THE NATURE OF CARBONATE ALTERATION IN BASALT AT ERICKSON GOLD MINE, CASSIAR, NORTH-CENTRAL BRITISH COLUMBIA

by

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We accept this thesis as conforming to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

March 1986
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Frontispiece. Entrance to Erickson Gold Mines Ltd.'s Cassiar operations. The 1210, 1280 and 1350 portals are visible in the background.
ABSTRACT

The Erickson mine is within the McDame lode gold camp, approximately 12 km southeast of Cassiar, British Columbia. The mine is in mafic volcanic, ultramafic and sedimentary rocks of the Upper Paleozoic to Lower Mesozoic Sylvester Allochthon.

Gold-silver mineralization occurs in white quartz veins that are mostly within mafic volcanic rocks. K-Ar dates from sericite in gold-silver-bearing white quartz veins indicate that mineralization occurred in the Early Cretaceous at about 130 Ma. Thus, these veins predate the mid-Cretaceous Cassiar batholith and Lower Cretaceous and Early Tertiary plutons in the immediate area. However, the Early Cretaceous date probably represents a thermal event, precursor to emplacement of the Cassiar batholith, which may have caused circulation of the meteoric fluids responsible for the veins.

Rocks within the Erickson mine were affected by four types of alteration: synvolcanic hydrothermal, regional metamorphic, epigenetic hydrothermal and contact metamorphic. The most common type is epigenetic carbonatization of basalt, which occurs as well-developed envelopes around gold-silver-bearing white quartz veins and carbon veins. Dolomite veins are surrounded by similar carbonate alteration envelopes; these veins postdate white quartz veins and carbon veins. Disseminated and fracture-controlled carbon may be present around white quartz veins and carbon veins.

An idealized model of carbonate alteration envelopes is presented based on field observations and mineralogical studies.
Rocks within carbonate alteration envelopes are composed of ankerite, siderite, dolomite, quartz, sericite, kaolinite, pyrite, carbon and minor titanium oxides. A generalized model of mineral species distribution throughout the envelopes around white quartz veins, carbon veins and dolomite veins was also developed.

Mass balance calculations, using Gresens' (1967) metasomatic equation, indicate the following compositional changes around a gold-silver-bearing white quartz vein: gain of $K_2O$ and $SiO_2$; loss of $Na_2O$, $Fe_2O_3$, and $MgO$; loss of $CaO$ from the outer portion of the envelope and gain in the inner. Loss on ignition and the alteration mineral assemblage indicate gain of at least $CO_2$, $H_2O$ and $S$.

Geochemistry of carbonate alteration envelopes was investigated using an aqua regia digestion with multi-element inductively coupled plasma (ICP) analyses and gold-silver fire assays. The ICP analyses were compared to X-ray fluorescence (XRF) analyses to determine the range of extraction and to assist in interpretation. The comparison indicates that if there is strong enrichment in carbonate alteration envelopes surrounding gold-silver-bearing white quartz veins, the ICP analyses will show these patterns well. Strong enrichment in potassium, barium, boron and arsenic, and sporadic enrichment in gold, silver, copper, lead, zinc and antimony occur in carbonatized basalt around gold-silver-bearing white quartz veins.
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CHAPTER 1. INTRODUCTION

1.1 LOCATION AND HISTORY

The Erickson mine is 12 kilometres southeast of Cassiar, British Columbia (Fig. 1; map sheet 104P/4; longitude 129 37'W; latitude 59 13'N). The mine is one of several gold producers in the McDame lode gold camp.

The McDame camp, which covers approximately 150 square km, was first known for its placer gold production. About 70,000 ounces of gold (2.40 million grams) were recovered; most of it during the late 1800's. Several operations still continue today. The largest nugget of gold ever recovered in British Columbia, 72 ounces (2,469 grams), came from this camp.

Exploration for lode gold deposits became significant only after the discovery of free gold in quartz in the 1930's. During the next forty years, only sporadic production was achieved from a few small deposits. In the 1970's, advanced exploration and development was performed by several companies. The first successful lode gold mining operation was that of the Agnes and Jennie Mining Co. and Nu-Energy Development Corp., later merged into Erickson Gold Mines Ltd., and currently known as Total Erickson Resources Ltd. of North Vancouver, B.C. Production commenced in late 1978 on the Jennie vein. An initial milling capacity of 100 tons per day was increased to 300 tons per day in 1984. Mill heads have averaged 0.43 ounces of gold per ton (14.7 grams/tonne) and 0.39 ounces of silver per ton (13.4 grams/tonne).
Figure 1. Location of the Erickson mine, north-central B.C
Total production to the end of 1985 was 149,082 ounces of gold (5.11 million grams) and 119,429 ounces of silver (4.09 million grams) from 370,818 tons (337,107 tonnes). Gold recovery has been 93%; silver 83%. The mill was shut down in late 1985 for renovations and was destroyed by fire in early 1986, prior to resuming operation. A new mill is planned on an adjacent site.

Other companies that have conducted advanced surface and underground development are Taurus Resources Ltd., Table Mountain Mines Ltd., Plaza Resources Ltd. and Cusac Industries Ltd., all of Vancouver, B.C. Erickson Gold Mines Ltd. took over Plaza Resources Ltd., gained control of Table Mountain Mines Ltd. and optioned Cusac Industries Ltd. in 1984. Taurus Resources Ltd. was operating at the end of 1985.

1.2 PURPOSE AND SCOPE OF STUDY

Gold-silver-bearing white quartz veins in the McDame gold camp are associated with carbonate alteration envelopes in mafic volcanic rocks. A study of carbonatized mafic volcanic rocks at the Erickson mine was conducted to investigate the nature of carbonate alteration, and to develop exploration guidelines for gold-silver-bearing white quartz veins using mineralogical and geochemical characteristics of carbonate alteration. All types of veins and alterations were documented to determine their relationships. Early fieldwork indicated that sericite-rich samples could be obtained to determine the age of mineralization;
consequently, a sampling program was undertaken for that purpose.

1.3 METHODOLOGY

Field work was performed during 1983 and 1984 while the author was employed by Erickson Gold Mines Ltd. The author gained familiarity with the geology of the Erickson mine and surrounding area through diamond drill core logging, underground mapping and surface mapping, prospecting and sampling.

Initially the study was directed towards documenting characteristics of all vein and alteration types in the mine, but subsequently focused on carbonatized mafic volcanic rocks spatially related to gold-silver-bearing white quartz veins. This detailed study began with the development of an ideal zoning model based on megascopic characteristics of carbonate alteration envelopes. A detailed systematic sampling program was undertaken to provide a basis for both mineralogical and geochemical studies of the alteration envelopes. Mass balance calculations using Gresens' (1967) metasomatic equation were done to estimate losses and gains of major oxides during carbonate metasomatism. These results assisted in understanding chemical reactions and processes by which metasomatism took place, and the geochemistry of carbonate alteration envelopes. Lastly, the geochemistry was investigated using an aqua regia digestion with inductively coupled plasma (ICP) analyses, X-ray fluorescence (XRF) analyses and gold-silver fire assays. The ICP analyses were compared to
XRF analyses to determine the range of extraction and to assist in interpretation.
CHAPTER 2. GEOLOGICAL SETTING

2.1 REGIONAL GEOLOGY

The Erickson mine is in the Sylvester Allochthon, an accreted Late Paleozoic to Early Mesozoic oceanic terrane (Fig. 2). The allochthon was emplaced onto autochthonous rocks of the North American miogeocline after the Triassic and prior to the mid-Cretaceous; later it was intruded by mid- to Late Cretaceous quartz monzonite of the Cassiar Complex (Tempelman-Kluit, 1979; Gabrielse and Mansy, 1980; Gordey et al., 1982; Harms, 1984, 1985A and 1985B; M.J. Orchard and K.M. Dawson, written communication, 1986). The geology of the central part of the allochthon, the underlying autochthonous rocks and quartz monzonite intrusions was reviewed first by Gabrielse (1963). Later work by Diakow and Panteleyev (1981), Panteleyev and Diakow (1982) and Gordey et al. (1982) involved similar rocks in the vicinity of the Erickson mine. A generalized geological map of the Cassiar area is presented in Figure 3.

Autochthonous rocks of the North American miogeocline include a conformable shelf assemblage of Precambrian to Late Paleozoic sedimentary rocks. The Sylvester Allochthon consists of volcanic, sedimentary and ultramafic rocks of the Mississippian to Triassic Sylvester Group.

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Figure 2. Geological setting of the Erickson mine (modified from Gordey et al., 1982).
Figure 3. Generalized geological map of the Cassiar area, north-central British Columbia (after Gabrielse, 1963 and Panteleyev, 1980).
2.2 MINESITE GEOLOGY

2.2.1 Introduction

In the vicinity of Erickson mine (Fig. 4), the Sylvester Allochthon is composed of two discrete fault-bounded assemblages, a lower and upper (Gordey et al., 1982). The lower assemblage consists of mafic volcanic, ultramafic and sedimentary rocks; the upper of sedimentary rocks. Both assemblages are intruded by post-vein mafic dykes. Quartz veins that contain the ore bodies at the Erickson mine are in the upper part of the lower assemblage. A summary of rock types is presented in Table I. A generalized cross-section of the mine illustrating the spatial relationships of the most common rock types and major veins is in Figure 5. Brief descriptions of rock types are provided below. Locations referred to in the descriptions are keyed in Figure 6.

2.2.2 Mafic Volcanic, Ultramafic and Sedimentary Rocks of the Lower Assemblage

Mafic volcanic rocks of the lower assemblage fall within the tholeiitic basalt field of the Jensen Cation Plot for subalkalic volcanic rocks (Jensen, 1976; Fig. 7). Basalt comprises about sixty-five percent of the rocks in the mine. Massive, rounded and cliff-forming surface exposures are dark green to black. Basalt is mostly massive or pillowed; less commonly pillow breccias were observed. Some basalt is sheared extensively as indicated by cataclastic textures. Constituent minerals of basalt

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Figure 4. Generalized geological map of the area surrounding the Erickson mine. See Figure 5 for cross-section A-A'. Mine workings; 1 = Cusac Industries mine, 2 = Table Mtn. mine, 3 to 8 = Vollaug vein open pits, 9 = Troutline mine, 10 and 11 = Newcoast Silver adits. Adapted from Erickson Gold Mines Ltd.'s map 1E, 1982.
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<th>ROCK TYPE</th>
<th>LITHOLOGY</th>
<th>OCCURRENCE</th>
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<tbody>
<tr>
<td>dyke</td>
<td>A. diabase</td>
<td>crosscuts all rocks in upper and lower assemblages; east-west trending, vertical and up to 15 metres thick; frequently parallels veins</td>
</tr>
<tr>
<td></td>
<td>B. biotite lamprophyre</td>
<td></td>
</tr>
<tr>
<td>upper</td>
<td>A. shale, argillite, siltstone, wacke</td>
<td>comprises all of upper assemblage in vicinity of mine</td>
</tr>
<tr>
<td>mafic</td>
<td>A. massive basalt</td>
<td>forms majority of lower assemblage within the mine; breccias uncommon and localized</td>
</tr>
<tr>
<td>volcanic</td>
<td>B. pillow breccia basalt</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C. pillow breccia basalt</td>
<td></td>
</tr>
<tr>
<td>ultramafic</td>
<td>A. serpentine</td>
<td>sill-like bodies hundreds of metres long and less than five metres thick</td>
</tr>
<tr>
<td></td>
<td>B. talc-breunerite</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C. quartz-breunerite-fuchsite</td>
<td></td>
</tr>
<tr>
<td>sedimentary</td>
<td>A. black to grey ribbon chert, siliceous argillite, shale</td>
<td>interbedded with basalt; exhalite is observed only east of the 21-03 drift</td>
</tr>
<tr>
<td></td>
<td>B. pale green to buff ribbon chert, shale</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C. massive white, pale-green, buff and red chert + magnetite (exhalite)</td>
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Figure 5. Generalized geological cross-section of the Erickson mine. Refer to Figure 4 for location of cross-section. Adapted from Erickson Gold Mines Ltd.'s cross-sections Maura 512, Jennie 108 and Bear 500, 1984.
Figure 7. A: Jensen Cation Plot (Jensen, 1976). B: Mafic volcanic rocks of the Sylvester Group fall within the tholeiitic basalt field. Analyses are tabulated in Appendix A (A = 80-88-JH-6; B = 80-88-JH-7; C = 82-212-MF-5; D = 82-212-MF-6; E = 83-257-DF-8; F = 83-257-DF-9).
include plagioclase with lesser chlorite, actinolite and epidote. Minor amounts of augite, calcite and titanium oxides are present also. Most veins occur within this rock type.

About ten percent of the rocks in Erickson mine are ultramafic rocks composed of varying amounts of serpentine, talc, breunerite, quartz and fuchsite. The serpentine and talc-rich rocks are recessive weathering; the breunerite and quartz-rich rocks commonly form low-rounded knobs. All types weather to varying shades of brown and green. Breunerite-rich rocks in particular weather orange-brown.

Altered ultramafic rocks occur as sill-like bodies hundreds of metres long and less than five metres thick, although thicknesses of up to sixty metres were noted locally. Within the mine, ultramafic rocks occur at the contact between the upper and lower assemblages and within the basalt between the 1,250 m and 1,350 m elevations. They are exposed on the 1280, 1350 and 1390 levels (Fig. 5). In the vicinity of the mine ultramafic rocks also occur as small discontinuous bodies.

The occurrence of ultramafic bodies within sheared rocks suggests that tectonic emplacement is likely. The protoliths of altered ultramafic rocks were not observed in the mine area, although according to Gabrielse (1963) peridotite, dunite and pyroxenite occur throughout the Sylvester Allochthon.

Sedimentary rocks of the lower assemblage occur as beds within the basalt; they form about twenty percent of the rocks in the mine. These rocks are composed of ribbon chert, siliceous argillite, shale and rare magnetite-rich siliceous exhalite.
Surface exposures are grey, buff and pale-green. Pale-green to buff ribbon chert and shale occur throughout the mine; grey to black ribbon chert, siliceous argillite, argillite and shale are well-exposed in the footwall of the Alison vein on the 1210 and 1280 levels (Fig. 5). The exhalite was noted only in drill holes 50 metres east of the 21-05 drift (Fig. 6) at the 1,180 m elevation.

Cherty and siliceous sedimentary rocks are composed of interlocking silica grains with minor clay, chlorite and carbon. Disseminated carbonate, pyrite and titanium oxides are present locally. Argillaceous sedimentary rocks are composed of quartz and clay with some chlorite, carbon, carbonate, pyrite and titanium oxides.

Exhalite consists of white, pale-green, buff and red chert that contains abundant magnetite locally. The magnetite occurs in the lower portion as disseminations, wispy layers and laminations. Carbonatized chert fragments occur in the laminated magnetite.

2.2.3 Sedimentary Rocks of the Upper Assemblage

Sedimentary rocks of the upper assemblage are composed of black shale and argillite, brown to black siltstone and wacke and minor black limestone. Black shale and argillite are locally carbon-rich. Ripple marks and cross-bedding were observed in some siltstone and wacke beds. Sedimentary rocks of the upper
assemblage form small cliffs and rounded hills with dark grey to brown talus on top of Table Mountain (Fig. 4).

2.2.4 Diabase and Lamprophyre Dykes

Diabase and biotite lamprophyre dykes are the youngest rocks observed in the mine; they form approximately five percent of all rocks. Similar biotite lamprophyre dykes six km south of Erickson mine were dated at $110^{\pm}4$ Ma (A. Panteleyev, personal communication, 1985). Surface exposures weather brown and are friable. The dykes are easterly trending, vertical and up to fifteen metres thick. Good exposures were observed in the main 1210 and 1280 levels (Fig. 5). A single diabase sill, one to three metres thick, trending north-northeastly and dipping moderately to the west, occurs in the 21-10 drift (Fig. 6).

Diabase dykes are fine to medium grained, massive, speckled light-grey, dark-green to black and have chilled margins. Amygdules up to one-half centimetre in diameter are locally common near the margins. Diabase is ophitic and composed of plagioclase and augite with trace amounts of titanium oxides, apatite, pyrite and pyrrhotite. Minor biotite, chlorite, ankerite and sericite are present locally.

Biotite lamprophyre dykes are fine to medium grained, massive dark-brown to dark-green and have chilled margins. Some xenoliths of granitic rock were observed in one locality on the east flank of Table Mountain. Biotite lamprophyre dykes are
composed of coarse-grained biotite in a groundmass of biotite and plagioclase with trace amounts of apatite, titanium oxides and magnetite. Chlorite, carbonate, sericite and epidote were noted locally.

2.3 STRUCTURE

The structure of the Sylvester Allochthon was reviewed by Gordy et al. (1982) and Harms (1984 and 1985). Their work indicates that the allochthon is a mildly deformed, flat, imbricated sheet preserved in a broad synclinorium. According to Harms (1984), the allochthon is composed of "a stack of structurally interleaved fault-bounded slices of an order of magnitude smaller than the terrane itself...each slice may consist of one lithology...or a few related or repeated lithologies". In the vicinity of the Erickson mine, two discrete fault-bounded assemblages, an upper and a lower, are observed (Gordy et al, 1982). Within each of these shear zones are locally common.

Two, possibly three, folding events are recognized in the vicinity of the Erickson mine (Panteleyev and Diakow, 1982). The mine is within a locally developed, shallow, northwesterly trending synclinal basin (R. Somerville, personal communication, 1986) situated in north to northeasterly shallow to moderate dipping rocks. The Jennie, Maura, Alison and Caitlin veins are on the southern limb of the basin; the McDame, Dease, Devine,
Bear and Goldie are on the northern limb (Fig. 5).

Faults are common throughout the Erickson mine and its vicinity. Northerly trending steep lateral faults, some with offsets of over 500 metres, predominate (Fig. 4). Easterly trending steep normal faults with smaller offsets are less common. Easterly to northeasterly trending, steep to shallow dipping faults that control the major veins were also noted.
CHAPTER 3. VEINS

3.1 INTRODUCTION

Gold-silver mineralization at the Erickson mine occurs in clear quartz within white quartz veins. Characteristics of white quartz veins were summarized by Mandy (1935 and 1937), Diakow and Panteleyev (1981) and Panteleyev and Diakow (1982). In addition, Grant (1981), Fjeltdal (1982), Hooper (1984) and Dussell (1986) examined the mineralogy of white and clear quartz veins. White quartz and clear quartz veins, carbon veins, dolomite veins, pyrite veins, white calcite and clear calcite veins were observed in the Erickson mine and are described below. A summary of vein mineralogy and associated alteration is provided in Table II. The locations of major veins in the Erickson mine are presented in Figures 5 and 8.

3.2 QUARTZ VEINS

White quartz veins are the most common type throughout the Erickson mine. Most occur in basalt but a few are in ultramafic and sedimentary rocks.

Within basalt, most white quartz veins trend easterly to northeasterly and have steep to moderate northern or southern dips. Most veins are uniform in width, ranging from a few centimetres to over six metres, but some pinch and swell or
### TABLE II

Vein type, mineralogy and associated alteration

<table>
<thead>
<tr>
<th>TYPE</th>
<th>MINERALOGY&lt;sup&gt;a&lt;/sup&gt;</th>
<th>HOSTS</th>
<th>ALTERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>white quartz</td>
<td>white macrocrystalline quartz, ankerite + carbon + pyrite + sphalerite + sericite + clay + titanium oxides</td>
<td>basalt, chert, argillite, shale, serpentinite</td>
<td>carbonatization  silicification</td>
</tr>
<tr>
<td>clear quartz</td>
<td>clear microcrystalline quartz + carbonate + pyrite + sphalerite + tetrahedrite + chalcopyrite + gold + galena + arsenopyrite + carbon</td>
<td>white quartz, dolomite, basalt</td>
<td>carbonatization  silicification</td>
</tr>
<tr>
<td>carbon</td>
<td>carbon, white quartz, ankerite, + pyrite</td>
<td>basalt</td>
<td>carbonatization</td>
</tr>
<tr>
<td>dolomite</td>
<td>dolomite, clear quartz + fine-grained pyrite</td>
<td>basalt</td>
<td>carbonatization</td>
</tr>
<tr>
<td>pyrite</td>
<td>fine-grained pyrite</td>
<td>basalt, layered dolomite</td>
<td>carbonatization</td>
</tr>
<tr>
<td>white calcite</td>
<td>white calcite + clear quartz</td>
<td>basalt, diabase and lamprophyre dykes</td>
<td>argillization</td>
</tr>
<tr>
<td>clear calcite</td>
<td>clear calcite</td>
<td>basalt</td>
<td>----</td>
</tr>
</tbody>
</table>

<sup>a</sup> Opaque mineralogy for white quartz and clear quartz is from Dussell (1986).
Figure 8. Composite plan map of the Erickson mine main levels with locations and attitude of major veins. See Figures 4 and 5 for details of cross-section A-A'.
split. Large veins may persist for hundreds of metres along strike and then terminate by pinching or horsetailing; downdip, the extent has not yet been determined. A moderate to steep westward plunge was noted in the veins and ore shoots, and slickensides along the margins of veins. En echelon tension gash veins were noted in the hanging wall and footwall of large veins. One of the major veins in the mine, Jennie vein, is cymoid because of deflection at the volcanic-sedimentary contact of the upper and lower assemblages (Fig. 9).

