

Barium-Strontium relationships

at the Highland Valley porphyry copper deposits, BC

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Variations in Ba and Sr concentrations in granitic host rocks of the Highland Valley porphyry copper deposits are reported. At Valley Copper and a large part of Lornex, Ba concentrations decrease progressively from the outer margins to central zones of intense argillic/phyllitic alteration and mineralization. In contrast, at Bethlehem/JA and part of Lornex where potassic alteration is dominant, enhanced values are encountered. Sr levels consistently decrease from the periphery to inner zones of alteration and metallization. Ba/Sr ratios exceeding 1 define mineralized zones. On the basis of these results, absolute and relative concentrations of Ba and Sr could be a useful geochemical tool in exploration for porphyry copper deposits in the Highland Valley.

In a recent study, Warren *et al* (1974) demonstrated that the relative and absolute concentrations of Ba and Sr in volcanic wall rocks of a Ag-Au and a Cu deposit in British Columbia were indicative of hydrothermal alteration associated with mineralization. Studies by Olade and Fletcher (in press) demonstrate that primary halos of Rb and Sr around porphyry copper deposits can be utilized in outlining zones of intense hydrothermal activity and metallization. These encouraging results and the fact that Ba and Sr are readily determined by either semi-quantitative emission spectroscopy or X-ray fluorescence spectrometry, prompted further studies on Ba-Sr relationships at porphyry copper deposits in granitic host rocks.

Geochemistry of Ba and Sr in igneous

rocks has been documented by numerous workers (Goldschmidt, 1954; Turekian and Kulp, 1956; Fischer and Puchelt, 1972). Because of similarity in ionic properties, Ba generally substitutes for K in alkali feldspars and micas and, of course, occurs as barite in hydrothermal environments. Sr substitutes for Ca in plagioclase as well as K in alkali feldspars. During hydrothermal processes, Sr is commonly enriched in Ca-carbonates and sulphates. Average abundances of Ba and Sr in high-Ca granites are 420 and 440 ppm respectively (Turekian and Wedepohl, 1961).

The objective of this paper is to examine the nature, relationships and applications of Ba and Sr halos around porphyry copper deposits in the Highland Valley district (Fig 1).

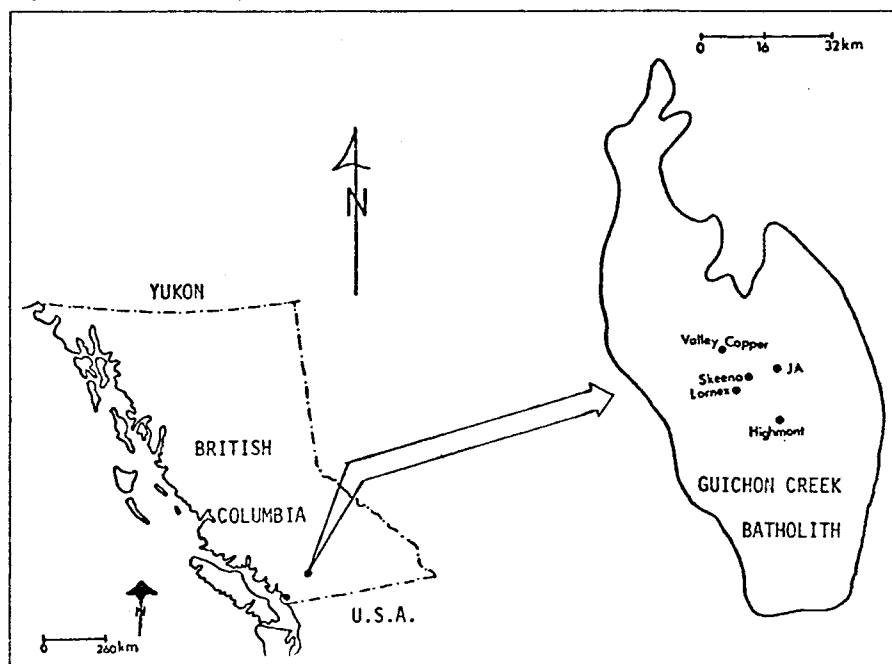
General geology

Geology and mineral deposits of the Highland Valley have been described by numerous workers, notably White *et al* (1957), Northcote (1969), McMillan (1970, 1972) and Hylands (1972). Major porphyry copper deposits in the district are associated with the relatively youngest central facies of the Guichon Creek batholith.

