



PRELIMINARY LITHOGEOCHEMICAL STUDY OF SLOCAN GROUP

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INTRODUCTION

Lithogeochemistry is being used increasingly as a basis for examining genetic models of ore deposition and characterization of hydrothermal affects that extend beyond such features as megascopically recognizable mineralization and alteration zones.

Here we present results of a preliminary lithogeochemical study of the Slocan Group, motivated by (1) the prior recognition of syngenetic sulphides in the clastic sequence, and (2) an earlier, restricted lithogeochemical study by Cox (1979) on the basis of which he rejected the likelihood that the Slocan Group provided the metals for the silver-lead-zinc-gold veins of the Slocan mining camp.

SAMPLING ANALYSES AND DATA

Rock samples were collected from outcrops representative of parts of both the Slocan Group and the Rosslund Group. Cox (1979), on the basis of lithogeochemistry, suggested that these sedimentary units were an unlikely source for metals in contained vein deposits. Our sampling was therefore directed toward potential source beds and should not be construed as representative of the units in their entirety. Sampling included carbonaceous units, pyritic horizons, tuffaceous intervals and volcanic units. Sample descriptions and locations are given by Logan (1986). All samples were examined closely and any crosscutting mineralized fractures were removed prior to crushing and grinding. Thus, it was hoped, each sample represented metal abundances of the original sedimentary rocks (\pm diagenetic \pm metamorphic changes) with little or no epigenetic additions.

Sample analysis ($n=69$) by atomic absorption spectrophotometry with an aqua regia extraction was carried out in North Vancouver by Vangeochem Labs Limited. The geochemical data for lead, zinc, silver, cobalt, nickel, barium, cadmium and sulphur, together with means, standard deviations and standard errors of the means, are tabulated in stratigraphic order (Table 5-7-1). Duplicate analyses of samples were undertaken to test the analytical precision. Precisions, estimated as the mean relative error in per cent for each element, are as follows: silver, 5 per cent; lead, zinc and nickel, 20 to 30 per cent; cobalt and cadmium, 30 to 40 per cent; sulphur, 65 per cent; and barium, 121 per cent.

Total carbon was determined for a set of five pyritic and carbonaceous slate samples (Table 5-7-2). These samples

were crushed and ground to -200 -mesh and analysed by Canadian Microanalytical Service Ltd. of Vancouver.

DATA ANALYSIS

Histogram and probability plots of both arithmetic and \log_{10} transformed values for all variables were computer-generated and show multiple lognormal distributions for all elements except cobalt. The probability plots were partitioned graphically (compare Sinclair, 1976) into separate populations. Three populations are indicated for lead, silver, cadmium and sulphur; two for zinc, nickel and barium; and one for cobalt. Means, standard deviations and threshold values for the partitioned populations are listed in Table 5-7-3.

Three populations are evident in the probability plot for silver (Figure 5-7-1). The upper population (A) with a lower threshold of 0.49 ounce silver per ton corresponds to epigenetic mineralization. Population B (lower threshold = 0.04 ounce silver per ton) has been divided petrographically into two subsets: B_1 is characterized by stratabound sedimentary sulphides accompanied by remobilized, possibly epigenetic features, and B_2 corresponds to the slate belt which contains stratabound sulphides but little evidence of remobilization. The lower population (C) represents the remaining 45 samples from other rock units sampled.

The upper populations for lead, nickel and cadmium also correspond to samples exhibiting signs of epigenetic mineralization. The upper population for zinc corresponds to samples containing both epigenetic and stratabound sulphide textures. The upper population of barium represents samples of stratiform sulphide mineralization. Table 5-7-4 compares mean metal abundances of Slocan lithologic units, Rosslund Group, Nelson plutonic rocks and average shale values. Of these, the slate belt ($n=11$) shows the most significant enrichment in silver, barium and sulphur relative to average shale (Vine and Tourtelot, 1970). Sulphur values show a large variability, are high relative to other units and clearly correlate with the amount of pyrite. Mean barium values in slate belt samples indicate enrichment by a factor of 10 over average shales and, interestingly, are comparable to barium in the weakly mineralized samples reported here. Silver may be enriched in "Unit-1", although this could be an artifact of the small data set.

Variation of the cobalt and nickel abundances is greater within individual "lithologic units" than for averages among units. Weakly mineralized samples here are enriched in nickel by an order of magnitude compared with unmineralized rock. Cobalt(%) / nickel(%) ratios also indicate

this enrichment. Cobalt/nickel ratios (calculated from means) for the various Slocan lithological units range from 0.5 to 0.95, are 0.84 for the Rosslund Group, but are 0.15 for epigenetic mineralized rocks.

TRIANGULAR PLOTS

Metal ratios for deposits in four polymetallic vein camps in southeastern British Columbia have been characterized using triangular plots (Sinclair, 1979; Goldsmith and Sinclair, 1984). One of these is the Slocan camp. For the Slocan,

production plots of silver, lead and zinc best describe the vein mineralogy. These three variables also permit comparison with lithogeochemical data of the present study.

