

THE SIXTEEN-TO-ONE EPITHERMAL SILVER-GOLD DEPOSIT,
ESMERALDA COUNTY, NEVADA:
A WALL ROCK ALTERATION AND FLUID INCLUSION STUDY

by

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TABLE OF CONTENTS

	Page
LIST OF ILLUSTRATIONS.....	vi
LIST OF TABLES.....	viii
ABSTRACT.....	ix
1. INTRODUCTION.....	1
Current Research.....	1
Previous Geological Investigations.....	4
2. REGIONAL AND LOCAL GEOLOGICAL SETTINGS.....	5
Regional Geology.....	5
Structure.....	9
District Mineral Deposits.....	9
Geology of the Sixteen-to-One Deposit.....	10
Mine Geology.....	10
The Sixteen-to-One Vein System.....	13
3. ALTERATION STUDY.....	17
Method of Study.....	17
Stratigraphy.....	22
Andesite.....	22
Rhyolite.....	25
Volcanic Breccia.....	27
Alteration Assemblages - Descriptions.....	28
Regional Alteration - Mineralogy.....	29
Vein-Controlled Alteration - Fracture Filling and Metasomatism.....	35
Vein-Controlled Alteration - Mineralogy.....	35
4. FLUID INCLUSION STUDY.....	48
Method of Study.....	49
Inclusion Descriptions.....	50
Observations.....	50
Homogenization Temperatures.....	50
Homogenization Temperatures Versus Melting Temperatures.....	53
Crushing Experiments.....	56

TABLE OF CONTENTS — CONTINUED

	Page
5. DISCUSSION AND INTERPRETATIONS.....	58
Discussion of Alteration Assemblages.....	58
Regional Alteration.....	58
Vein-Controlled Alteration.....	60
Relationships Between Alteration Assemblages and the Vein System.....	64
Interpretation of Fluid Inclusion Observations.....	65
Homogenization Versus Melting Temperature Patterns.....	65
Sixteen-to-One Trends.....	66
Overall Pattern.....	67
Enthalpy Versus Salinity.....	69
Comparisons With Geothermal Systems.....	72
Epithermal Silver Deposition.....	76
Proposed Sixteen-to-One Model.....	77
6. SUMMARY AND CONCLUSIONS.....	82
Alteration.....	82
Significance of Wall Rock Alteration.....	83
Fluid Inclusions.....	83
7. APPENDIX A: REGIONAL ALTERATION.....	85
APPENDIX B: VEIN-CONTROLLED ALTERATION.....	90
APPENDIX C: FLUID INCLUSION DATA.....	97
REFERENCES.....	100

LIST OF ILLUSTRATIONS

Figure	Page
1. Location Map of the Sixteen-to-One Deposit, Esmeralda County, Nevada.....	2
2. Geologic Map of the Silver Peak Volcanic Center, Esmeralda County, Nevada (from Robinson 1972).....	7
3. Geologic Map of Sixteen-to-One Canyon, Esmeralda County, Nevada (from Keith 1977).....	11
4. Cross Section of the Sixteen-to-One and Colorado Veins.....	18
5A. Plan View of Underground Sample Locations.....	19
5B. Plan View of Surface Sample Locations.....	21
6. Cross Section Illustrating Lithologies Encountered During Sampling.....	23
7. Propylitic Alteration of Groundmass and Olivine by Chlorite, and Calcite With Lesser Chlorite, Respectively.....	32
8. Irregular Calcite Masses Rimmed by Fibrous Chlorite.....	33
9. Web-like Vein Texture.....	40
10. Clear Anhedral Quartz Masses Grading to a Web-like Vein Texture.....	40
11. Anhedral Quartz Mass With Silicified Rim.....	42
12. "Snowflake" Quartz.....	42
13. Chlorite Spicules in Anhedral Quartz Mass.....	44
14. Masses of Chlorite Spicules Replacing Plagioclase.....	44
15. Zoisite Crystals in Anhedral Quartz Mass.....	46
16. Nontronite With Quartz Replacing Potassium Feldspar.....	47

LIST OF ILLUSTRATIONS -- CONTINUED

Figure	Page
17. Histogram of Primary Fluid Inclusion Homogenization Temperatures for Each Level.....	51
18. Histogram of Primary Fluid Inclusion Homogenization Temperatures.....	54
19. Primary Fluid Inclusion Homogenization Versus Melting Temperature Diagrams for Each Level.....	55
20. Enthalpy Versus Salinity Diagram.....	70
21. Mineral Stability Diagrams for Calcium and Potassium Minerals, Broadlands, New Zealand (from Browne and Ellis 1970).....	75
22. Alteration, Fluid Inclusion, and Mineralization Summary Diagram.....	80

LIST OF TABLES

Table	Page
1. Stratigraphic and Age Relations of Volcanic Units and Hydrothermal Events, Silver Peak Range, Nevada (after Robinson, 1972).....	6
2. Regional Alteration.....	30
3. Vein-Controlled Alteration.....	37
4. Fluid Inclusion Data.....	52

ABSTRACT

Fluid inclusion and wall rock alteration data from the Sixteen-to-One deposit indicate precious metals precipitated in response to temperature decrease resulting from fluid mixing and boiling. Fluid temperatures and salinities varied from 145° to 225°C and from 3.5 to 11.5 wt% NaCl equivalent, respectively; fluids decrease an average of 40°C and 1.4 wt% NaCl equivalent over an elevation increase of 130 meters. Homogenization temperatures and salinities become more variable in upper levels coincident with increased precious metal abundances. Fluids contained variable amounts of CO₂.

Fracturing and open space filling are the most important wall rock changes produced by the hydrothermal event; metasomatism is minor. Vein-controlled alteration minerals include primarily quartz with lesser calcite, chlorite, pyrite, adularia, epidote, and montmorillonite, and trace white micas; zoning is typical of that present in active geothermal systems. Observed enthalpy-chloride relationships are consistent with mixing of deep, 225°C fluids and shallow, 93°C fluids.