The Valley Copper deposit is localized within a porphyritic granodiorite to quartz monzonite of the Bethesda Phase (Fig 2). Wall-rock alteration is characterized by moderate to intense pervasive argillic alteration (sericite-kaolinite), on which has been superimposed a later phase of quartz veining in the southeast, and intense quartz-sericite and K-feldspar alteration in the central and northwest portions of the property.

The Lornex orebody occurs mainly within granodiorite of the Bethlehem (Skeena) Phase, east of the Lornex Fault. Fresh rocks of the Bethesda Phase outcrop west of the fault (Fig 3). Quartz porphyry and aplite dykes occur within the deposit. Hydrothermal altera-

Fig. 1 Location of study area



tion is characterized by propylitic alteration (epidote-chlorite-carbonates) at the eastern periphery of the deposit. This zone grades westward into mixed assemblages of propylitic and argillic (kaolinite-montmorillonite) and finally into intense argillic (sericite-kaolinite) at the central and western zones of intense mineralization. Irregular zones of quartz-sericite and argillic selvages are relatively abundant adjacent to the Lornex Fault and within a (?) porphyry dyke. Gypsum and quartz-carbonate veins are common in the ore zone.

The recently discovered Bethlehem-JA deposit (Ewanchuk and Anderson, 1972) is localized along the contact between quartz diorite of the Guichon Phase and granodiorite of the younger Bethlehem Phase, within and north of an intrusive quartz latite porphyry (Fig 4). Hydrothermal alteration effects comprise a core of potassic alteration (sericite-K-feldspar) centred upon the porphyry dyke and adjacent Bethlehem Phase. Argillic and typical propylitic alteration are confined to the periphery of the deposit.

Sampling and analysis

Sixty-one rock-chip samples were collected from the '3600 level' of Valley Copper, eighty-five samples from a section across Lornex, and fifty-four samples from Bethlehem—JA '2800 level'. Each sample, weighing approximately 4 kg, consisted of several half-fist-sized drill-core chips collected over a distance of 3m around a central sampling point. Samples were collected within and as far from the mineralized zone as available drill holes permit. Fresh, unmineralized samples, used and described by Northcote (1969) were utilized in the estimation of regional background concentrations.

After crushing samples to minus 10-mesh, the powders were analysed for Ba and Sr by semi-quantitative emission spectroscopy, and for Sr (Valley Copper and JA) by X-ray fluorescence spectrometry as described by Volborth (1963). Analytical precision at the 95% confidence level is estimated as $\pm 39\%$ for Ba, $\pm 42\%$ for Sr (ES) and $\pm 1\%$ for Sr (XRF).

RESULTS

Regional background contents of Ba and Sr in fresh rocks of Guichon Creek batholith are tabulated with corresponding data from Valley Copper, Lornex and Bethlehem-JA in Table 1.

1. Valley Copper

Geochemical dispersion of Ba, Sr and Ba/Sr ratios are depicted in Fig 5. Ba levels decrease from more than 700 ppm at the outer margins of the deposit, to less than 440 ppm at the core of intense metallization and phyllic alteration (Fig 5a). The apparent extension of relatively

