

Alteration with special reference to precious metal deposits, U.B.C. 1985<sup>1.</sup>

APPLICATION OF MINERALOGICAL AND GEOCHEMICAL CHARACTERISTICS OF CARBONATE ALTERATION ENVELOPES TO EXPLORATION FOR AURIFEROUS WHITE QUARTZ VEINS AT THE ERICKSON GOLD MINE, CASSIAR, NORTH-CENTRAL BRITISH COLUMBIA

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INTRODUCTION

The Erickson mine is 12 kilometres southeast of Cassiar, British Columbia (Fig. 1; NTS Map Sheet 104P/4). Production commenced in December, 1978 and averaged 170 tonnes per day at the end of 1984. Mill heads have averaged 14.3 g gold per tonne and 12.8 g silver per tonne. Total production to the end of 1984 was 4.03 million g gold and 3.23 million g silver from 274,530 tonnes.

129,570 oz

10385002

249,570 t

Gold-silver-bearing white quartz veins occur in mafic volcanic, ultramafic and sedimentary rocks of the Sylvester allochthon (Fig. 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 characteristics of the veins, and alteration zones and geochemistry of the alteration envelope with exploration guidelines.

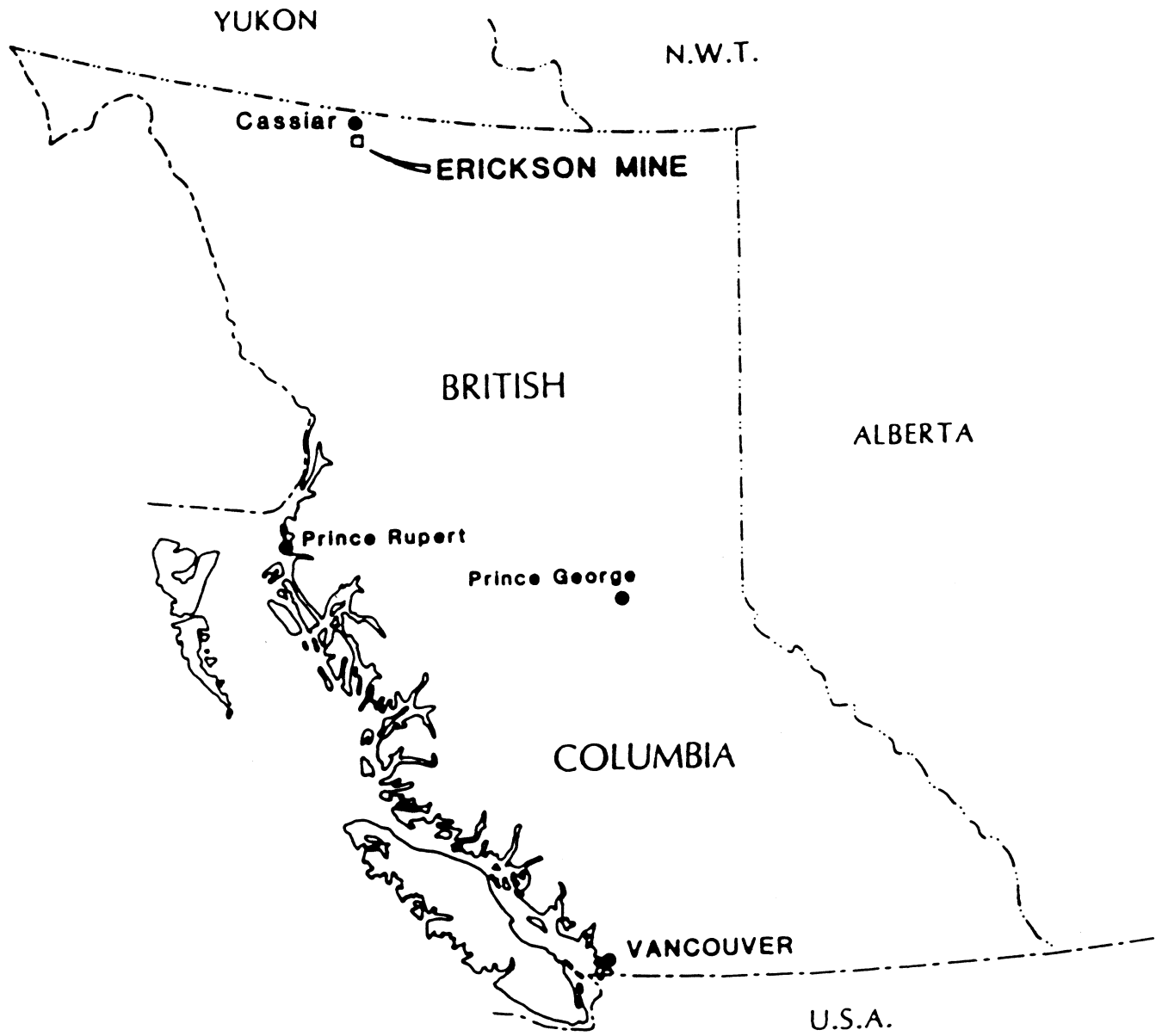


Figure 1. Location of the Erickson mine.