Figure 5-7-2(a) shows average production information plotted for 128 vein deposits from the Slocan camp (from Goldsmith and Sinclair, 1984). Silver(oz)/lead(%) ratios for the deposits are greater than 0.7. A group of zinc-rich deposits cluster within this high silver/lead field close to the zinc vertex with lead(%) /zinc(%) ratios of less than 0.25. The remaining deposits have lead/zinc ratios mostly greater than

TABLE 5-7-1
SLOCAN REGIONAL ROCK-GEOCHEMISTRY DATA AND STATISTICS
(See Logan, 1986, for sample locations and descriptions.)

SLOCAN GROUP (Fine-grained clastics)

Lithological Unit 1

Sample No.	Pb %	Zn %	Ag oz/ton	Co %	Ni %	Ba %	Cd %	S %
WW W2202A	0.0016	0.0104	0.071	0.0025	0.0050	0.176	0.00026	2.13
WW W2202B	0.0012	0.0019	0.062	0.0005	0.0010	0.016	0.00006	0.12
Arithmetic mean	= 0.0014	0.0062	0.066	0.0015	0.0030	0.096	0.00016	1.13
Std. deviation	= 0.0002	0.0060	0.006	0.0014	0.0028	0.113	0.00014	1.42
Std. error mean	= 0.0001	0.0042	0.004	0.0010	0.0020	0.079	0.00010	1.00

Lithological Unit 2

Sample No.	Pb %	Zn %	Ag oz/ton	Co %	Ni %	Ba %	Cd %	S %
CC 1501B	0.0030	0.0105	0.021	0.0030	0.0065	0.016	0.00018	1.34
CC 1502	0.0025	0.0135	0.006	0.0035	0.0040	0.096	0.00029	0.67
CC 1504A	0.0027	0.0115	0.026	0.0045	0.0035	0.096	0.00022	1.03
CC 1515	0.0030	0.0098	0.044	0.0035	0.0080	0.016	0.00019	1.10
CC 1516	0.0020	0.0110	0.017	0.0040	0.0040	0.016	0.00032	1.32
BO B1003	0.0034	0.0110	0.021	0.0060	0.0040	0.016	0.00030	1.31
BO B1004	0.0014	0.0114	0.012	0.0035	0.0050	0.056	0.00037	0.96
BO B1005	0.0018	0.0255	0.017	0.0035	0.0055	0.056	0.00062	1.48
BO B1006	0.0026	0.0140	0.029	0.0050	0.0040	0.005	0.00022	1.35
BO B1007	0.0023	0.0127	0.006	0.0050	0.0030	0.056	0.00026	0.91
BO B1008	0.0020	0.0130	0.015	0.0040	0.0025	0.096	0.00021	0.91
BO 2004	0.0024	0.0105	0.017	0.0055	0.0040	0.056	0.00026	1.24
BO B2009	0.0023	0.0139	0.006	0.0045	0.0030	0.096	0.00018	0.68
Arithmetic mean	= 0.0024	0.0129	0.018	0.0043	0.0044	0.052	0.00028	1.14
Std. deviation	= 0.0005	0.0040	0.011	0.0009	0.0015	0.036	0.00012	0.33
Std. error mean	= 0.0001	0.0011	0.003	0.0002	0.0004	0.010	0.00003	0.09

Lithological Unit slate belt

Sample No.	Pb %	Zn %	Ag oz/ton	Co %	Ni %	Ba %	Cd %	S %
PA 606	0.0023	0.0105	0.082	0.0025	0.0050	0.256	0.00019	8.42
PA 606A-4	0.0010	0.0073	0.109	0.0035	0.0090	1.272	0.00022	8.83
PA 606A-11	0.0005	0.0081	0.006	0.0010	0.0015	0.376	0.00022	0.29
PA 606A-14	0.0024	0.0083	0.074	0.0080	0.0080	0.136	0.00031	16.27
CD 1404C	0.0065	0.0090	0.044	0.0040	0.0075	0.576	0.00044	10.23
CD 1405C	0.0052	0.0500	0.053	0.0025	0.0080	0.422	0.00109	1.58
CD 1406C	0.0060	0.0135	0.065	0.0040	0.0045	0.096	0.00044	2.15
CD 1408C	0.0052	0.0111	0.038	0.0020	0.0030	0.096	0.00066	0.30
CD 1410C	0.0016	0.0014	0.032	0.0005	0.0010	0.136	0.00007	0.26
PR 1902	0.0019	0.0085	0.015	0.0030	0.0060	0.096	0.00035	0.96
PR 1904	0.0022	0.0099	0.106	0.0040	0.0155	0.196	0.00012	5.00
Arithmetic mean	= 0.0031	0.0125	0.057	0.0032	0.0063	0.333	0.00037	4.94
Std. deviation	= 0.0020	0.0120	0.032	0.0020	0.0041	0.349	0.00029	5.33
Std. error mean	= 0.0006	0.0036	0.009	0.0006	0.0012	0.105	0.00009	1.61