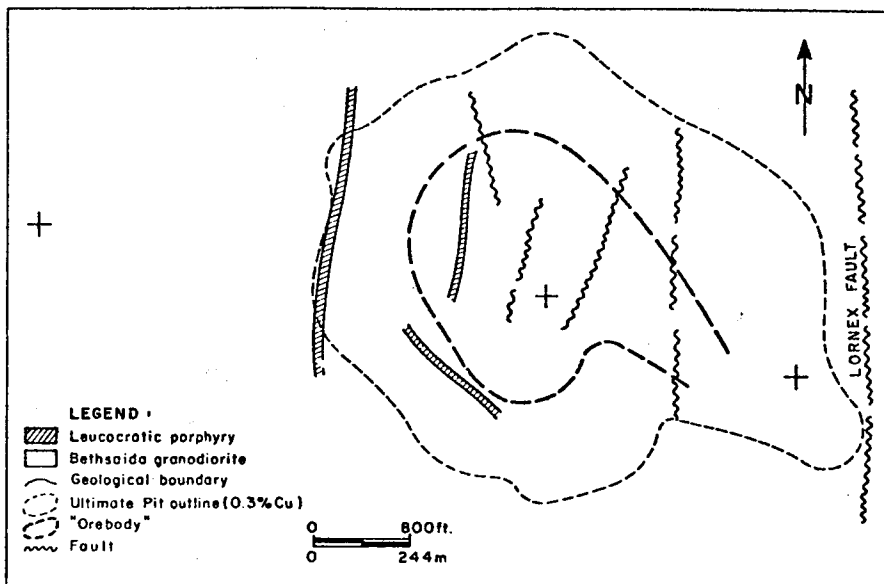


Fig 2. Generalized geology at Valley Copper (Modified in part from McMillan, 1970)

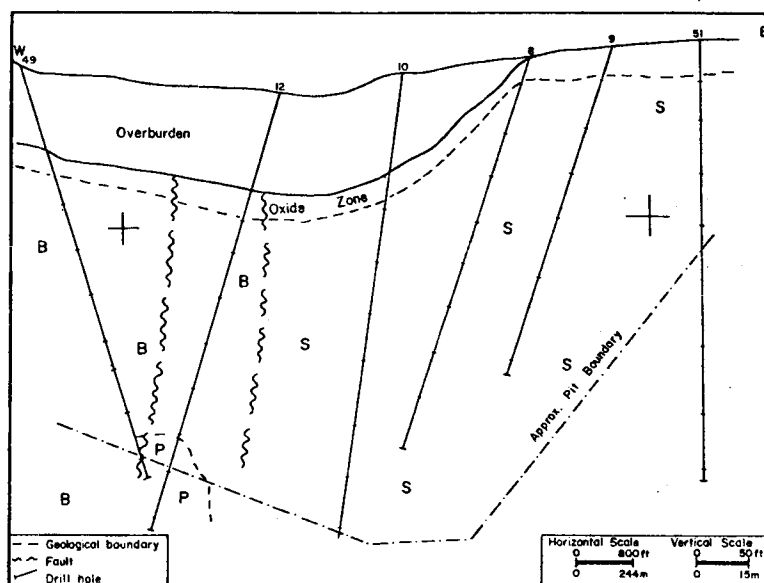


Fig 3. Generalized geology of a section at Lornex (based in part on data provided by Lornex Mining Corporation)

Fig 4. Generalized geology of the 2800 level at Bethlehem JA (based in part on data provided by Bethlehem Copper Corporation)

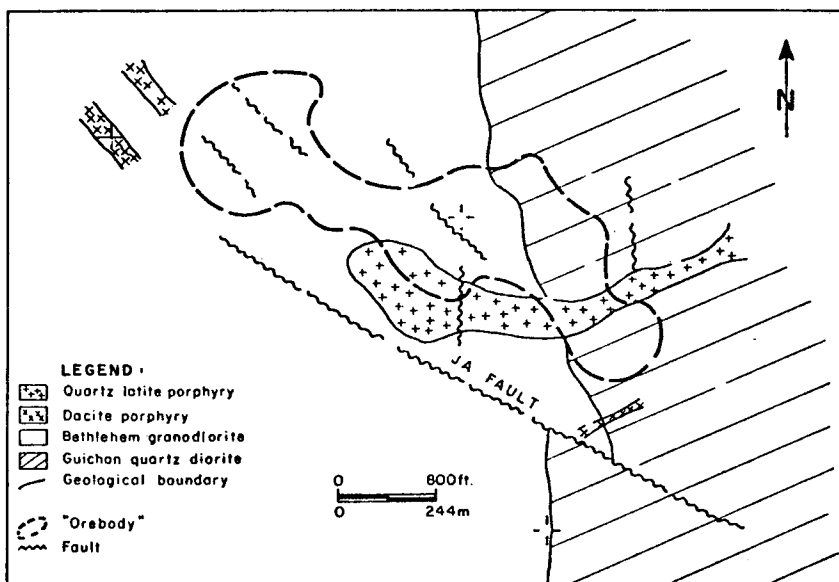


TABLE 1: *Means and Ranges for Ba and Sr

	Ba (ppm)	Sr (ppm)
Valley Copper (61 samples)	568 400-1000	1562 72-2223
Lornex (85 samples)	384 100-950	2464 150-1500
Bethlehem-JA (54 samples)	493 100-1500	1579 100-932
Regional background samples		
(i) Bethsaida phase (6 samples)	554 500-700	588 55-627
(ii) Bethlehem phase (12 samples)	538 500-800	693 580-829
(iii) Guichon phase (8 samples)	306 200-500	935 434-2013

*Geometric means. ¹X-ray fluorescence. ²Emission spectroscopy.