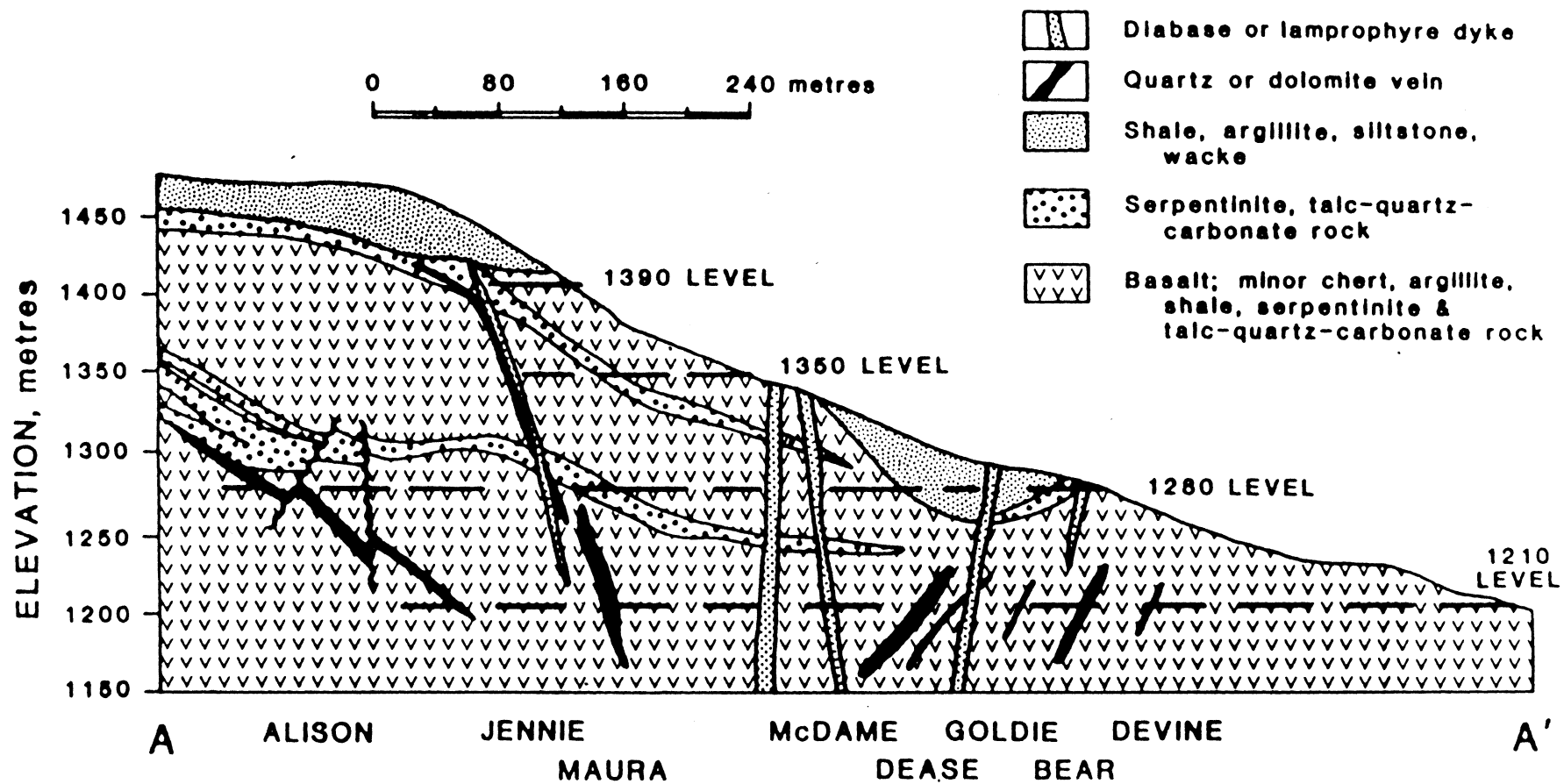


Figure 2. Generalized geological cross-section of the Erickson mine.

## VEINS

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

Carbon veins are uncommon in the Erickson mine; 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 veins. 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.