CHAPTER 1

INTRODUCTION

The Sixteen-to-One epithermal vein system formed in southwestern Nevada, during a five million-year-old (Keith, Silberman, and Erd 1976), calc-alkaline volcanic event. Hydrothermal fluids invaded recently erupted caldera-related andesites and rhyolites and deposited precious metals in ore-grade abundances. The deposit is located in the Silver Peak Range, southwestern Esmeralda County, near the town of Silver Peak, Nevada (Figure 1). Sunshine Mining Company developed the deposit and began mining in 1982. Current mining removes 840 tons of ore per day averaging 6 oz/t (187 g/t) silver and 0.03 oz/t (0.93 g/t) gold (Earnest, private communication 1986).

Current Research

The principal objectives of this study were to characterize the mineralizing fluids and to determine those physical and chemical changes in the system responsible for precious metal precipitation. The Sixteen-to-One deposit provided an excellent opportunity to pursue these objectives through examination of an economic, epithermal precious metal system and by comparison of this deposit with active geothermal systems (Browne and Ellis 1970, Browne 1978, Keith, White, and Beeson 1978) and with current epithermal models (Buchanan 1981).

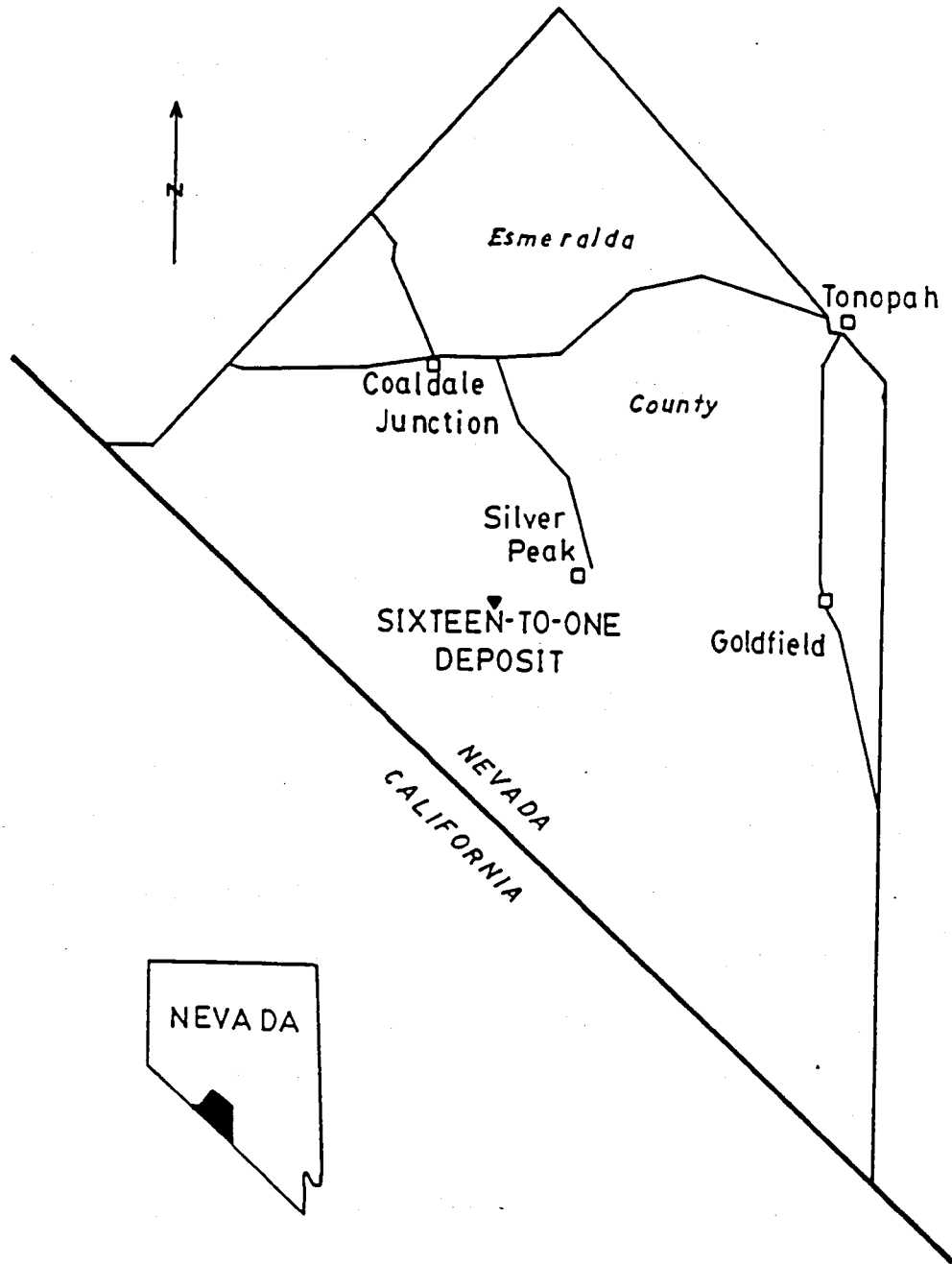


Figure 1. Location Map of the Sixteen-to-One Deposit, Esmeralda County, Nevada.

The recently opened mine provided access to the vein system to a depth of 230 meters. Underground workings, which intersect the vein on six levels, permitted examination of vertical changes within the system including variations in precious metal abundances, alteration mineralogy, and vein width. The deposit also provided an opportunity to examine the effects of the hydrothermal fluid on various volcanic wallrock lithologies. The underground ramp system and numerous cross-cuts permitted sample collection at regular distances perpendicular to the vein and enabled the study of lateral alteration effects resulting from fluid penetration of the wall rocks.

Methods of investigation consisted of wall rock alteration and fluid inclusion studies. Alteration samples included vein hanging and footwall rocks collected from the Sixteen-to-One and Colorado veins in surface exposures, underground mine workings, and the spiral ramp system which provides mine access. Mine level numbers refer to elevations in feet; ramp samples are similarly referenced. Samples were examined using a combination of transmitted and reflected light petrography and X-ray diffraction.

Vein samples for fluid inclusion work were collected from drill core, underground mine workings, and the underground ramp system. Inclusions were analyzed on an SGE, Inc. gas-flow heating and freezing stage; selected inclusions were crushed for qualitative CO₂ determinations.