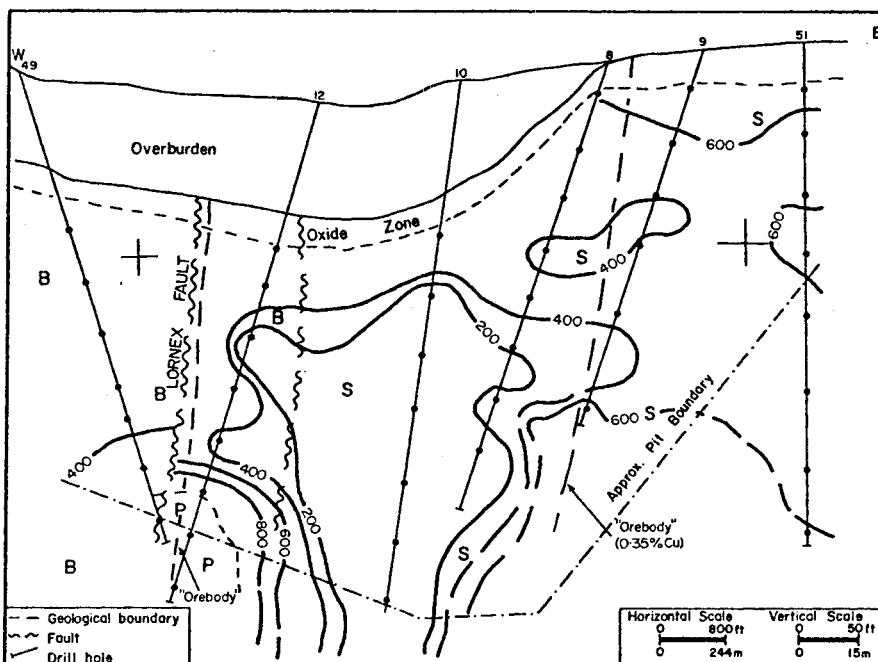
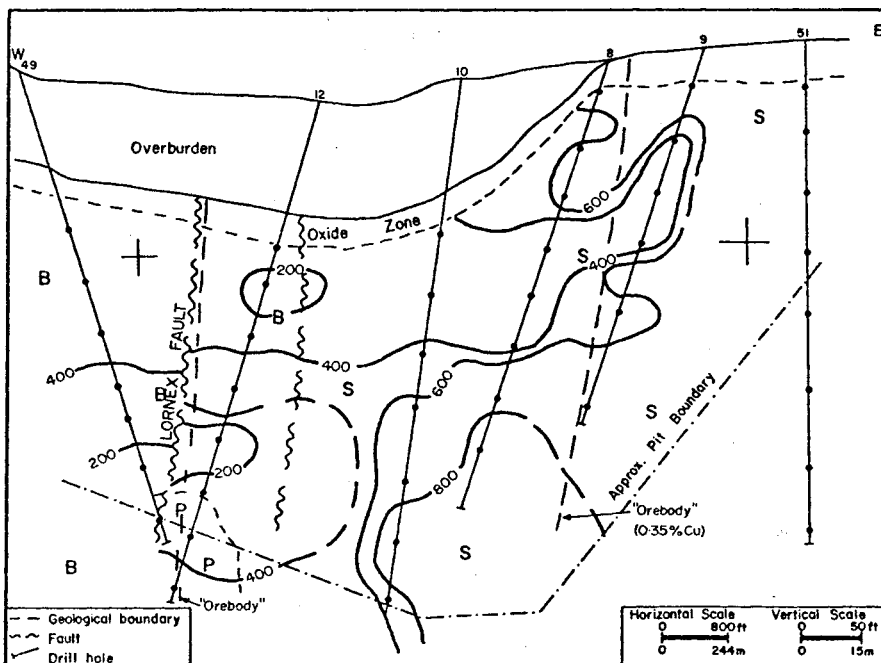