## ALTERATION ZONES

An idealized model of the vein-alteration envelope is illustrated in Figure 3. Typical cross sections through the vein-alteration envelope are indicated in the same diagram for major veins in the mine. Veins commonly range up to 5 metres in thickness and associated alteration envelopes extend from nearly 0 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 and an inner carbon. 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 wall rock and the individual alteration zones are presented in the following sections. These start with the unaltered wall rock and continue with zones toward the vein. A summary of descriptions is provided in Table 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 consist of aphanitic to medium-grained massive to pillowed rocks. Less commonly breccias and layered rocks were observed. A cross-cutting network of dark green to black hairline fractures may be present imparting a 'crackled' texture to the rocks. Constituent minerals of the unaltered

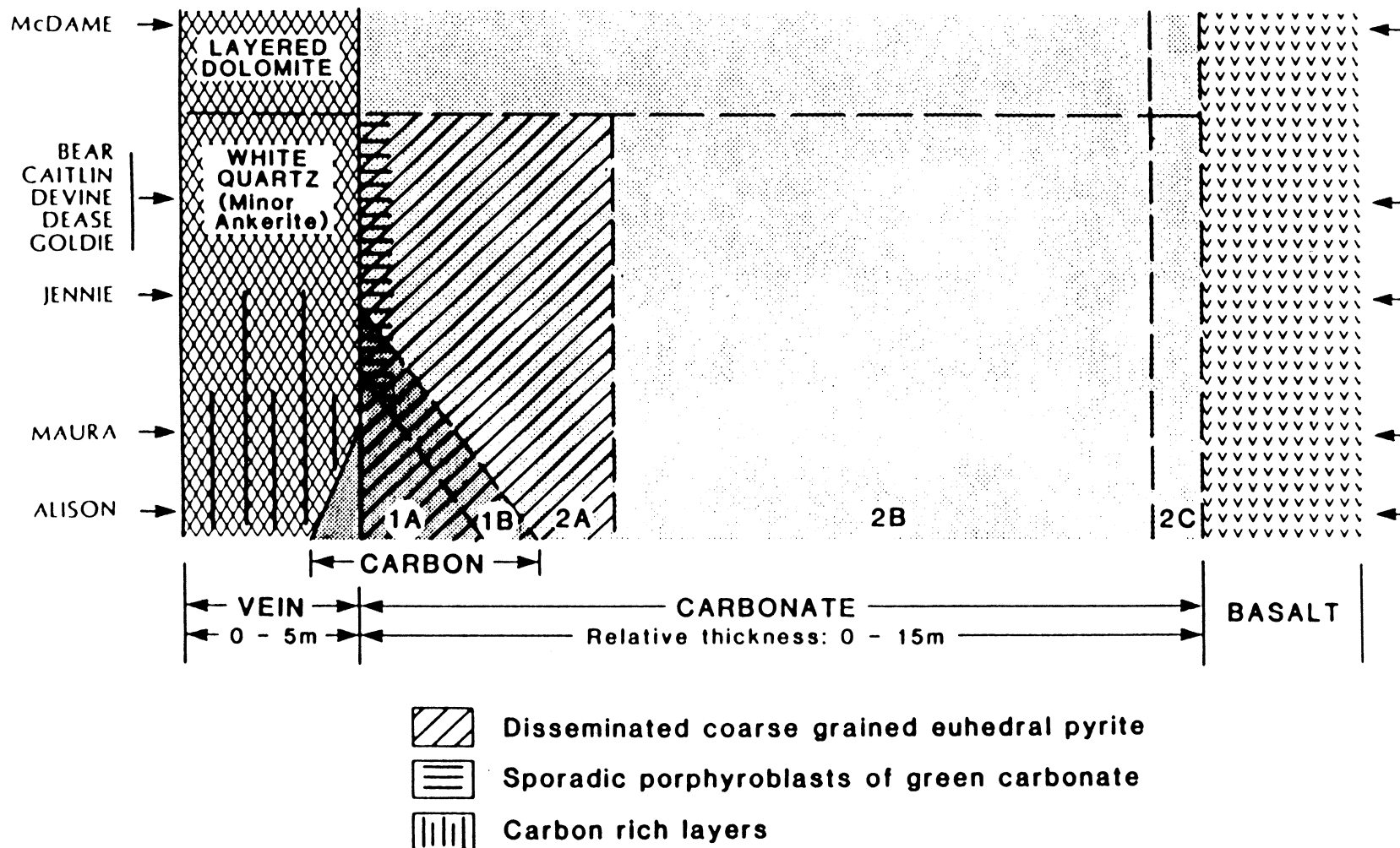


Figure 3. Cross-section of idealized alteration envelope characteristic of white quartz, carbon and layered dolomite veins. Carbon vein and carbon alteration envelope are depicted by triangular areas. Cross-sections typical of major veins are indicated on the left. Alteration zones are: 1A = inner carbon, 1B = outer carbon, 2A = inner carbonate, 2B = intermediate carbonate, 2C = outer carbonate.