Lithological Unit 3

Sample No.	Pb %	Zn %	Ag oz/ton	Co %	Ni %	Ba %	Cd %	S %
NB 1408	0.0058	0.0104	0.017	0.0030	0.0050	0.096	0.00017	0.81
ID 1707	0.0028	0.0190	0.012	0.0055	0.0030	0.216	0.00018	1.13
ID 1708	0.0045	0.020	0.024	0.0040	0.0030	0.005	0.00027	0.96
ID 1709	0.0021	0.0110	0.012	0.0050	0.0030	0.016	0.00013	0.71
ID 1709C	0.0015	0.0084	0.012	0.0035	0.0050	0.056	0.00019	1.05
RD 2003	0.0011	0.0310	0.017	0.0030	0.0065	0.056	0.00102	1.03
RD 2004	0.0017	0.0170	0.009	0.0035	0.0045	0.016	0.00043	1.46
RD 2005	0.0011	0.0119	0.015	0.0030	0.0035	0.016	0.00021	1.52
RD 2006	0.0017	0.0120	0.015	0.0035	0.0050	0.005	0.00043	1.35
Arithmetic mean	= 0.0025	0.0015	0.015	0.0038	0.0043	0.054	0.00034	1.11
Std. deviation	= 0.0015	0.0066	0.004	0.0009	0.0012	0.068	0.00028	0.28
Std. error mean	= 0.0005	0.0022	0.001	0.0003	0.0004	0.022	0.00009	0.09

TABLE 5-7-1—Continued
SLOCAN REGIONAL ROCK-GEOCHEMISTRY DATA AND STATISTICS
(See Logan, 1986, for sample locations and descriptions.)

ROSSLAND GROUP (volcanic and clastic rocks, undivided)

Sample No.	Pb %	Zn %	Ag oz/ton	Co %	Ni %	Ba %	Cd %	S %
CU CU8201	0.0015	0.0068	0.003	0.0055	0.0065	0.036	0.00015	0.35
CU CU8204	0.0019	0.0126	0.012	0.0045	0.0065	0.096	0.00026	0.06
CU CU8206	0.0018	0.0099	0.006	0.0050	0.0060	0.096	0.00019	0.07
CU CU8207	0.0015	0.0035	0.006	0.0030	0.0020	0.076	0.00014	0.79
CU CU8207A	0.0022	0.0040	0.006	0.0025	0.0020	0.036	0.00010	2.07
SS J8404S	0.0020	0.0240	0.017	0.0020	0.0025	0.176	0.00011	0.07
SS J8406S	0.0018	0.0061	0.003	0.0030	0.0020	0.056	0.00007	6.43
SS J8407S	0.0020	0.0164	0.006	0.0045	0.0075	0.016	0.00022	0.10
SL 8201	0.0021	0.0045	0.009	0.0055	0.0035	0.056	0.00017	0.05
SL 8202	0.0022	0.0096	0.006	0.0050	0.0050	0.176	0.00018	.06
SL 8203A	0.0027	0.0190	0.015	0.0070	0.0110	0.096	0.00038	0.45
SL 8203B	0.0020	0.0072	0.006	0.0065	0.0021	0.176	0.00019	0.17
SL 8203C	0.0022	0.0119	0.009	0.0060	0.0075	0.036	0.00022	0.25
SL 8204	0.0020	0.0085	0.003	0.0050	0.0065	0.005	0.00016	0.79
SL 8205	0.0022	0.0084	0.012	0.0055	0.0080	0.056	0.00019	0.95
SL 8206	0.0016	0.0055	0.009	0.0050	0.0060	0.016	0.00015	0.31
SL 8207	0.0018	0.0128	0.006	0.0060	0.0085	0.016	0.00015	0.47
SL 8208	0.0025	0.0062	0.006	0.0055	0.0060	0.056	0.00030	0.34
SL 8209	0.0019	0.0137	0.009	0.0055	0.0085	0.056	0.00020	0.04
SL 8210	0.0018	0.0065	0.006	0.0035	0.0045	0.036	0.00018	0.10
SL 8218	0.0016	0.0089	0.001	0.0035	0.0055	0.016	0.00018	0.02
Arithmetic mean	= 0.0019	0.0098	0.007	0.0047	0.0056	0.066	0.00019	0.71
Std. deviation	= 0.0003	0.0052	0.004	0.0013	0.0025	0.053	0.00007	1.40
Std. error mean	= 0.0007	0.0011	0.001	0.0003	0.0005	0.012	0.00001	0.31

EPIGENETIC MINERALIZATION (undivided)