Previous Geological Investigations

Initial geological reconnaissance of the Red Mountain Mining District began in the late 1800's with investigations by Spurr (1903, 1906) and Turner (1909). Albers and Stewart (1972) provide the most recent summary of regional geology and mineral deposits of Esmeralda County. Detailed stratigraphy of the Silver Peak region and petrology of the Silver Peak volcanic center are described by Robinson, McKee, and Moiola (1968) and Robinson (1972), respectively.

The geology in the vicinity of the Sixteen-to-One deposit has been mapped and described by Keith (1977). Mine geology has been most thoroughly reported by Earnest (1984); Nelson (1984) provides detailed information about vein mineralogy.

CHAPTER 2

REGIONAL AND LOCAL GEOLOGICAL SETTINGS

Regional Geology

The mining district is floored by a sequence of Precambrian and lower Paleozoic marine sedimentary rocks which have been intruded and deformed by Jurassic and Cretaceous plutons. Tertiary volcanic rocks overlying this basement are alkaline and potassic, and are part of a late Tertiary volcanic province in western Nevada and eastern California that is chemically distinct from the rest of the Basin and Range (Robinson 1972).

The volcanic history of the Silver Peak volcanic center has been interpreted and described by Robinson (1972). Volcanism began about 22 m.y. ago with deposition of a voluminous rhyolite tuff (Table 1, Figure 2). Andesite flows, breccias, tuffs, and related sediments overlie this tuff and are locally propylitized and silicified. A few small trachybasalt flows accompanied andesite deposition. Post-andesite Basin and Range faulting created large basins which filled with thick sequences of fluviatile and lacustrine sedimentary rocks. These fine grained lake sediments exhibit thicknesses to 9000 feet.

The Silver Peak volcanic center resumed activity during late Miocene time when potassic lavas were erupted during a 1 to 1.5 m.y. period. Composition of these lavas ranged from rhyolite to trachybasalt. Radial distribution and outward dip of the volcanic rocks

Table 1. Stratigraphic and Age Relations of Volcanic Units and Hydrothermal Events, Silver Peak Range, Nevada (after Robinson, 1972).

Basalt and latite flows, dikes, and plugs	4.8 \pm 0.6 my (1)
Intracaldera sediments	
<u>Hydrothermal alteration and silver mineralization</u>	5.0 \pm 0.2 my (2)
Latite flows and ash flow tuffs	6.1 \pm 0.3 my (1)
Propylitic alteration (?)	
Trachyandesite to quartz latite flows and domes	5.9 \pm 0.2 my (1)
Rhyolite flows and domes; <u>unit contains</u> <u>Sixteen-to-One volcanic host rocks</u>	
Caldera collapse	
Rhyolite air fall tuff	6.0 \pm 0.5 my (1)
Fluviatile and lacustrine sedimentation	
Basin and range faulting	
Andesite flows, breccias, and tuffs	
Rhyolite ash flow tuff	approx. 22 my

1 K-Ar dates in million years by Robinson, McKee, and Moiola, 1968.

2 K-Ar date in million years by Keith, Silberman, and Erd, 1976.

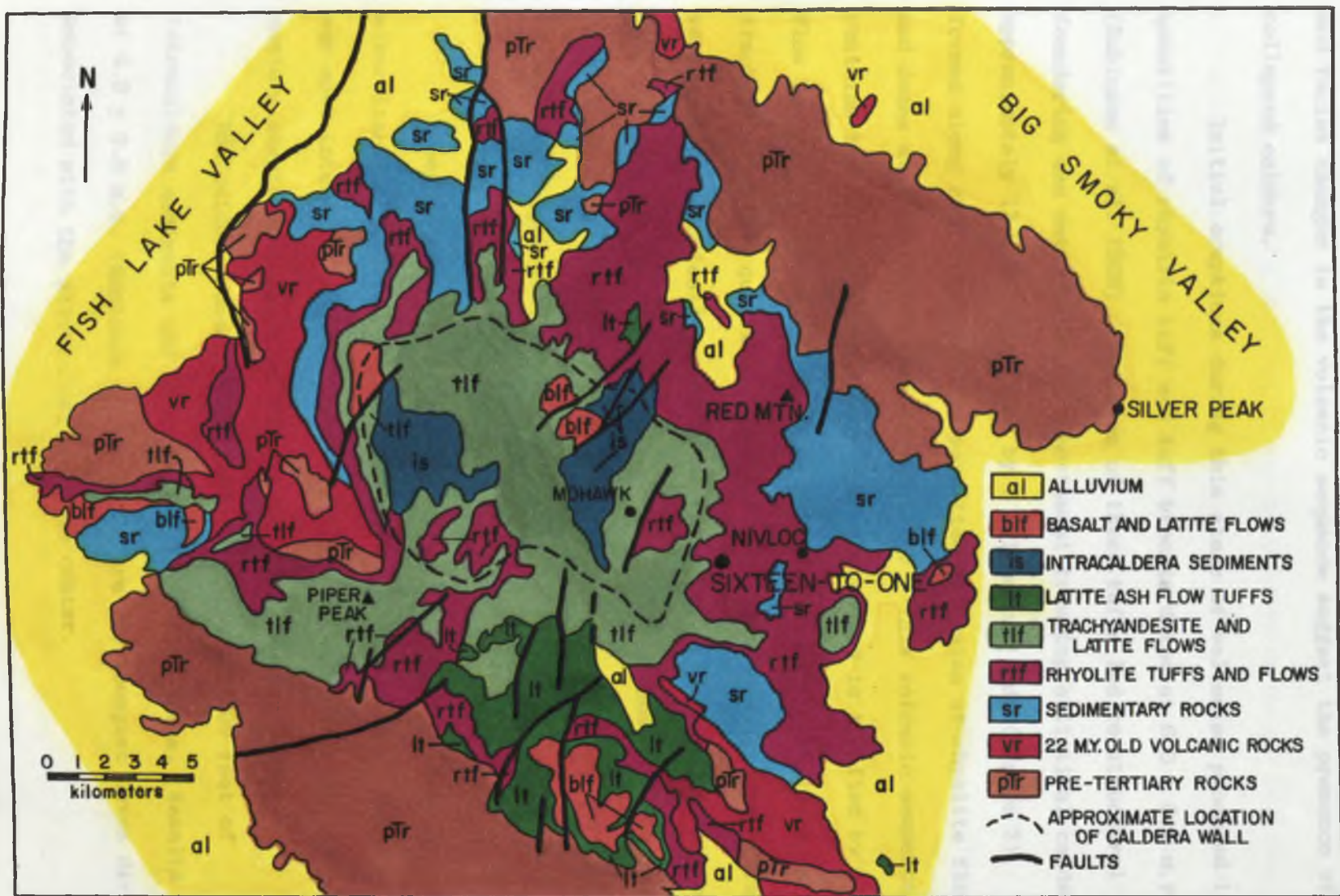


Figure 2. Geologic Map of the Silver Peak Volcanic Center, Esmeralda County, Nevada (Robinson, 1972).

and facies changes in the volcanic sequence suggest the presence of a collapsed caldera.