Kaolinite is peripheral to C<sub>1</sub> zone  
 No relation of C to Au, some fault  
 of section

TABLE 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 rock	pale to dark green	plagioclase, chlorite, actinolite, epidote, augite, calcite, titanium-oxides ± pyrite, quartz
2C outer carbonate	<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 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, arseno- pyrite
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

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, evident because of dark green to black hairline fractures, 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 one 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. Constituents include ankerite, siderite,



quartz, sericite, titanium-oxides and possibly kaolinite, dolomite, pyrite and carbon. Zone 2B is usually less than 10 metres wide, it commonly occurs adjacent to white quartz and layered dolomite veins.

#### 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 one 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 occurs also adjacent to the contact with white quartz veins. Zone 2A is less than four metres wide and is noted 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 in envelopes associated with carbon and white quartz veins. It is typically less than one 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. Constituents 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 three 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 divide the rock crudely 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 all zones in variable amounts. Two types are noted: coarse-grained euhedral and fine-grained subhedral to anhedral pyrite. Concentration of coarse-grained pyrite increases up to five percent toward quartz veins; crystal size also increases up to 5 millimetres in diameter. Fine-grained pyrite is erratic, unlike the coarse-grained variety.

## 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 widths in the hanging wall range up to twice that in the foot wall. Hanging wall and foot wall 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; however, were not noted in some cases.

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 carbonate zones. Therefore,

the presence of the inner carbonate zone may 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 white quartz vein. However, 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 percent carbonate, 20 percent quartz, 20 percent sericite and kaolinite and five percent 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, and only in the outer portion of some envelopes surrounding white quartz veins. Sericite occurs only throughout envelopes surrounding white quartz veins.

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

## GEOCHEMISTRY

The geochemical characteristics of carbonate alteration envelopes, in the Erickson mine, 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 be applied:

1. Sampling should conform to commonly used geochemical procedures
2. Multi-element analyses must be available commercially, be economical and give results that reflect actual trends
3. Data interpretation procedures should be as simple and straight forward as possible.

The procedures used in this study are presented in figure 4 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 and split. Several intervals of the unaltered basalt that surrounds each envelope were included where possible. In total, 106 samples of carbonate and carbon altered basalt and 25 of unaltered basalt were obtained. In addition, 34 pulp samples of veins were retrieved from the Erickson mine laboratory for use in this study.