Sample No.	Pb %	Zn %	Ag oz/ton	Co %	Ni %	Ba %	Cd %	S %
NB 14-B	0.1600	1.140	0.629	0.0030	0.0040	0.276	0.0118	3.04
NB 1401A	3.6000	0.0040	4.694	0.0051	0.0035	0.016	0.00054	22.68
NB 1409	0.5600	0.9600	1.576	0.0020	0.0035	1.176	0.0088	.70
NB 1410	0.0035	0.0780	0.141	0.0055	0.0300	0.176	0.00192	5.42
PA 606A-6	0.0019	0.4400	0.092	0.0030	0.0140	0.216	0.00590	3.48
PA 606A-8	0.0045	0.0960	0.129	0.0065	0.0300	0.336	0.00144	12.31
CD 1402C	0.172	0.0138	0.147	0.0065	0.0085	0.176	0.00049	7.96
CD 1403C	0.0251	0.0548	0.071	0.0025	0.0065	0.096	0.00112	2.13
CD 1409C	0.0088	0.345	0.088	0.0055	0.0450	0.016	0.0056	0.12
SS J8401S	0.0091	0.2500	0.582	0.0050	0.0400	0.096	0.0057	0.65
SS J8402S	0.0047	0.2900	0.965	0.0050	0.0450	0.456	0.0064	1.17
SS J8403S	0.0020	1.4500	0.144	0.0045	0.0950	0.296	0.00154	0.82
SS J8405S	0.0024	0.5500	0.188	0.0035	0.0500	0.016	0.00035	0.29
Arithmetic mean	= 0.3503	0.4363	0.727	0.0044	0.0288	0.253	0.00397	4.20
Std. deviation	= 0.9888	0.4681	1.270	0.0015	0.0266	0.309	0.00366	5.44
Std. error mean	= 0.2739	0.1297	0.353	0.0004	0.0074	0.086	0.00101	1.78

0.7. In comparison, Figure 5-7-2(b) shows the silver(oz)-lead(%)-zinc(%) plot of rock geochemical data. The most obvious difference between Figures 5-7-2(a) and 2(b) is the relative depletion of rocks in lead. Silver(oz)/lead(%) ratios of the lithochemical data are mostly greater than 2.5 and lead(%)/zinc(%) ratios less than 1.0. This restricts data to less than half the area of the plot area. Symbols in Figure 5-7-2(b) separate lithologic units and epigenetic mineralization and indicate higher relative silver for the slate belt data. A cluster of mineralized samples near the zinc vertex corresponds to the zinc-rich deposits of Figure 5-7-2(a). The remaining mineralized samples (except two) are close to the silver-zinc line indicating low relative lead abundances.

The silver-nickel-cobalt plot (Figure 5-7-3) shows data extending outward from the silver vertex about the 1:1 Co(%)/Ni(%) ratio line. Mineralized samples cluster near the silver vertex and extend along the silver-nickel line suggestive of an enrichment of nickel relative to cobalt. Slate belt data plot closest to the silver vertex. Distribution of samples about the 1:1 cobalt-nickel line suggests a sympathetic variation for the two.

DISCUSSION

Three main stages of sulphide formation (diagenetic, metamorphic, hydrothermal) have been defined for the sediments on the basis of texture (Logan, 1986). There is an increased abundance of copper, nickel, zinc and lead sulphides with each successive stage of sulphide formation (that is, hydrothermal > metamorphic > diagenetic). The total content of trace metals is assumed to have remained unchanged during diagenesis.

Trace metal distribution within the sedimentary rocks is as important as total metal concentration in assessing whether the sedimentary units were capable of providing metals to mineralizing solutions. Analysis of organic matter from the carbonaceous mudstones hosting the XY deposit at Howards Pass, Yukon-Northwest Territories boundary, indicates that less than 22 per cent of copper, nickel, cobalt, zinc and silver is bound in the organic component and that the bulk of trace metals occurs within the sulphides (Goodfellow *et al.*, 1983). Trace elements in pyrite separates from Black Sea carbonaceous sediments (Bulugara, 1969, referred to in Good-

TABLE 5-7-2
TOTAL CARBON AND HYDROGEN,
SLATE BELT SAMPLES,
SLOCAN DISTRICT

(See Logan, 1986, for sample locations and descriptions.)

Sample	Lithology	Element (%)	
		C	H
San 01	slate	5.25	<0.02
WW 2B	slate	2.10	<0.02
PA 606	slate	4.52	<0.02
PA 606	slate	4.51	<0.02
CD-1	slate	5.25	<0.02
W1-1	greywacke	1.82	<0.02

TABLE 5-7-3
STATISTICAL PARAMETERS AND THRESHOLDS FOR
PARTITIONED POPULATIONS,
SLOCAN ROCK-GEOCHEMICAL DATA

(See Sinclair, 1976, for methodology.)

Element Units	Populations %	B ¹	b + s ²	b - s ³	Thresholds
Pb %	A(0.06)	0.70	6.0	0.009	0.015
	B(0.15)	0.007	0.01	0.0049	0.0055
	C(0.79)	0.0021	0.0033	0.0014	0.0033
Zn %	A(0.15)	0.45	0.80	0.25	0.05
	B(0.85)	0.01	0.019	0.0056	
Ag oz/ton	A(0.07)	0.94	1.25	0.7	0.49
	B(0.27)	0.10	0.20	0.048	0.04
	C(0.66)	0.01	0.02	0.0052	0.022
Co ⁴ ppm	A(1.0)	42.0	56.0	29.0	67.5
Ni ppm	A(0.10)	440.0	540.0	360.0	370
	B(0.90)	44.0	80.0	25.0	200
Ba %	A(0.03)	1.2	1.35	1.10	0.65
	B(0.97)	0.07	0.21	0.025	
Cd ppm	A(0.08)	64.0	80.0	50.0	38
	B(0.10)	18.0	26.0	13.0	8.5
	C(0.82)	2.3	4.2	1.4	
S %	A(0.15)	9.3	10.3	6.2	2.5
	B(0.65)	0.90	1.4	0.57	0.35
	C(0.20)	0.10	0.18	0.053	

% of data in population.