Initial eruptions during this stage of volcanism produced large quantities of rhyolite tuff and tuff breccia dated at 6.0 ± 0.5 m.y. (Robinson et al. 1968). Eruption of these tuffs led to structural foundering and development of a northwest trending elliptical caldera approximately 13 kilometers long by 7 kilometers wide (Figure 2). Vents formed along ring fractures and permitted extrusion of rhyolite flows and domes at and beyond the caldera walls. This volcanic sequence contains the Sixteen-to-One epithermal system and is typified by steep flow banding and abundant fragments of older andesite. Voluminous trachyandesite and quartz latite flows, also extruded from ring fracture vents, stratigraphically overlie the rhyolites. The latites have been dated at 5.9 ± 0.2 m.y. (Robinson et al. 1968) and host other epithermal mineral deposits within the district. Volcanism continued with eruption of coarsely porphyritic latite flows and ash flow tuffs dated at 6.1 ± 0.3 m.y. (Robinson et al. 1968).

A period of intense hydrothermal alteration and local silver mineralization closely followed extrusion of the latites. Alteration was most intense in the north-central part of the caldera and along the eastern margin where most of the productive veins are located.

The caldera subsequently filled with nearly 800 feet of intracaldera sediments and minor basalt and latite flows. Basalts dated at 4.8 ± 0.6 m.y. (Robinson et al. 1968) are the youngest lavas directly associated with the Silver Peak volcanic center.

Structure

Structures within the Silver Peak volcanic center have been attributed to different tectonic forces by various workers. Albers (1967) and Albers and Stewart (1972) discuss the Silver Peak-Palmetto-Montezuma "oroflex" or arcuate trend produced by tectonic bending of the crust. Oroclinal flexuring in the region between the northeast trending Death Valley-Furnace Creek fault zone and Walker Lane lineament, occurred in response to the "building of stresses" within the block. Robinson et al. (1968) and Robinson (1972) propose that a collapsed caldera exists within the Silver Peak volcanic center and that major faults within the district are part of its ring fracture system. Keith (1977) further suggests that the northeast trending structures containing epithermal mineralization (heavy lines, Figure 2) formed during northwest-southeast crustal extension resulting from caldera-related subsidence.

District Mineral Deposits

Significant production within the district has been reported from two epithermal vein deposits in addition to the Sixteen-to-One system. The Nivloc mine, (Figure 2) located 2.4 km east of the Sixteen-to-One mine, produced between \$2 and \$3 million between 1937 and 1943. Ore mined to depths of nearly 400 meters averaged 11 oz/t (342 g/t) silver and 0.05 oz/t (1.56 g/t) gold. The Mohawk mine, located west of the Sixteen-to-One mine, within the caldera margin, was most productive in the late 1950's when ore averaging 20 to 25 oz/t (622 to 778 g/t) silver was mined to a depth of 183 meters. Lead, zinc, and copper were also produced (Albers and Stewart 1972, Keith 1977). Intermittent

production continued through 1982 and total production is reported at 106,500 tons ore averaging 18 oz/t (560 g/t) silver (Earnest 1984). Additional vein systems located northwest of the more productive deposits, have been minor silver producers. All deposits exhibit the same general geology and were localized within northeast trending, steeply dipping fault zones.

Geology of the Sixteen-to-One Deposit

The Sixteen-to-One vein system is located within the Silver Peak volcanic center, approximately 1.6 km east of the southeastern caldera margin (Figure 2).

Mine Geology

The oldest surface rocks in the mine area are sedimentary breccias which contain large Paleozoic rock fragments and exhibit textures suggesting a fanglomeratic origin. A camel bone found near the base of the breccia identifies the unit as Miocene in age (Robinson et al. 1968). Fine grained lake sediments were deposited with angular discordance on the breccias and were subsequently tilted.

Lithologies encountered within the mine unconformably overlies the lake sediments and include various andesite and rhyolite flows, tuffs, and breccias. These rocks are part of the succession Robinson (1972) grouped as "rhyolite flows and domes" (Table 1). A series of latitic tuffaceous sediments and flows cap the ridge above the mine area and are correlative with Robinson's "trachyandesite to quartz latite flows and domes." Keith (1977) mapped the mine area (Figure 3) and defined the following stratigraphy.

