite; Rock 2 = fault gouge material; Rock 3 = fresh andesite; +80 = -40 to +80 mesh size fraction; -80 = -80 mesh size fraction; -270 = -270 mesh size fraction; +270 = +270 mesh size fraction, low-density fraction following methylene iodide heavy mineral separation; All copper values in ppm; all gold values in ppb;

water. Upon interaction with the groundwater table at a lower depth, iron-enriched surface water is buffered to a higher pH, resulting in the precipitation of iron as ferruginous cement. In a similar manner, copper as chalcopyrite or related sulphides, is released and mobilized as the Cu^{+2} ion. Precipitation occurs upon encountering a soil pH exceeding 5.3.

Lateral Variations of Copper and Gold in Glaciofluvial Sediments

The source of elevated gold and copper concentrations within the glaciofluvial outwash exposed in the Esker zone is the underlying mineralized bedrock. Evidence to this effect is seen in the close relationship between mineralized bedrock and abundant mineralized float and ferro-manganous concretions in the surrounding fluvioglacial sediment.

Near-surface plumes of copper and gold-enriched sediment can be traced down paleocurrent from mineralized bedrock in test pit 95 to test pit 98, giving a minimum anomalous dispersion length of 50 metres. The plumes likely extend further; lack of a backhoe to extend the trench prevented further sampling. Concentrations of copper and gold in test pit 98 are still significantly above (95th percentile) background. The juxtaposition of the copper plume at a lower depth relative to gold is due to

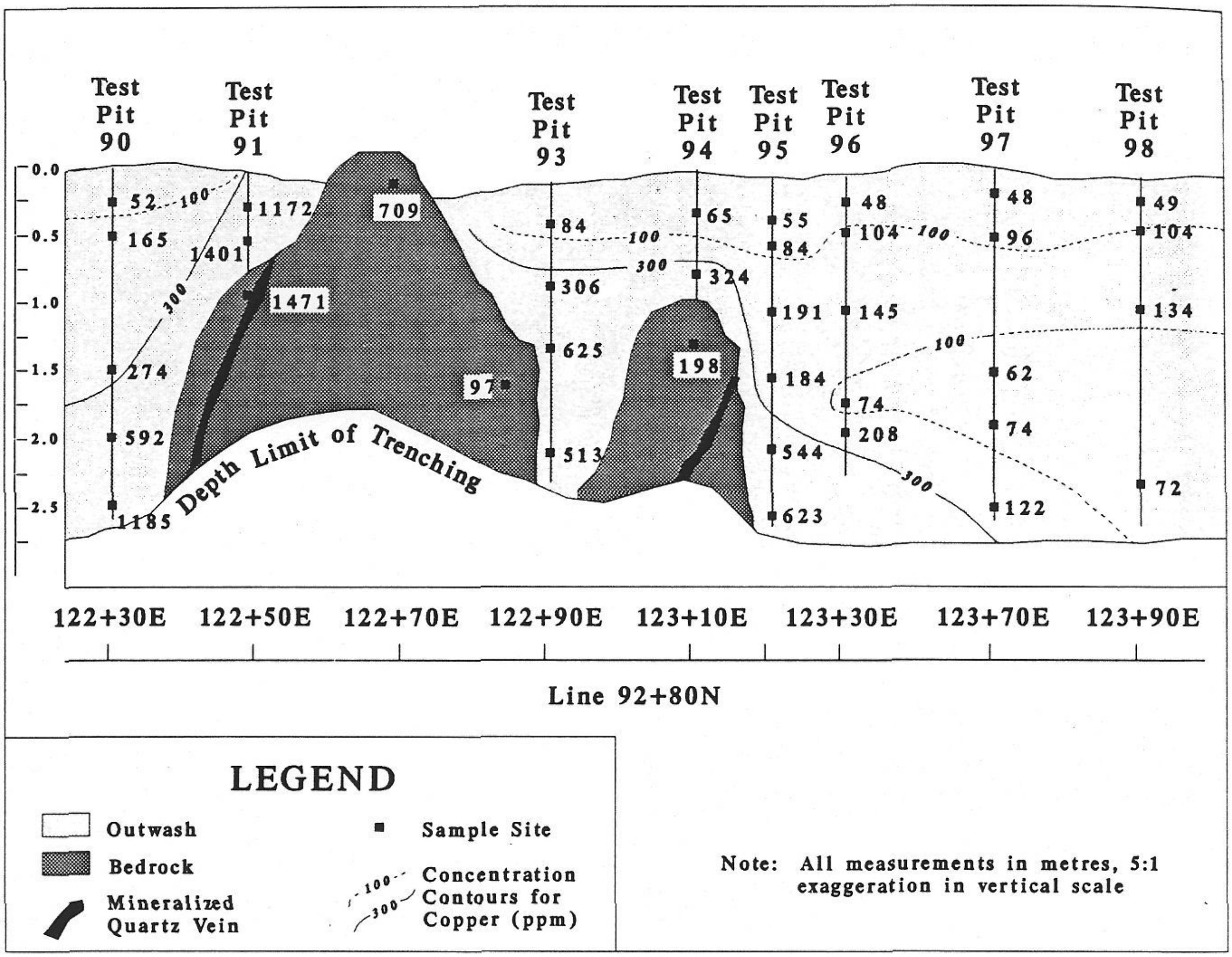


Figure B-6-6. Vertical and horizontal variations in gold concentration along the Esker zone trench.

