MULTI-ELEMENT LITHOGEOCHEMISTRY OF ALTERATION ASSOCIATED WITH GOLD-QUARTZ VEINS OF THE ERICKSON MINE, CASSIAR DISTRICT* (104P/4)

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INTRODUCTION

The Erickson mine is 12 kilometres southeast of Cassiar (NTS 104P/4). Production commenced in December 1978 and averaged 170 tonnes per day at the end of 1984. Mill heads have averaged 14.3 grams gold per tonne and 12.8 grams silver per tonne. Total production to the end of 1984 was 4.03 million grams of gold and 3.23 million grams of silver from 274 530 tonnes milled.

Gold-silver-bearing white quartz veins occur in mafic volcanic, ultramafic and sedimentary rocks of the Sylvester Allochthon (Figure 2-9-2). Carbonate and less commonly carbon alteration envelopes are generally well developed at contacts of white quartz, carbon and layered dolomite veins with volcanic rocks. This paper presents a summary of the characteristics of the veins and alteration zones, the geochemistry of the alteration envelope and exploration guidelines.

VEINS

Two major groups of veins are observed in the Erickson mine (Figure 2-9-1); early gold-silver-bearing white quartz veins with associated carbon veins and late carbonate, clear quartz and pyrite veins. Early white quartz veins are the most common. Most are composed of white quartz with minor amounts of scattered ankerite (Bear, Devine, Dease, Goldie, Caitlin and the lower part of Jennie) some also contain carbon-rich layers (Alison, Maura and the upper part of Jennie). In addition, pyrite, tetrahedrite, chalcopyrite, sphalerite and gold may occur throughout white quartz veins. Fragments of carbonate and carbon-altered wallrock are occasionally present along vein margins.

Carbon veins are uncommon; they were noted only adjacent to the Alison and Maura veins. Carbon veins are composed of fine to coarse-grained massive carbon with lesser quartz and ankerite and traces of pyrite.

Late veins consist of layered dolomite, clear quartz, pyrite, white calcite and clear calcite. They comprise only a small portion of all veins in the mine. Layered dolomite veins, which usually contain minor quartz and pyrite, have only carbonate alteration envelopes associated with them. The McDame vein is an example of a large vein of this type.

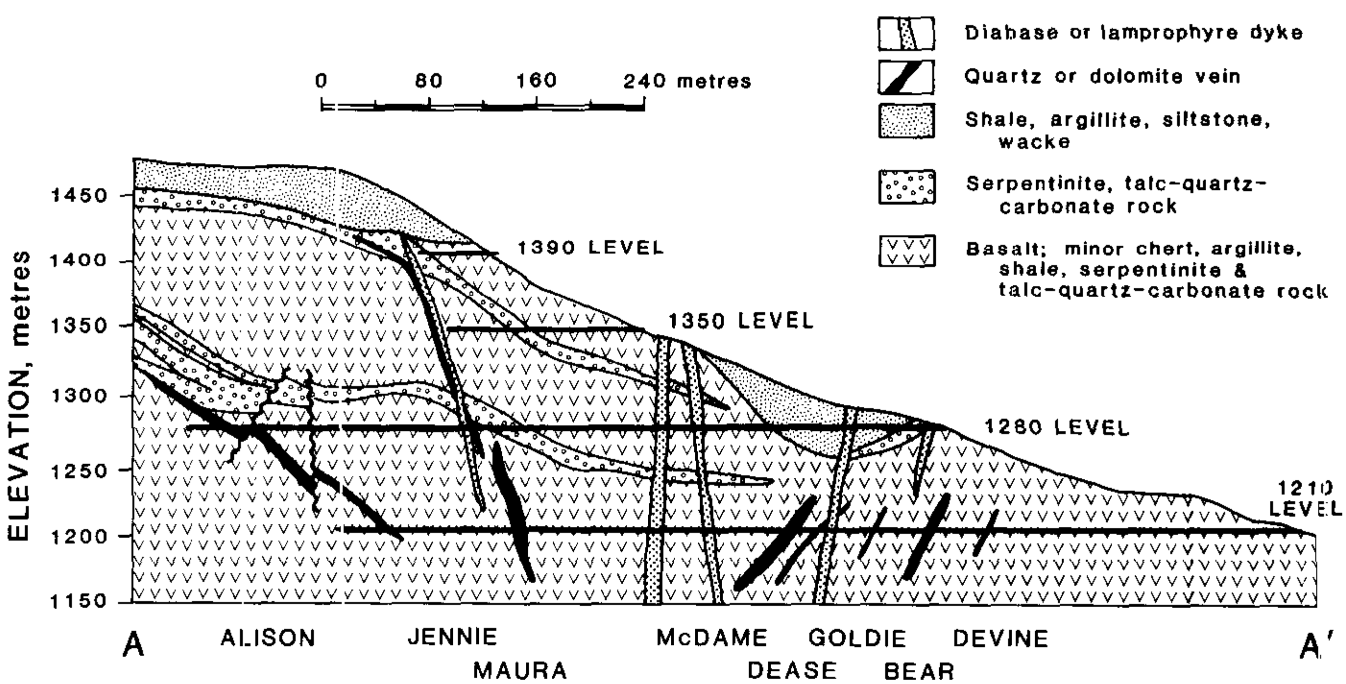

Figure 2-9-1: Generalized geological cross-section of the Erickson mine, Cassiar district, showing the relation of veins to major rock units.