Carbonatization of basalt, occurring as well-developed envelopes around white quartz veins, is the most common type of alteration (Plate 1). Silicification of basalt, although uncommon, is noteworthy. Silicification also occurs around quartz veins in siliceous sedimentary rocks. An alteration assemblage of talc, breunerite, quartz and fuchsite is associated with white quartz veins in ultramafic rocks.

White quartz veins are composed of white macrocrystalline quartz with minor ankerite, clots of white to pale-green sericite and white clay. Inclusions of altered wall rock are locally common. An irregular network of limonitic fractures is also locally common. Fracturing, brecciation and flooding of the white quartz by clear microcrystalline quartz impart a white and grey mottled texture. In addition, clear quartz veins less than one cm thick, with minor carbonate and rare carbon, crosscut white quartz veins (Plate 2).

Alison, Maura, and parts of Jennie vein contain carbon-rich layers composed of clay, ankerite, quartz, carbon, pyrite and
Plate 1. Outcrop of basalt with white quartz vein and carbonate alteration envelope, in road cut on Highway 37 near entrance to mine. Note characteristic orange-brown weathering of carbonatized basalt.
Plate 2. Close-up view of contact between white quartz vein (Wh Qtz) and carbon vein (Cbn Vn). Sketch interpreting plate is in the inset in lower left corner of Figure 10. Note brecciation and flooding of the white quartz by clear quartz (Bx), layered and brecciated nature of carbon vein, late cross-cutting clear quartz-carbonate-carbon veins (Cl Qtz-Cbnt-Cbn Vn) and offset contacts.
iron-titanium oxides (Plates 3 and 4). The carbon-rich layers generally parallel vein margins and may extend for several metres along strike. They vary from thin layers, locally with stylolitic form, to layers and lenses up to several centimetres thick.

White quartz contains only minor pyrite and sphalerite. Three generations of clear quartz occur in the mine. Most of the mineralization, consisting of pyrite, tetrahedrite, spalerite, chalcopyrite and gold, occurs in the first generation of clear quartz within white quartz veins. Galena and arsenopyrite are rare. Second generation clear quartz contains only minor pyrite; the third appears barren (Dussell, 1986).

Paragenetic studies by Grant (1981), Fjetland (1982), Hooper (1984) and Dussell (1986) indicate the following general sequence of deposition: arsenopyrite, pyrite, galena, sphalerite, tetrahedrite and chalcopyrite. They found gold as inclusions and fracture fillings replacing pyrite, and less commonly sphalerite, chalcopyrite and tetrahedrite.

Measurement of homogenization temperatures by Hooper (1984) in primary fluid inclusions in clear quartz within white quartz veins, gave a mean temperature of 278 ±10 °C. According to Hooper (1984) "Panteleyev obtained similar homogenization temperatures ...from a suite of samples throughout the Erickson Gold Camp.... which resulted in a mean homogenization temperature of 264 ±1 °C". A representative homogenization temperature of 285 °C was selected by Dussell (1986) from measurements on primary fluid inclusions in the first and second generations of clear quartz. Based on an
Plate 3. Underground exposure of the Alison vein, 21-20 drift (Fig. 6). Note black carbon-rich layers (near hammer).
Plate 4. Close-up view of carbon-rich layers (Cbn-rich Lay), Alison vein (Qtz = quartz). Note varying thickness of layers and stylolitic forms in thinner examples. Tetrahedrite (Tt) and pyrite (Py) are also present.
arbitrarily assumed load pressure of 625 atms, Dussell determined that the temperature of entrapment would have been 350°C.

Gold-silver-bearing white quartz veins occur throughout the McDame gold camp. South of the Erickson mine, veins occur along and near the contact of the upper and lower assemblages (Fig. 4). North of the Erickson mine, they occur in mafic volcanic rocks as a series of easterly to northeasterly trending veins that include the Taurus mine (Fig. 3).

3.3 CARBON VEINS

Carbon veins were observed only in basalt next to white quartz veins containing carbon-rich layers. They are locally common adjacent to the margins of the Alison vein, and less so the Maura vein. The best-known exposure is next to the margin of the Alison vein, where the carbon vein is up to several metres thick and can be traced for at least ten metres along strike (Fig 10; Plate 5).

Carbon veins are associated with carbon-rich carbonatized basalt. Contacts of the veins with basalt are sharp (Plates 5 and 6). Carbon veins are sheared commonly along contacts with white quartz veins as indicated by well-developed slickensides and friability. Contacts between carbon veins and white quartz veins are sharp and offset locally by late clear quartz-carbonate-carbon veins. The crosscutting veins within carbon veins mostly occur as breccia zones or open spaces with clear
Figure 10. Geological relationships of carbon veins to the Alison vein and the wall rock in 28-17 drift (Fig. 6). The contact between white quartz and carbon veins, with cross-cutting clear quartz-carbonate-carbon veins, in the inset in the lower left corner is also shown in Plate 2. The cross-cutting nature of the carbon vein in the lower right corner of the diagram is also shown in Plate 5. A close-up view of contact between a carbon vein and carbon-rich carbonatized basalt is shown in Plate 6.
Plate 5. Underground exposure of a carbon vein within carbon-rich carbonatized basalt, in the footwall of the Alison vein, 28-17 drift (Fig. 6). Note the sharp contacts. A close-up view of the lower contact is shown in Plate 6. Sketch interpreting plate is in Figure 10.
Plate 6. Close-up view of contact (arrows) between carbon vein (Cbn Vn) and carbon-rich carbonatized basalt (Cbn-rich Cbnt Bas). Note white quartz vein within carbon vein.
drusy quartz (Plate 2).

Carbon veins are black, fine to coarse-grained and massive; however, local layering due to grain size was noted parallel to contacts (Plate 2). White quartz is locally common as blebs and stringers within the carbon veins (Plate 6). Carbon veins are composed of 50 to 90 percent carbon, 15 to 45 percent quartz, up to 5 percent ankerite and traces of pyrite. A weak diffraction pattern obtained for the carbon indicates a poorly crystalline structure.

Microscopically, carbon veins resemble a breccia composed of discrete angular fragments of carbon, up to 1.0 mm, in a matrix of granular quartz and ankerite (Plate 7). Disseminations and fracture fillings of fine-grained anhedral pyrite were observed locally within carbon fragments. Fragments are matrix-supported and up to 1.0 mm apart. Small irregularly-shaped voids are locally common within the matrix.

Geological age relationships between carbon veins and white quartz veins are complex. Carbon veins and quartz stringers within them parallel major white quartz veins. Carbon-rich layers within major white quartz veins also parallel contacts of these veins. Some carbon veins crosscut white quartz stringers in basalt. In some carbonate alteration envelopes, fracture-controlled carbon crosscuts emerald-green porphyroblast-like aggregates.
Plate 7. Photomicrograph of carbon vein. Note angular fragments of carbon (Cbn) in matrix of quartz and ankerite (Qtz-Ank). Irregular dark areas are voids (Vd).
3.5 DOLOMITE VEINS

Dolomite veins postdate white quartz veins and are only locally common in the Erickson mine. Dolomite veins trend easterly to northeasterly, are steeply dipping and less than half a metre thick. However, within and near the 21-06 and 21-11 drifts (Fig. 6), the McDame dolomite vein attains a thickness of 10 metres and persists for 160 metres along strike.

Dolomite veins are composed of white to creamy dolomite with minor clear quartz and fine-grained pyrite. Colloform and thin wavy banded textures are characteristic of dolomite veins. These textures are disrupted by fractures and breccia zones filled with dolomite, clear quartz or pyrite (Plate 8).

Well-developed carbonate alteration envelopes surround dolomite veins in basalt. Clear quartz veins with associated carbonatization and silicification, and pyrite veins with associated carbonatization were observed rarely in basalt around McDame vein.

3.5 CALCITE VEINS

White calcite veins up to 10 cm thick, nearly vertical and easterly trending, are locally common throughout the Erickson mine. Argillization of basalt and dykes is associated with these veins. White calcite veins are composed of calcite that contains some clear quartz.
Plate 8. Underground exposure of a portion of the McDame dolomite vein, 1210 crosscut near 21-06 drift (Fig. 6). The footwall contact is visible on the left side of the photograph (banding to breccia). Note colloform and thin wavy banded textures and brecciated areas with clear quartz matrix within vein (right side of the photograph)
Uncommon vuggy clear calcite veins, less than 5 cm thick, occur in basalt throughout the Erickson mine. Alteration was not apparent around these veins.
CHAPTER 4. AGE OF GOLD-SILVER MINERALIZATION

4.1 INTRODUCTION

Gold-silver-bearing white quartz veins in the Cassiar area generally have been considered by workers in the area to be related to nearby mid- to Late Cretaceous and Early Tertiary plutons. K-Ar dates range from 89 to 109 Ma for the Cassiar batholith (Baadsgard et al., 1961; Lowdon, 1961; Wanless et al., 1970, 1972 and 1978; A. Panteleyev, personal communication, 1985), 69.3 to 76.5 Ma for the Cassiar stock and related intrusions (Christopher, 1972; Panteleyev, 1980; Cooke and Godwin, 1984; A. Panteleyev, personal communication, 1985) and 48.8 to 51.4 Ma for the Mt. Reed and Mt. Haskin stocks (Christopher, 1972). Location of these plutons are in Figure 3. The Cassiar batholith was dated also by a Rb-Sr whole rock isochron with a model age of 111 Ma (R.L. Armstrong, personal communication, 1985). An Early Cretaceous age for the gold-silver mineralization was first indicated by Panteleyev and Diakow (1982) who obtained a single K-Ar date of 131±5 Ma for a sample of white mica from a tourmaline-bearing auriferous quartz vein in the Snowy Creek area (Fig. 3). Data for the the Cassiar area are summarized in Figure 11. All model ages listed are derived using decay constants recommended by Steiger and Jager (1977).

Geology of the Cassiar area is summarized in Figure 3. Gold-silver-bearing white quartz veins of the area are within Upper Paleozoic and Lower Mesozoic volcanic, sedimentary and ultramafic
using the decay constants recommended by Stutzer and Jasper, 1977.

Figure II. Histogram of K-Ar model ages for granitic rocks, dyke rock and quartz veins in the Cassiar area. See text for specific references on dates used. Dates were calculated (this study) quartz veins (Cook), granitic rocks (Christopher), granitic rocks (Panatellar), dyke rock (Panatellar), quartz veins.

K-Ar Dates - Cassiar Area

<table>
<thead>
<tr>
<th>Age (Ma)</th>
<th>Mt. Reed and Mt. Haskins stocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-45</td>
<td></td>
</tr>
<tr>
<td>45-65</td>
<td></td>
</tr>
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<td>65-85</td>
<td></td>
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<td>85-95</td>
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<td>95-105</td>
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<td>105-115</td>
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</tr>
<tr>
<td>115-125</td>
<td></td>
</tr>
<tr>
<td>125-135</td>
<td></td>
</tr>
</tbody>
</table>

quartz vein

vein and dyke

Cassiar batholith

Cassiar stock and related intrusions

Mt. Reed and Mt. Haskins stocks

NUMBER OF AGES

Isotopic dating of the gold-silver-bearing white quartz veins had been hampered because of the difficulty in locating adequate amounts of sericite in the veins. However, while sampling systematically for a wall rock alteration study during the field seasons of 1983 and 1984, the author found locally abundant sericite in gold-silver-bearing white quartz veins and altered wall rock. Some of these sericite occurrences were sampled for K-Ar dating to test the validity of the 131 Ma model age obtained by Panteleyev and Diakow (1982) and to compare the age of mineralization with established igneous events.

4.2 SAMPLING AND ANALYTICAL RESULTS

Rock samples with sericite were collected from more than fifteen sites. All sites are in and near either the Erickson mine or the Taurus mine (Fig. 3). Weathered samples and those that may not be related to gold-silver-bearing white quartz veins were rejected for dating. The four samples from gold-silver-bearing white quartz veins that were selected for K-Ar dating are described in Appendix A; markedly green fuchsitic sericite was not included. Analytical results and model ages are in Table III. Ages from Table III are compared to previous work in the area in Figure 11.
TABLE III

Analytical data\(^a\) and \(^{39}\)Ar dates for sericite in gold-silver-bearing white quartz veins, Cassiar area, north-central British Columbia. Samples are located in Figure 3 and described in the Appendix.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Location</th>
<th>(%K+q)</th>
<th>(^{40})Ar(rad)(^c)</th>
<th>(^{40})Ar(total) ((10^{-5} \text{cm}^3 \text{STP/g}))</th>
<th>Date</th>
<th>Time(^e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>83-146</td>
<td>Erickson mine</td>
<td>8.36±0.02</td>
<td>0.968</td>
<td>4.114</td>
<td>122±4</td>
<td>Early Cretaceous</td>
</tr>
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<td>sericite</td>
<td>Lat. 59°13'40&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>83-188</td>
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<td>0.951</td>
<td>4.248</td>
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<td>Early Cretaceous</td>
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<td></td>
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<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>83-250</td>
<td>Erickson mine</td>
<td>2.86±0.04</td>
<td>0.916</td>
<td>1.282</td>
<td>112±4</td>
<td>Early Cretaceous</td>
</tr>
<tr>
<td>sericite</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Long. 129°40'15&quot;</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>83-316</td>
<td>Taurus mine</td>
<td>6.72±0.07</td>
<td>0.954</td>
<td>3.716</td>
<td>137±5</td>
<td>Early Cretaceous</td>
</tr>
<tr>
<td>sericite</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80AP160(^f)</td>
<td>Snowy Creek</td>
<td>8.58±0.06</td>
<td>0.849</td>
<td>4.541</td>
<td>131±5</td>
<td>Early Cretaceous</td>
</tr>
<tr>
<td>sericite</td>
<td>Lat. 59°17'00&quot;</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
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<td>Long. 129°40'00&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) All analyses were done in the Geochronology Laboratory, Department of Geological Sciences, U.B.C. Mineral separates and potassium analyses were by K. Scott; Argon analyses were by J. Harakal.

\(^b\) One half range of difference between duplicate analyses.

\(^c\) \(^{40}\)Ar(rad) is radiogenic.

\(^d\) Constants used in calculations (Steiger and Jäger, 1977): \(\lambda_e=0.581\times10^{-10}\ \text{year}^{-1}\), \(\lambda_B=4.960\times10^{-10}\ \text{year}^{-1}\), \(^{40}\)K/\(^{39}\)K=1.167\times10^{-4} \text{atom ratio. Dates have estimated one sigma errors.}

\(^e\) Time designation is after Armstrong (1978).

\(^f\) Data from Panteleyev and Dikow (1982).
4.3 DISCUSSION

K-Ar model ages for gold-silver-bearing white quartz veins range from 112 to 137 Ma (Table III). However, four of the five model ages cluster and yield a mean date of 129±4 Ma (Fig. 11). Two different events at 129 Ma, and at 112 Ma, are indicated and examined below.

The mean age of four samples from the gold-silver-bearing white quartz veins of 129±4 Ma coincides with a magmatic lull that existed in the Canadian Cordillera at that time (Armstrong, 1986). Thus, no evidence exists that relates the mineralization at Cassiar to a known magmatic event. The oldest K-Ar date obtained for the Cassiar batholith is 109±5 Ma (Wanless et al., 1978); the Rb-Sr whole rock age is 111 Ma. The youngest probable age for the mineralizing event is 122 Ma. Therefore, the gold-silver-bearing white quartz veins predate the Cassiar batholith by at least 11 Ma. This suggests that the heat source for circulating fluids responsible for the gold-silver mineralization might have been an event that was a thermal precursor to the emplacement of the Cassiar batholith. Alternatively the mineralization may be related to emplacement of the Sylvester Allochthon. Based on isotopic evidence, Nesbitt et al. (1986) proposed that the veins "formed from deep circulation of meteoric water in major fault zones".

The 112±4 Ma date (Appendix A: sample 83-250) is reasonably excluded from the age of gold-silver mineralization because its model age coincides with the igneous event of the Cassiar
batholith suggesting resetting or alteration of the sample; an anomalously low potassium content (Table I) coincidently makes the sample suspect. Biotite lamprophyre dykes from six km south of the Erickson mine were dated at 110±4 Ma (A. Panteleyev personal communication, 1985). Similar dykes in the Erickson mine may have thermally reset the sericite at 112 Ma.
CHAPTER 5. ROCK ALTERATION

5.1 INTRODUCTION

Alteration at the Erickson mine is of four main types: synvolcanic hydrothermal, regional metamorphic, epigenetic hydrothermal and contact metamorphic. Alteration types are illustrated in Figure 12, summarized in Table IV and described individually below.

5.2 SYNVOLCANIC HYDROTHERMAL ALTERATION

Synvolcanic hydrothermal alteration within the Erickson mine was noted only 50 m east of the 21-05 drift, at 1,180 m elevation. The alteration occurs within basalt immediately underlying magnetite-bearing siliceous exhalite, and extends up to 35 metres below the exhalite-basalt contact.