¹ Antilog of mean of lognormal population.

² Antilog of mean plus one standard deviation of lognormal population.

³ Antilog of mean minus one standard deviation of lognormal population.

⁴ Normal distribution.

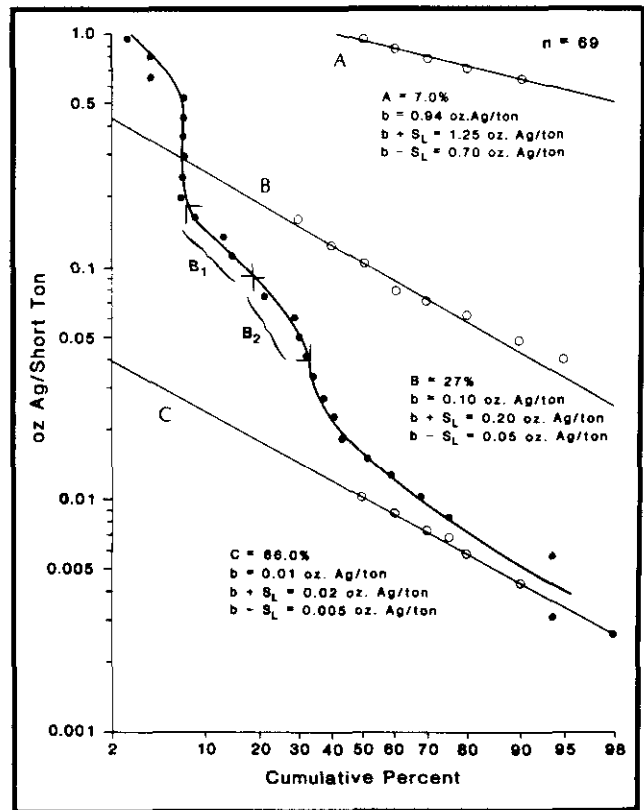


Figure 5-7-1. Probability graph of 69 Ag values for samples from sedimentary and volcanic rocks in the Sandon area, Slocan mining camp. Black dots are original data, open circles are estimated partitioning points. Procedure after Sinclair (1976).

fellow *et al.*, 1983) and black shales from Amjhere, India (Pandalai *et al.*, 1983) show that most of these metals are incorporated in iron sulphides (Co²⁺ and Ni²⁺ substitute isomorphously for Fe²⁺ in the pyrite lattice owing to similar ionic radii, other elements probably occur as discrete sulphide phases).

Reflected light microscopy combined with scanning electron microscope energy dispersive spectroscopy studies of the Slocan sedimentary samples indicates the presence of inclusions of sphalerite, chalcopyrite, millerite and galena in pyrite, and less commonly in pyrrhotite. Discrete silver

TABLE 5-7-4
COMPARATIVE ROCK GEOCHEMISTRY, SLOCAN DATA VERSUS OTHERS

Element	Lithologic Units Slocan Group					Rosland Group n=21	Nelson Batholith n=19 ¹	Black Shale ²
	1 n=2	2 n=13	2 n=20 ¹	Slate Belt = 11	3 n=9			
Pb (ppm)	14	24	32	31	25	31	33	20
Zn (ppm)	62	129	58	125	156	175	101	<300
Ag (oz/ton)	0.066	0.018	n.c.	0.057	0.015	n.c.	0.007	<0.029
Co (ppm)	15	43	n.c.	32	38	n.c.	47	10
Ni (ppm)	30	44	n.c.	63	43	n.c.	56	50
Ba (%)	0.096	0.052	n.c.	0.333	0.054	n.c.	0.0066	0.030
Cd (ppm)	1.6	2.8	n.c.	3.7	3.4	n.c.	1.9	n.c.
S (%)	1.13	1.14	n.c.	4.94	1.11	n.c.	0.71	n.c.

¹ Cox (1979).

² Vine and Tourtelot (1970).