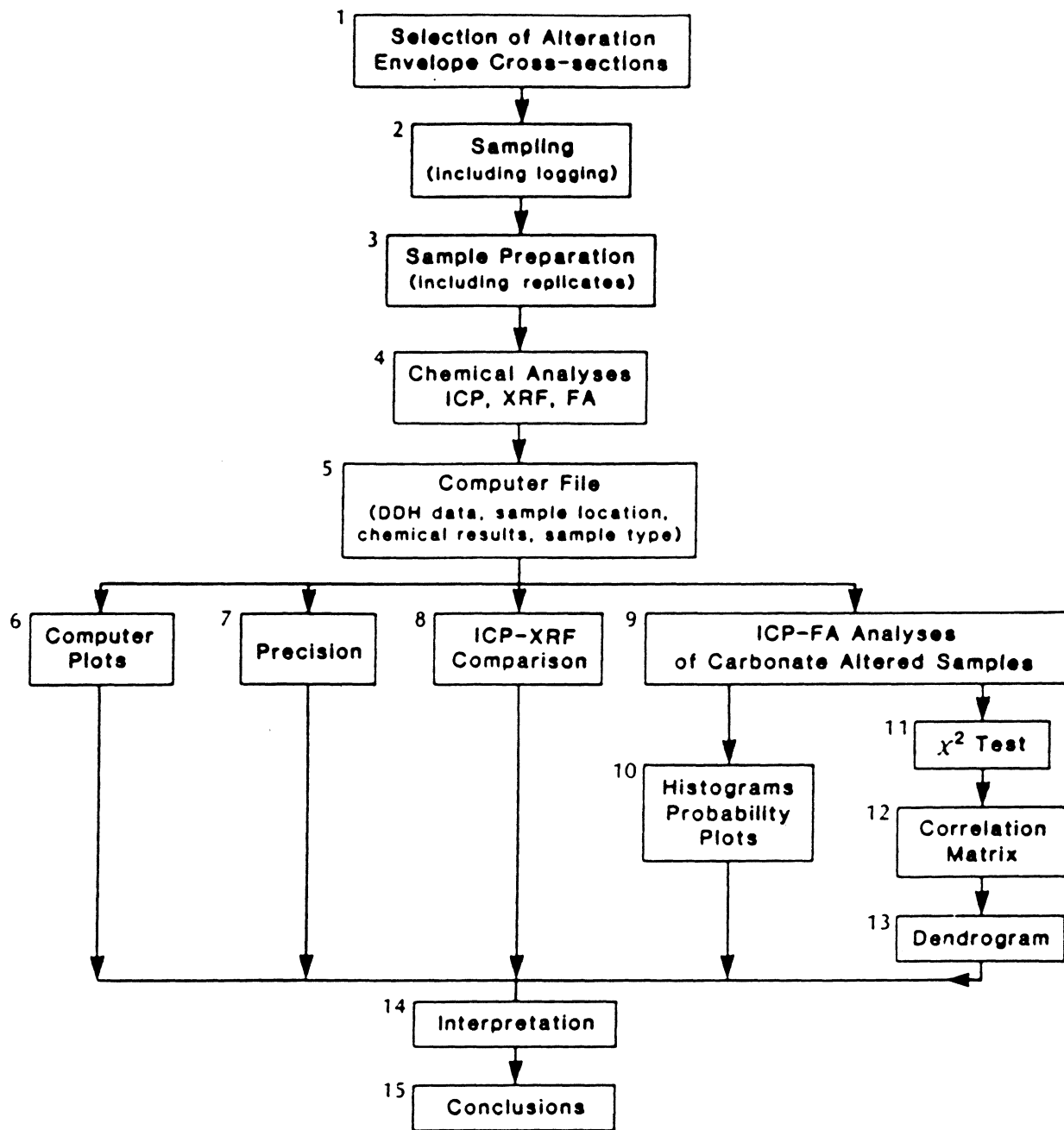


Figure 4. Flow diagram for carbonate alteration geochemistry study.

Loss on ignition (LOI) was determined for samples of altered and unaltered basalt. All samples were analyzed for gold and silver by fire assaying. All samples were digested with aqua regia solution and analyzed for 30 elements by Inductively Coupled Plasma Spectroscopy (ICP). The thirty 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, U, W, Mo, U, Th, La and Bi. Sixteen samples of altered basalt and six of unaltered basalt were also analyzed by X-Ray Fluorescence Spectrometry (XRF) for the following:  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{TiO}_2$ ,  $\text{Fe}_2\text{O}_3$ , MnO, MgO, CaO,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ,  $\text{P}_2\text{O}_5$ , 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 by 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 Ba is shown in figure 5. 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 5. The slope of the regression line is 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.