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British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.

ALTERATION ZONES

An idealized model of the vein-alteration envelope is illustrated in Figure 2-9-2. Typical cross sections through the vein-alteration envelopes in the mine are illustrated in the same diagram. Veins commonly range up to 5 metres in thickness and associated alteration envelopes may extend outward up to 40 metres, although 1 to 15 metres is common where volcanic material is the host.

The entire alteration envelope is generally divisible into two zones: an outer carbonate zone and an inner carbon zone. Each of the zones can be further subdivided. Fracture-controlled carbon alteration may be present in the carbonate zone and uncommonly in unaltered basalt. General descriptions of unaltered wallrock and the individual alteration zones are presented below, starting with the unaltered wallrock and progressing toward the vein. A summary of descriptions is provided in Table 2-9-1.

VOLCANIC COUNTRY ROCK

Volcanic country rocks are of basaltic composition; typically they are pale to dark green and weather dark green to black. Most exposures are aphanitic to medium-grained massive to pillowed rocks. Breccias and layered rocks are less common. A crosscutting network of dark green to black hairline fractures may be present, imparting a "crackled" texture to the rocks. Constituent minerals of the unaltered basalt include plagioclase, chlorite, actinolite, epidote, augite, calcite and titanium oxides. Quartz and disseminated pyrite may be present.

ALTERATION ZONE 2C — OUTER CARBONATE

Zone 2C marks the transition from country rock to carbonate-altered rock; it is typically pale green to buff and pale grey, weathers buff to orange-brown and may have a speckled or mottled appearance. Most of the altered volcanic rocks are fine to medium-grained and massive, although primary textures may be visible. A "crackled" texture, as previously described, may be superimposed on the rock. Mineralogically the zone is characterized by partial alteration of silicate minerals to ankerite, siderite, quartz and sericite. Titanium oxides, kaolinite, dolomite, pyrite, carbon and calcite may be present. The width of the outer zone is generally less than 1 metre, but may be much wider, especially if abundant stringer veins are present. The zone is present in the outer portion of most carbonate alteration envelopes.

ALTERATION ZONE 2B — INTERMEDIATE CARBONATE

Zone 2B consists of completely carbonate-altered volcanic rocks. Ghost textures may be present in coarser grained, layered and pillowed varieties. Rocks are buff to pale grey and weather orange-brown. Most are fine to medium-grained and massive. A "crackled" texture of black hairline fractures may be present locally. Constituent minerals include ankerite, siderite, quartz, sericite, titanium oxides and possibly kaolinite, dolomite, pyrite and carbon. Zone 2B is usually less than 10 metres wide and commonly occurs adjacent to white quartz and layered dolomite veins.