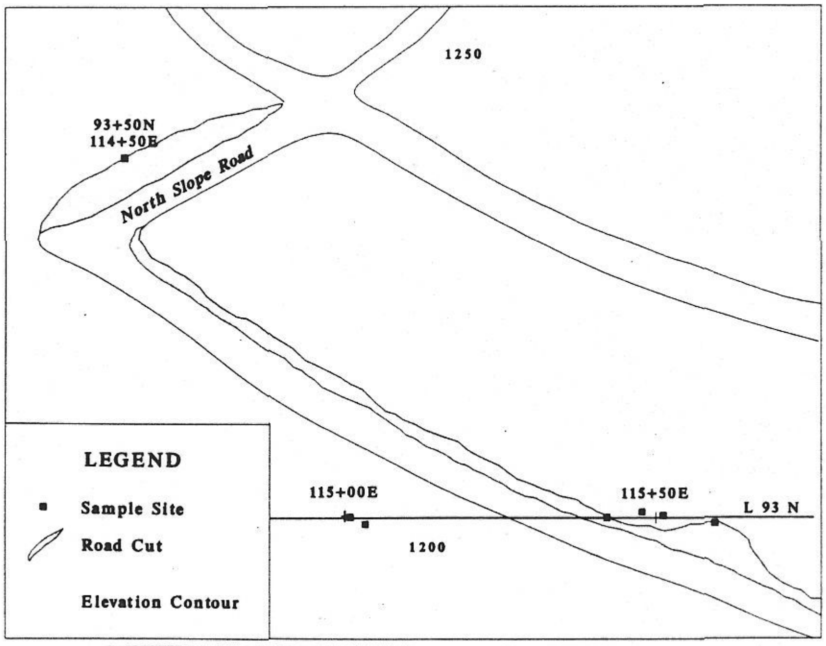


Figure B-6-7. Sample locations at the North Slope site.

post-glacial weathering of near-surface sediment with downward hydromorphic movement of copper. Gold distribution reflects mechanical dispersion developed during initial deposition of the sediment.

GEOCHEMICAL BEHAVIOR OF COLLUVIUM

Local (immediately up-slope) point sources of mineralization containing fine-grained gold are thought to underlie the North Slope zone. Gold concentrations in site duplicates and subsamples are reproducible (Table B-6-5) suggesting sufficient grains are available to limit the nugget effect (Ingamells, 1981). Comparable values in coarse and fine fraction subsamples suggest a uniform distribution of fine grains in a lithic or mineral matrix. Additional evidence for fine-grained gold is seen in the apparent lack of coarse (> 50 micron) grains recovered in the heavy mineral and panned concentrates as well as the high content of gold in the light-density separate from site 93N, 115 + 50E.

Abrupt lateral concentration gradients for gold in thin, bedrock-derived colluvium surrounding site 93N, 115 + 50E suggests a local source with minimum lateral mixing during colluvial processes. Studies by Averill (1978), Averill and Zimmerman (1983), Sauerbrei *et al.* (1987) and DiLabio (1990) document abrasion of gold grains in morainal deposits. Abundance of gold grains and their morphology can be used as a qualitative guide to distance of travel. Insufficient gold grains were recovered from the North Slope samples to qualitatively determine distance of travel, however pristine features on the few grains recovered seem to indicate a local source.

CONCLUSIONS

The following conclusions are made concerning some aspects of the geochemical patterns observed in the complex drift at Mount Milligan.

Significant differences in mean copper and gold concentrations exist in soils derived from till versus soils derived from outwash. The source of this difference is related to the origin of the surficial deposits, specifically the relative proportions of local mineralized material to nonlocal barren material incorporated in the two types of drift. Failure to correctly classify surficial deposit types will complicate interpretation of soil geochemistry and may mask true anomalies and create false anomalies.

Hydromorphic remobilization of copper resulting from oxidation and acid leaching in the near surface environment produces steep vertical concentration gradients within soil. B-horizon samples over mineralization may be so depleted in copper as to be indistguishable from background. Indiscriminant sampling of the B and C soil horizons could generate false anomalies.

Highest copper concentrations are noted in the fine (-80 mesh / -177 micron) fraction, probably due to remobilized copper precipitating as a surface coating on grains.

In the Esker zone trench, a mineralized dispersion train within the glaciofluvial outwash can be traced for a minimum of 50 metres down paleocurrent from a bedrock source and probably extends beyond this distance. Grid soil sampling employing 50 metre spacings would detect the anomalous drift.

Small mineralized subcrops are thought to lie immediately up-slope from the North Slope study site, as suggested by the thin bedrock-derived colluvium and by gold concentrations which exhibit abrupt lateral gradients and good within-site reproducibility.

In summary, anomalous dispersion patterns of gold and copper in surficial materials at Mount Milligan are influenced by the type of surficial deposit and post glacial remobilization due to weathering. Successful application of geochemical techniques in drift prospecting requires a solid understanding of glacial and post-glacial processes. Preliminary mapping of surficial deposits will significantly aid the design and subsequent interpretation of geochemical soil surveys. Orientation surveys, involving detailed sampling of soil profiles in various surficial materials, can delineate influences due to mechanical or weathering effects on dispersion patterns.

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