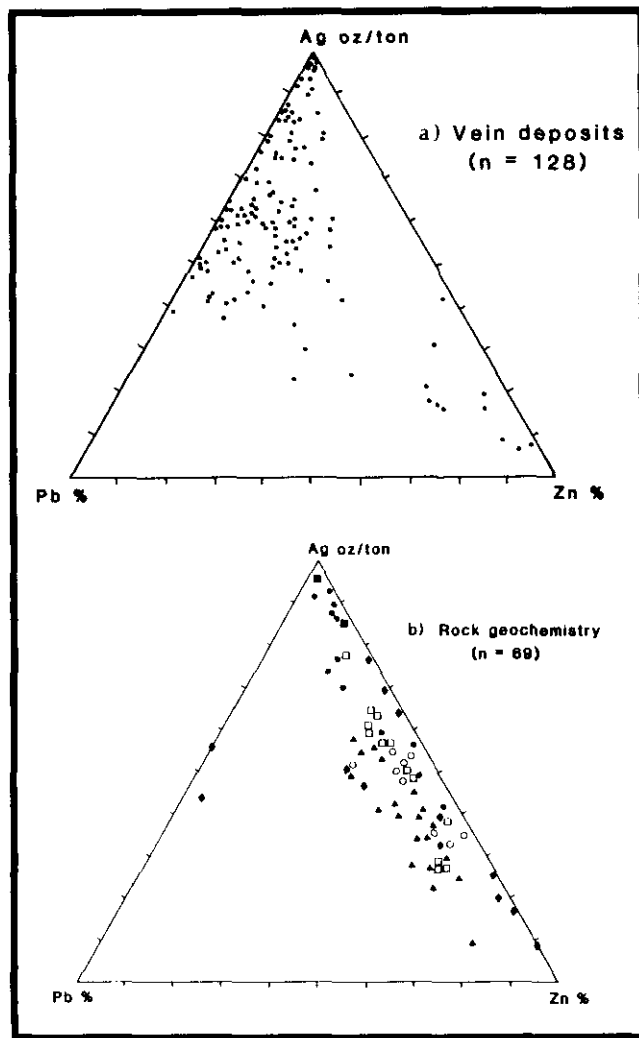


Figure 5-7-2. Ag-Pb-Zn triangular plots: (a) average production grades, Slocan mining camp (Goldsmith and Sinclair, 1984), (b) regional lithochemical data, this study. Solid squares are Slocan Unit 1, open squares are Unit 2, solid circles are slate belt and open circles are Unit 3. Triangles represent Rossland Group and diamonds denote mineralized samples.

sulphide minerals could not be identified in the sedimentary rocks.

Boyle (1968) has emphasized that for silver, the degree of diagenesis and metamorphism determines trace metal sites. Where only slightly metamorphosed, the trace metals are associated with clays, carbonaceous substances (bitumen, humic and fluvic acids) and fine-grained, nearly colloidal sulphides (Boyle, 1968). Increased metamorphism causes localization of trace metals, commonly as inclusions within iron sulphides. In Slocan sedimentary rocks, pyrrhotite is associated spatially with hornfels aureoles around intrusive bodies. This suggests regional/contact metamorphism of pyritic sediments has released sulphur during the conversion of pyrite to pyrrhotite. Sulphur isotope studies of vein minerals define an S^{34} spread of -11.0 to -1.0 per mil, averaging -7.0 (Brame, 1979). These values are characteristic of sulphur in sedimentary sulphides. During replacement of pyrite by pyrrhotite or simple recrystallization, the impurities

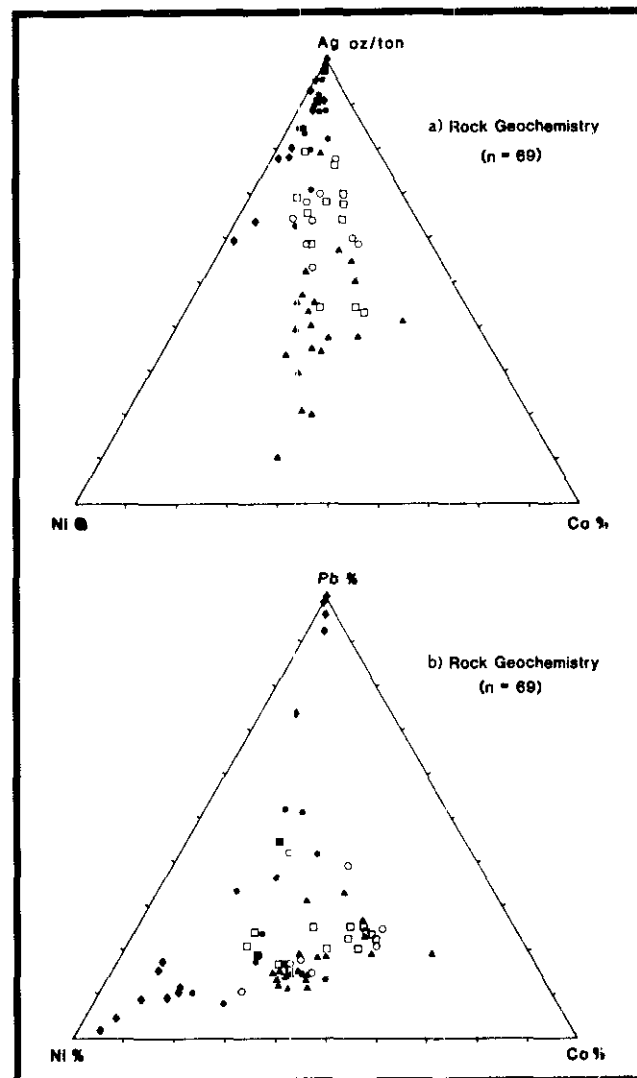


Figure 5-7-3. Ag-Ni-Co and Pb-Ni-Co triangular plots of regional rock geochemistry, Sandon area, Slocan mining camp. Symbols as described in Figure 5-7-2.