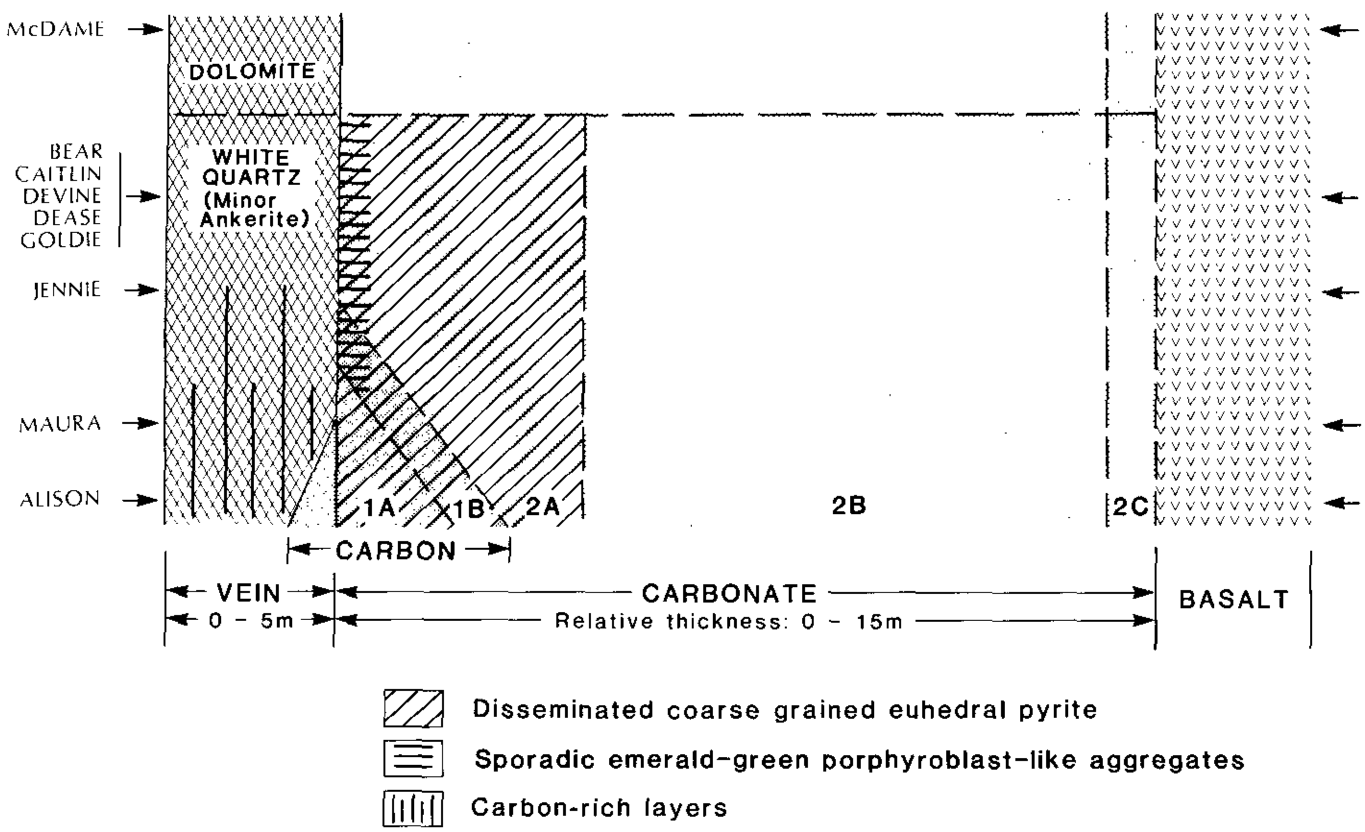

Figure 2-9-2: Hypothetical cross-section of idealized alteration envelopes enclosing white quartz, carbon and dolomite veins, Erickson gold mine, Cassiar district. Carbon vein and carbon alteration are shown as triangles to emphasize their local occurrence. Cross-sections characteristic of major veins are illustrated by the positions of vein names on the left. Alteration zones are: 1A — inner carbon, 1B — outer carbon, 2A — inner carbonate, 2B — intermediate carbonate, 2C — outer carbonate.

TABLE 2-9-1.
CHARACTERISTICS OF IDEAL ALTERATION ZONING
RELATED TO WHITE QUARTZ, CARBON AND LAYERED DOLOMITE VEINS AT ERICKSON GOLD MINE

Zone	Thickness (m)	Occurrence	Colour	Mineralogy
basalt	—	country	pale to dark green	plagioclase, chlorite, actinolite, epidote, augite, calcite, titanium oxides ± pyrite, quartz
2C —	<1	very common	pale green to buff and pale grey	plagioclase, chlorite, ankerite, siderite, quartz, sericite, titanium oxides ± kaolinite, dolomite, pyrite, carbon calcite, epidote, augite, actinolite
2B — intermediate carbonate	<10	very common	buff to pale grey	ankerite, siderite, quartz, sericite, titanium oxides ± kaolinite, dolomite, pyrite, carbon
2A — inner carbonate	<4	common	buff to pale grey with minor green mottling	ankerite, quartz, sericite, pyrite, titanium oxides ± siderite, carbon, arsenopyrite
1B — outer carbon	<1	uncommon	buff to black	ankerite, quartz, sericite, pyrite, titanium oxides, carbon ± siderite, arsenopyrite
1A — inner carbon	<3	uncommon	black	ankerite, quartz, sericite, carbon, pyrite, titanium oxides ± siderite, arsenopyrite

ALTERATION ZONE 2A — INNER CARBONATE

Zone 2A is similar to zone 2B with the following exceptions: the occurrence of coarse euhedral pyrite crystals, the presence of emerald green carbonate porphyroblasts, pistachio to lime green mottling and an increase in quartz content. Pyrite is more abundant closer to quartz veins. The carbonate porphyroblasts, less than 1 centimetre in diameter, occur sporadically only in the part of the zone adjacent to the contact with quartz veins. The pistachio to lime green mottling is uncommon; it also occurs adjacent to the contact with white quartz veins. Zone 2A is less than 4 metres wide and occurs only around white quartz veins.