Basalt that has undergone synvolcanic hydrothermal alteration is characterized by an anastomosing pattern of nearly-vertical hairline fractures, three to five cm apart, filled with chlorite and calcite. The fractures are surrounded by up to one cm wide selvages of epidotized rock. If fractures are absent and pillow interstices common, basalt is epidotized pervasively and crosscut by irregular veinlets of epidote and calcite. Hematite commonly occurs with chloritized augite phenocrysts and along fractures in epidotized rocks. Chlorite and minor calcite, quartz, epidote,
Figure 12. Sketches illustrating alteration types at the Erickson mine.
### TABLE IV

Alteration mineral assemblages classified according to alteration type (Fig. 12) and host lithology

<table>
<thead>
<tr>
<th>HOST LITHOLOGY</th>
<th>BASALT</th>
<th>PERIDOTITE, DUNITE AND PYROXENITE</th>
<th>RIBBON CHERT, ARGILLITE AND SHALE</th>
<th>DIABASE AND LAMPROPHYRE DYKES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SYNOLGICAN HYDROTHERMAL</strong></td>
<td>plagioclase, epidote, chlorite, calcite, Ti-oxide, hematite + quartz + pyrite + magnetite + chlorite</td>
<td>plagioclase, epidote, chlorite, calcite, Ti-oxide, hematite + quartz + pyrite + magnetite + chlorite</td>
<td>plagioclase, epidote, chlorite, calcite, Ti-oxide, hematite + quartz + pyrite + magnetite + chlorite</td>
<td>plagioclase, epidote, chlorite, calcite, Ti-oxide, hematite + quartz + pyrite + magnetite + chlorite</td>
</tr>
<tr>
<td><strong>REGIONAL METAMORPHIC</strong></td>
<td>plagioclase, epidote, chlorite, actinolite, calcite, Ti-oxide, hematite + quartz + pyrite + magnetite + chlorite</td>
<td>serpentine + talc, + chromite + magnetite + pyrrhotite</td>
<td>quartz, clay + chlorite + carbon + carbonate + pyrite + Ti-oxides</td>
<td>quartz, clay + chlorite + carbon + carbonate + pyrite + Ti-oxides</td>
</tr>
<tr>
<td><strong>EPGENETIC HYDROTHERMAL</strong></td>
<td>ankerite, siderite, quartz, sericite, Ti-oxide + kaolinite dolomite + pyrite + carbon + arsenopyrite + plagioclase</td>
<td>breunerite + talc, + quartz + fuchsite + chromite + pyrite + chalcopyrite + pyrrhotite + carbon</td>
<td>quartz, carbon, pyrite, carbon + kaolinite + Ti-oxides + arsenopyrite</td>
<td>quartz, carbon, pyrite, carbon + kaolinite + Ti-oxides + arsenopyrite</td>
</tr>
<tr>
<td><strong>SILIFICATION</strong></td>
<td>quartz, ankerite, siderite, sericite, Ti-oxide + pyrite, carbon</td>
<td>quartz, ankerite, siderite, sericite, Ti-oxide + pyrite, carbon</td>
<td>quartz, ankerite, siderite, sericite, Ti-oxide + pyrite, carbon</td>
<td>quartz, ankerite, siderite, sericite, Ti-oxide + pyrite, carbon</td>
</tr>
<tr>
<td><strong>ARGILLIZATION</strong></td>
<td>montmorillonite, chlorite, calcite, quartz, plagioclase kaolinite, pyrite, ankerite, Ti-oxides</td>
<td>montmorillonite, chlorite, calcite, quartz, plagioclase kaolinite, pyrite, ankerite, Ti-oxides</td>
<td>montmorillonite, chlorite, calcite, quartz, plagioclase kaolinite, pyrite, ankerite, Ti-oxides</td>
<td>montmorillonite, chlorite, calcite, quartz, plagioclase kaolinite, pyrite, ankerite, Ti-oxides</td>
</tr>
<tr>
<td><strong>CONTACT METAMORPHIC</strong></td>
<td>actinolite, epidote, plagioclase, carbonate, chlorite, quartz, pyrite, Ti-oxides + andradite</td>
<td>actinolite, epidote, plagioclase, carbonate, chlorite, quartz, pyrite, Ti-oxides + andradite</td>
<td>actinolite, epidote, plagioclase, carbonate, chlorite, quartz, pyrite, Ti-oxides + andradite</td>
<td>actinolite, epidote, plagioclase, carbonate, chlorite, quartz, pyrite, Ti-oxides + andradite</td>
</tr>
</tbody>
</table>
pyrite and hematite, and uncommon magnetite and chalcopyrite were noted in pillow interstices.

Synvolcanic hydrothermal alteration at the Erickson mine may be more extensive than recognized because it is not easily distinguished from a similar mineral assemblage developed during regional metamorphism.

5.3 REGIONAL METAMORPHIC ALTERATION

Regional metamorphism at the Erickson mine is of upper greenschist facies as indicated by the mineral assemblage of albite, chlorite, epidote, actinolite and calcite developed in basalt (Gabrielse, 1963). Shearing is common in the rocks; foliation absent.

Ultramafic rocks in the Erickson mine, originally peridotite, dunite and pyroxenite (Gabrielse, 1963), are extensively altered to serpentinite. Serpentinization is related to regional metamorphism or possibly other hydration processes.

Effects of regional metamorphism are less pronounced in sedimentary rocks. Recrystallization is locally common in siliceous rocks. A weak foliation is present in some rocks.
5.4 EPIGENETIC HYDROTHERMAL ALTERATION

5.4.1 Carbonatization in Basalt

Pervasive carbonatization of basalt occurs as well-developed envelopes around white quartz veins, carbon veins and dolomite veins. Most carbonate alteration envelopes extend less than fifteen metres from vein margins, although some may be up to forty metres wide. Carbonatized basalt is a buff to pale grey, fine-grained rock composed of varying amounts of ankerite, siderite, dolomite, quartz, sericite and kaolinite with minor pyrite and titanium oxides.

Pervasively disseminated carbon occurs in carbonate alteration envelopes around carbon veins and some white quartz veins, particularly those with carbon-rich layers. Carbon occurs rarely in the outer part of the carbonate alteration envelopes and noncarbonatized basalt.

Fracture-controlled carbon is characterized by an irregular network of black hairline fractures that impart a "crackled" texture to the rocks. Fine-grained carbon occurs in and around fractures that are most common in the inner portion of carbonate alteration envelopes. However, some fractures extend into the outer portion of the envelope and into noncarbonatized basalt.
5.4.2 Silicification of Basalt

Silicification of basalt is restricted to carbonate alteration envelopes surrounding white quartz veins. Flat zones of silicification occur above the Maura and Bear veins (R. Somerville, personal communication, 1986). Quartz occurs as veinlets and as blebs mixed with fine-grained quartz, carbonate and sericite. Carbonatized basalt rarely contains small breccia zones with clasts almost totally replaced by quartz.

5.4.3 Argillization of Basalt

Argillization of basalt occurs as envelopes, up to one metre wide, around locally common white calcite veins. Argillization was also noted adjacent to faults and fractures where white calcite veins were not apparent. Argillized basalt is a pale-green, friable rock composed of fine-grained montmorillonite and chlorite with minor calcite, quartz, plagioclase, kaolinite, pyrite, ankerite and titanium oxides. Argillized basalt swells up to several times its original volume when exposed to moisture.

5.4.4 Alteration of Ultramafic Rocks

Ultramafic rocks in the Erickson mine are altered to serpentine, talc, breunerite, quartz and fuchsite; such rocks are
known as listwanites (Boyle, 1979). Serpentinite, the most common rock type, is probably related to regional metamorphism of dunite, peridotite and pyroxenite. Epigenetic hydrothermal alteration of serpentinite near white quartz veins produced talc-breunerite and quartz-breunerite-fuchsite-bearing rocks. Fuchsitic alteration adjacent to white quartz veins grades into talcose rocks, and then to serpentinite progressively away from veins. This zoning was observed at the end of the 28-03 drift and along the 28-07 drift (Fig. 6). Dussell (1986) examined this zoning in detail.

Serpentinite is a dark green to black rock composed of serpentine and minor amounts of talc, chromite, magnetite and pyrrhotite. In the 28-03 drift (Fig. 6), small clasts of epidotized basalt were observed in serpentinite. Shears and sinuous slickensides subparallel to contacts are abundant. Talcose alteration may occur along contacts and slickensided surfaces. Small talc veinlets are present locally.

Talc-breunerite-bearing rocks are creamy, grey, brown, medium grained and massive to well-layered. Layering is due to variation in mineralogy, grain size and colour. These rocks are composed of talc and breunerite. Minor quartz may be present. Disseminated chromite may be present imparting a speckled appearance to the rock. Although uncommon, carbon may be present also.

Quartz-breunerite-fuchsite-bearing rocks are less abundant than talc-breunerite-bearing rocks. Quartz-breunerite-fuchsite-bearing rocks are massive to well-layered, mottled emerald-green
to cream, grey and brown. Layering is due to variation in mineralogy, grain size and colour. These rocks are composed of varying amounts of quartz and breunerite with minor fuchsite and trace amounts of chromite. Although uncommon, carbon may be present also. Less commonly, some rocks are composed of clear quartz, and lesser breunerite, pyrite and fuchsite with traces of chromite, chalcopryite and pyrrhotite.

5.4.5 Silicification of Chert and Siliceous Argillite

Silicification of chert and siliceous argillite was observed around quartz veins in drill holes between the 21-03 and 21-09 drifts (Fig. 5). This type of alteration is marked by colour changes, recrystallization and obliteration of "crackled" texture, bedding and carbonate concretions. Silicification is patchy or pervasive and may extend up to several metres from the veins. In drill hole 82-222, 15 metres east of the 21-03 drift (Fig. 6, Appendix D), 30 metres of rock with abundant silicification was intersected.

Silicification of chert and siliceous argillite imparts a mottled white to pale-grey colour to the rocks. In rare cases these rocks have carbon-rich stylolites. Silicified rocks are composed dominantly of interlocking coarse-grained quartz. Minor clay, chlorite, carbonate, pyrite, titanium-oxides and arsenopyrite are present locally.
5.4.6 Argillization of Diabase and Lamprophyre Dykes

Argillization of diabase was observed in the main 1210 and 1280 crosscuts (Fig. 6). It forms well-developed envelopes up to several metres wide around white calcite veins. Argillization was noted also around fractures parallel to the margins of diabase dykes. Only minor argillization of lamprophyre dykes was noted.

Argillized diabase is composed of kaolinite, ankerite, siderite and quartz with trace amounts of titanium oxides and apatite. Disseminated pyrite is present in variable amounts; sheet-like concentrations were observed parallel to some dyke margins.

5.5 CONTACT METAMORPHIC ALTERATION

Contact metamorphic alteration was observed only in basalt and ribbon chert. Alteration of basalt was noted around diabase dykes intersected in drill holes near the main 1210 crosscut (Fig. 6). Altered basalt is an aphanitic, massive, dark purple-brown rock composed of fine grained actinolite, epidote and plagioclase with minor amounts of carbonate, chlorite, quartz, pyrite and titanium oxides. Irregular fractures filled with epidote, andradite, carbonate and chlorite are common locally.

Contact metamorphic alteration of ribbon chert was observed
only adjacent to a diabase sill in the 21-10 drift (Fig. 6). Dark-grey to black ribbon chert is altered to a buff to pale-grey rock, which extends for up to several metres from the contact. Altered ribbon chert is composed of quartz-rich and clay-rich layers with lesser carbonate; traces of pyrite and titanium oxides may be present.
CHAPTER 6. CARBONATE ALTERATION ENVELOPES

6.1 INTRODUCTION

Well-developed carbonate alteration envelopes occur around white quartz veins (Plates 1 and 9), carbon veins and dolomite veins. Pervasive disseminated carbon is present adjacent to carbon veins (Plates 5 and 6) and some white quartz veins (Plate 10) in carbonate alteration envelopes. Fracture-controlled carbon is also present in the carbonatized basalt (Plate 10) and uncommonly in noncarbonatized basalt.

Field observations, chemical staining, a petrographic microscope, a scanning electron microscope-energy dispersive spectrometer (SEM-EDS), and an X-ray diffractometer (XRD) were used to examine the mineralogy of the alteration envelopes. Four species of carbonate were identified: calcite, siderite, ankerite and dolomite. Methods used to identify carbonate minerals are summarized in Table V.

An idealized model of carbonate alteration envelopes (Fig. 13) was developed based on the field observations and mineralogical studies. An ideal envelope is divided into five zones: 2C - outer carbonate, 2B - intermediate carbonate, 2A - inner carbonate, 1B - outer carbon and 1A - inner carbon. Ideal cross-sections of carbonate alteration envelopes surrounding specific veins are shown in the model (Fig. 13).

A generalized distribution of mineral species throughout the envelopes around white quartz veins and carbon veins is
Plate 9. Underground exposure of a portion of a carbonate alteration envelope, 21-03 drift (Fig. 6). Note zoning within envelope and gradational and sharp contacts between zones.
Plate 10. Underground exposure of carbon-rich carbonatized basalt (Cbn-rich Cbnt Bas) surrounding white quartz vein (Qtz Vn), 28-01 drift (Fig. 6). Note the presence of fracture-controlled carbon (Frt-con Cbn) within the carbonatized basalt (Cbnt Bas).
<table>
<thead>
<tr>
<th>CHARACTERISTIC</th>
<th>CALCITE</th>
<th>SIDERITE</th>
<th>ANKERITE</th>
<th>DOLOMITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>weathering color</td>
<td>grey</td>
<td>buff to orange-</td>
<td>buff to orange-</td>
<td>grey to</td>
</tr>
<tr>
<td></td>
<td></td>
<td>brown</td>
<td>brown</td>
<td>buff</td>
</tr>
<tr>
<td>effervescence with hot</td>
<td>strong</td>
<td>weak</td>
<td>weak</td>
<td>weak</td>
</tr>
<tr>
<td>dilute HCL</td>
<td></td>
<td>weak</td>
<td>weak</td>
<td>weak</td>
</tr>
<tr>
<td>chemical stain&lt;sup&gt;a&lt;/sup&gt;</td>
<td>red</td>
<td>brown</td>
<td>purple</td>
<td>none</td>
</tr>
<tr>
<td>(alizarin red and NAOH)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>structure&lt;sup&gt;b&lt;/sup&gt;</td>
<td>distinct</td>
<td>distinct</td>
<td>coinciding peaks</td>
<td></td>
</tr>
<tr>
<td>(XRD)</td>
<td>peak</td>
<td>peak</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(20 = 29.43)</td>
<td>(20 = 32.08)</td>
<td>(20 = 30.84)</td>
<td></td>
</tr>
<tr>
<td>relative composition&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Ca&gt;Fe,Mg</td>
<td>Fe&gt;Ca,Mg</td>
<td>Ca&gt;Fe&gt;Mg</td>
<td>Ca&gt;Mg&gt;Fe</td>
</tr>
<tr>
<td>(SEM-EDS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

<sup>a</sup> See Appendix H for a summary of chemical staining techniques.

<sup>b</sup> XRD: Phillips X-ray diffractometer - model PW 1060/65
Filter = Cu Kα; Slits = 1°
Kv = 40; Ma = 20
Sample preparation = acetone smear

<sup>c</sup> SEM: Semco - model nanolab 7
EDS: Kevex - model 7000
Figure 13. Cross-section of idealized carbonate alteration envelope characteristic of white quartz veins, carbon veins and McDame dolomite vein. Carbon veins and carbon-rich zones that are not always present are depicted by triangular areas. Ideal cross-sections of carbonate alteration envelopes surrounding specific veins are shown. Zones are: 1A = inner carbon, 1B = outer carbon, 2A = inner carbonate, 2B = intermediate carbonate, 2C = outer carbonate.
illustrated in Figure 14. A similar distribution for the McDame dolomite vein is illustrated in Figure 15.

Descriptions of noncarbonatized basalt and carbonate alteration zones are presented individually in the following sections. A summary is provided in Table VI.

6.2 NONCARBONATIZED BASALT

Noncarbonatized basalt is massive to pillowed, aphanitic to medium grained, pale to dark-green, and weathers dark-green to black. Extensive shearing is locally common. Basalt is composed of fine plagioclase and lesser chlorite with minor calcite, epidote and titanium oxides (Plate 11). Chlorite also fills small, discontinuous, irregular fractures. Epidote and calcite are common locally as irregular veinlets and granular clots. Fibrous actinolite occurs as isolated patches. Phenocrysts of plagioclase and partially chloritized augite occur locally. A cross-cutting network of black hairline fractures is present near some carbonate alteration envelopes, imparting a "crackled" texture to the rock.

Pillowed basalt is characterized by well-formed pillows up to one metre in diameter. Cores are fine grained and may contain augite and plagioclase phenocrysts. Radial fractures filled with chlorite are common in selvages. Interstices are filled with chlorite and minor calcite, quartz, epidote and pyrite; hematite and magnetite are rare. Pillow breccias, characterized by
Figure 14. Generalized distribution of mineral species throughout carbonate alteration envelopes around white quartz veins and carbon veins. All alteration zones are assumed to be present; widths from the Alison vein in Figure 13 were used.
Figure 15. Generalized distribution of mineral species throughout carbonate alteration envelope around McDame dolomite vein. Widths for the McDame vein in Figure 13 were used.
**TABLE VI**

Characteristics of ideal alteration zoning related to white quartz veins, carbon veins and McDame dolomite vein

<table>
<thead>
<tr>
<th>ZONE</th>
<th>THICKNESS (M)</th>
<th>OCCURRENCE</th>
<th>COLOUR</th>
<th>MINERALOGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>noncarbonatized</td>
<td>-</td>
<td>host</td>
<td>pale to dark green</td>
<td>plagioclase, chlorite, actinolite, epidote, augite, calcite, titanium oxides + pyrite + quartz + hematite + magnetite</td>
</tr>
<tr>
<td>basalt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2C outer</td>
<td>&lt;1</td>
<td>very common</td>
<td>pale green to buff and pale grey</td>
<td>plagioclase, chlorite, ankerite, siderite, quartz, sericite, titanium oxides + kaolinite + dolomite + pyrite + carbon + calcite + epidote + augite + actinolite</td>
</tr>
<tr>
<td>carbonate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2B intermediate</td>
<td>&lt;10</td>
<td>very common</td>
<td>buff to pale grey</td>
<td>ankerite, siderite, quartz, sericite, titanium oxides + kaolinite + dolomite + pyrite + carbon</td>
</tr>
<tr>
<td>carbonate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2A inner</td>
<td>&lt;4</td>
<td>common</td>
<td>buff to pale grey with minor green mottling</td>
<td>ankerite, quartz, sericite, pyrite, titanium oxides + siderite + carbon + arsenopyrite + plagioclase</td>
</tr>
<tr>
<td>carbonate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1B outer</td>
<td>&lt;1</td>
<td>uncommon</td>
<td>buff to black</td>
<td>ankerite, quartz, sericite, pyrite, titanium oxides, carbon + siderite + arsenopyrite</td>
</tr>
<tr>
<td>carbon</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1A inner</td>
<td>&lt;3</td>
<td>uncommon</td>
<td>black</td>
<td>ankerite, quartz, sericite, pyrite, titanium oxides, carbon + siderite + arsenopyrite</td>
</tr>
<tr>
<td>carbon</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Plate 11. Photomicrograph of noncarbonatized basalt (sample 83-257-DF-9, Appendix D). Note matrix is composed of plagioclase (Pl) with lesser augite (Aug), actinolite (Act) and chlorite (Chl). A chlorite filled fracture is visible in upper left corner.
fine-grained, subangular fragments in a chloritic matrix, were also noted.

6.3 ALTERATION ZONES

6.3.1 Zone 2C-Outer Carbonate

The outer carbonate zone marks a transition from noncarbonatized to completely carbonatized basalt. Rocks in this zone are massive, fine to medium-grained, pale-green to buff and pale-grey; they weather buff to orange-brown. Pillows, phenocrysts and pre-existing shearing are recognizable in the outer zone. Preferential replacement occurs along shears and around pillow selvages. Rare quartz and carbonate veinlets crosscut the rocks. Dark green to black hairline fractures impart a "crackled" texture to the rocks locally.

The outer carbonate zone is generally composed of plagioclase, chlorite, actinolite, epidote and augite, all partially altered to ankerite, siderite, quartz and sericite (Plate 12). Ankerite is the dominant carbonate species. Sericite occurs in the outer zone of envelopes surrounding only white quartz veins. Pyrite and titanium oxides are scattered throughout the groundmass. Carbon occurs in some fractures. Kaolinite, dolomite, and calcite may be present also. Kaolinite occurs in the outer zone of some envelopes surrounding white
Plate 12. Photomicrograph of fine-grained carbonate (Cbnt) replacing plagioclase (Pl) in outer carbonate zone (sample 83-257-DF-7, Appendix C). Note cross-cutting coarse-grained carbonate vein (Cbnt Vn).
quartz veins, and is always present in envelopes surrounding dolomite veins. Dolomite occurs only around dolomite veins.

The outer carbonate zone is generally less than one metre wide, but can be wider if abundant stringer veins are present. This zone is present in most alteration envelopes. It is absent if completely carbonatized basalt extends to an impermeable rock.

6.3.2 Zone 2B-Intermediate Carbonate

The intermediate carbonate zone is marked by complete carbonatization of basalt. Rocks in this zone are fine to medium-grained, buff to pale-grey and weather orange-brown. Pillows (Plate 13), phenocrysts and pre-existing shearing are recognizable in the intermediate zone. Discontinuous white ankerite-quartz veinlets are locally common in the inner portion of the zone around dolomite veins. Quartz veinlets may also crosscut the rock. A "crackled" texture of black hairline fractures is present locally.