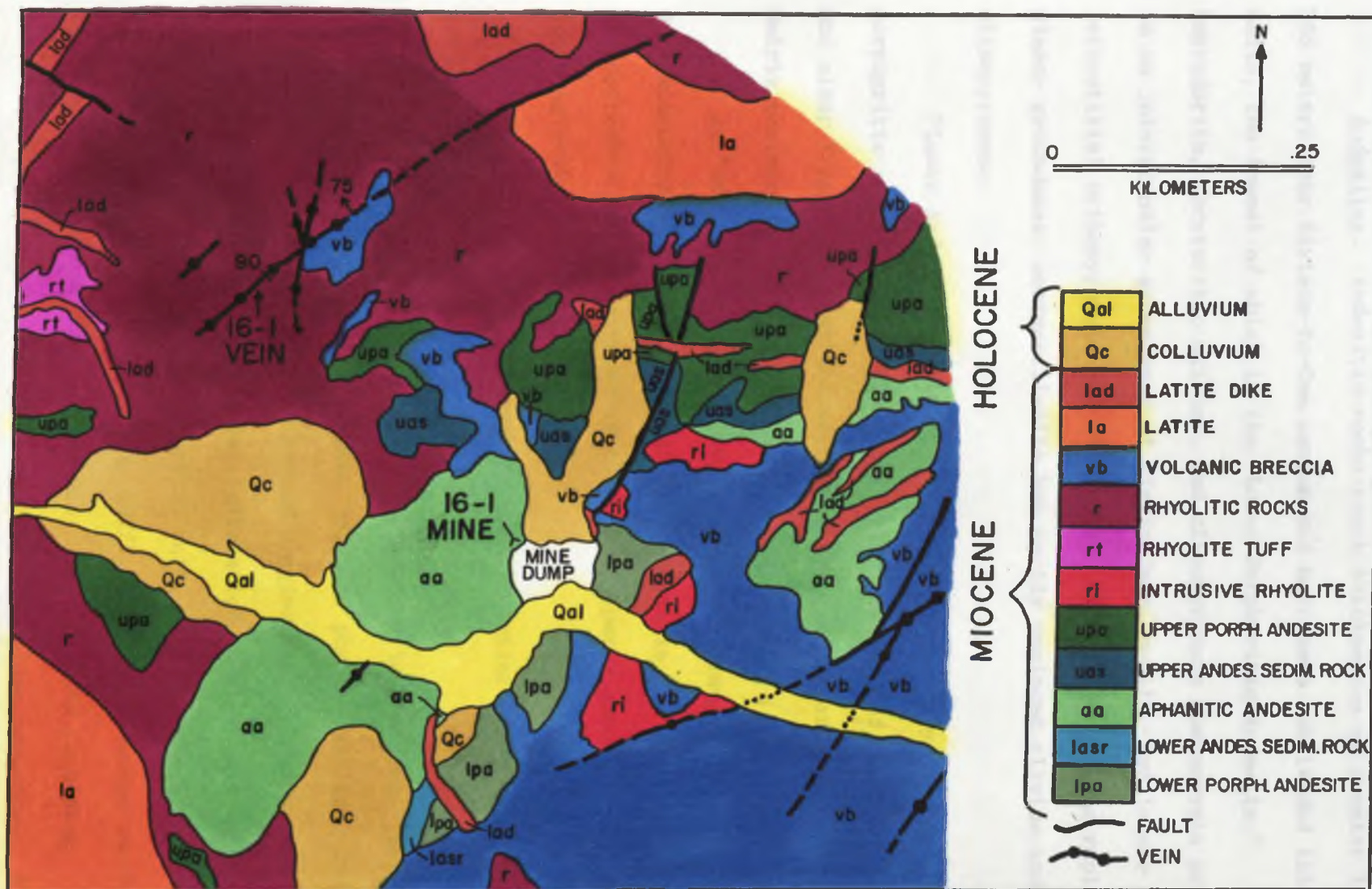


Figure 3. Geologic Map of Sixteen-To-One Canyon, Esmeralda County, Nevada (from Keith 1977).

Andesites. Andesitic rocks reach thicknesses of greater than 245 meters near Sixteen-to-One canyon and have been subdivided into five units, the lowest of which is the "Lower Porphyritic Andesite." Labradorite, forsteritic olivine, and clinopyroxene phenocrysts are set in an intergranular groundmass of plagioclase, augite, and lesser interstitial orthopyroxene and magnetite. Minor chlorite has replaced glassy groundmass; montmorillonite has partly replaced olivine and clinopyroxene.

"Lower Andesitic Sedimentary Rocks" conformably overlie the porphyritic andesite and contain andesite, pumice, and quartz fragments and minor fragmental plagioclase, limestone, and granite. Detrital matrix contains illite, kaolinite, and quartz.

An "Aphanitic Andesite" overlying the sedimentary rocks consists of a microcrystalline mat of plagioclase crystals and interstitial orthopyroxene(?), now altered to chlorite. Sparse xenocrysts of quartz and plagioclase may be present.

"Upper Andesitic Sedimentary Rocks" similar to the lower sedimentary unit overlie the aphanitic andesite.

An "Upper Porphyritic Andesite" similar to the lower porphyritic unit overlies the sedimentary rocks. Similar phenocrysts are contained in a pilotaxitic groundmass containing plagioclase, 7 to 10% magnetite, and minor ferromagnesian minerals. Alteration in this unit is somewhat stronger than in the lower porphyritic unit.

Rhyolites. Rhyolite flows, tuffs, and flow breccias reach thicknesses of greater than 180 meters. Fine grained rhyolites occasionally show intrusive relationships with older sequences. Flows

contain quartz and alkali feldspar and commonly contain well-developed perlitic fractures. Tuffs consist of interlayered crystal and lithic air-fall sequences containing pumice and lithic fragments, quartz, and minor lithophysae. Small intrusives are frequently porphyritic and contain biotite, quartz, feldspar, and andesite xenoliths.

Volcanic Breccia. A matrix-supported breccia containing fragments of andesite and rhyolite, and minor pumice and Paleozoic rocks is found interbedded with upper andesites and lower rhyolites. The unit is probably laharic in origin although local vent breccias indicate some complexities.

Latites. Latitic tuffaceous rocks and flows stratigraphically overlying the rhyolites have been dated at 5.9 ± 0.2 m.y. This unit caps the ridge above the mine and hosts the Mohawk deposit located west of the Sixteen-to-One deposit.

The Sixteen-to-One Vein System

Structurally, the Sixteen-to-One vein conforms with other mineralized veins in the district. Strike varies from $N40^{\circ}$ to $70^{\circ}E$ and dips are close to vertical (Figure 3). Most veins in the district dip northwest; the Sixteen-to-One commonly dips 75° SE but locally varies through vertical to 75° NW. Vertical displacement on the vein is unknown, but has been estimated at 60 meters. The vein widens from about 3 meters in surface outcrop at 7330 feet, to a maximum of about 18 meters on the 7000 and 6890 levels.

Adularia from altered wallrock adjacent to the vein has been dated at 5.0 ± 0.2 m.y. (Keith et al. 1976). This date places the mineralization within one million years of the age of the volcanic rocks

containing the deposit and suggests a single heat source was responsible for the generation of both (Table 1).

Two additional veins, the Colorado and Montana, split from the Sixteen-to-One footwall and diverge towards the north. The Colorado vein is the widest, averaging 2 meters. Both veins are mineralogically similar to the Sixteen-to-One vein and all are part of a single hydrothermal system (Earnest 1984).