ALTERATION ZONE 1B — OUTER CARBON

Zone 1B marks the transition from carbonate to carbon-altered rocks. The transition is gradational with colour changes from buff to black. The rocks are fine to medium-grained and massive. A "crackled" texture of black hairline fractures is common. Compositionally, the zone is characterized by ankerite, quartz, sericite, pyrite, titanium oxides and carbon. Siderite and arsenopyrite may also be present. Coarse euhedral pyrite crystals are scattered throughout the zone and concentrated closer to quartz veins. Zone 1B is not present in all alteration envelopes. It generally occurs associated with carbon and white quartz veins and is typically less than 1 metre wide.

ALTERATION ZONE 1A — INNER CARBON

Zone 1A is characterized by the presence of abundant carbon. Rocks are black, fine to medium grained and massive. Constituent minerals include ankerite, quartz, sericite, carbon, pyrite and titanium oxides. Siderite and arsenopyrite may also be present. Coarse euhedral pyrite crystals are scattered throughout the zone and concentrated closer to quartz veins. Zone 1A is uncommon; its occurrence is similar to zone 1B. It is generally less than 3 metres wide.

FRACTURE CONTROLLED CARBON ALTERATION

Fracture-controlled carbon alteration is characterized by an irregular network of black hairline fractures that impart a "crackled" texture to the rocks. Individual fractures are generally continuous. Oriented fractures that crudely divide the rock into elongate domains are locally common. Fractures are marked by the addition of very fine-grained carbon. A higher fracture density appears to be coincident with an increase in width of the carbon alteration around fractures. In areas of intense fracturing rocks resemble a breccia.

PYRITE

Pyrite occurs in variable amounts in all zones. Two types are noted: coarse-grained euhedral and fine-grained subhedral to anhedral pyrite. Concentration of coarse-grained pyrite increases up to 5 per cent toward quartz veins; crystal size also increases up to 5 millimetres in diameter. The distribution of fine-grained pyrite is erratic.

DISCUSSION

Systematic patterns within alteration envelopes vary little throughout the mine. The most important differences are the absence of specific zones and the variation in width and mineral abundances from one envelope to another. In general envelopes are nearly symmetrical, but in some cases the width in the hangingwall ranges up to twice that in the footwall. Hangingwall and footwall widths are generally from two to six times that of the adjacent vein. White quartz, and less commonly layered dolomite and carbon veins, generally occur in the core of alteration envelopes but are not always present.

Carbonate alteration envelopes surround all white quartz, layered dolomite and carbon veins; carbon alteration envelopes surround carbon veins and some white quartz veins. In general, auriferous white quartz veins are surrounded by all the carbonate alteration zones; carbon alteration zones may or may not be present. Layered dolomite veins are surrounded only by the intermediate and outer