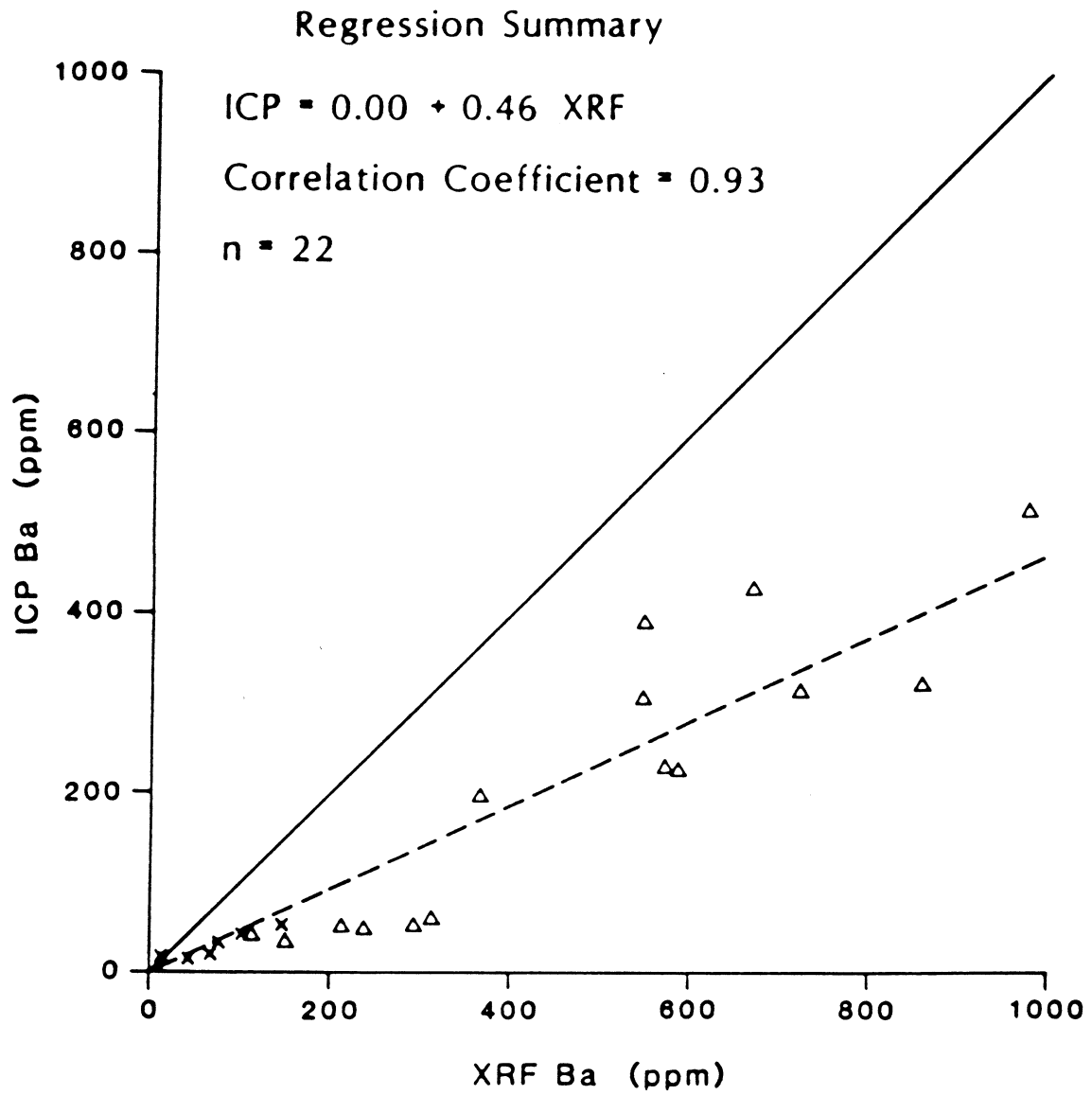


Figure 5. ICP partial analyses versus XRF total analyses for barium (X = unaltered basalt, Δ = carbonate altered basalt).



The average level of digestion and detection by ICP analyses, is between 25 and 50 percent 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. 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 analyzed by ICP were used for statistical analysis. Au and Ag fire assaying 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 6.

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

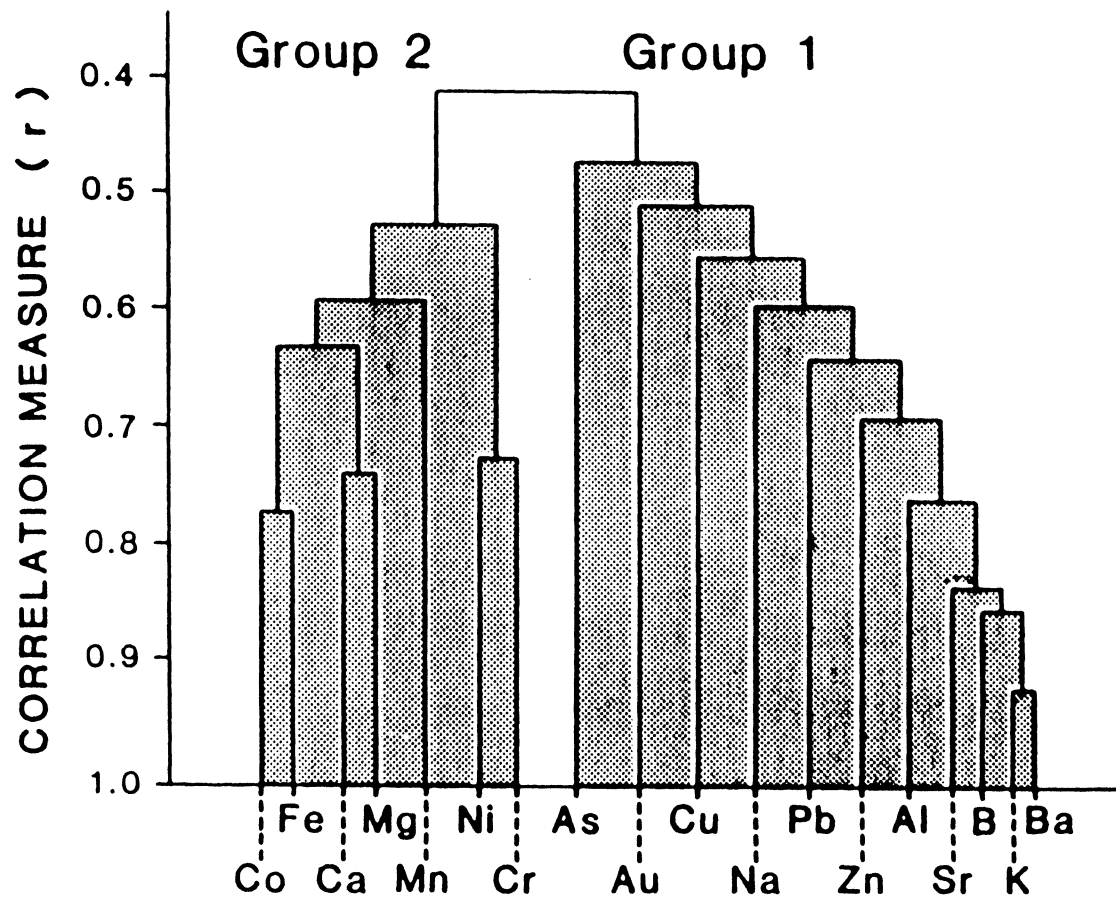


Figure 6. Dendrogram illustrating element groups with substantial intracorrelation.