Fig 6a. Distribution of Ba at Lornex (values in ppm)

Fig 6b. Distribution of Sr at Lornex (values in ppm)



low values to the eastern margins of the property reflects the Lake Zone mineralization (Bethlehem Mines) which adjoins Valley Copper in the East. Small salients of enhanced Ba levels (700-1000 ppm) in the southeast and immediately northwest of the orebody are related to greater abundance of K-feldspar in association with quartz and sericite veins respectively.

Sr distribution is similar to that of Ba (Fig 5b). Enhanced values exceeding 700 ppm occur at the periphery, progressively decreasing towards the centre, and attaining lowest values (300 ppm) in the eastern half of the orebody. Ba/Sr ratios are generally less than 1 at the outer margins, but exceed 1 in a broad central zone which opens out to the south, and defines the orebody and its possible extensions (Fig 5c).

II. Lornex

Ba concentrations at Lornex range from 100 to 950 ppm. Values decrease from the eastern periphery of the deposit (Hole 51) to less than 200 ppm in a central zone of intense argillic alteration and metallization (Fig 6a). Ba levels are enriched (>800 ppm) immediately east of the Lornex Fault, where K-feldspar veins are relatively abundant.

Sr shows a slightly different distribution from Ba. Low values (<200 ppm) occur immediately east of the Lornex Fault (Fig 6b). In contrast anomalous levels are confined to the lower parts of Holes 8 and 10 where Ba values are lowest. This anomaly is attributed to the relative abundance of gypsum veins. Ba/Sr ratios do not show consistent patterns as a result of the irregular occurrence of gypsum veins. Nevertheless, Ba/Sr ratios are less than 1 at the periphery, but exceed 1 in a large part of the ore zone.

III. Bethlehem-JA

Distribution of Ba is controlled partly by primary lithology. Rocks of the Guichon Phase in the eastern portion of the property are relatively impoverished in Ba (<450 ppm) (Fig 7a). In contrast, the more felsic rocks of the Bethlehem Phase and the porphyry dyke are characterized by values exceeding 450 ppm. A narrow belt of anomalous Ba levels (650-1500 ppm) coincides with a large portion of the orebody and zone of potassic alteration.

Sr concentrations range from 100 to 932 ppm. Values progressively decrease from the outer margins of the property, to less than 200 ppm within the porphyry dyke and zone of potassic alteration (Fig 7b). Ba/Sr ratios exceeding 1, define a broad anomalous zone which includes most of the orebody (Fig 7c).

DISCUSSION

Results of this study demonstrate that Ba levels may either decrease or increase as

mineralized zones are approached, depending on the type and intensity of wall-rock alteration. Primary lithology has only a subtle effect on Ba distribution as demonstrated at Bethlehem-JA.

At Valley Copper and Lornex, intense argillic and phyllic alteration are associated with obvious depletion of Ba in the mineralized zone. In contrast, at Bethlehem-JA and immediately east of Lornex Fault at Lornex mine, enrichment in Ba is associated with K-feldspar alteration. The close relationship between Ba and K-feldspar distribution is

attributed to the geochemical affinity between Ba and K in alkali feldspars. However, depletion of Ba in the phyllic (quartz-sericite) zone at Valley Copper and parts of Lornex suggests that Ba might not enter sericite lattices in appreciable amounts. Moreover, no obvious or significant relationship is evident between overall distribution of Ba and K, as demonstrated by correlation coefficients $r = -0.18$ at Valley Copper; 0.23 at Lornex; and 0.30 at JA). According to Fischer and Puchelt (1972), juvenile hydrothermal fluids do not contain sig-

nificant amounts of Ba, but obtain this element by metasomatic leaching of suitable wall rocks. Thus, the enhanced Ba levels in the potassic zone might be of local origin.