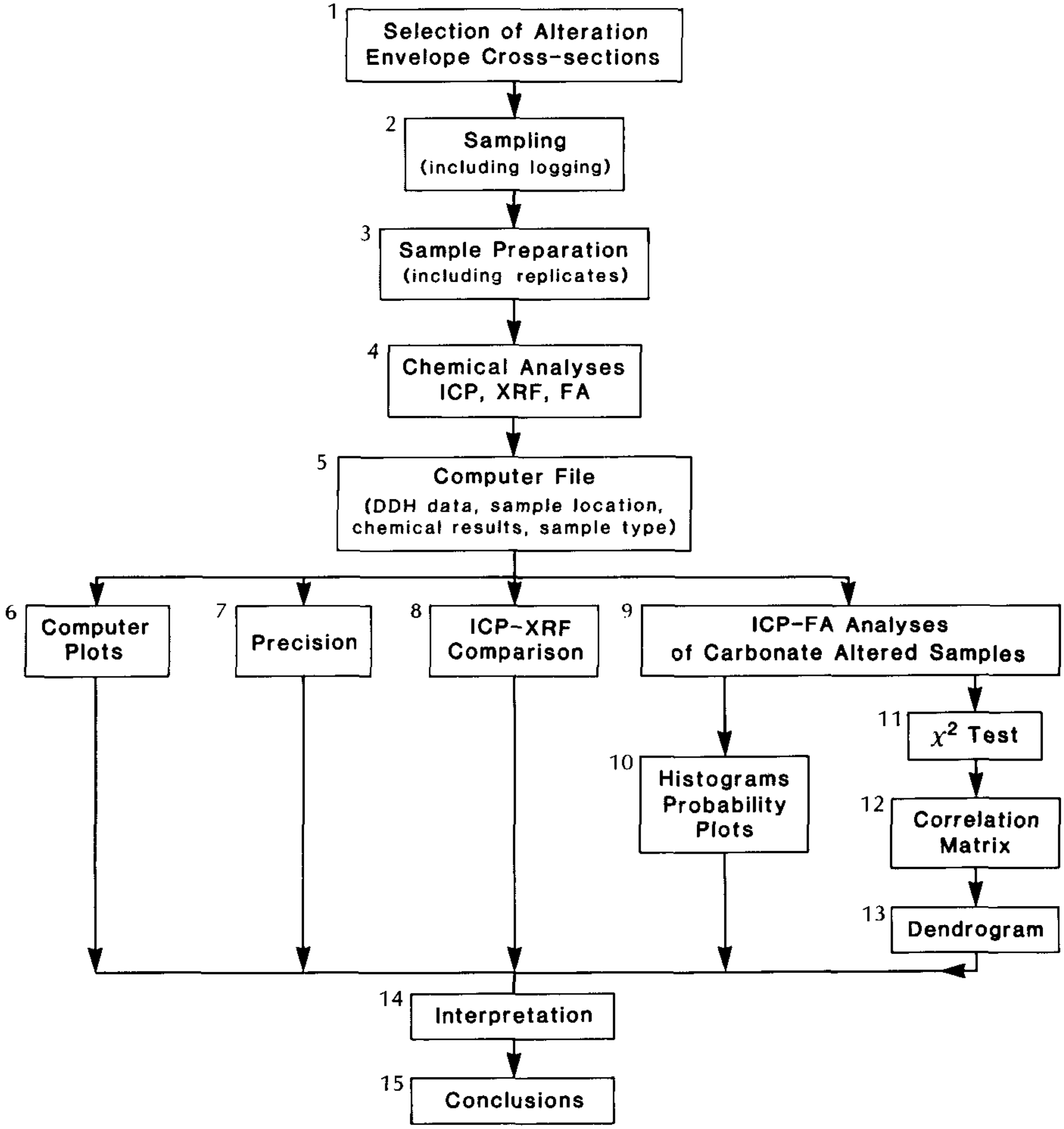

Figure 2-9-3: Flow diagram illustrating interpretive process for ICP-based lithogeochemical study of carbonate alteration haloes.

carbonate zones. The presence of the inner carbonate zone may therefore be used to identify carbonate alteration envelopes associated with potentially auriferous white quartz veins.

The presence of carbon alteration envelopes does not appear to have any bearing on the gold content of a quartz vein, but local concentrations of gold may be associated with carbon alteration. The occurrence of carbon alteration is probably related to nearby carbon-rich sedimentary rocks.

Carbonate and carbon alteration envelopes are composed mostly of carbonate with lesser quartz, sericite, kaolinite, titanium oxides, pyrite and carbon. In general, the rock is composed of approximately 55 per cent carbonate, 20 per cent quartz, 20 per cent sericite and kaolinite and 5 per cent titanium oxides, pyrite and carbon.

Carbonate minerals noted in the alteration envelopes are ankerite, siderite and dolomite. Ankerite occurs throughout all envelopes;

siderite is most common in the outer portion; dolomite is noted only in envelopes surrounding layered dolomite veins.

Kaolinite occurs throughout envelopes surrounding layered dolomite veins but only in the outer portion of some envelopes surrounding white quartz veins. Sericite occurs throughout envelopes surrounding white quartz veins.

The absence of dolomite and kaolinite and the presence of sericite in the inner portion of carbonate alteration envelopes provides a means of identifying envelopes associated with potentially auriferous white quartz veins.

GEOCHEMISTRY

The geochemical characteristics of carbonate alteration envelopes were investigated to test for patterns that might be useful as exploration guides. For the results of this orientation study to be of practical use, the following should apply:

(1) Sampling should conform to commonly used geochemical procedures.
(2) Multi-element analyses must be available commercially, at economic cost, and provide accurate results.
(3) Data interpretation procedures should be as simple as possible.

The procedures used in this study are presented in Figure 2-9-3 and discussed in the following sections.

SAMPLING AND ANALYSES

Seven carbonate and carbon alteration envelope cross-sections were selected from diamond-drill holes. Each was subdivided into 0.3 to 1.6-metre intervals of megascopically uniform character for sampling. Several intervals of the unaltered basalt surrounding each envelope were included where possible. A total of 106 samples of carbonate and carbon-altered basalt and 25 samples of unaltered basalt was collected. In addition 34 pulp samples of veins were retrieved from the Erickson mine laboratory for use in this study.