Rocks in the intermediate carbonate zone are composed of fine-grained, generally less than 0.1 mm, carbonate, quartz, sericite, kaolinite and minor titanium oxides. However, carbonate-rich aggregates, up to two mm in diameter, may be present (Plate 14). These aggregates occur singly or in coalescing clusters and are generally optically continuous. Some rocks are composed almost entirely of these aggregates. Plagioclase phenocrysts are completely altered to quartz and
Plate 13. Underground exposure of carbonatized pillowed basalt, 28-01 drift (Fig. 6). Note complete preservation of pillow structures.
Plate 14. Photomicrograph of carbonatized basalt (sample 82-212-MF-3, Appendix D). Note optically continuous coarse carbonate aggregates (Cbnt Agg; varying shades of white, pink, green, yellow, orange and brown) in fine grained matrix of carbonate, quartz and kaolinite (Cbnt-Qtz-Klt; pale grey-brown).
sericite with minor carbonate. Sheared basalt, appears crudely layered microscopically due to variations in grain size and composition.

In the intermediate carbonate zone, carbonate is principally ankerite with subordinate siderite. Siderite content is highest in the outer portion of the intermediate zone and decreases towards veins. Dolomite occurs in envelopes around dolomite veins. Sericite occurs only in envelopes around white quartz veins. Kaolinite is present in the intermediate zone in envelopes around dolomite veins; it also occurs in the outer portion of the intermediate zone around some white quartz veins. Carbon also may be present around white quartz veins.

Minor pyrite occurs in the intermediate carbonate zone. However, some rocks contain up to five percent fine-grained disseminated pyrite. Pyrite also occurs as concentrations around hairline fractures and as irregular fracture fillings up to three mm wide. In brecciated vuggy rocks near McDame vein, some pyrite occurs around carbonate altered clasts and in the matrix of clear quartz.

The intermediate carbonate zone is present in most carbonate alteration envelopes. It is generally less than 10 m wide, unless abundant stringer veins are present.

6.3.3 Zone 2A—Inner Carbonate

Basalt in the inner carbonate zone is completely carbonatized
as in the intermediate zone. Although the inner zone's colour, texture and mineralogy are similar to the intermediate zone, it can be distinguished by features characteristic of only the inner zone. These features are: coarse-grained euhedral pyrite crystals, sporadic emerald-green porphyroblast-like aggregates and uncommon pistachio-green and pale-green mottling.

Coarse-grained pyritohedrons and less commonly cubes of pyrite occur throughout the inner carbonate zone. Microscopically, pyrite crystals exhibit a well-developed sieve texture with up to 15 percent inclusions of carbonate, quartz and sericite. Voids filled with quartz and carbonate are present around some pyrite crystals. Pyrite concentration increases up to five percent toward white quartz veins; crystal size also increases up to five mm in diameter (Plate 15). Rocks with high concentrations of pyrite contain up to 0.2 ounces of gold per ton (six grams/tonne).

Emerald-green porphyroblast-like aggregates occur sporadically adjacent to white quartz veins. They are optically continuous, rounded to angular, less than one cm in diameter, and occur singly or in clusters (Plate 16); some are rhombohedral (Plate 17). SEM-EDS work shows that these aggregates are composed of ankerite, quartz and sericite with minor siderite, fuchsite and titanium oxides. Grains within these aggregates are generally less than 0.02 mm. The emerald-green colour appears to be due to disseminated fuchsite.

Pistachio-green and pale-green mottling occur in the inner carbonate zone adjacent to some white quartz veins. The mottling
Plate 15. Close-up view of carbonatized basalt with disseminated coarse-grained euhedral pyrite crystals adjacent to quartz vein and in included wall rock fragments. Note pyrite crystals decrease in size and amount away from vein (Taurus mine, 3400 level, Fig. 3).
Plate 16. Close-up view of emerald-green porphyroblast-like aggregates (Porph-like Agg) of ankerite, quartz, sericite and minor siderite, fuchsite and titanium oxides (sample 83-322, Appendix D). Note coarse-grained euhedral pyrite and cross-cutting quartz veins.
Plate 17. Photomicrograph of emerald-green porphyroblast-like aggregate (Porph-like Agg) of ankerite, quartz, sericite, and minor siderite, fuchsite and titanium oxides. Matrix is carbonate, quartz and sericite (Cbnt-Qtz-Ser). Note rhombohedral shape.
is related to aggregates of carbonate, up to 0.5 mm, with jagged to straight edges, that occur as isolated or partly-connected clusters up to five mm in diameter. An unidentified fine-grained opaque mineral is disseminated throughout the aggregates. A green colour pervades these aggregates imparting a mottled appearance (Plate 18).

Other differences between the intermediate and inner zones include an increase in quartz content in the inner zone. Quartz occurs as irregular blebs and veinlets that are most abundant close to white quartz veins. Minor siderite may be present throughout the inner carbonate zone. Minor plagioclase was identified in a few samples adjacent to white quartz veins. Rare arsenopyrite also occurs adjacent to some white quartz veins. Kaolinite is absent.

The inner carbonate zone is up to four metres wide but may be narrower if carbon-rich zones are present. The inner carbonate zone occurs around white quartz veins but is absent around dolomite veins.

6.3.4 Zone 1B-Outer Carbon

The outer carbon zone marks the transition from carbonatized to carbon-rich carbonatized basalt. The transition is gradational with colour changes from buff to black. The zone is characterized by appearance of disseminated carbon which makes up to several percent of the rock. Carbon occurring in and around
hairline fractures imparts a "crackled" texture to some rocks. Carbon-rich rocks are fine to medium-grained and massive. They are composed of ankerite, quartz, sericite, pyrite, titanium oxides and carbon. Siderite and arsenopyrite are less abundant. Coarse-euhedral pyrite crystals occur throughout the zone and are concentrated near white quartz veins and carbon veins.

The outer carbon zone occurs in envelopes associated with carbon veins and some white quartz veins within 100 metres of carbon-rich sedimentary rocks in the southern part of the mine. It is uncommon in the rest of the mine. The outer carbon zone is up to one metre wide, although it may be absent if the inner carbon zone abuts an impermeable rock. It is also absent around dolomite veins.

6.3.5 Zone 1A-Inner Carbon

The inner carbon zone is similar to the outer carbon zone except for a marked increase in carbon content in the inner zone. Carbonate alteration is no longer recognizable megascopically because carbon imparts a black color to the rock obscuring mineralogy and textures.

The inner carbon zone occurs around carbon veins and some white quartz veins close to carbon-rich sedimentary rocks in the southern part of the mine. It is generally less than three metres wide.
6.4 FRACTURE-CONTROLLED CARBON

Fracture-controlled carbon, commonly called "crackled" texture at the Erickson mine, occurs as an irregular network of hairline fractures filled with fine-grained carbon. Disseminated carbon occurs in rock adjacent to fractures. An increase in width of the carbon-rich rock around fractures is coincident with increasing fracture density. Some fractures are oriented dividing the rock into elongate domains. In areas of intense fracturing, the rocks resemble a breccia (Plate 19; Fig. 16).

Fracture-controlled carbon occurs adjacent to veins, fracture zones and faults in carbonatized basalt and less so in chert, altered ultramafic rocks and noncarbonatized basalt. In carbonatized basalt fracture-controlled carbon is most prevalent adjacent to white quartz veins and carbon veins. Fracture-controlled carbon also occurs in the vicinity of carbon-rich sedimentary rocks adjacent to the contact between the upper and lower assemblages.

6.5 DISCUSSION

Zoning patterns within carbonate alteration envelopes around veins are relatively uniform throughout the mine. However, zones vary in width and mineralogy, and specific zones may be absent.

Most alteration envelopes extend less than 15 metres from vein margins, although some are up to 40 metres wide. Envelopes
Plate 19. Close-up view of fracture-controlled carbon. See Fig. 16 for explanation. Blocks are about 2.5 cm across. Spotted texture in block on left side of photo is coarse-grained pyrite.

Figure 16. Schematic illustration of fracture-controlled carbon. Note fracture width increases with increasing fracture density until rock resembles a breccia.
around veins are generally symmetrical; however in some, width in the hanging wall is up to twice that in the footwall. Hanging wall and footwall widths of envelopes are generally two to six times that of the associated vein. Although carbonate alteration envelopes are associated with white quartz veins, and less commonly dolomite veins and carbon veins, such veins were not noted in some envelopes.

Carbonate alteration zones surround white quartz veins, dolomite veins and carbon veins; carbon zones surround carbon veins and some white quartz veins. In general, gold-silver-bearing white quartz veins are surrounded by all three carbonate alteration zones; carbon zones may or may not be present. Dolomite veins are surrounded only by the intermediate and outer carbonate zones. Therefore, the presence of the inner carbonate zone can be used to identify carbonate alteration envelopes associated with potentially gold-silver-bearing white quartz veins.

The presence of carbon zones 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.

Rocks in carbonate alteration envelopes are composed of approximately 45 percent carbonate, 25 per cent quartz, 25 percent sericite and/or kaolinite, and minor titanium oxides (Figs. 14 and 15). Pyrite makes up to five percent of the inner carbonate zone. Carbon zones contain up to five percent carbon.

Carbonate minerals in the alteration envelopes are ankerite, siderite and dolomite. Ankerite occurs throughout the envelopes;
siderite is most common in the outer portion. Dolomite occurs only in envelopes surrounding dolomite veins.

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

The absence of dolomite and kaolinite, and presence of sericite in the inner portion of carbonate alteration envelopes can be used to identify envelopes associated with potentially gold-silver-bearing white quartz veins.
CHAPTER 7. CARBONATE AND MAJOR ELEMENT METASOMATISM

7.1 INTRODUCTION

Alteration studies benefit from estimates of losses and gains of chemical components, and an understanding of chemical reactions and processes by which metasomatism took place. Estimates of losses and gains are made by comparing chemical analyses of parent and product rock using a variety of computational methods, each with its own constraints. A common factor that exists in each method is an attempt to define a characteristic of the parent rock that remains constant throughout metasomatism. In contrast, the metasomatic equation derived by Gresens (1967) is applicable to all conditions of metasomatism; it is used here to determine losses and gains during carbonate metasomatism.

7.2 MASS BALANCE CALCULATIONS

7.2.1 Procedure

The fundamental equation derived by Gresens (1967) for mass balance calculations is:
\[ X_N = a [ F_v X_B (P_B/P_A) - X_A ] \]

where \( X \) = loss or gain (in grams) of component \( N \) to produce rock \( B \)
from rock \( A \).

\( a \) = initial quantity of rock \( A \) (commonly designated as 100
grams so that \( X \) is expressed in weight percent).

\( F \) = volume factor (volume ratio of product to parent
rock).

\( X \) and \( X \) = weight fraction of component \( N \) in parent rock
\( A \) and product rock \( B \). If \( a = 100 \) grams,
then \( X \) and \( X \) are in weight percent.
\( A \) \( B \)

\( P \) and \( P \) = specific gravity of parent rock \( A \) and product
\( A \) \( B \) rock \( B \).

Thus, to calculate chemical losses and gains using Gresens' (1967) equation, the following are required:

1) quantitative chemical analyses for parent and product
rocks \( (X \) and \( X \),
\( A \) \( B \)

2) specific gravities for parent and product rocks \( (P \) and
\( P \), and
\( A \) \( B \)

3) an estimate of the volume change of the rock mass during
metasomatism \( (F_v) \).
Alternatively, one may calculate the volume change if losses or gains can be estimated.

Application of Gresens' (1967) equation for varying volume factors enables calculation of losses and gains, which can be used to construct a composition-volume diagram for all possible examples of mass exchange. Composition-volume diagrams can then be examined for component immobility when is indicated by clustering at zero chemical transfer. Volume factors for each sample are calculated assuming zero chemical transfer for immobile components, and solving Gresens' (1967) equation. Clustering of volume factors calculated in this manner provides a basis for estimating the volume change during metasomatism.

Volume change constraints are then applied to estimate component losses and gains by inspection of the composition-volume diagrams or by calculation using Gresens' (1967) equation.

Parent rock in the Erickson mine example is noncarbonatized basalt. Product rock is carbonatized basalt from the alteration envelope surrounding the gold-silver-bearing Jennie white quartz vein. Individual samples of parent and product rock are continuous sections of split BQ diamond drill core, 0.4 to 1.6 metres long, from drill hole 80-88 (Fig. 6, Appendix D). Each segment analyzed represents megascopically uniform rock.

Chemical analyses were performed by X-ray fluorescence (XRF) at the Department of Oceanography, The University of British Columbia. Results were obtained for all major oxides and Ba, Sr, Rb, Zr, Y, Nb, Cu, Pb, Zn, Cr, Ni, Co, V and Mo. Losses on ignition (LOI) at 550 °C and 1,000 °C were determined by Vangeochem
Lab Limited of North Vancouver. Specific gravity measurements of representative specimens were obtained by the author using a Jolly balance. All analyses are tabulated in Appendix B.

7.2.2 Results

A series of composition-volume diagrams for six carbonatized basalt samples are presented with increasing distance to the vein in Figure 17. These diagrams depict weight percent changes as a function of volume factor. Composition-volume diagrams indicate immobility for $\text{Al}_2\text{O}_3$ and $\text{TiO}_2$. These components and $\text{Zr}$ are empirically known to be relatively immobile. Figure 18A depicts volume factors obtained by assuming immobility of $\text{Al}_2\text{O}_3$, $\text{TiO}_2$ and $\text{Zr}$ and applying Gresens' (1967) equation. In general, the following relationship is noted

\[
\frac{V(\text{Al}_2\text{O}_3)}{F^{2/3}} = \frac{V(\text{TiO}_2)}{F^2} = \frac{V(\text{Zr})}{F} = \frac{V(\text{Al}_2\text{O}_3)}{I^{2/3}} = \frac{V(\text{TiO}_2)}{I^2} = \frac{V(\text{Zr})}{I}
\]

However, the above equivalence does not hold immediately adjacent to the vein implying the basic assumption of element immobility is not well-approximated there. An average volume factor for the three constraining components for each of the six samples is shown graphically in Figure 18A. These average volume factors are
Figure 17. Composition-volume diagrams for six carbonatized basalt samples presented with increasing distance to the vein (1 to 6). Weight percent changes as a function of volume factors are indicated for the conversion of parent to product rock. Note sample 3 contains a quartz veinlet that is indicated in Figures 18, 19 and 20. Volume factor used in loss and gain calculations is $V_2$; its derivation is summarized in Figure 18 and Appendix F. Assumed parent rock is sample 80-88-JH-7. Product rocks 1 to 6 are samples 80-88-JH-1 to 6. Analyses are in Appendix B; sample locations in Appendix D.
Figure 18. Volume factors and changes for six carbonatized basalt samples (1 to 6) and one noncarbonatized basalt sample (7). A: Volume factors for constraining components and an average used in loss and gain calculations. B: Volume percent change using average volume factor from A. Volume change for sample 3 is anomalous due to the presence of a quartz veinlet. Calculation of volume factors and changes are summarized in Appendix F.
used to estimate component losses and gains from composition-volume diagrams or by calculation.

Volume percent changes that correspond to average volume factors are presented in Figure 18B. Volume changes across the carbonate alteration envelope increase systematically from near zero at the outer margin of the envelope to 30 percent adjacent to the vein. An exception to this is a volume change of 70 percent which coincides with a quartz veinlet.

Changes in volatile content during carbonate metasomatism, expressed as loss on ignition (LOI) in weight percent, are illustrated in Figure 19. Losses and gains of major oxides during carbonate metasomatism, expressed as weight percent of the parent rock, are given in Figures 20A to 20H. A compilation of these changes along with volume factors and specific gravities used in calculations is in Appendix F.

The major chemical changes that took place during the development of a carbonate alteration envelope in basalt are:

1. volatiles increase progressively toward the vein,
2. \( K_2 O \) is added throughout but is most pronounced near the vein,
3. \( Na_2 O \) is depleted throughout,
4. \( SiO_2 \) increases in most areas, particularly where a quartz vein is present,
5. \( CaO \) is depleted in the outer portion and added to the inner portion,
6. \( MgO \) and \( Fe_3 O_2 \) are depleted throughout except where a quartz veinlet is present (depletion is greater in the outer
Figure 19. Loss on ignition (LOI) for six carbonatized basalt samples (1 to 6) and one noncarbonatized basalt sample (7) expressed as weight percent of rock (V = vein; B = noncarbonatized basalt). Samples 1 to 7 correspond to 80-88-JH-1 to 7. LOI determinations are in Appendix B; sample locations in Appendix D.
Figure 20. Losses and gains of major oxides in six carbonatized basalt samples, expressed as weight percent of noncarbonatized basalt sample (assumed parent rock). Based on volume change constraints. Loss and gain calculations are summarized in Appendix F.
7. Al\(^{2+}\) and Ti\(^{2+}\) increase throughout (changes are minor except adjacent to the vein).

### 7.2.3 Discussion

Results from mass balance calculations are consistent with observations. Variations in mineralogy are a function of host rock composition and losses and gains of components. Minerals noted in the carbonatized basalt are: ankerite, siderite, quartz, sericite, kaolinite, titanium oxides and pyrite. The presence of carbonates, hydrous aluminum silicates and pyrite implies that the volatiles include at least CO\(_2\), H\(_2\)O and S. An increase in volatile content corresponds to a volume increase.

Carbonate composition is determined by availability of calcium, iron and magnesium. Ankerite is generally the dominant carbonate mineral throughout alteration envelopes. A net loss of CaO relative to FeO\(^{2+}\) in the outer portion of the envelopes explains why siderite is abundant only near the limit of metasomatism. Al\(^{2+}\) of the parent rock is accounted for by sericite and kaolinite in carbonatized rocks. Sericite formed where gain of K\(^{2+}\) occurred; otherwise kaolinite developed. Sodium-rich minerals do not occur because of marked depletion of Na\(^{2+}\). Addition of SiO\(_2\) explains the presence of some quartz in carbonatized basalt. Other sources of SiO\(_2\) are hydrolysis, carbonation and hydration of silicates during carbonate metasomatism (Fig. 21). TiO\(^{2+}\) occurs in titanium oxides in the
Figure 21. Schematic illustration of carbonate metamorphism of basalt with generalization.

\[
\begin{align*}
\text{Basalt} & \quad \rightarrow \quad \text{Vein} \\
(Ca', Fe', Mg) Carbonates + SiO_2 & = (Ca', Fe', Mg) Silicates + CO_2 \\
\text{Secondary Al Silicates + SiO}_2 + Na^+ & = \text{Primary Al Silicates + H}_2O + K^+ + Na^+
\end{align*}
\]
parent and product rocks. The occurrence of pyrite indicates addition of sulphur.

7.3 CHEMICAL REACTIONS

Decomposition of the basaltic mineral assemblage and formation of carbonate, sericite and quartz during carbonate metasomatism takes place by hydrolysis, carbonation and hydration. These reactions involve an introduction of CO₂, H₂O and K, and a depletion of Na. Sulphurization occurs adjacent to veins.