Except at the lower part of the Lornex deposit where gypsum veins are abundant, Sr shows a consistent pattern of distribution in all the deposits examined in this study. It generally decreases from the outer margins where host rocks are fresh or weakly altered, to inner zones of mineralization and intense alteration where K-feldspar, sericite and kaolinite

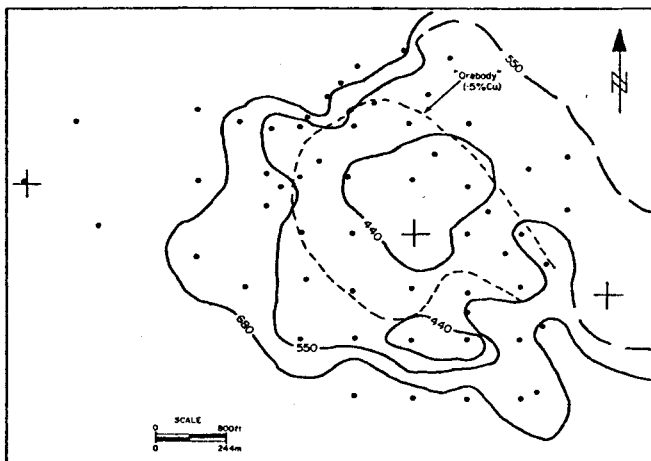


Fig 5a. Distribution of Ba at Valley Copper (values in ppm)

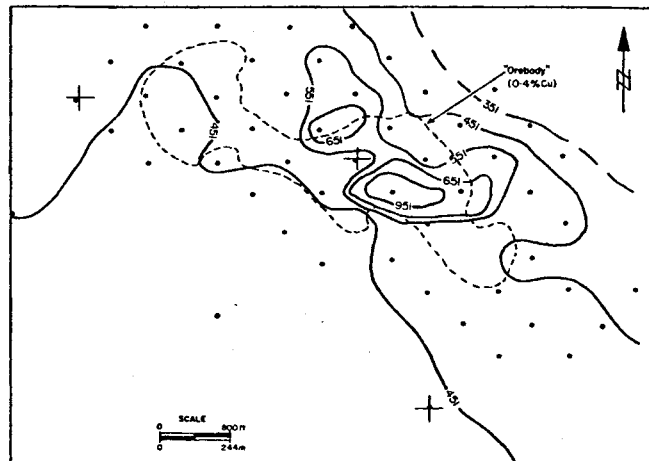


Fig 7a. Distribution of Ba at Bethlehem JA (values in ppm)

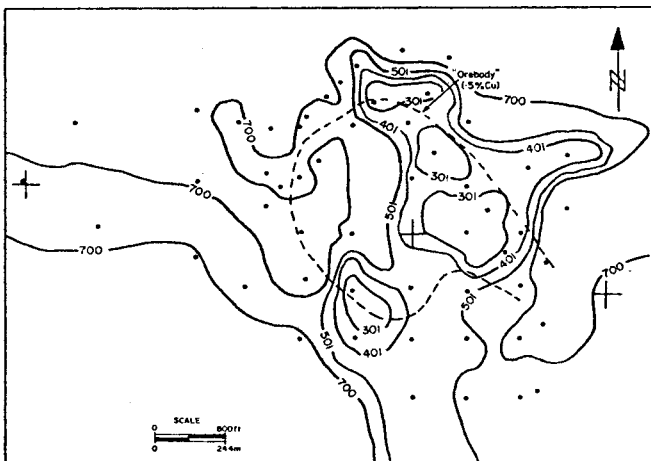


Fig 5b. Distribution of Sr at Valley Copper (values in ppm)

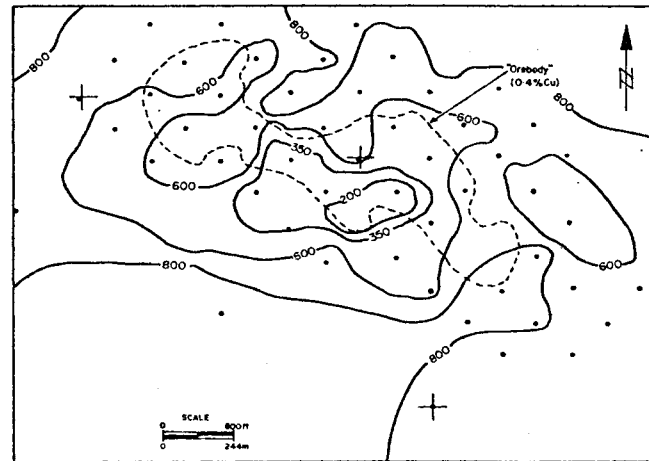


Fig 7b. Distribution of Sr at Bethlehem JA (values in ppm)