Loss-on-ignition (LOI) was determined for samples of altered and unaltered basalt. All samples were analysed for gold and silver by fire assay. All samples were digested with aqua regia solution and analysed for 30 elements by Inductively Coupled Plasma (ICP) spectroscopy. The 30 elements were: Al, Ti, Fe, Mn, Mg, Ca, Na, K, P, Au, Ag, As, Sb, Ba, B, Sr, Cu, Pb, Zn, Cd, Cr, Ni, Co, V, W, Mo, U, Th, La and Bi. Sixteen samples of altered basalt and six of unaltered basalt were also analysed by X-Ray Fluorescence (XRF) spectrometry for the following: SiO_2, Al_2O_3, TiO_2, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5, Ba, Sr, Rb, Zr, Y, Nb, Cu, Pb, Zn, Cr, Ni, Co, U and Mo.

COMPARISON OF ICP AND XRF DATA

ICP partial analyses and XRF total analyses from 22 samples of altered and unaltered basalt were compared by simple regression scatter plots using the following elements: Al, Ti, Fe, Mn, Mg, Ca, Na, K, P, Ba, Sr, Cu, Zn, Cr, Ni, Co and V. An example for calcium is shown in Figure 2-9-4. A least-squares line that passes through the origin was fitted to the data by regressing ICP on XRF analyses. The equation of the line and a linear correlation coefficient are included in Figure 2-9-4. The slope of the regression line provides an estimate of the average amount of an element released during digestion and detected by ICP analysis. The linear correlation coefficient is a measure of how well the ICP analyses reflect trends in the XRF analyses.

The average level of digestion and detection by ICP analyses is between 25 and 50 per cent for most elements; linear correlation coefficients range from 0.4 to 0.9. In general, results of the ICP-XRF comparison indicate that ICP partial analyses reflect trends shown in XRF total analyses reasonably well. This means that ICP partial analyses may be used as an economical analytical technique to obtain multi-element data for the purpose of a lithogeochemical survey. These data can then be examined for patterns that might be useful as exploration guides.

STATISTICAL ANALYSES OF ICP-FIRE ASSAY DATA

Only samples of carbonate-altered basalt analysed by ICP were used for statistical analysis. Gold and silver fire assay results were available and used in place of ICP results. A matrix of correlation coefficients was examined. Elements were divided into three groups: two with substantial intracorrelation and one without. Limited correlation exists between groups. Correlation measures for the first two groups are illustrated by a dendrogram in Figure 2-9-5.

The first group of elements (Ba, K, B, Sr, Al, Zn, Pb, Na, Cu, Au and As) are characterized by enrichment or depletion in carbonate alteration envelopes. The second group of elements (Cr, Ni, Mn, Mg, Ca, Fe and Co) are characteristically present in unaltered basalt and may be redistributed with enrichment adjacent to veins and depletion in the outer portion of the envelopes. Most of the third group of elements (Ag, Bi, Sb, U, V, W, Ti and Cd) are near or below detection limits; some may be enriched locally in alteration envelopes and the others lack discernible patterns. Four elements (La, Th, Mo and P) excluded from the matrix of correlation coefficients show patterns similar to the third group.

EXPLORATION PARAMETERS

Distribution patterns (Figure 2-9-6) for all elements were examined to determine those enriched in carbonate alteration envelopes surrounding auriferous white quartz veins. Potassium, barium, boron and arsenic show consistent and strong enrichment

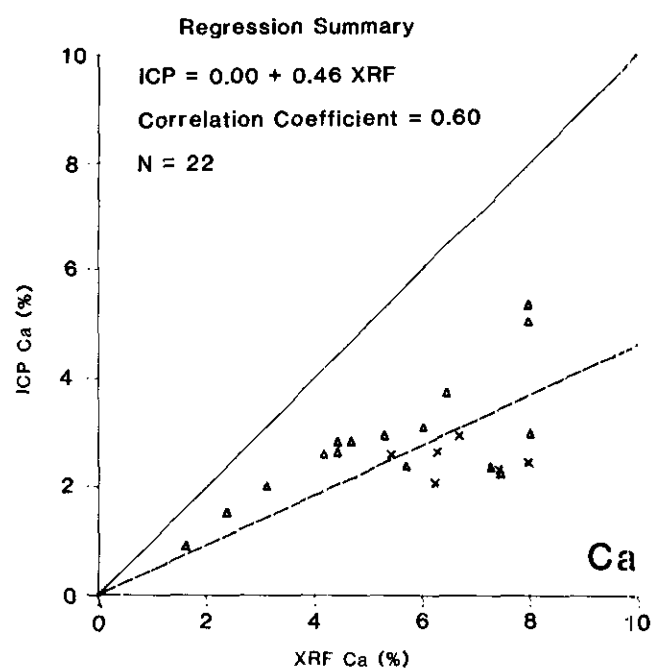

Figure 2-9-4: Plot of Inductively Coupled Plasma (ICP) partial analyses versus X-ray fluorescence (XRF) whole rock analyses for calcium in unaltered (Xs) and altered (open triangles) basalt, Erickson gold mine.