and Cd) are near or below detection limits; some may be enriched locally in alteration envelopes, and the others lack discernable 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 for all elements were examined to determine those enriched in carbonate alteration envelopes surrounding auriferous white quartz veins. K, Ba, B and As show consistent and strong enrichment throughout envelopes. Fire assay results for Au show enrichment in carbonate alteration envelopes adjacent to some veins; however, those for ICP do not because they are below detection limit.

Cu, Pb, Zn, Sb and Ag are enriched in carbonate alteration envelopes surrounding auriferous quartz veins and occur in minerals associated with Au. Enrichment in Cu, Pb, Zn and Sb generally occurs immediately adjacent to auriferous white quartz veins. Copper enrichment is noted in most envelopes; whereas enrichment of Pb, Zn and Sb in only a few. Ag fire assay results are suspect because of their erratic nature and therefore, are of little practical use. Ag ICP analyses show enrichment adjacent to a few veins and appear to be useful.

Sr, Ca, Mg, Fe and Mn 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 for

exploration. Redistribution involves migration of bivalent metal cations from the outer portion of envelopes toward veins and combination with  $\text{CO}_2$  to form carbonate minerals.

Thresholds 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%, Ba = 90 ppm, B = 20 ppm, As = 15 ppm, Au = .03 oz/t, Ag = 1 ppm, Cu = 30 ppm, Pb = 9 ppm, Zn = 40 ppm and Sb = 4 ppm.

#### Discussion

Enrichment in K, Ba and B 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 enrichment in K, Ba and B 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 white quartz vein. As, Au, Ag, Cu, Pb, Zn or Sb enrichment in addition to K, Ba and B, suggests that an alteration envelope probably surrounds an auriferous white quartz vein that may also contain chalcopyrite, tetrahedrite, galena, sphalerite and arsenopyrite.

Application of the results of this orientation study to the auriferous Jennie white quartz vein is illustrated in Figure 7. Enrichment in K, Ba, B and As characterizes the carbonate alteration envelope surrounding the