Metal Zoning. Earnest (1984) has divided the deposit into upper and lower precious metal zones; base metal abundances are greatest in lower mine levels and a base metal zone probably extends downward. The lower precious metal zone extends from the 6570 level at the bottom of the mine upward to the 6770 level. Silver averages about 6 oz/t (187 g/t) and gold averages 0.06 oz/t (1.87 g/t); lead and zinc are present to 1 to 2%. The upper precious metal zone extends from the 6770 level to the 7140 level. Silver increases to an average of 9 oz/t (280 g/t), but gold decreases to 0.02 oz/t (0.62 g/t). Less than 1% lead and zinc are present. Minor supergene enrichment is indicated by trace amounts of native silver.

Precious Metals. The dominant ore mineral is acanthite; minor amounts of pyrrargyrite and native silver are also mined. Identified silver-bearing minerals also include polybasite, stephanite, tetrahedrite, and stromeyerite. Gold, probably native, has been observed once in thin section as an 8 micron grain in acanthite (Earnest 1984). Its presence within pyrrargyrite has been confirmed by microprobe analysis (Nelson 1984). Silver varies locally from nil to greater than 100 oz/t (3110 g/t); the deposit averages about 6 to 7 oz/t (187 to 218

g/t). Gold ranges from nil to 0.90 oz/t (28.00 g/t) and averages 0.03 oz/t (0.93 g/t) (Earnest 1984).

Base Metals. Sphalerite and galena and lesser amounts of chalcopyrite and pyrite are the most common base metals present; tetrahedrite, marcasite, and covellite have also been identified. Sphalerite and galena occur locally to 10%, but average less than 1% each. Sphalerite occurs as the iron-poor, pale yellow variety known as "honeyjack" (Earnest 1984, Nelson 1984).

Paragenetic Sequence. Reflected light microscopy indicates silver minerals are generally formed later than base metal sulfides. Cross-cutting relationships suggest sphalerite is the earliest base metal sulfide formed and is followed by first galena and then chalcopyrite. Pyrite shows somewhat ambiguous textures and may occasionally form before sphalerite, but is most commonly cogenetic with chalcopyrite.

Nelson (1984) observed both acanthite and pyrargyrite replacing galena, and acanthite replacing sphalerite. Pyrargyrite may also be replaced by acanthite. Marcasite and tetrahedrite are two rare base metal sulfides which accompany silver mineralization.

Gangue Minerals. Quartz and calcite are the two most abundant gangue minerals and usually occupy 60% and 40%, respectively, of the vein volume. Calcite frequently occurs in a bladed habit and much calcite contains minor amounts of manganese, causing it to resemble siderite. Sulfide abundances in calcite are significantly lower than in quartz. Additional gangue minerals include adularia, chalcedony, amethyst, opal, fluorite, and chlorite. Green montmorillonite forms

bands with other gangue minerals and sulfides in the lower levels
(Earnest 1984, Nelson 1984).

CHAPTER 3

ALTERATION STUDY

Alteration assemblages form as a result of interaction between hydrothermal fluids and rocks they are traversing. The altered minerals represent an attempt by the original rock assemblages to equilibrate with the fluid. Knowledge of both the original mineralogy and the changes which were forced upon it provides clues to the physical and chemical make-up of the hydrothermal fluids contributing to that change.

A major portion of this study was directed toward characterizing original lithologies and alteration assemblages at the Sixteen-to-One deposit; the results of this part of the study are summarized below.

Method of Study

Wall rock samples were collected from five underground levels and surface exposures along traverses in vein hanging walls and footwalls. Underground samples were collected from the 7140, 7000, 6890, and 6585 levels and from the vein intersection in G ramp at an elevation of 6570 feet (Figures 4, 5A). Underground sample traverses trend perpendicular to and intersect the central, productive portion of the Sixteen-to-One vein on all levels except the 6585 level where the vein is no longer accessible. Samples on this level were collected along a traverse perpendicular to and intersecting the Colorado vein in the footwall of the Sixteen-to-One vein (Figure 4). With the exception of surface sample locations, sample traverses lie in a roughly vertical