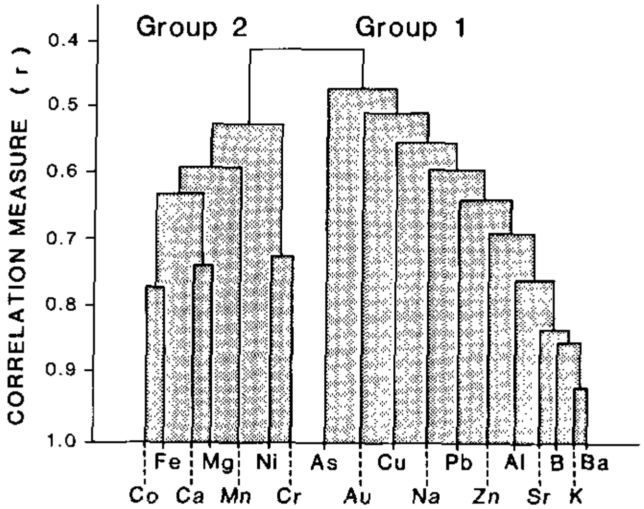

Figure 2-9-5: Dendrogram illustrating two principal intracorrelated grouping of elements based on ICP partial extraction data for Erickson gold mine.

throughout envelopes. Fire assay results for gold show enrichment in carbonate alteration envelopes adjacent to some veins, but ICP results do not as values are below the detection limit.

Copper, lead, zinc, antimony and silver are enriched in carbonate alteration envelopes surrounding auriferous quartz veins and occur in minerals associated with gold. Enrichment in copper, lead, zinc and antimony generally occurs immediately adjacent to auriferous white quartz veins. Copper enrichment is noted in most envelopes but enrichment of lead, zinc and antimony in only a few. Silver fire assay results are suspect because of their erratic nature and are of little practical use. Silver ICP analyses show enrichment adjacent to a few veins and may be useful.

Strontium, calcium, magnesium, iron and manganese are also enriched in carbonate-altered basalt adjacent to auriferous white quartz veins. These elements are associated with carbonate minerals. Because enrichment is due wholly or in part to redistribution within envelopes, these elements are not useful as exploration guides. Redistribution involves migration of bivalent metal cations from the outer portion of envelopes toward veins and combination with CO_2 to form carbonate minerals.

Thresholds of significance for selected elements enriched in envelopes surrounding auriferous quartz veins were determined from probability plots for multiple populations or from histograms and element profile plots for a single population. The thresholds are: K = 0.03 per cent, Ba = 90 ppm, B = 20 ppm, As = 15 ppm, Au = 1 ppb (0.03 ounce per ton), Ag = 1 ppm, Cu = 30 ppm, Pb = 9 ppm, Zn = 40 ppm and Sb = 4 ppm.

DISCUSSION

Enrichment in potassium, barium and boron reflects geological processes that are an inherent part of carbonate alteration in basalt surrounding auriferous white quartz veins. In contrast there appears to be no similar enrichment in carbonate alteration envelopes surrounding layered dolomite veins. Consequently enrichment in these elements is indicative of a carbonate alteration envelope that surrounds a potentially auriferous quartz vein. Arsenic, gold, silver, copper, lead, zinc or antimony enrichment, in addition to potassium, barium and boron, suggests that an alteration envelope probably surrounds an auriferous quartz vein that may also contain chalcopyrite, tetrahedrite, galena, sphalerite and arsenopyrite.

Application of the results of this orientation study to the Jennie vein is illustrated in Figure 2-9-6. Enrichment in potassium, barium, boron and arsenic characterizes the carbonate alteration envelope surrounding the vein. Enrichment in gold and copper in carbonate-altered basalt adjacent to the vein correlates with their occurrence in the vein. Zinc occurs only in the vein. Elevated antimony values occur in and adjacent to the stringer vein in the profile plot.

EXPLORATION GUIDELINES

A systematic examination of carbonate alteration envelopes for characteristics indicative of auriferous white quartz veins can be used as a guide to exploration. Assuming that diamond-drill core is being examined, the following steps are recommended:

(1) Log core and subdivide alteration envelope into zones.

(2) If a vein is not intersected in a carbonate alteration envelope, the presence of the inner carbonate zone indicates an auriferous white quartz vein may be present close by. Alternatively representative specimens of the inner portion of the envelope may be stained for dolomite and ankerite. The presence of dolomite indicates a layered dolomite vein. If dolomite is absent and ankerite present, the alteration envelope may contain an auriferous white quartz vein.

(3) Subdivide the zones into intervals of megascopically similar rock. Suggested sampling intervals are 0.5 metre for the inner carbonate zone and 10 metres for the intermediate and outer carbonate zones.