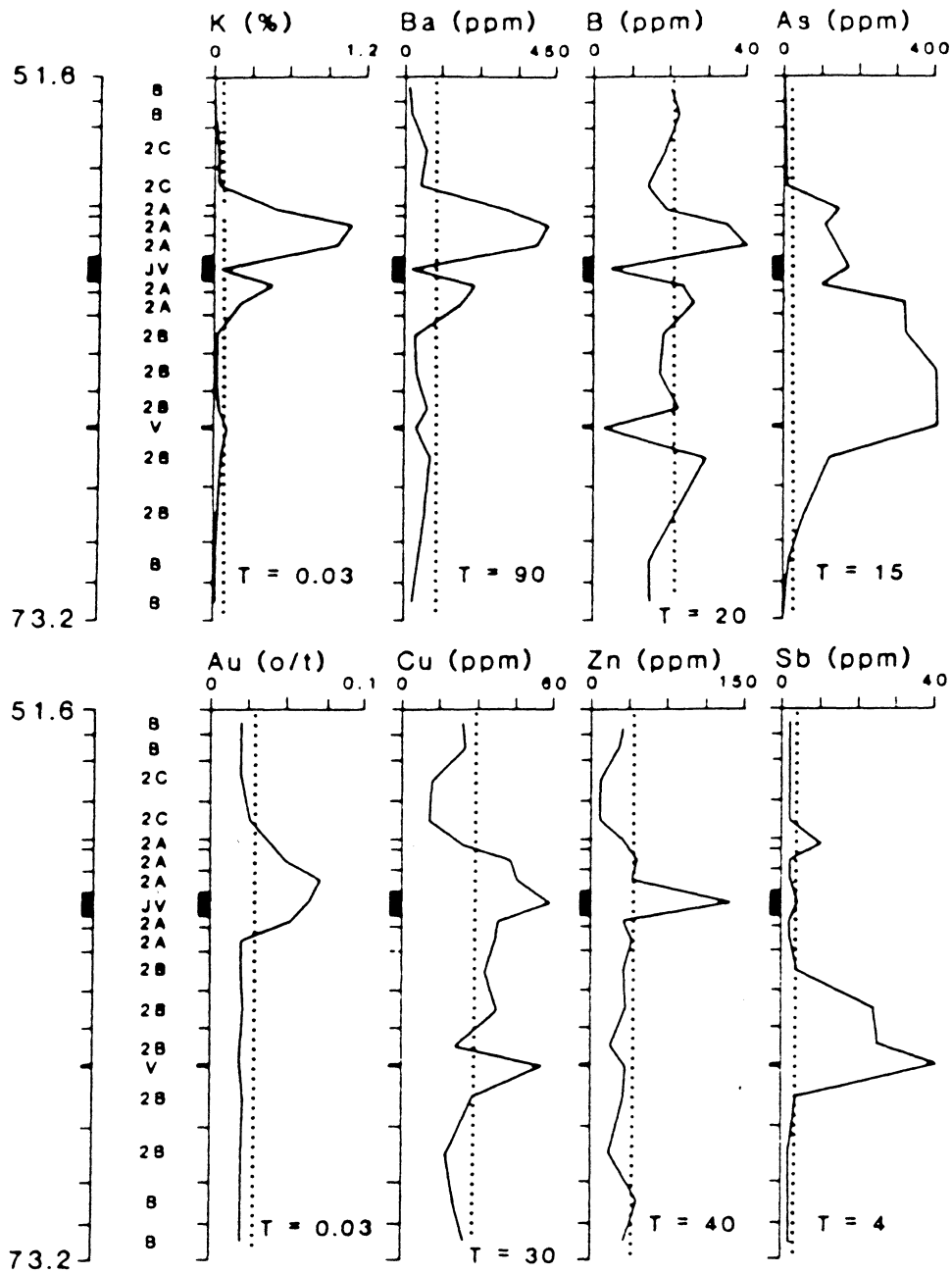


Figure 7. Carbonate alteration envelope cross-section 80-88 of Jennie vein with location of unaltered basalt (B), zones of carbonatized basalt (2A, 2B and 2C) and quartz veins (JV = Jennie vein, U = stringer vein). Profiles are from ICP partial analyses except Au, which is from fire assaying. Scale on left in metres shows sample intervals. Values are plotted in the middle of each sample interval. Thresholds (T) separate enriched from background values.

vein. Enrichment in Au and Cu in carbonate-altered basalt adjacent to the vein correlates with their occurrence in the vein. Zn occurs only in the vein. Elevated Sb occurs 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 may be undertaken by using the results of this orientation study. 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 the carbonate alteration envelope, the presence of the inner carbonate zone indicates a potentially auriferous white quartz vein. Alternatively one may stain representative specimens of the inner portion of the envelope for dolomite and ankerite. The presence of dolomite indicates a layered dolomite vein. If dolomite is absent and ankerite predominates, the alteration envelope may contain an auriferous white quartz vein.
3. Subdivide the zones into intervals of macroscopically similar rock. Suggested sampling intervals are 0.5 m for the inner carbonate zone and 10 m for the intermediate and outer carbonate zones.

The objective is to increase sample density in the inner portion of the envelope where most enrichment occurs.

4. Analyze for gold and silver, by fire assaying. Do potassium, barium, boron, arsenic, silver, copper, lead, zinc and antimony analyses by ICP following partial digestion with aqua regia solution.
5. Plot results on graphs similar to those in figure 7 and examine. 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 present in the vein.

TABLE 1 ERICKSON CREEK GOLD MINE PROPERTY  
SUMMARY ORE RESERVE ESTIMATES - as of October 31st, 1985

	CATEGORY (TONS)		Tonnes	GRADE	
	Proven	Probable		oz Au/ton	g/T
104A 029	<u>Main Mine Area (table 2)</u>				
	12,602	11432		0.397	13.611
		7,572	6869	0.431	14.777
019	<u>Table Mt. Mine Zones (table 3)</u>				
	23,005	20870		0.241	8.263
		6,859	6222	0.167	5.726
		30,289	27477	0.349	11.966
		71,409	64781	0.365	12.514
Vollang Nein	<u>Troutline Zones (table 4)</u>				
		38,240	34690	0.294	10.08
070	<u>Eileen and Eileen East Veins (table 5)</u>				
		33,565	30450	0.893	30.617 (cut)
	<u>Summary Totals</u>				
	35,607	32302		0.296	10.149
		187,934	170491	0.438	15.017
		223,541		0.415	14.229
	<u>Summary Totals (after allowing 5% general mining dilution)</u>				
	37,387	33917		0.282	9.669
		197,331	179016	0.417	14.297
		234,718	212933	0.395	13.543

Note: As outlined on Table 2, a high proportion of the total reserves in the Main Mine area are tied up in support pillars and may only be partially recoverable on a final salvage basis.

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