Sericite forms by hydrolytic decomposition of plagioclase in the presence of K as shown by the reaction (Hemley and Jones, 1964):

\[
\text{plagioclase} \quad 3\text{Na}_2\text{CaAl}_4\text{Si}_8\text{O}_{24} + 8\text{H}^+ + 4\text{K}^+ = \\
\text{sericite} \quad \text{quartz} \quad 4\text{KAl}_3\text{Si}_3\text{O}_{10}(\text{OH})_2 + 12\text{SiO}_2 + 6\text{Na}^+ + 3\text{Ca}^{++} \quad (1)
\]

If K is not present, kaolinite forms as shown by the reaction (Hemley and Jones, 1964):

\[
\text{plagioclase} \quad \text{Na}_2\text{CaAl}_4\text{Si}_8\text{O}_{24} + 4\text{H}^+ + 2\text{H}_2\text{O} = \\
\text{kaolinite} \quad \text{quartz} \quad 2\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4 + 4\text{SiO}_2 + 2\text{Na}^+ + \text{Ca}^{++} \quad (2)
\]

A later addition of K to a rock containing kaolinite may produce sericite as demonstrated in the following reaction.
Hemley and Jones, 1964):

\[
3\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4 + 2\text{K}^+ = 2\text{KAl}_3\text{Si}_3\text{O}_{10}(\text{OH})_2 + 3\text{H}_2\text{O} + 2\text{H}^+ \quad (3)
\]

Studies by Harte and Graham (1975) on basaltic rocks with mineralogy similar to those at the Erickson mine indicate that the following carbonation and hydration reactions are applicable:

\[
3\text{Ca}_2(\text{Mg,Fe})_5\text{Si}_8\text{O}_{22}(\text{OH})_2 + 2\text{Ca}_2\text{Al}_3\text{Si}_3\text{O}_{12}(\text{OH}) + 10\text{CO}_2 + 8\text{H}_2\text{O} = 3(\text{Mg,Fe})_5\text{Al}_2\text{Si}_3\text{O}_{10}(\text{OH})_8 + 10\text{CaCO}_3 + 21\text{SiO}_2 \quad (4)
\]

and

\[
19\text{Ca}_2(\text{Mg,Fe})_5\text{Si}_8\text{O}_{22}(\text{OH})_2 + 6\text{Ca}_2\text{Al}_3\text{Si}_3\text{O}_{12}(\text{OH}) + 100\text{CO}_2 + 14\text{H}_2\text{O} = 9(\text{Mg,Fe})_5\text{Al}_2\text{Si}_3\text{O}_{10}(\text{OH})_8 + 50\text{Ca}(\text{Mg,Fe})(\text{CO}_3)_2 + 143\text{SiO}_2 \quad (5)
\]

and

\[
3(\text{Mg,Fe})_5\text{Al}_2\text{Si}_3\text{O}_{10}(\text{OH})_8 + 19\text{CaCO}_3 + 11\text{CO}_2 = 15\text{Ca}(\text{Mg,Fe})(\text{CO}_3)_2 + 2\text{Ca}_2\text{Al}_3\text{Si}_3\text{O}_{12}(\text{OH}) + 3\text{SiO}_2 + 11\text{H}_2\text{O} \quad (6)
\]

and

\[
\text{Ca}_2(\text{Mg,Fe})_5\text{Si}_8\text{O}_{22}(\text{OH})_2 + 3\text{CaCO}_3 + 7\text{CO}_2 = 5\text{Ca}(\text{Mg,Fe})(\text{CO}_3)_2 + 8\text{SiO}_2 + \text{H}_2\text{O} \quad (7)
\]

Carbonation of calcium, iron and magnesium aluminum silicates may result in the formation of sericite as well as carbonate minerals. The following reaction demonstrates this (Kerrich and Fyfe, 1981):
aluminous chlorite \[ 3(Mg,Fe)_{4}Al_{2}Si_{2}O_{10}(OH)_{8} + 6Ca_{2}Al_{3}Si_{3}O_{10}(OH) + 6SiO_{2} \]

epidote + 24CO_{2} + 10K^{+} =

sericite

ankerite

\[ 10KAl_{3}Si_{3}O_{10}(OH)_{2} + 12Ca(Mg,Fe)(CO_{3})_{2} + 10H^{+} \] (8)

A schematic illustration of carbonate metasomatism and generalized major reactions at Erickson mine are shown in Figure 21.

Sulphurization is manifested by the formation of pyrite concomitant with destruction of iron silicate minerals. A generalized reaction is (Boyle, 1979):

\[ \text{Fe-silicates} + S = \text{pyrite} + \text{SiO}_{2} \] (9)

This process is important because of the association of gold with pyrite in the inner portions of carbonate alteration envelopes.

7.3 ALTERATION PROCESSES

During wall rock alteration, mass transfer takes place by diffusion and infiltration. In diffusion metasomatism, chemical components move by diffusion through a stationary pore solution; in infiltration metasomatism, the components are transported by a stream of aqueous solutions percolating through pores in the rocks (Korzhinskii, 1970). Infiltration is the dominant process if mass transfer is in one direction over large distances. However, if mass transfer is in more than one direction, then
diffusion, not infiltration is the dominant process (Hofmann, 1972).

Mass balance calculations indicate addition and depletion of major elements throughout the carbonate alteration envelopes around Jennie vein. This implies mass transfer in more than one direction suggesting that diffusion was more important than infiltration. However, diffusion is not an efficient process of mass transfer over large distances. It is more likely that most fluid moved by infiltration along fractures or large pores to a point near the replacing front. Replacement then took place by diffusion.
8.1 INTRODUCTION

A study of geochemical characteristics of carbonate alteration envelopes surrounding gold-silver-bearing white quartz veins was conducted using inductively coupled plasma (ICP) analyses with an aqua regia digestion. ICP analyses were used because they are readily available, relatively inexpensive and give multi-element results. The ICP analyses were compared to XRF analyses to determine the range of extraction during aqua regia digestion to assist in interpretation. Procedures used are summarized in Figure 22 and discussed in the following sections.

8.2 SAMPLING AND ANALYSES

All diamond drill cores at Erickson mine were examined and seven intersections of carbonate alteration envelopes were selected for this geochemical study. Six intersections enclose white quartz veins (Appendix D: DDH's 77-44, 80-84, 80-88, 82-222, 82-247 and 83-257); one a dolomite vein (Appendix D: DDH 82-212). Each intersection was divided into 0.3 to 1.6 metre intervals of megascopically uniform rock. Each interval was split parallel to the core axis and then sampled. In total, 106 samples of carbonatized basalt and 26 of noncarbonatized basalt were obtained. In addition, 34 pulverized samples of veins were
Figure 22. Flow diagram for geochemical study of carbonate alteration at Erickson mine.
retrieved from the Erickson mine laboratory.

Losses on ignition (LOI) at 550 °C and 1000 °C were determined for basalt using 0.5 gram pulverized samples. The residues of the 1000 °C ignition were digested with three ml of 3:1:3 HCL to HNO to H₂O at 90 °C for one hour, and then diluted to ten ml with distilled water and analyzed for 30 elements using a Jarrell-Ash 0.75 meter grating ICAP instrument. All ICP analyses are expressed as a proportion of the initial sample weight. Samples of veins were also analyzed for 30 elements by ICP. Elements determined by ICP are: 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. Since gold extracted by aqua regia is below the three ppm ICP detection limit, gold and silver were determined by fire assaying. Sixteen samples of carbonatized basalt and six of noncarbonatized basalt were analyzed by XRF for the following: SiO₂, Al₂O₃, TiO₂, Fe₂O₃, MnO, MgO, CaO, Na₂O, K₂O, P₂O₅, Ba, Sr, Rb, Zr, Y, Nb, Cu, Pb, Zn, Cr, Ni, Co, V and Mo.

LOI and ICP analyses performed by Vangeochem Lab Limited, North Vancouver; fire assays by Erickson Gold Mines Ltd., Cassiar. XRF analyses were done at the Department of Oceanography, The University of British Columbia. Analytical results and profile plots for each intersection are in Appendix B. A summary of analytical methods is in Appendix C. Sample locations and rock types are in Appendix D.
8.3 QUALITY OF DATA

Ten samples of wall rock from diamond drill core, each fragmented to approximately three cm chips, were split to obtain duplicates. LOI and ICP analyses with an aqua regia digestion were performed on original - duplicate pairs to determine the combined sampling, sample preparation and analytical errors. An additional twelve duplicates of wall rock were obtained by splitting pulverized samples of diamond drill core to determine the combined sample preparation and analytical error for gold-silver fire assays. The combined sample preparation and analytical errors for XRF analyses were determined for seven duplicates of wall rock, obtained by splitting pulverized samples of diamond drill core.

Errors were determined for each element in two steps. The mean concentration of each original - duplicate pair was compared graphically to the absolute difference of pairs (Thompson and Howarth, 1978). Outliers and values occurring at the laboratory detection limit were removed and mean relative errors were determined for specific concentration ranges. Results are summarized in Tables VII, VIII and IX.

In general, the total mean relative errors for LOI and ICP analyses with aqua regia digestion range from six to twenty-two percent. Total mean relative errors of forty percent for lead, silver and titanium, and thirty-five for cadmium (Table VII) occur probably because most values for these elements are near laboratory detection limits. Barium, potassium and arsenic have
TABLE VII
Summary of Data Quality: Combined Sampling, Sample Preparation and Analytical Errors for LOI and ICP Analyses with an Aqua Digestion

<table>
<thead>
<tr>
<th>ELEMENT DETECTION LIMIT</th>
<th>DUPLICATE PAIRS</th>
<th>$\bar{x}^a$</th>
<th>$s^b$</th>
<th>$S/X^c$ (%)</th>
<th>CONCENTRATION RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al 0.01 %</td>
<td>10</td>
<td>2.86</td>
<td>0.28</td>
<td>10</td>
<td>1.90 - 4.30</td>
</tr>
<tr>
<td>Ti 0.01 %</td>
<td>10</td>
<td>0.04</td>
<td>0.01</td>
<td>25</td>
<td>0.02 - 0.10</td>
</tr>
<tr>
<td>Fe 0.01 %</td>
<td>10</td>
<td>3.21</td>
<td>1.31</td>
<td>10</td>
<td>1.60 - 3.90</td>
</tr>
<tr>
<td>Mn 1.0 ppm</td>
<td>10</td>
<td>559.75</td>
<td>73.33</td>
<td>13</td>
<td>280.00 - 840.00</td>
</tr>
<tr>
<td>Mg 0.01 %</td>
<td>10</td>
<td>1.07</td>
<td>0.17</td>
<td>16</td>
<td>0.40 - 2.10</td>
</tr>
<tr>
<td>Ca 0.01 %</td>
<td>10</td>
<td>3.36</td>
<td>0.37</td>
<td>11</td>
<td>1.50 - 5.30</td>
</tr>
<tr>
<td>Na 0.01 %</td>
<td>7</td>
<td>0.18</td>
<td>0.03</td>
<td>17</td>
<td>0.10 - 0.25</td>
</tr>
<tr>
<td>K 0.01 %</td>
<td>5</td>
<td>0.04</td>
<td>0.007</td>
<td>18</td>
<td>0.02 - 0.10</td>
</tr>
<tr>
<td>K 0.01 %</td>
<td>2</td>
<td>1.33</td>
<td>0.35</td>
<td>26</td>
<td>0.35 - 2.25</td>
</tr>
<tr>
<td>P 0.01 %</td>
<td>8</td>
<td>0.03</td>
<td>0.004</td>
<td>13</td>
<td>0.02 - 0.06</td>
</tr>
<tr>
<td>Au d 3.0 ppm</td>
<td>10</td>
<td>1.04</td>
<td>0.42</td>
<td>40</td>
<td>0.50 - 3.70</td>
</tr>
<tr>
<td>Ag 0.1 ppm</td>
<td>10</td>
<td>8.30</td>
<td>6.36</td>
<td>77</td>
<td>3.00 - 22.00</td>
</tr>
<tr>
<td>As 3.0 ppm</td>
<td>5</td>
<td>229.63</td>
<td>51.80</td>
<td>23</td>
<td>62.00 - 395.00</td>
</tr>
<tr>
<td>As d 3.0 ppm</td>
<td>4</td>
<td>68.50</td>
<td>8.34</td>
<td>12</td>
<td>34.00 - 109.00</td>
</tr>
<tr>
<td>Ba 1.0 ppm</td>
<td>5</td>
<td>403.00</td>
<td>64.52</td>
<td>41</td>
<td>187.00 - 871.00</td>
</tr>
<tr>
<td>Ba d 1.0 ppm</td>
<td>3</td>
<td>26.55</td>
<td>4.03</td>
<td>15</td>
<td>7.00 - 59.00</td>
</tr>
<tr>
<td>Sr 1.0 ppm</td>
<td>10</td>
<td>95.35</td>
<td>18.74</td>
<td>20</td>
<td>23.00 - 168.00</td>
</tr>
<tr>
<td>Cu 1.0 ppm</td>
<td>9</td>
<td>33.05</td>
<td>4.64</td>
<td>14</td>
<td>19.00 - 64.00</td>
</tr>
<tr>
<td>Pb 1.0 ppm</td>
<td>10</td>
<td>5.60</td>
<td>2.26</td>
<td>40</td>
<td>2.00 - 13.00</td>
</tr>
<tr>
<td>Zn 1.0 ppm</td>
<td>10</td>
<td>75.83</td>
<td>11.08</td>
<td>15</td>
<td>39.00 - 121.00</td>
</tr>
<tr>
<td>Cd 1.0 ppm</td>
<td>9</td>
<td>28.00</td>
<td>4.95</td>
<td>18</td>
<td>16.00 - 45.00</td>
</tr>
<tr>
<td>Cr 1.0 ppm</td>
<td>9</td>
<td>3.83</td>
<td>1.34</td>
<td>35</td>
<td>2.00 - 8.00</td>
</tr>
<tr>
<td>Ni 1.0 ppm</td>
<td>10</td>
<td>23.50</td>
<td>4.38</td>
<td>19</td>
<td>12.00 - 43.00</td>
</tr>
<tr>
<td>Co 1.0 ppm</td>
<td>10</td>
<td>10.25</td>
<td>1.77</td>
<td>17</td>
<td>5.00 - 17.00</td>
</tr>
<tr>
<td>V 3.0 ppm</td>
<td>9</td>
<td>133.85</td>
<td>8.27</td>
<td>6</td>
<td>97.00 - 188.00</td>
</tr>
<tr>
<td>W d 3.0 ppm</td>
<td>10</td>
<td>143.05</td>
<td>3.65</td>
<td>12</td>
<td>115.00 - 171.00</td>
</tr>
<tr>
<td>Mo d 1.0 ppm</td>
<td>10</td>
<td>50.00</td>
<td>2.36</td>
<td>20</td>
<td>46.00 - 54.00</td>
</tr>
<tr>
<td>U d 3.0 ppm</td>
<td>10</td>
<td>10.25</td>
<td>1.77</td>
<td>17</td>
<td>5.00 - 17.00</td>
</tr>
<tr>
<td>Th d 3.0 ppm</td>
<td>10</td>
<td>133.85</td>
<td>8.27</td>
<td>6</td>
<td>97.00 - 188.00</td>
</tr>
<tr>
<td>La d 3.0 ppm</td>
<td>10</td>
<td>143.05</td>
<td>3.65</td>
<td>12</td>
<td>115.00 - 171.00</td>
</tr>
<tr>
<td>Bi d 3.0 ppm</td>
<td>10</td>
<td>50.00</td>
<td>2.36</td>
<td>20</td>
<td>46.00 - 54.00</td>
</tr>
<tr>
<td>LOI 0.01 %</td>
<td>19</td>
<td>6.23</td>
<td>1.37</td>
<td>22</td>
<td>1.00 - 12.80</td>
</tr>
</tbody>
</table>

---

a. $\bar{x}$ = Mean of original - duplicate samples.
b. $s$ = Mean standard deviation of original - duplicate pairs.
c. $S/X$ = Total mean relative error.
d. Errors not calculated as most values are close to or below laboratory detection limits.
### TABLE VIII
Summary of Data Quality: Combined Sample Preparation and Analytical Errors for XRF analyses

<table>
<thead>
<tr>
<th>ELEMENT DETECTION LIMIT</th>
<th>DUPLICATE PAIRS</th>
<th>$\bar{x}$</th>
<th>S&lt;sup&gt;b&lt;/sup&gt;</th>
<th>$\bar{S}/\bar{x}$&lt;sup&gt;c&lt;/sup&gt;</th>
<th>CONCENTRATION RANGE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO&lt;sub&gt;2&lt;/sub&gt; 0.64 %</td>
<td>6</td>
<td>45.39</td>
<td>0.74</td>
<td>2</td>
<td>38.84 - 57.78</td>
</tr>
<tr>
<td>Al&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt; 0.54 %</td>
<td>6</td>
<td>10.54</td>
<td>0.06</td>
<td>&lt;1</td>
<td>5.90 - 12.08</td>
</tr>
<tr>
<td>TiO&lt;sub&gt;2&lt;/sub&gt; 0.02 %</td>
<td>6</td>
<td>1.32</td>
<td>0.01</td>
<td>&lt;1</td>
<td>0.71 - 1.87</td>
</tr>
<tr>
<td>FeO&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt; 0.02 %</td>
<td>6</td>
<td>10.17</td>
<td>0.11</td>
<td>1</td>
<td>6.43 - 13.40</td>
</tr>
<tr>
<td>MnO 0.02 %</td>
<td>6</td>
<td>0.16</td>
<td>0.002</td>
<td>2</td>
<td>0.12 - 0.18</td>
</tr>
<tr>
<td>MgO 0.10 %</td>
<td>6</td>
<td>5.63</td>
<td>0.06</td>
<td>1</td>
<td>3.64 - 7.28</td>
</tr>
<tr>
<td>CaO 0.05 %</td>
<td>6</td>
<td>9.79</td>
<td>0.06</td>
<td>&lt;1</td>
<td>7.97 - 11.21</td>
</tr>
<tr>
<td>Na&lt;sub&gt;2&lt;/sub&gt;O 0.03 %</td>
<td>6</td>
<td>0.73</td>
<td>0.01</td>
<td>1</td>
<td>0.06 - 2.34</td>
</tr>
<tr>
<td>K&lt;sub&gt;2&lt;/sub&gt;O 0.05 %</td>
<td>6</td>
<td>1.57</td>
<td>0.03</td>
<td>2</td>
<td>0.05 - 3.20</td>
</tr>
<tr>
<td>Fe&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;5&lt;/sub&gt; 0.03 %</td>
<td>6</td>
<td>0.10</td>
<td>0.001</td>
<td>1</td>
<td>0.02 - 0.15</td>
</tr>
<tr>
<td>Ba 38 ppm</td>
<td>5</td>
<td>348.44</td>
<td>7.65</td>
<td>2</td>
<td>151.55 - 668.18</td>
</tr>
<tr>
<td>Sr 10 ppm</td>
<td>6</td>
<td>155.44</td>
<td>1.70</td>
<td>1</td>
<td>121.09 - 208.66</td>
</tr>
<tr>
<td>Rb 8 ppm</td>
<td>6</td>
<td>93.12</td>
<td>2.19</td>
<td>2</td>
<td>16.44 - 188.26</td>
</tr>
<tr>
<td>Zr 8 ppm</td>
<td>6</td>
<td>89.20</td>
<td>1.50</td>
<td>2</td>
<td>54.66 - 122.36</td>
</tr>
<tr>
<td>V 13 ppm</td>
<td>6</td>
<td>359.06</td>
<td>359.06</td>
<td>2</td>
<td>233.44 - 474.95</td>
</tr>
<tr>
<td>Y 10 ppm</td>
<td>6</td>
<td>30.30</td>
<td>30.30</td>
<td>3</td>
<td>19.54 - 37.76</td>
</tr>
<tr>
<td>Nb 9 ppm</td>
<td>6</td>
<td>15.20</td>
<td>0.50</td>
<td>15</td>
<td>1.26 - 5.66</td>
</tr>
<tr>
<td>Cu 25 ppm</td>
<td>6</td>
<td>63.73</td>
<td>2.41</td>
<td>4</td>
<td>24.41 - 100.47</td>
</tr>
<tr>
<td>Pb 19 ppm</td>
<td>6</td>
<td>6.16</td>
<td>0.64</td>
<td>10</td>
<td>3.07 - 11.90</td>
</tr>
<tr>
<td>Zn 14 ppm</td>
<td>6</td>
<td>93.33</td>
<td>5.76</td>
<td>6</td>
<td>59.80 - 131.22</td>
</tr>
<tr>
<td>Cr 11 ppm</td>
<td>7</td>
<td>200.50</td>
<td>8.32</td>
<td>4</td>
<td>106.99 - 349.87</td>
</tr>
<tr>
<td>Ni 20 ppm</td>
<td>6</td>
<td>53.09</td>
<td>1.72</td>
<td>3</td>
<td>24.74 - 75.73</td>
</tr>
<tr>
<td>Co 39 ppm</td>
<td>6</td>
<td>36.32</td>
<td>1.92</td>
<td>5</td>
<td>25.31 - 50.23</td>
</tr>
<tr>
<td>Mo 7 ppm</td>
<td>7</td>
<td>1.92</td>
<td>0.48</td>
<td>25</td>
<td>0.62 - 3.07</td>
</tr>
</tbody>
</table>

### TABLE IX
Summary of Data Quality: Combined Sample Preparation and Analytical Errors for Fire Assays

<table>
<thead>
<tr>
<th>ELEMENT DETECTION LIMIT</th>
<th>DUPLICATE PAIRS</th>
<th>$\bar{x}$</th>
<th>S&lt;sup&gt;b&lt;/sup&gt;</th>
<th>$\bar{S}/\bar{x}$&lt;sup&gt;c&lt;/sup&gt;</th>
<th>CONCENTRATION RANGE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au 0.020 o/t</td>
<td>3</td>
<td>0.067</td>
<td>0.016</td>
<td>23</td>
<td>0.032 - 0.094</td>
</tr>
<tr>
<td>Ag 0.020 o/t</td>
<td>8</td>
<td>0.105</td>
<td>0.038</td>
<td>36</td>
<td>0.04 - 0.24</td>
</tr>
</tbody>
</table>

a. $\bar{x}$ = Mean of original - duplicate samples.
b. S = Mean standard deviation of original - duplicate pairs.
c. $\bar{S}/\bar{x}$ = Mean relative error.
total mean relative errors for two concentration ranges. Higher errors for barium and potassium occur for higher concentration ranges where there is enrichment, whereas for arsenic a higher error occurs at a lower concentration range close to the laboratory detection limit. Errors cannot be determined for gold, antimony, tungsten, molybdenum, uranium, thorium, lanthanum and bismuth as most values are close to or below the laboratory detection limit.