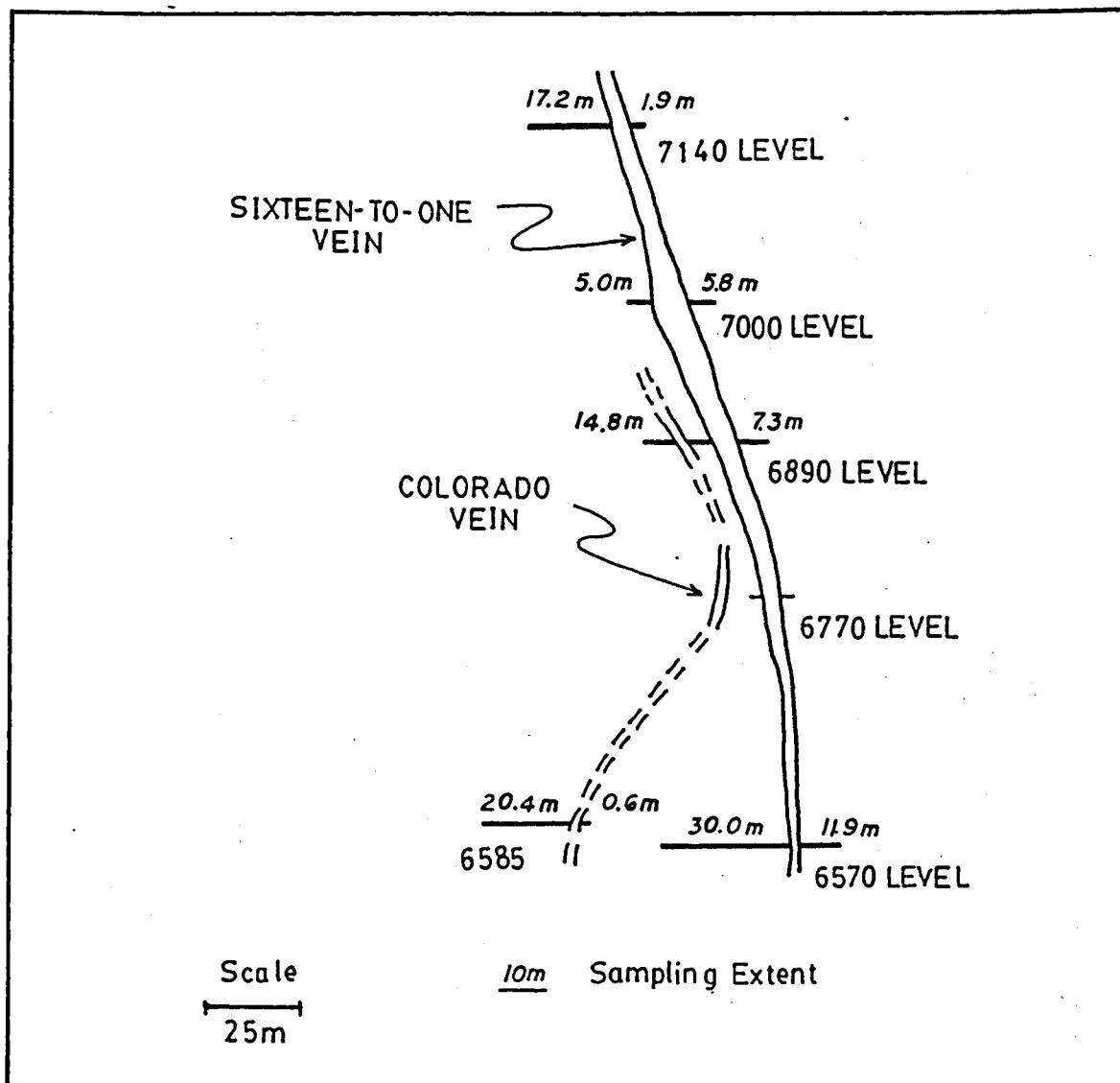


Figure 4. Cross Section of the Sixteen-to-One and Colorado Veins.

Heavy lines indicate the lateral extent of sampling into vein hanging and footwalls. Sample locations have been projected short distances into the plane of the section.

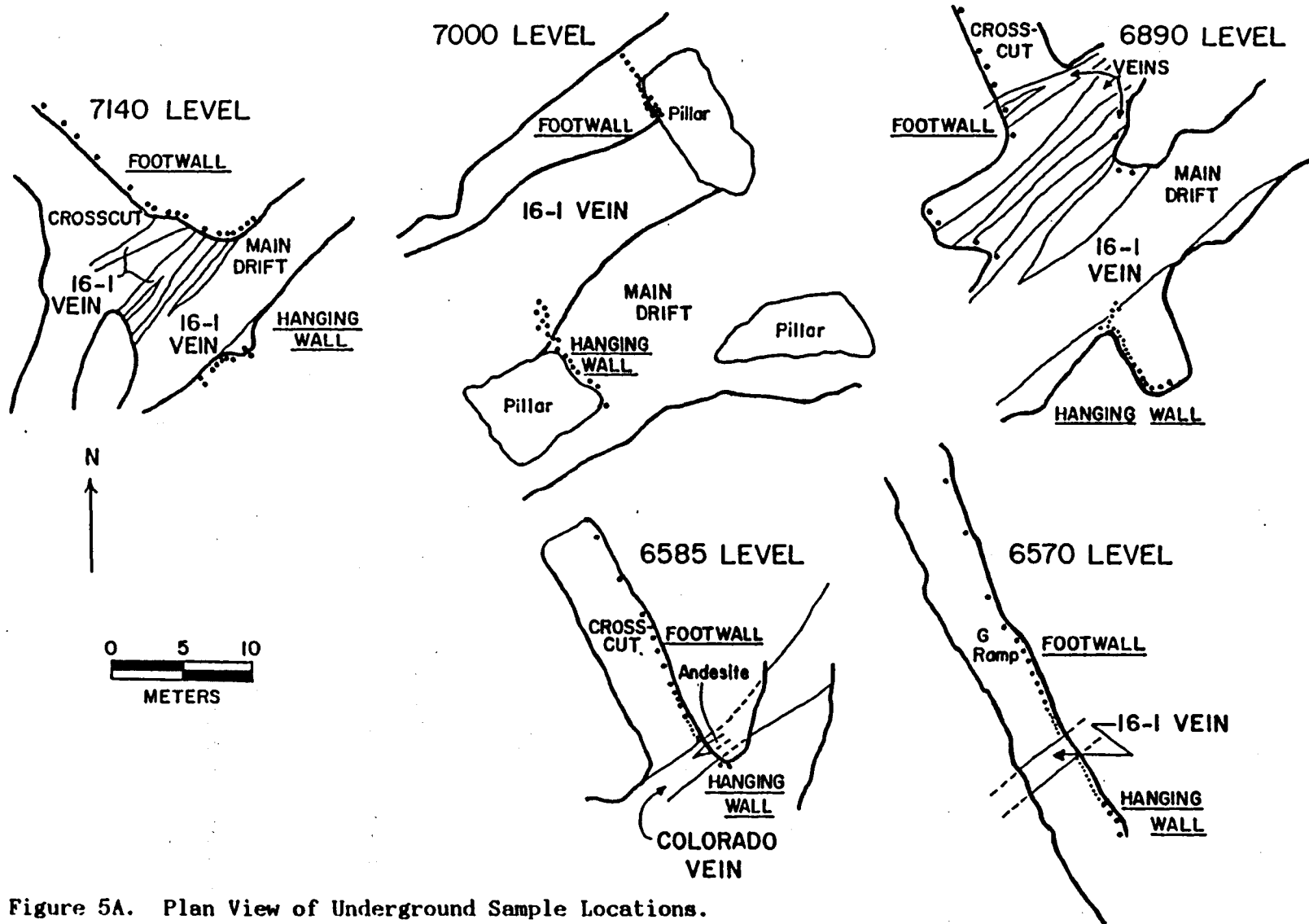


Figure 5A. Plan View of Underground Sample Locations.

Sample sites are indicated by . .

plane. Underground samples were collected from ribs along cross-cuts wherever possible, and in backs of cross-cuts or drifts where mining had removed wall rock/vein contacts from ribs. Surface samples were collected along a traverse perpendicular to the vein at the original discovery site, approximately 180 meters southwest of the vertical plane containing other sample locations (Figure 5B).