(4) Analyse for gold and silver by fire assaying. Analyse for potassium, barium, boron, arsenic, silver, copper, lead, zinc and antimony by ICP, following partial digestion with aqua regia solution.

(5) Plot results on graphs similar to those in Figure 2-9-6. Enrichment in potassium, barium and boron implies a potentially auriferous quartz vein is present. Enrichment in arsenic, gold, silver, copper, lead, zinc and antimony implies minerals containing these elements are probably also present in the vein.

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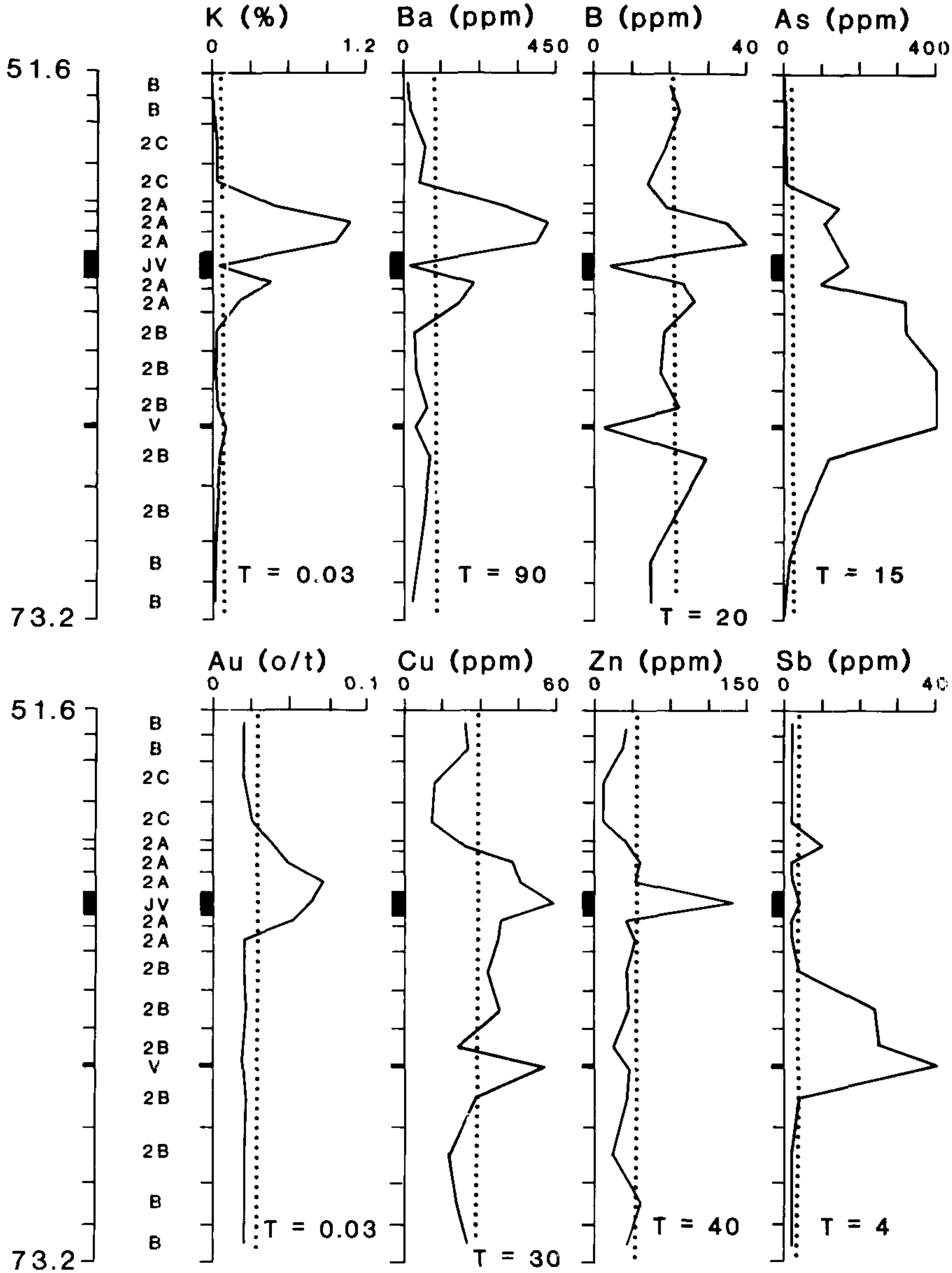

Figure 2-9-6: Element profiles across Jennie vein and adjacent altered and unaltered basalt, Erickson gold mine. Letter codes are: basalt (B), Jennie vein (JV), alteration zones (1B, 2A, etc.) as in Figure 2-9-2, thresholds between anomalous and background values (T).