The mean relative error of twenty-three percent for gold is based on only three samples because the other nine are close to or below the laboratory detection limit. Silver fire assays have a mean relative error of thirty-six percent based on eight samples. The high errors for gold and silver are probably related to a nugget effect.

The mean relative errors for major elements analyzed by XRF are less than two percent; for most minor elements they are less than seven percent. Errors for niobium, lead and molybdenum are greater because most values are near detection limits.

Comparison of original - duplicate results for ICP analyses with an aqua regia digestion indicates that for most elements reproducibility of results by resampling is adequate for the purposes of this study.
8.4 ICP - XRF COMPARISON

ICP analyses were compared to XRF analyses for 22 samples, using scatter plots, to determine the range of extraction during digestion by aqua regia. Prior to plotting, XRF analyses for oxides were converted to cation weight percent. The following elements were used in this comparison: Al, Ti, Fe, Mn, Mg, Ca, Na, K, P, Ba, Sr, Cu, Zn, Cr, Ni, Co and V. Scatter plots for barium, calcium, and zinc are given in Figure 23; the remaining scatter plots are in Appendix G.

ICP analyses were regressed on XRF analyses and a least squares line that passes through the origin was fitted to the data. The line and its equation are included on the scatter plots. A linear correlation coefficient for the ICP - XRF element pairs is also included. The slope of the regression line is an estimate of the average amount of an element extracted during aqua regia digestion. A summary of average extraction levels, extraction ranges and linear correlation coefficients are given in Table X.

All scatter plots were examined for obvious distribution patterns in XRF and ICP analyses. XRF analyses generally show two clusters of data; one for carbonatized basalt and one for noncarbonatized basalt. Concentrations of most elements in carbonatized basalt are generally less than or equal to those in noncarbonatized basalt. This is due to an apparent depletion caused by an increase in volume or by a true depletion. Examples of apparent depletion for calcium and zinc are shown in Figure
Figure 23. ICP analyses with an aqua regia digestion plotted against XRF total analyses for Ba, Ca and Zn. Regression line is dashed (X = noncarbonatized basalt; Δ = carbonate altered basalt).
**TABLE X**

Summary of Comparison of ICP Analyses with an aqua regia digestion to XRF analyses

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>LINEAR&lt;sup&gt;a&lt;/sup&gt; CORRELATION COEFFICIENT</th>
<th>AVERAGE&lt;sup&gt;b&lt;/sup&gt; EXTRACTION LEVEL (%)</th>
<th>EXTRACTION RANGE&lt;sup&gt;c&lt;/sup&gt; FOR NONCARBONATIZED BASALT (%)</th>
<th>EXTRACTION RANGE&lt;sup&gt;c&lt;/sup&gt; FOR CARBONATIZED BASALT (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>0.77</td>
<td>44</td>
<td>35-60</td>
<td>35-60</td>
</tr>
<tr>
<td>Ti</td>
<td>0.56</td>
<td>4</td>
<td>3-6</td>
<td>1-8</td>
</tr>
<tr>
<td>Fe</td>
<td>0.65</td>
<td>30</td>
<td>25-35</td>
<td>17-50</td>
</tr>
<tr>
<td>Mn</td>
<td>0.43</td>
<td>29</td>
<td>15-30</td>
<td>15-50</td>
</tr>
<tr>
<td>Mg</td>
<td>-0.10</td>
<td>26</td>
<td>10-20</td>
<td>10-65</td>
</tr>
<tr>
<td>Ca</td>
<td>0.60</td>
<td>46</td>
<td>30-45</td>
<td>30-65</td>
</tr>
<tr>
<td>Na</td>
<td>0.78</td>
<td>15</td>
<td>10-40</td>
<td>50</td>
</tr>
<tr>
<td>K</td>
<td>0.90</td>
<td>28</td>
<td>tr</td>
<td>tr-40</td>
</tr>
<tr>
<td>P</td>
<td>0.84</td>
<td>60</td>
<td>50-85</td>
<td>35-80</td>
</tr>
<tr>
<td>Ba</td>
<td>0.93</td>
<td>46</td>
<td>30-50</td>
<td>20-65</td>
</tr>
<tr>
<td>Sr</td>
<td>0.97</td>
<td>59</td>
<td>50-60</td>
<td>60-65</td>
</tr>
<tr>
<td>Cu</td>
<td>0.45</td>
<td>35</td>
<td>30-40</td>
<td>20-65</td>
</tr>
<tr>
<td>Zn</td>
<td>0.43</td>
<td>32</td>
<td>25-30</td>
<td>30-60</td>
</tr>
<tr>
<td>Cr</td>
<td>0.57</td>
<td>24</td>
<td>20-30</td>
<td>10-35</td>
</tr>
<tr>
<td>Ni</td>
<td>0.59</td>
<td>29</td>
<td>20-35</td>
<td>10-60</td>
</tr>
<tr>
<td>Co</td>
<td>0.18</td>
<td>22</td>
<td>15-25</td>
<td>7-40</td>
</tr>
<tr>
<td>V</td>
<td>0.82</td>
<td>35</td>
<td>25-40</td>
<td>25-45</td>
</tr>
</tbody>
</table>

---

<sup>a</sup> n = 22 (carbonatized basalt = 16; noncarbonatized basalt = 6).  
<sup>b</sup> Average extraction level (%) = (regression line slope x 100).  
<sup>c</sup> Amount of extraction (%) = [((ICP analysis)/(XRF analysis)) x 100].
23. Concentrations of barium and potassium in carbonatized basalt are greater than those in noncarbonatized basalt because of strong enrichment in these elements. An example for barium is given in Figure 23.

Element concentrations determined by ICP analyses are much lower than those determined by XRF analyses because of partial digestion by aqua regia. Extraction ranges for aluminum, titanium, phosphorous, strontium, chromium, and vanadium (Table X) are similar for carbonatized and noncarbonatized basalt. The extraction of titanium is particularly low due to the refractory nature of titanium oxides. Better extraction of elements in carbonatized basalt relative to noncarbonatized basalt may mask depletion noted in XRF analyses or indicate enrichment. Examples for zinc and calcium are given in Figure 23. Better extraction of the major carbonate forming elements calcium, magnesium and manganese (Table X) in carbonatized basalt is particularly noticeable. This is also noted to a lesser extent for iron, copper, zinc, cobalt and nickel (Table X). Therefore, ICP analyses with an aqua regia digestion should be used with caution for weakly enriched elements because better extraction in carbonatized basalt may give a misleading enrichment pattern. However, if there is strong enrichment or depletion as in potassium, barium and sodium, then ICP analyses with an aqua regia digestion will show these patterns well.
8.5 STATISTICS

A statistical study was performed for carbonatized basalt using the results of ICP analyses with an aqua regia digestion. Since gold extracted by aqua regia is below the 3 ppm ICP detection limit, fire assays for gold and silver were used. A chi square test showed that most elements have approximations of lognormal distributions; a few are nearly normal (Ni, Co, Mn, Fe, V, Ca, Al). Appropriate data were log-transformed and a matrix of linear correlation coefficients was generated for 26 elements (Appendix H). 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 in a dendrogram (Fig. 24).

Group 1 elements (K, Ba, B, Sr, Al, Zn, Pb, Na, Cu, Au, As) are characterized by enrichment or depletion in carbonate alteration envelopes. Group 2 elements (Cr, Ni, Mn, Mg, Ca, Fe, Co) may be redistributed with enrichment adjacent to veins and depletion in the outer portion of the envelopes. Group 3 elements (Ag, Bi, Sb, U, V, W, Ti, Cd) are mostly near or below detection limits. Some are enriched locally in alteration envelopes; the remaining elements lack discernable patterns.

8.6 APPLICABILITY TO EXPLORATION

Distribution patterns for all elements were examined for
Figure 24. Dendrogram showing grouping of elements in carbonatized basalt. Correlation measures were determined from a matrix of correlation coefficients (Appendix H) based on ICP analyses with an aqua regia digestion and gold-silver fire assays of 106 carbonatized samples (Appendix B).
enrichment in carbonate alteration envelopes surrounding gold-silver-bearing white quartz veins. Potassium, barium, boron and arsenic are strongly enriched. Silver, copper, lead, zinc and antimony are useful because of their association with gold in white quartz veins. Silver ICP analyses show some enrichment adjacent to veins in a few carbonate alteration envelopes; however, silver fire assays are erratic. Copper enrichment occurs adjacent to white quartz veins in most envelopes; lead, zinc and antimony in only a few. Gold fire assays also show some enrichment adjacent to gold-silver-bearing white quartz veins.

Thresholds for potassium, barium, boron, arsenic and silver in carbonatized basalt were determined from probability graphs (Sinclair, 1976). Thresholds were chosen at the 2nd and/or 98th cumulative percentiles of partitioned populations to isolate background from enriched values. Thresholds for copper, lead, zinc, gold and antimony in carbonatized basalt were chosen subjectively by examination of histograms and element profile plots.

Potassium data occur in three populations (Fig. 25). The upper population (A) corresponds to enrichment adjacent to veins; the intermediate (B) to enrichment away from veins; the lowest (C) to background in the outer portion of envelopes. The enriched populations for potassium are related to the presence of sericite, whereas the background is related to kaolinite. A threshold of 0.03 percent separates the enriched values from background values (Appendix H).

Barium, boron and silver data occur in two populations (Figs.
Figure 25. Probability graphs for 106 potassium values and 106 barium values from carbonatized basalt. Original data are plotted as black dots; open diamonds are estimated partitioning points; black triangles are check points obtained by ideal combination of partitioned populations. Inflection points are shown by small arrows. Estimated thresholds are explained in Appendix H.
25 and 26). The upper population (A) corresponds to strong enrichment near veins; the lower to background. The enriched population for barium is related to the presence of sericite, whereas the background is related to the presence of kaolinite. The enriched population for boron is probably related to tourmaline which was observed in the vicinity of the mine. The enriched population for silver is probably related to sulphides. Thresholds of 140 ppm for barium, 40 ppm for boron and 2.5 ppm for silver separate most of the enriched values from all of the background values (Appendix H). Thresholds of 90 ppm for barium, 20 ppm for boron and 1.5 ppm for silver separate most of the background values from all of the enriched values (Appendix H).

Arsenic data occur in four populations (Fig. 27). The two upper populations (A and B) correspond to enrichment adjacent to veins; the intermediate (C) to enrichment away from veins; the lowest (D) to background in the outer portion of envelopes. Population A is related to the presence of arsenopyrite, whereas population B is related to the presence of pyrite. Population C appears to be due to enrichment where pyrite is not abundant. A threshold of 15 ppm separates enriched values from background values (Appendix H).

Only one population can be identified for each of copper, lead and zinc. Thresholds were set at 30 ppm for copper, 10 ppm for lead and 40 ppm for zinc to separate enriched values from most background values.

Most gold and antimony values were below detection limits. Thresholds were set at 0.03 oz/t for gold and 4 ppm for antimony
Figure 26. Probability graphs for 106 boron values and 106 silver values from carbonatized basalt. Original data are plotted as black dots; open diamonds are estimated partitioning points; black triangles are check points obtained by combination of partitioned populations. Inflection points are shown by small arrows. Estimated thresholds are explained in Appendix H.
Figure 27. Probability graph for 106 arsenic values from carbonatized basalt. Original data are plotted as black dots; open diamonds are estimated partitioning points; black triangles are check points obtained by combination of partitioned populations. Inflection point is shown by small arrow. Estimated thresholds are explained in Appendix H.
to separate enriched values from background values.

Analytical profiles and thresholds for the gold-silver-bearing Jennie white quartz vein are illustrated in Figure 28. Enrichment in potassium, barium, boron and arsenic characterizes the carbonate alteration envelope surrounding the vein. Enrichment in gold and copper in carbonatized basalt adjacent to the vein correlates with their occurrence in the vein. Elevated antimony values occur in and adjacent to the stringer vein in the profile plot.

8.7 DISCUSSION

Enrichment in potassium, barium, boron and arsenic reflects geological processes that are an inherent part of carbonate alteration in basalt surrounding gold-silver-bearing white quartz veins at Erickson mine. In contrast, there appears to be no enrichment in potassium, barium and boron, and only sporadic enrichment in arsenic in carbonate alteration envelopes surrounding dolomite veins. Consequently, strong enrichment in potassium, barium, boron and arsenic is indicative of a carbonate alteration envelope that contains a potentially gold-silver-bearing white quartz vein. Enrichment in gold, silver, copper, lead, zinc and antimony in addition to potassium, barium, boron and arsenic suggests that an alteration envelope surrounds a gold-silver-bearing white quartz vein that contains pyrite, chalcopryite, tetrahedrite, sphalerite, arsenopyrite and galena.
Figure 28. Analytical profiles for carbonate alteration envelope surrounding the Jennie white vein. Location of noncarbonatized basalt (B), zones of carbonatized basalt (2A, 2B and 2C) and white quartz veins (V; JV = Jennie vein; V = stringer vein) are indicated. Gold profile is from fire assays, the remainder from ICP analyses with an aqua regia digestion (Appendix B). Scale on left shows sample intervals in metres. Values are plotted in the middle of each sample interval. Thresholds (T) separate enriched values from most background values.
CHAPTER 9. CONCLUSIONS AND RECOMMENDATIONS

9.1 CONCLUSIONS

This study has revealed much about the nature of carbonate alteration envelopes developed in basalt around gold-silver-bearing white quartz veins, carbon veins and dolomite veins at the Erickson mine. K-Ar dates from sericite in gold-silver-bearing white quartz veins indicate that mineralization occurred in the Early Cretaceous at about 130 Ma. Thus, these veins predate the mid-Cretaceous Cassiar batholith and Late Cretaceous and Early Tertiary plutons in the immediate area. However, the Early Cretaceous date probably represents a thermal event, precursor to emplacement of the Cassiar batholith, which may have caused circulation of the meteoric fluids responsible for the veins.

Carbonatized basalt around white quartz veins and carbon veins is composed of ankerite, siderite, quartz, sericite, pyrite and titanium oxides; kaolinite may be present in the outer portion of the envelopes. Disseminated carbon occurs in carbonatized basalt adjacent to carbon veins and some white quartz veins. Fracture-controlled carbon is common in the carbonatized basalt, but rare in noncarbonatized basalt. Carbonatized basalt around dolomite veins is composed of ankerite, siderite, dolomite, quartz, kaolinite, pyrite and titanium oxides.

An ideal carbonate alteration envelope consists of five
zones: outer carbonate, intermediate carbonate, inner carbonate, outer carbon and inner carbon. Most carbonate alteration envelopes around white quartz veins lack the carbon zones. The inner carbonate zone and the carbon zones are absent around dolomite 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 gold-silver-bearing white quartz veins.

Mass balance calculations indicate the following compositional changes around a gold-silver-bearing white quartz vein during carbonate metasomatism: gain of $\text{K}_2\text{O}$ and $\text{SiO}_2$; loss of $\text{Na}_2\text{O}$, $\text{Fe}_2\text{O}_3$ and $\text{MgO}$; and loss of $\text{CaO}$ from the outer portion of the envelope and gain in the inner. Loss on ignition and the alteration assemblage indicate gain of $\text{CO}_2$, $\text{H}_2\text{O}$ and $\text{S}$.

Comparison of ICP analyses with an aqua regia digestion to XRF analyses indicates that if there is strong enrichment in carbonate alteration envelopes surrounding gold-silver-bearing white quartz veins, the ICP analyses will show these patterns well.

Strong enrichment in potassium, barium, boron and arsenic is indicative of a carbonate alteration envelope that contains a potentially gold-silver-bearing white quartz vein. Enrichment in potassium, barium and boron is absent around dolomite veins; enrichment in arsenic sporadic. Enrichment in gold, silver, copper, lead, zinc and antimony, in addition to potassium, barium, boron and arsenic, suggests that an alteration envelope surrounds a gold-silver-bearing white quartz vein that contains
pyrite, chalcopyrite, tetrahedrite, sphalerite, arsenopyrite and galena.

9.2 RECOMMENDATIONS

9.2.1 Exploration Guidelines

A systematic examination of carbonate alteration envelopes for characteristics indicative of gold-silver-bearing white quartz veins may be undertaken by using the results of this 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 that a potentially gold-silver-bearing white quartz vein occurs within the envelope. Staining (Appendix J) of representative specimens of the inner portion of the envelope for dolomite and ankerite is useful. Presence of dolomite indicates a dolomite vein. The alteration envelope contains a potentially gold-silver-bearing white quartz vein if dolomite is absent.
3. Subdivide the alteration envelope into intervals of megascopically similar rock. Increase sample density in the inner portion of the envelope where most enrichment occurs. (Suggested sampling intervals are 0.5 m for the inner
carbonate zone and 1.0 m for the intermediate and outer carbonate zones.)

4. Analyze all samples for gold and silver by fire assaying and for potassium, barium, boron, arsenic, silver, copper, lead, zinc and antimony by ICP following an aqua regia digestion (Appendix B).

5. Plot results on graphs similar to those in Figure 28 and compare to thresholds. Enrichment in potassium, barium, boron and arsenic indicates that a potentially gold-silver-bearing white quartz vein is present. Enrichment in gold, silver, copper, lead, zinc and antimony indicates that minerals containing these elements are present in the vein.

6. If a gold-silver-bearing white quartz vein is present (samples are anomalous in potassium, barium, boron and arsenic), plot all gold, silver, copper, lead, zinc and antimony analyses from carbonatized rocks surrounding the vein on a longitudinal section. Drill targets are defined by clustering of anomalous samples, which may indicate an ore shoot.

9.2.2 Additional Research

This study has outlined the mineralogical and geochemical characteristics of carbonate alteration envelopes surrounding gold-silver-bearing white quartz veins. More detailed studies are required to investigate the relationship of element enrichment levels in carbonate alteration envelopes to ore shoots. Most
trace element enrichment occurs adjacent to veins in carbonatized basalt with abundant pyrite. Pyrite geochemistry should be examined particularly with regard to usefulness in delineating ore shoots. The source of carbon and its relationship to gold need to be determined. The distribution of carbonatized basalt throughout the McDame lode gold camp and its relationship to gold-silver-bearing veins need to be determined also.
REFERENCES


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Wanless, R.K., Stevens, R.D., Lachance, G.R., and Delabio, R.N.,


APPENDICES

A. SAMPLE DESCRIPTIONS FOR K-Ar DATING
B. ANALYTICAL DATA
C. SUMMARY OF ANALYTICAL METHODS
D. SUMMARY OF SAMPLE LOCATIONS AND ROCK TYPES
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F. SUMMARY OF MASS BALANCE CALCULATIONS
G. ICP - XRF COMPARISON
H. STATISTICS
I. EXAMPLE DIAMOND DRILL LOG
J. CHEMICAL STAINING METHODS

-130-
A. SAMPLE DESCRIPTIONS FOR K-AR DATING
SAMPLE DESCRIPTIONS

Sample 83-146 is a sericite separate from a rock consisting mostly of coarse grained white quartz and lesser pale green sericite (18%) that occurs as scattered fine flakes or in clusters. Clusters are composed of unoriented to radiating sericite with minor ankerite and quartz. Minor fine to medium grained pyrite (1%) and ankerite (1%) are scattered throughout the quartz. Sample is from a quartz stringer vein in the hanging wall of the Alison vein, on upper wall and back of the 28-17 drift Erickson mine (Fig. 3).