Fig 5c. Distribution of Ba/Sr ratios at Valley Copper

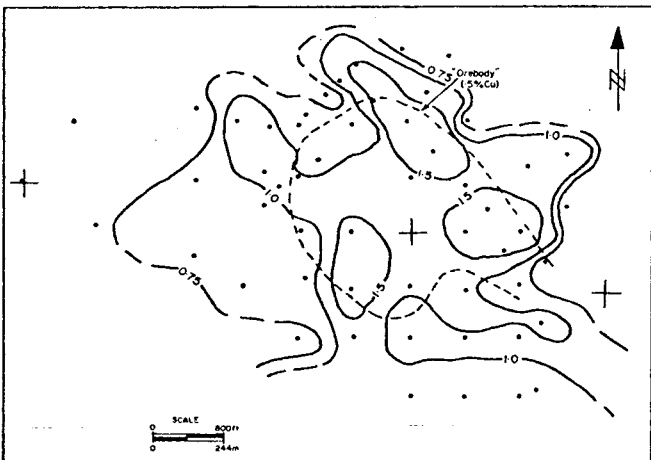
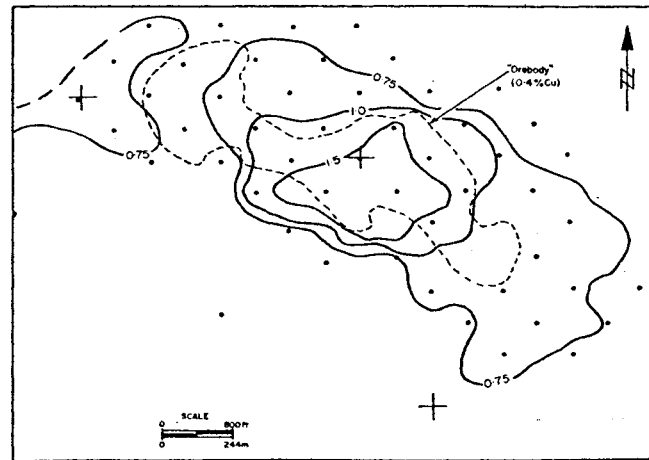


Fig 7c. Distribution of Ba/Sr ratios at Bethlehem JA



are prevalent. Since plagioclase feldspar, which carries most of the Sr, is most susceptible to alteration by acidic hydrothermal solutions, Sr is readily leached from zones of intense hydrothermal activity and metallization. The leached Sr is deposited at the periphery of the deposits in association with carbonates and other propylitic minerals.

Despite the inconsistency in the behaviour of Ba, Ba/Sr ratios consistently increase from values less than 1 in fresh background samples, to more than 1 in mineralized and altered rocks. This relationship applies both where Ba and Sr decrease, and where Ba increases and Sr decreases as the ore zone is approached. Greater depletion of Sr than Ba in altered rocks is attributed to the greater solubility of Sr relative to Ba in thermal solutions (Tooker, 1963).

From the foregoing discussion, it is apparent that Ba and Sr dispersions are related closely to intensity and type of hydrothermal alteration. Dispersion patterns are equally apparent in data obtained by both semi-quantitative emission spectroscopy and more precise X-ray fluorescence spectrometry. Furthermore, Ba/Sr ratios delineate intensely altered and mineralized zones. Since both Ba and Sr are determined readily by routine methods, and their distribution more readily quantified than fine-grained mineralogy characteristic of

alteration zones, Ba and Sr analyses can be useful in outlining orebodies in the Highland Valley.

CONCLUSIONS

Anomalous dispersion of Ba and Sr is associated with hydrothermal and mineralization processes in granitic wall rocks of the Highland Valley porphyry copper deposits. Ba/Sr ratios exceeding 1 define mineralized zones in rocks of Guichon Creek batholith. In conjunction with wall-rock alteration studies, determinations of Ba and Sr can be useful in detailed exploration for porphyry copper deposits.

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