(trace metals and sulphide inclusions) migrate to crystal edges where precipitation or dissolution occurs, depending upon the ambient temperature, pressure and chemical activities. The solubilities of most sulphides are greatest in the bisulphide (HS^-) stability region (Fyfe *et al.*, 1978) and sulphur released during metamorphism would increase the activities of the aqueous sulphur species. Sulphide complexes of silver, lead, zinc and copper are more stable than chloride complexes in the temperature range suggested by fluid inclusions, (Reinsbakken, 1968) for vein formation. Chloride complexes are more stable for silver above $300^\circ C$ and for lead below $300^\circ C$ (Barnes, 1979). The paragenetic sequence and mineralogic zonal pattern for lode deposits results from changing solution chemistry (pH, Eh, sulphur activity), temperature and pressure during vein deposition.

The general paragenetic sequence of ore deposition is pyrite - sphalerite - tetrahedrite - galena - silver sulphosalts and native silver (Cairnes, 1934). The age of mineralization is believed to be related to intrusion and therefore equivalent

in age to the Nelson batholith (Reynolds and Sinclair, 1971; Andrew *et al.*, 1984). Metamorphogenic hydrothermal fluids, either generated or modified through additions during contact metamorphism by intrusion of the Nelson batholith, were likely sulphide-rich solutions. The relative solubilities for lead, zinc and copper sulphide complexes, and the release of sulphur coincident in time with the initial mineralizing fluids, are compatible with vein paragenesis. Fluid inclusion studies of late-stage minerals (12 deposits) suggest that ore fluids were dilute brines (Reinsbakken, 1968). Limited fluid inclusions in quartz from the Scranton deposit contain daughter crystals, and up to 40 NaCl equivalent per cent salinity (Brame, 1979). Saline solutions such as these are capable of transporting lead and silver as chloride complexes. Assuming precipitation during decreasing fluid temperatures, late-stage silver deposition suggests changing from an initial Cl^- -dominated hot brine to a less saline HS^- -rich system. Factors such as decreasing temperature of fluids, the batholith, or the ambient temperature, longer pathlines for fluid circulation that facilitates more thorough sediment buffering of solutions, and decrease in activity of specific chemical species such as sulphur could produce this change in solution chemistry. Flow rate versus reaction rate determines whether the wallrock can buffer fluid compositions. If the flow rate is greater than the reaction rate, disequilibrium mass transport results (Fyfe *et al.*, 1978). This characterizes conditions of near-surface vein formation. The lack of wall-rock alteration and the fact that the mineralization occupies

large continuous through-going structures suggests that temperature is the factor controlling precipitation. Throttling or boiling can provide a pressure decrease resulting in deposition, but fluid inclusion studies (Reinsbakken, 1968) show no evidence of fluid boiling.

Comparisons between lithological units of the Slocan and Rosslund groups indicate enrichments of silver, barium and sulphur concentrations for only the slate belt (Figure 5-7-4). This northwesterly trending zone coincides spatially with quadratic trend highs established for trace inclusions of silver in galena, tin in sphalerite and arsenic in pyrite (Sinclair, 1967). Sinclair (1967) suggests the distribution pattern of trends reflects a temperature gradient with the relatively high-temperature centre located near Sandon. Sulphide textures establish the syn/diagenetic nature of the slate belt sulphides. The coincidence of high metal concentrations centred on the highest spatial density of deposits and those with relatively more silver suggests this unit may have acted as a source for vein metals. Carbonaceous parts of the slate belt are enriched in trace metals but recognizable metallic minerals other than pyrite are not common. The abundance of sulphides in modern sediments has been shown to be directly proportional to the organic content of the sediments (Berner, 1970). A mean value of 4.2 per cent total carbon ($n=5$) places the slate belt rocks in the black shale category of Vine and Tourtelot (1970). These may represent "metal sinks" where metals have been trapped in immobile organic or sulphide phases rather than likely source beds.