Sample 83-188 is a sericite separate from a rock consisting mostly of coarse grained white quartz with minor scattered carbonate altered wall rock fragments (8%), white sericite (2%) and traces of ankerite and pyrite. Sericite occurs as clusters of fine flakes that are unoriented to radiating. Sample is from a quartz vein in the footwall of Jennie vein, intersected in DDH 83-283 at 191.1 metres, Erickson mine (Fig. 3).

Sample 83-250 is a sericite separate from a rock consisting mostly of coarse to fine grained white quartz and fine grained ankerite intermixed in varying amounts. Both vein minerals are highly fractured and dirty looking under plane polarized light. Minor white sericite (2%) occurs as clusters of fine flakes within ankerite and less so quartz. Rare pyrite occurs as scattered grains. Carbon-rich wisps are locally common. Limonite staining occurs around some pyrite and carbon-rich wisps. Sample is from a quartz-carbonate vein near the Caitlin vein, intersected in DDH 83-333, at 36.2 metres Erickson mine (Fig. 3).

Sample 83-316 is a sericite separate from a loose aggregate of white sericite flakes with minor quartz (1%) and rare ankerite as scattered grains. It was obtained from a narrow lense of sericite on the margin of a white quartz vein exposed on the back of the 34-34 crosscut, 3400 level, near the 48 drift E, Taurus mine (Fig. 3).
B. ANALYTICAL DATA

B.1 XRF Analyses
B.2 LOI
B.3 ICP Analyses
B.4 Gold-Silver Fire Assays
B.5 Analytical Profiles
B.1 XRF Analyses
TABLE B-1

Abundance of major and selected trace elements for DDH 80-88 (Appendix D).
(major elements in weight percent, minor elements in ppm)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>38.84</td>
<td>39.55</td>
<td>41.82</td>
<td>48.19</td>
<td>52.60</td>
<td>46.81</td>
<td>47.90</td>
</tr>
<tr>
<td>A₁₂O₃</td>
<td>11.40</td>
<td>12.07</td>
<td>10.02</td>
<td>15.15</td>
<td>13.43</td>
<td>13.52</td>
<td>14.14</td>
</tr>
<tr>
<td>TiO₂</td>
<td>1.00</td>
<td>1.02</td>
<td>0.86</td>
<td>1.40</td>
<td>1.27</td>
<td>1.24</td>
<td>1.32</td>
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<tr>
<td>Fe₂O₃</td>
<td>8.69</td>
<td>8.93</td>
<td>8.97</td>
<td>10.61</td>
<td>10.38</td>
<td>10.87</td>
<td>11.33</td>
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<td>MnO</td>
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<tr>
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<td>1.24</td>
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<td>0.01</td>
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<td>2.11</td>
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<td>K₂O</td>
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<td>2.25</td>
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<td>95.20</td>
<td>96.19</td>
<td>96.71</td>
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Ba  547.61  668.18  595.51  110.29  312.08  69.98  43.72
Sr  167.55  151.59  131.84  35.52  29.87  113.19  139.39
Rb  170.69  184.60  139.83  12.57  36.57  6.07   4.01
Zr  73.89   70.75   64.92   88.68   81.41  83.06  87.58
V   307.04  322.55  293.02  390.78  390.94 323.51 323.05
Y   26.87   25.92   26.34   24.40   32.67  26.05  30.01
Nb  3.20    2.30    2.05    3.39    1.59   2.18   1.82
Cu  77.14   61.73   57.16   87.06   89.23  85.16  82.10
Pb  0.14    3.93    1.92    3.24    4.99   8.03   3.76
Zn  72.50   69.51   72.51   101.53  101.69 95.63  104.51
Cr  225.30  246.79  254.24  329.46  293.93 266.79 278.03
Ni  73.26   75.73   76.36   120.32  115.26 124.77 114.52
Co  36.83   38.08   40.44   53.55   55.30  44.19  45.18
Mo  1.61    1.62    1.12    1.03    2.34   1.64   0.33

a. LOI = Total loss on ignition at 550°C and 1000°C.
b. Analyses done at the Department of Oceanography, The University of British Columbia.
### Table B-2

Abundance of major and selected trace elements for DDH 82-212 (Appendix D).
(major elements in weight percent, minor elements in ppm)

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<th>82-212 MF-4</th>
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<th>82-212 MF-6</th>
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<tr>
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<tr>
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<td>0.10</td>
<td>0.11</td>
<td>0.16</td>
<td>0.17</td>
<td>0.18</td>
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<tr>
<td>MgO</td>
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<td>7.28</td>
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<td>8.81</td>
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<tr>
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<td>0.27</td>
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<tr>
<td>P2O5</td>
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<td>0.14</td>
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</tr>
<tr>
<td>LOI b</td>
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<td>8.24</td>
<td>9.94</td>
<td>10.64</td>
<td>5.98</td>
<td>7.82</td>
</tr>
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<td>96.77</td>
<td>96.03</td>
<td>95.97</td>
<td>97.19</td>
</tr>
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Ba 312.38 292.66 213.46 238.12 147.41 104.51
Sr 52.43 52.41 51.44 64.56 175.27 140.56
Rb 27.61 22.61 21.32 26.79 41.19 31.78
Zr 73.32 84.69 66.44 102.15 125.77 115.01
Y 240.03 296.11 253.17 400.52 419.59 410.64
Yb 27.07 31.60 24.24 36.58 34.95 35.20
Sm 2.29 2.71 1.51 3.00 3.88 4.36
Cu 121.36 73.22 46.07 64.76 93.97 100.47
Pb 4.84 2.37 7.28 3.52 1.85 3.07
Zn 92.56 101.64 98.84 111.76 146.37 131.22
Cr 147.17 189.31 189.91 185.16 165.53 158.10
Ni 36.45 38.87 39.81 45.15 75.21 67.41
Co 31.96 43.26 34.02 36.79 48.00 50.23
Mo 1.70 1.65 1.01 2.13 1.18 2.33

---

a LOI = Total loss on ignition at 550° C and 1000° C.
b Analyses done at the Department of Oceanography, The University of British Columbia.
### TABLE B-3

Abundance of major and selected trace elements for DDH 83-257 (Appendix D). (major elements in weight percent, trace elements in ppm)

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<tbody>
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<td>57.78</td>
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**a.** LOI = Total loss on ignition at 550° C and 1000° C.

**b.** Analyses done at the Department of Oceanography, The University of British Columbia.
TABLE B-4

Abundance of major and selected trace elements for duplicate analyses for DDH's 80-88, 82-212 & 83-257 (Appendices D & E).
(major elements in weight percent; minor elements in ppm)

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<th>80-88</th>
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</tr>
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<td>8.74</td>
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<td>0.01</td>
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<td>105.16</td>
<td>100.91</td>
<td>100.10</td>
<td>99.25</td>
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</table>

| Ba      | 550.46 | 649.09 | 93.82  | 155.54 | 395.06 | 964.14 | 72.76  |
| Sr      | 160.48 | 151.79 | 138.69 | 20.30  | 198.46 | 122.20 | 150.05 |
| Rb      | 162.04 | 188.26 | 33.27  | 16.44  | 48.71  | 108.50 | 1.60   |
| Zr      | 73.02  | 71.65  | 116.67 | 30.18  | 54.66  | 101.64 | 116.56 |
| V       | 312.73 | 309.44 | 407.88 | 45.95  | 252.10 | 408.84 | 471.01 |
| Y       | 28.07  | 27.46  | 34.74  | 1.98   | 20.72  | 35.60  | 37.64  |
| Nb      | 2.21   | 1.74   | 5.66   | 1.85   | 2.12   | 2.67   | 5.23   |
| Cu      | 74.26  | 62.51  | 96.69  | 24.41  | 14.51  | 60.38  | 55.44  |
| Pb      | 1.73   | 5.11   | 4.13   | 4.35   | 6.03   | 11.90  | 7.03   |
| Zn      | 66.36  | 71.00  | 126.14 | 115.97 | 29.62  | 63.16  | 97.79  |
| Cr      | 236.30 | 245.58 | 149.83 | 349.87 | 222.44 | 123.18 | 108.01 |
| Ni      | 69.63  | 74.14  | 62.46  | 14.40  | 26.89  | 30.57  | 49.67  |
| Co      | 33.45  | 37.51  | 46.62  | 5.94   | 26.60  | 26.93  | 39.91  |
| Mo      | 2.33   | 1.87   | 2.00   | 3.07   | 2.20   | 1.61   | 0.62   |

---

a. LOI = Total loss on ignition at 550° C and 1000° C.
b. Analyses done at the Department of Oceanography, The University of British Columbia.
B.2 LOI
<table>
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**NOTES:**
- **nd** = none detected
- **—** = not analysed
- **is** = insufficient sample
B.3 ICP Analyses
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### Notes

- **Sample**: DALE A Sketchley Project # Solution from VangoChem Job # 84-017
- **File**: D-0224
- **Page**: 3
| SAMPLE | No. | Ca | Pb | Zn | Ag | Au | Cu | Pb | Cd | Hg | Bi | Pb | Cr | Fe | Al | Ni | K |  |
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| 82-247-09-12 | 1 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| 82-247-09-13 | 1 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 |
| 83-001-FD-1 | 1 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 |
| 83-001-FD-2 | 1 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 |
| 83-001-FD-3 | 1 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 |
| 83-001-FD-4 | 1 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 |
| 83-001-FD-5 | 1 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 |
| 83-001-FD-6 | 1 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 |
| 83-001-FD-7 | 1 | 32 | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
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| 83-001-FD-17 | 1 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 |

**Sample Notes:**
- **DALE A SKETCHLEY PROJECT: SOLUTION FROM VANGEOCHEM JOB # 84-017 FILE # 84-0224**
- **PAGE 5**
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**DAILY ASSAY REPORT**

**ERICKSON GOLD MINING CORP.**

**JUNE 25 & 26, 1984**
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B.5 Analytical Profiles

-all fire assays recorded as trace are recoded as 0.02 o/t for profile plotting.

-abbreviations:

B = Basalt  
2C = Outer Carbonate Zone  
2B = Intermediate Carbonate Zone  
2A = Inner Carbonate Zone  
1B = Outer Carbon Zone  
1A = Inner Carbon Zone  
V = Vein  
C = Chert  
S = Silicified Chert and Siliceous Argillite
CARBONATE ALTERATION ANALYTICAL PROFILES

DDH - 77-44  NORHTING - 4278.00  EASTING -1776.50  ELEVATION - 1418.00  AZIMUTH - 180.0  DIP - -68.0  LENGTH - 83.27

MAJOR/TRACE ELEMENT ICP ANALYSES AND FA

K (%)  P (%)  LOI (%)  Au (o/t)  Ag (o/t)  Ag (ppm)

77.4  60.0  1.0  0.08  25.0  0.20  0.20  6.00
CARBONATE ALTERATION ANALYTICAL PROFILES
TRACE ELEMENT ICP ANALYSES

DDH - 77-44  NORTHING - 4278.00  EASTING -1776.50  ELEVATION - 1418.00  AZIMUTH - 180.0  DIP - -68.0  LENGTH - 83.27

As (ppm)  Sb (ppm)  Bo (ppm)  B (ppm)  Sr (ppm)
0  1200.00  0  24.00  0  600.00  0  80.00  0  200.00
CARBONATE ALTERATION ANALYTICAL PROFILES

DDH - 80-88
NORTHING - 4401.54
EASTING - 1702.28

Al (55) Ti (%) Fe (55)
0 0 6.00 0.12 0.80

MAJOR ELEMENT ICP ANALYSES

ELEVATION - 1276.50
AZIMUTH - 197.9
DIP - -48.7
LENGTH - 155.50

Mn (ppm) Mg (%) Co (55)
0 4000.00 0 6.00 0 16.00
CARBONATE ALTERATION ANALYTICAL PROFILES

As (ppm), Sb (ppm), Ba (ppm), B (ppm), Sr (ppm)

51.6

73.2
CARBONATE ALTERATION ANALYTICAL PROFILES

DDH - 82-222  NORTHING - 4585.47  EASTING -1891.71  ELEVATION - 1272.10  AZIMUTH - 27.7  DIP - -56.8  LENGTH - 128.93

As (ppm)  Sb (ppm)  Ba (ppm)  B (ppm)  Sr (ppm)

0  0  0  0  0  24.00  0  0  0  0  0  0  0  0  0  0  0  0  0  0  200.00

TRACE ELEMENT ICP ANALYSES
CARBONATE ALTERATION ANALYTICAL PROFILES

TRACE ELEMENT ICP ANALYSES

DDH - 82-228 NORTHING - 4544.32 EASTING - 1941.06 ELEVATION - 1299.97 AZIMUTH - 328.8 DIP - -62.5 LENGTH - 214.88

As (ppm) Sb (ppm) Bo (ppm) B (ppm) Sr (ppm)
CARBONATE ALTERATION ANALYTICAL PROFILES

DDH - 83-257  NORTHING - 4524.82  EASTING - 1856.95
K (55)  P (%)  LOI (%)
O 1.60 0 0.08 0 25.00

MAJOR/TRACE ELEMENT ICP ANALYSES AND FA

ELEVATION - 1205.56  AZIMUTH - 320.4  DIP - -27.1  LENGTH - 136.25

Au (o/t)  Ag (o/t)  Ag (ppm)
0 0 0.20 0 0.20 0 0.20 0
CARBONATE ALTERATION ANALYTICAL PROFILES

TRACE ELEMENT ICP ANALYSES

DDH - 63-257  NORTHING - 4524.82  EASTING - 1856.95  ELEVATION - 1205.56  AZIMUTH - 320.4  DIP - -27.1  LENGTH - 136.25

Cu (ppm)  Pb (ppm)  Zn (ppm)  Cd (ppm)  Cr (ppm)  Ni (ppm)  Co (ppm)

0 100.00 0 160.00 0 28.00 0 180.00 0 60.00 0 20.00
CARBONATE ALTERATION ANALYTICAL PROFILES

TRACE ELEMENT ICP ANALYSES

DDH - 83-257 NORTHING - 4524.82 EASTING - 1856.95 ELEVATION - 1205.56 AZIMUTH - 320.4 DIP - -27.1 LENGTH - 136.25

V (ppm) W (ppm) Mo (ppm) U (ppm) Th (ppm) Lo (ppm) Bi (ppm)
CARBONATE ALTERATION ANALYTICAL Profiles

DDH - 80-88  NORTHING - 4401.54  EASTING - 1702.28  ELEVATION - 1276.50  AZIMUTH - 197.9  DIP - -48.7  LENGTH - 135.90

CoO (%)  Na2O (%)  K2O (%)  P2O5 (%)  LOI (%)
CARBONATE ALTERATION ANALYTICAL PROFILES

MAJOR ELEMENT XRF ANALYSES

DDH - 82-212 NORTHING - 4576.40 EASTING - 1860.94 ELEVATION - 1203.09 AZIMUTH - 169.3 DIP - -7.0 LENGTH - 97.84

SiO₂ (%)  Al₂O₃ (%)  TiO₂ (%)  Fe₂O₃ (%)  MnO (%)  MgO (%)
CARBONATE ALTERATION ANALYTICAL PROFILES

MAJOR ELEMENT XRF ANALYSES

DDH - 82-212
NORTHING - 4576.40
EASTING - 1860.94
ELEVATION - 1203.09
AZIMUTH - 169.3
DIP - -7.0
LENGTH - 97.84

CoO (%)  No2O (%)  K2O (%)  P2O5 (%)  LOI (%)
O 12.00 0 4.00 0 0.16 24.00
O 4.00 0 4.00 0 0 24.00
O 0.16 0 4.00 0 0 24.00
O 12.00 0 4.00 0 0 24.00

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61.5
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CARBONATE ALTERATION ANALYTICAL PROFILES

DDH - 83-257
NORTHING - 4524.82
EASTING - 1856.95
ELEVATION - 1205.56
AZIMUTH - 320.4
DIP - -27.1
LENGTH - 136.25
C. SUMMARY OF ANALYTICAL METHODS

C.1 Sample Preparation
C.2 XRF Analyses
C.3 LOI
C.4 ICP Analyses
C.5 Fire Assays
C.1 Sample Preparation

Samples were crushed by jaw crusher and pulverized to -100 mesh or finer by a disc mill pulverizer.

C.2 XRF Analyses

Major element-oxide analyses were performed on fused glass discs whereas minor element analyses were performed on pressed powder pellets. Fused glass discs were prepared by fusing 0.4000 g of pulverized sample and 3.600 g of Spectroflux 105, in a platinum crucible at 1100 °C for 30 minutes. The sample was cooled and weight lost during fusion made up with Spectroflux 100. The sample was then remelted, mixed and poured into a mold.

Pressed powder pellets were prepared by mixing 3.0 g of pulverized sample with three drops of binding agent. This mixture was compressed by hand, in a stainless steel mold until it bound together forming a pellet. The pellet was covered with boric acid and compressed in a 10,000 kg hydraulic press for one minute.

Analyses were performed by a Philips PW 1400 X-Ray Spectrometer equipped with a 72 position automatic sample changer.

a. Spectroflux 100 is composed of 100% dilithium tetraborate.

b. Spectroflux 105 is composed of 47% dilithium tetraborate, 36.3% lithium carbonate and 16.3% lanthanum (III) oxide.
C.3 LOI

A 0.5 g pulverized sample was ignited at 550 °C for 30 minutes, cooled and then weighed (LOI 1). The residues of the first ignition were reignited at 1000 °C for 30 minutes, cooled and then reweighed (LOI 2). The weight lost during ignition was expressed as a percentage of the initial weight.

C.4 ICP Analyses

A 0.5 g pulverized sample, or the residues of the 1000 °C ignition, were digested with 3 ml of 3:1:3 HCl to HNO to H₂O, at 90 °C for one hour and then diluted to 10 ml with distilled water. Analyses were performed by using a Jarrell-Ash 0.75 meter grating ICAP instrument.

C.5 Fire Assays

A one-half assay ton (14.583 g) of pulverized sample was placed in a crucible with one scoop of standard flux, one-half tsp flour, one inquartz and one tsp of borax cover. The mixture was fused at 1060 °C for 45 minutes, cooled and glass removed from the lead button. The lead button was placed on a preheated cupel and left for 30 minutes at 970 °C. After cupellation the resulting gold-silver bead was hammered flat and weighed. If under 2.79 mg an appropriate amount of inquartz was added and the bead recupelled. It was then placed in diluted (16%) nitric acid
for 30 minutes to remove silver. The resulting gold bead was rinsed twice with deionized water, annealed to remove tarnish and weighed. Twice the weight is equivalent to the amount of gold in troy ounces per short ton. The first weight minus added in quartz and the gold bead, all doubled, is equivalent to the amount of silver in troy ounces per short ton.
D. SUMMARY OF SAMPLE LOCATIONS AND ROCK TYPES

-see Figure 6 to locate DDH collars

-abbreviations:

  B = Basalt
  2C = Outer Carbonate Zone
  2B = Intermediate Carbonate Zone
  2A = Inner Carbonate Zone
  1B = Outer Carbon Zone
  1A = Inner Carbon Zone
  V = Vein
  C = Chert
  S = Silicified Chert and Siliceous Argillite
DDH 77-44

(Jennie white quartz vein)

NORTHING = 4278.00N  EASTING = 1776.50E  ELEVATION = 1418.00M
AZIMUTH = 180.00°  DIP = -68.32°  LENGTH = 83.27M

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DDH 80-84

(Jennie white quartz vein)

NORTHING = 4399.88N  EASTING = 1522.22E  ELEVATION = 1399.11M
AZIMUTH = 201.84°  DIP = -47.96°  LENGTH = 144.50M

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DDH 80-88
(Jennie white quartz vein)

NORTHING = 4401.54N
EASTING = 1702.29E
ELEVATION = 1276.50M
AZIMUTH = 197.91°
DIP = -48.73°
LENGTH = 135.90M

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DDH 82-212

(McDame dolomite vein)

NORTHING = 4576.40N  EASTING = 1860.95E  ELEVATION = 1203.09M
AZIMUTH = 169.30°  DIP = -7.09°  LENGTH = 97.84M

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DDH 82-222

(carbonatized basalt and zone of silicified chert)

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AZIMUTH = 027.73°  DIP = -56.83°  LENGTH = 128.93M

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DDH 82-222

(Devine white quartz vein)

**NORTHING = 4585.48N**
**EASTING = 1891.72E**
**ELEVATION = 1272.11M**

**AZIMUTH = 027.73°**
**DIP = -56.83°**
**LENGTH = 128.93M**

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-237-
### DDH 82-228

(zone of chert, exhalite and basalt)

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## DDH 82-247

(Alison white quartz vein)

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EASTING = 1740.89E  
ELEVATION = 1447.27M

AZIMUTH = 168.33°  
DIP = -57.38°  
LENGTH = 245.97M

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TO  
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**DDH 83-257**

*(Devine? white quartz vein)*

NORTHING = 4524.82N  
EASTING = 1856.95E  
ELEVATION = 1205.56M  
AZIMUTH = 320.43°  
DIP = -27.12°  
LENGTH = 136.25

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ADDITIONAL DIAMOND DRILL HOLE INFORMATION

DDH 83-283
(Sample 83-188: sericite at 191.1M)
NORTHING = 4355.82N  EASTING = 1618.53  ELEVATION = 1279.23M
AZIMUTH = 175.37°  DIP = 12.20°

DDH 83-296
(Sample 83-327: pistachio green mottling at 33.5M)
NORTHING = 4331.34N  EASTING = 1569.54E  ELEVATION = 1279.84M
AZIMUTH = 339.40°  DIP = -34.82°

DDH 83-311
(Sample 83-322: emerald-green porphyroblast-like aggregates at 200M)
NORTHING = 4517.88N  EASTING = 2051.64E  ELEVATION = 1335.26M
AZIMUTH = 334.99°  DIP = 60.43°

DDH 83-333
(Sample 83-250: sericite at 36.2M)
NORTHING = 4011.90N  EASTING = 2045.02E  ELEVATION = 1500.00M
AZIMUTH = 142.70°  DIP = -44.77°
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<td>83-257-DF-3</td>
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<tr>
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<td><strong>(samples split after pulverizing)</strong></td>
</tr>
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<td>A4608A</td>
</tr>
<tr>
<td>A4615B</td>
<td>A4615A</td>
</tr>
<tr>
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<tr>
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<td>B8770A</td>
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<tr>
<td>B2622B</td>
<td>B2622A</td>
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<tr>
<td>FA Duplicate (samples split after pulverizing)</td>
<td>FA Original</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>-------------</td>
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<tr>
<td>77-44-JF-2(repeat)</td>
<td>77-44-JF-2</td>
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<td>83-001-FD-1(repeat)</td>
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F. SUMMARY OF MASS BALANCE CALCULATIONS
TABLE F-1

Compositional changes for the transformation of noncarbonatized basalt to carbonatized basalt. Based on volume change constraints (Fig. 18A). Results are in weight percent of parent rock (assumed parent rock is 80-88-JH-7). Absolute changes in parentheses are included to show the effects of volume changes. Volume factors ($F_v$) and specific gravities used in calculations are also included. Specific gravity of assumed parent rock is 2.95. Chemical analyses are contained in Appendix B, Table B-1.

<table>
<thead>
<tr>
<th>PARAMETER</th>
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<tr>
<td></td>
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<td>$SiO_2$</td>
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<tr>
<td>$Al_2O_3$</td>
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</tr>
<tr>
<td></td>
<td>(-2.24)</td>
</tr>
<tr>
<td>$TiO_2$</td>
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</tr>
<tr>
<td></td>
<td>(-0.32)</td>
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<tr>
<td>$Fe_2O_3$</td>
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</tr>
<tr>
<td></td>
<td>(-2.64)</td>
</tr>
<tr>
<td>$MgO$</td>
<td>0.01</td>
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<td></td>
<td>(-1.33)</td>
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<tr>
<td>$CaO$</td>
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<tr>
<td></td>
<td>(0.03)</td>
</tr>
<tr>
<td>$Na_2O$</td>
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<tr>
<td></td>
<td>(-1.81)</td>
</tr>
<tr>
<td>$K_2O$</td>
<td>3.35</td>
</tr>
<tr>
<td></td>
<td>(2.14)</td>
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<tr>
<td>Volatiles</td>
<td>(14.32)</td>
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<tr>
<td>$F_v(Al_2O_3)$</td>
<td>1.28</td>
</tr>
<tr>
<td>$F_v(TiO_2)$</td>
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<tr>
<td>$F_v(Zr)$</td>
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<tr>
<td>$F_v$ (average)</td>
<td>1.29</td>
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<tr>
<td>S.G.</td>
<td>2.92</td>
</tr>
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</table>
G. ICP - XRF COMPARISON

-abbreviations:

$X = \text{noncarbonatized basalt}$

$\Delta = \text{carbonatized basalt}$
REGRESSION SUMMARY

ICP = 0.0000 + 0.4387 XRF

Correlation Coefficient = 0.76783

N = 22

Altered & Unaltered Basalt
REGRESSION SUMMARY

ICP = \( 0.0000 + 0.0364 \times XRF \)

Correlation Coefficient = \( 0.56095 \)

\[ N = 22 \]

Altered & Unaltered Basalt
REGRESSION SUMMARY

$$ICP = 0.0000 + 0.2971 \times XRF$$

Correlation Coefficient = 0.65483

N = 22

Altered & Unaltered Basalt
REGRESSION SUMMARY
ICP = 0.0000 + 0.2885 XRF

Correlation Coefficient = 0.43468

N = 22

Altered & Unaltered Basalt
REGRESSION SUMMARY

ICP = 0.0000 + 0.2607 XRF

Correlation Coefficient = -0.1000

N = 22

Altered & Unaltered Basalt
REGRESSION SUMMARY

ICP = 0.0000 + 0.1498 XRF

Correlation Coefficient = 0.78120

N = 22

Altered & Unaltered Basalt
REGRESSION SUMMARY

ICP = 0.0000 + 0.2816 XRF

Correlation Coefficient = 0.90047

N = 22

Altered & Unaltered Basalt
REGRESSION SUMMARY

ICP = 0.0000 + 0.5965 XRF

Correlation Coefficient = 0.83751

N = 22

Altered & Unaltered Basalt
REGRESSION SUMMARY
ICP = .0000 + .5929 XRF

Correlation Coefficient = 0.97172

N = 22

Altered & Unaltered Basalt
REGRESSION SUMMARY

ICP = .0000 + .3466 XRF

Correlation Coefficient = .45469

N = 22

Altered & Unaltered Basalt
REGRESSION SUMMARY

ICP = 0.0000 + 0.2437 XRF

Correlation Coefficient = 0.57169

\( N = 22 \)

ICP CR [ppm]

XRF CR [ppm]

Altered & Unaltered Basalt
REGRESSION SUMMARY

ICP = 0.0000 + 0.2855 XRF

Correlation Coefficient = 0.59717

N = 22
REGRESSION SUMMARY

ICP = 0.0000 + 0.2200 XRF

Correlation Coefficient = 0.17985

N = 22

Altered & Unaltered Basalt
REGRESSION SUMMARY

$ICP = 0.0000 + 0.3518 \times XRF$

Correlation Coefficient = 0.81849

$N = 22$

Altered & Unaltered Basalt
H. STATISTICS
<table>
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<th>Element</th>
<th>Unit</th>
<th>n</th>
<th>Mean</th>
<th>Median</th>
<th>Standard Deviation</th>
<th>Coef. of Var.</th>
</tr>
</thead>
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<td>34.0</td>
<td>19.9</td>
<td>0.56</td>
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<tr>
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<td>ppm</td>
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<td>6.0</td>
<td>4.5</td>
<td>0.60</td>
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<td>ppm</td>
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<td>33.0</td>
<td>17.3</td>
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<td>0.6</td>
<td>0.4</td>
<td>0.89</td>
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<tr>
<td>Ni</td>
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<td>18.5</td>
<td>17.3</td>
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<td>Cd</td>
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<td>716.5</td>
<td>325.2</td>
<td>0.44</td>
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<td>3.2</td>
<td>1.1</td>
<td>0.34</td>
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<td>As</td>
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<td>250.4</td>
<td>395.6</td>
<td>1.77</td>
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<td>U</td>
<td>ppm</td>
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<td>3.0</td>
<td>2.6</td>
<td>0.79</td>
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<tr>
<td>Au</td>
<td>oz/t</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.00</td>
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<td>ppm</td>
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<td>0.0</td>
<td>2.0</td>
<td>0.00</td>
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<tr>
<td>Sr</td>
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<tr>
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<td>4.0</td>
<td>5.0</td>
<td>0.79</td>
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<tr>
<td>Cr</td>
<td>ppm</td>
<td>106</td>
<td>3.9</td>
<td>3.0</td>
<td>5.0</td>
<td>0.29</td>
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<td>Bi</td>
<td>ppm</td>
<td>106</td>
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<td>2.0</td>
<td>2.6</td>
<td>0.83</td>
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<tr>
<td>V</td>
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<tr>
<td>Ca</td>
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<td>3.6</td>
<td>3.4</td>
<td>1.3</td>
<td>0.36</td>
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<tr>
<td>P</td>
<td>ppm</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.00</td>
</tr>
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<td>La</td>
<td>ppm</td>
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<td>2.1</td>
<td>2.0</td>
<td>0.7</td>
<td>0.33</td>
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<tr>
<td>Cr</td>
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<td>Mg</td>
<td>ppm</td>
<td>106</td>
<td>1.7</td>
<td>1.4</td>
<td>1.1</td>
<td>0.61</td>
</tr>
<tr>
<td>Br</td>
<td>ppm</td>
<td>106</td>
<td>369.1</td>
<td>203.5</td>
<td>299.5</td>
<td>0.97</td>
</tr>
<tr>
<td>Ti</td>
<td>ppm</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.00</td>
</tr>
<tr>
<td>B</td>
<td>ppm</td>
<td>106</td>
<td>37.6</td>
<td>32.0</td>
<td>21.4</td>
<td>0.57</td>
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<tr>
<td>Al</td>
<td>ppm</td>
<td>106</td>
<td>2.9</td>
<td>2.0</td>
<td>0.9</td>
<td>0.29</td>
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<td>1.0</td>
<td>0.6</td>
<td>1.08</td>
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<tr>
<td>K</td>
<td>ppm</td>
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<td>1.5</td>
<td>1.2</td>
<td>0.7</td>
<td>1.19</td>
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<tr>
<td>W</td>
<td>ppm</td>
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<td>2.0</td>
<td>2.0</td>
<td>0.67</td>
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### TABLE H-2

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<th>GROUP</th>
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<th>K</th>
<th>Rb</th>
<th>Sr</th>
<th>Ca</th>
<th>Sr</th>
<th>Ba</th>
<th>Ca</th>
<th>Sr</th>
<th>K</th>
<th>Ba</th>
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<tr>
<td>I</td>
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<td>0.8596</td>
<td>0.8046</td>
<td>0.6326</td>
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<td>0.627</td>
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<tr>
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<td>1.0000</td>
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<td>0.1467</td>
<td>0.1467</td>
<td>0.2789</td>
<td>1.0000</td>
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</table>

Matrix of linear correlation coefficients for carbonate altered basalt.

1. n = 106 for all coefficients
2. r > 0.05, 105% = 170
3. Data with improper distribution was logtransformed.
Estimated thresholds for potassium ICP analyses with aqua regia digestion for carbonatized basalt (see Fig. 25 for probability graph).

<table>
<thead>
<tr>
<th>THRESHOLD CRITERIA</th>
<th>THRESHOLD</th>
<th>PRINCIPAL CONTENT OF RANGE</th>
<th>PERCENT OF TOTAL DATA</th>
<th>NUMBER OF SAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd/B</td>
<td>0.700 %</td>
<td>A</td>
<td>28</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A + B</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>98th/A</td>
<td>0.540 %</td>
<td>B</td>
<td>37</td>
<td>39</td>
</tr>
<tr>
<td>2nd/C &amp; 98th/D</td>
<td>0.030 %</td>
<td>C</td>
<td>31</td>
<td>33</td>
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</tbody>
</table>

Estimated thresholds for barium ICP Analyses with aqua regia digestion for carbonatized basalt (see Fig. 25 for probability graph).

<table>
<thead>
<tr>
<th>THRESHOLD CRITERIA</th>
<th>THRESHOLDS</th>
<th>PRINCIPAL CONTENT OF RANGE</th>
<th>PERCENT OF TOTAL DATA</th>
<th>NUMBER OF SAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd/B</td>
<td>140 ppm</td>
<td>A</td>
<td>48</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A + B</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>98th/A</td>
<td>90 ppm</td>
<td>B</td>
<td>38</td>
<td>40</td>
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</table>

Estimated thresholds for boron ICP analyses with aqua regia digestion for carbonatized basalt (see Fig. 26 for probability graph).

<table>
<thead>
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<th>THRESHOLD CRITERIA</th>
<th>THRESHOLDS</th>
<th>PRINCIPAL CONTENT OF RANGE</th>
<th>PERCENT OF TOTAL DATA</th>
<th>NUMBER OF SAMPLES</th>
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</thead>
<tbody>
<tr>
<td>2nd/B</td>
<td>40 ppm</td>
<td>A</td>
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<tr>
<td></td>
<td></td>
<td>A + B</td>
<td>44</td>
<td>47</td>
</tr>
<tr>
<td>98th/A</td>
<td>19 ppm</td>
<td>B</td>
<td>26</td>
<td>27</td>
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---

a. Percentile and population at which threshold chosen
**TABLE H-6**

Estimated thresholds for silver ICP Analyses with aqua regia digestion for carbonatized Basalt (see Fig. 26 for probability graph).

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>THRESHOLDS</th>
<th>PRINCIPAL CONTENT OF RANGE</th>
<th>PERCENT OF TOTAL DATA</th>
<th>NUMBER OF SAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd B</td>
<td>2.5 ppm</td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>98th A</td>
<td>1.5 ppm</td>
<td>A + B</td>
<td>20</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B</td>
<td>70</td>
<td>74</td>
</tr>
</tbody>
</table>

**TABLE H-7**

Estimated thresholds for arsenic ICP analyses with aqua regia digestion for carbonatized basalt (see Fig. 27 for probability graph).

<table>
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<tr>
<th>CRITERIA</th>
<th>THRESHOLDS</th>
<th>PRINCIPAL CONTENT OF RANGE</th>
<th>PERCENT OF TOTAL DATA</th>
<th>NUMBER OF SAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd B</td>
<td>430 ppm</td>
<td>A</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>2nd/C &amp; 98th/A</td>
<td>175 ppm &amp; 110 ppm</td>
<td>A + B, B + C</td>
<td>21, 10</td>
<td>22, 11</td>
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<tr>
<td>98th/B</td>
<td>110 ppm</td>
<td>C</td>
<td>54</td>
<td>57</td>
</tr>
<tr>
<td>2nd/D &amp; 98th/C</td>
<td>15 ppm</td>
<td>D</td>
<td>8</td>
<td>9</td>
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</table>

*a. Percentile and population at which threshold chosen*
I. EXAMPLE DIAMOND DRILL LOG
## PROJECT: EXAMPLE DIAMOND DRILL LOG

### GEOLOGICAL DESCRIPTION

<table>
<thead>
<tr>
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<th>LITHOLOGY</th>
<th>STRUCTURE</th>
<th>ALTERATION</th>
</tr>
</thead>
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<tr>
<td>0 - 5.0</td>
<td>Overburden</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.0 - 98.0</td>
<td>Basalt</td>
<td></td>
<td></td>
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<tr>
<td>5.0 - 90.0</td>
<td>unaltered</td>
<td>(description)</td>
<td></td>
</tr>
<tr>
<td>90.0 - 98.0</td>
<td>carbonate altered</td>
<td>(description)</td>
<td></td>
</tr>
<tr>
<td>90.0 - 96.0</td>
<td>carbonate zones</td>
<td>(description)</td>
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</tr>
<tr>
<td>96.0 - 98.0</td>
<td>carbon zones</td>
<td>(description)</td>
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<tr>
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<td>Quartz vein</td>
<td>(description)</td>
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<tr>
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<td>Basalt</td>
<td></td>
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<td>100.0 - 101.0</td>
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<td>101.0 - 108.0</td>
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<td></td>
</tr>
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<td>108.0 - 200.0</td>
<td>unaltered</td>
<td>EOH</td>
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<tr>
<td>200</td>
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**NOTE** - for carbonate zones the three columns refer to the outer, intermediate and inner zones
- for carbon zones the first two columns refer to the outer and inner carbon zones; the third column may be ignored or used for carbon veins
- intensity of fracture-controlled carbon is noted in structure
J. CHEMICAL STAINING METHODS
CHEMICAL REAGENTS

Dilute hydrochloric acid
Add 8-10 milliliters of concentrated HCl to 100 milliliters of demineralized water.

Alizarin Red S (sodium alizarin sulfonate) Solution
Dissolve 0.1 gram of alizarin red S in 100 milliliters of 0.2% HCL. Prepare the HCl solution by diluting 2 milliliters of concentrated HCl with 1000 milliliters of demineralized water.

5% Sodium Hydroxide Solution
Dissolve 5 grams of sodium hydroxide in 95 milliliters of demineralized water.

30% Sodium Hydroxide Solution
Dissolve 30 grams of sodium hydroxide in 70 milliliters of demineralized water.
PROCEDURE

1. Etch the material to be stained in dilute HCL. If the specimen effervesces briskly in the cold solution, allow it to react for about 3 minutes. Aragonite (CaCO$_3$), calcite (CaCO$_3$), and witherite (BaCO$_3$) react in this manner. Ankerite [Ca(Fe,Mg,Mn)(CO$_3$)], cerussite (PbCO$_3$), rhodochrosite (MnCO$_3$), smithsonite (ZnCO$_3$), and strontianite (SrCO$_3$) are poorly reactive with cold acid. Dolomite [CaMg(CO$_3$)$_2$], magnesite (MgCO$_3$) and siderite (FeCO$_3$) are inert in cold solutions. Etch nonreactive specimens with hot dilute HCL for 30 seconds prior to staining.

2. Cover the etched surface with cold alizarin red S solution and allow it to react for about 5 minutes. Pour off the solution and wash the etched surface carefully by decantation. Calcite, witherite, high magnesium calcite and aragonite stain a deep red. Ankerite and ferroandolomite, strontianite and cerussite are stained purple, while anhydrite (CaSO$_4$), siderite, dolomite, rhodochrosite, magnesite, smithsonite and gypsum (CaSO$_4$$\cdot$2H$_2$O) do not stain at all.

3. Repeat step 2 test using equal volumes of the alizarin red S and 30% sodium hydroxide solutions. Boil for 5 minutes. The minerals that were previously unstained by the alizarin red S solution will all be stained except for anhydrite, which remains unaltered. Siderite is stained a dark brown to black. Dolomite, rhodochrosite, magnesite, gypsum and smithsonite stain purple.
4. To further differentiate dolomite, rhodochrosite, magnesite, gypsum and smithsonite, boil the material in a solution made of equal volumes of alizarin red S and 5% sodium hydroxide solutions. Dolomite and rhodochrosite remain unstained while magnesite, gypsum and smithsonite stain purple.

5. The ankerite and ferroandolomite, cerussite and strontianite that stained purple in the alizarin red S solution become stained dark purple, dark red-brown and unstained respectively when boiled for 5 minutes in the alizarin red S and 30% sodium hydroxide solutions.