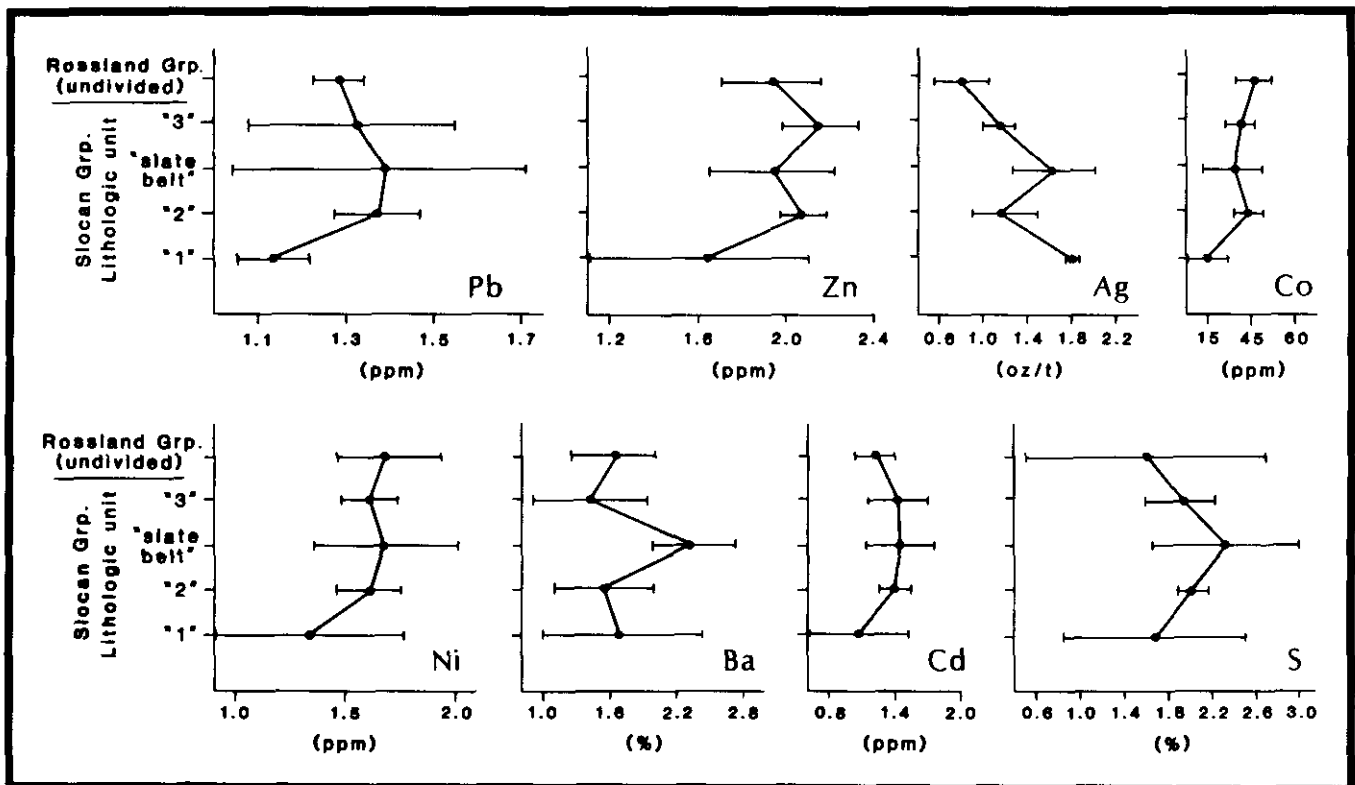


Figure 5-7-4. Variations in means and standard deviations of trace element concentrations for Slocan and Rosslund units arranged in the assumed stratigraphic order. All abscissa scales are log (base 10) transforms of original data except for Cd which is log (base 10) of $10 \times$ original data.

The validity of comparing absolute metal abundances for samples which contain variable amounts of carbonaceous material and pyrite is uncertain. Triangular diagrams display data as relative amounts and thus provide a means of comparing metal ratios in various substrates. Silver-lead-zinc plots for lithochemical data show that slate belt samples contain relatively high silver abundances. The rock geochemical ratios differ from ratios for average production figures for the camp only in the relative amount of zinc. The sedimentary rocks are enriched by a factor of two relative to the veins. A genetic model involving a sedimentary source for metal requires a 50-per-cent preferential depletion of zinc relative to both lead and silver to produce the ratios now found in veins from those now existing in the slate belt unit.

Source rock volumes can be determined using total production figures from the Slocan mining camp (Goldsmith *et al.*, 1986) to test the plausibility of sediment derivation for silver, lead and zinc in veins. The following calculations use mean metal values for slate belt rocks and assume 10 per cent extraction of metals from the source rock.

For silver, total production of 64×10^6 ounces and a mean metal value of 0.057 oz/ton:

$$\begin{aligned} \text{Amount of} \\ \text{source rock} &= \frac{64 \times 10^6 \text{ oz}}{0.1 (\text{extraction}) \times 0.057 \text{ oz/ton}} \\ &= \frac{11\,228 \times 10^6 \text{ tons} \times 0.905 \text{ tonne/ton}}{2.7 \text{ tonne/m}^3 (\text{volume conversion})} \\ &= 3.76 \times 10^9 \text{ m}^3 \text{ or } 3.7 \text{ km}^3. \end{aligned}$$

Calculations for lead, with a total production of 0.22×10^6 tonnes, requires $2.7 \times 10^8 \text{ m}^3$ and for zinc with total production of 0.24×10^6 tonnes, $7.0 \times 10^7 \text{ m}^3$ of source rock are required. From these calculations a sedimentary source seems a viable possibility for silver, lead and zinc in veins.

CONCLUSIONS

A variety of analytical data combined with crude mass balance calculations suggest that fine-grained clastic rocks of the Slocan Group could have been the source for metals in the spatially related silver-lead-zinc-gold veins. The geochemical data do not prove the genetic relationship but are permissive in terms of metal ratios, metal concentration ratios and estimated source rock volumes of 3 to 4 cubic kilometres, as well as other independent isotopic data (Logan, 1986).

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