Sample intervals ranged from continuous channel sampling at the vein contact to small intervals of 0.3 to 1.0 meters at distances of 1 to 3 meters from the vein; intervals were gradually increased to 3 to 5 meters at sample distances of 20 or more meters from the vein (Figures 5A and 5B). Wherever possible, sampling extended well beyond any visible effects of veining or vein alteration. The lateral extent of sampling in the 7140 hanging wall, 7000 hanging and footwalls, and 6890 hanging wall was limited by either narrow drifts or short cross-cuts (Figure 5A).

In order to obtain rock samples least affected by vein-related fluids, additional samples were collected from the outer turns in a spiral ramp system located in the vein footwall. The ramp permitted sampling to distances of 200 meters from the vein system and to depths of 240 meters beneath the surface.

A total of 220 samples were collected, sawed, and examined for alteration minerals and textures with a hand lens or under a binocular microscope. Polished thin sections were prepared from 135 samples, and were examined under transmitted and reflected light. X-ray diffraction aided in mineral identification.

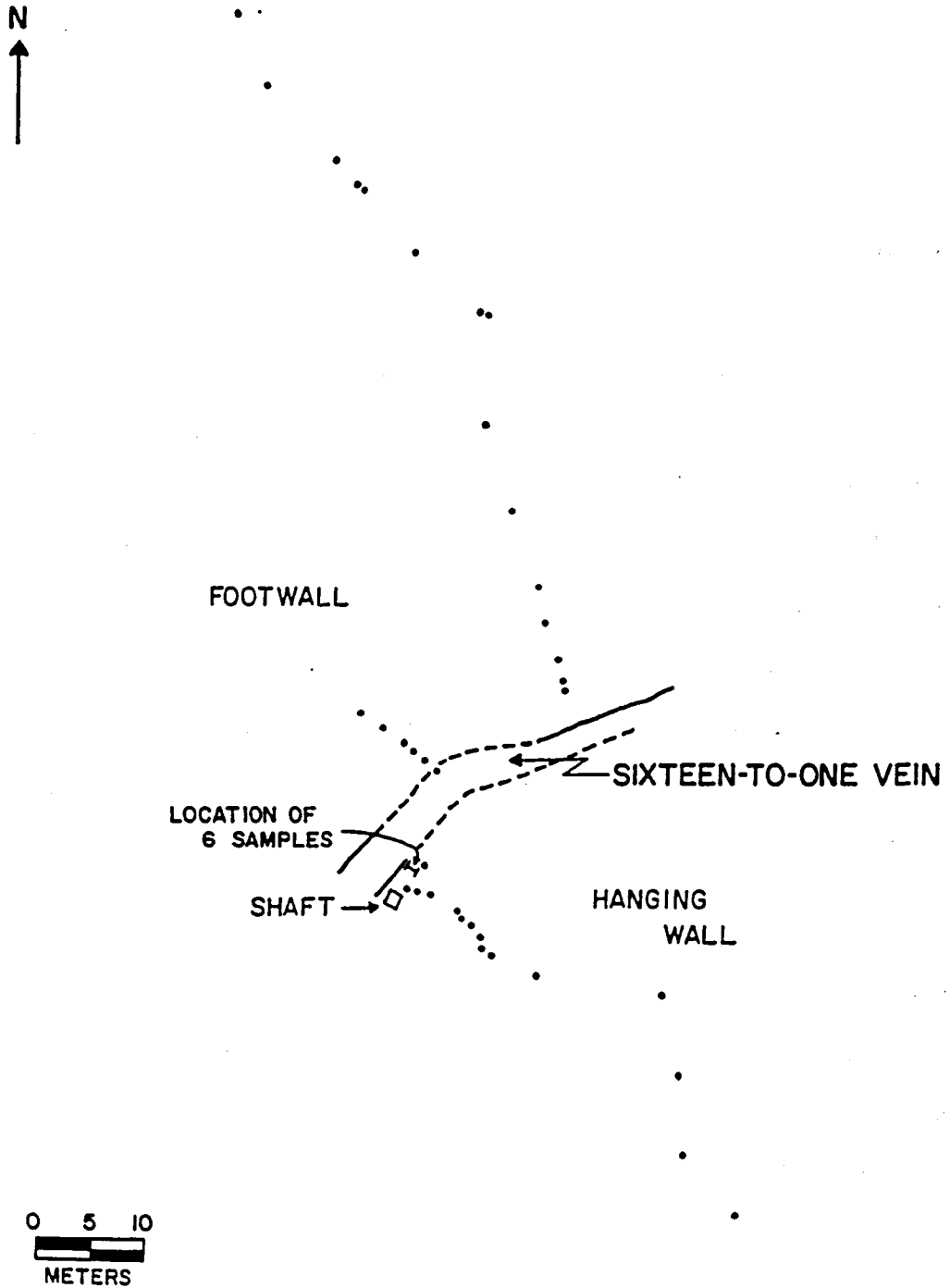


Figure 5B. Plan View of Surface Sample Locations.

Sample sites are indicated by . .

Stratigraphy

The primary mineralogy of any rock exerts a strong influence over the resulting alteration assemblage when alteration is selective rather than pervasive. Different primary minerals resist, to varying degrees, the effects of the invading hydrothermal fluids. Knowledge of which minerals were and were not affected by hydrothermal fluids, and to what degree, aids in interpreting the chemistry of the responsible fluids.

In order to distinguish alteration assemblages at the Sixteen-to-One deposit it was first necessary to determine the original lithologies of the volcanic units at all sample locations. Lithologies were found to be highly variable both laterally and vertically and reflect the discontinuous stratigraphy typical of a near-caldera setting. The volcanic units encountered during sampling are described below and have been correlated with Keith's (1977) units (Figure 6).

Andesite

Lower Porphyritic Andesite. This andesite is found on the 6585 level footwall of the Sixteen-to-One vein, in the hanging and footwalls of the Colorado vein (Figure 6). A fine grained groundmass contains fairly abundant plagioclase phenocrysts and numerous millimeter-sized or smaller dark green masses. Thin sections reveal a strongly altered, brecciated rock in which clasts are defined by different sized groundmass microlites. Phenocrysts include abundant large, corroded plagioclase, 2% to 5% pseudomorphs of ferromagnesian minerals, 1% magnetite, and rare biotite. The pilotaxitic groundmass consists of a

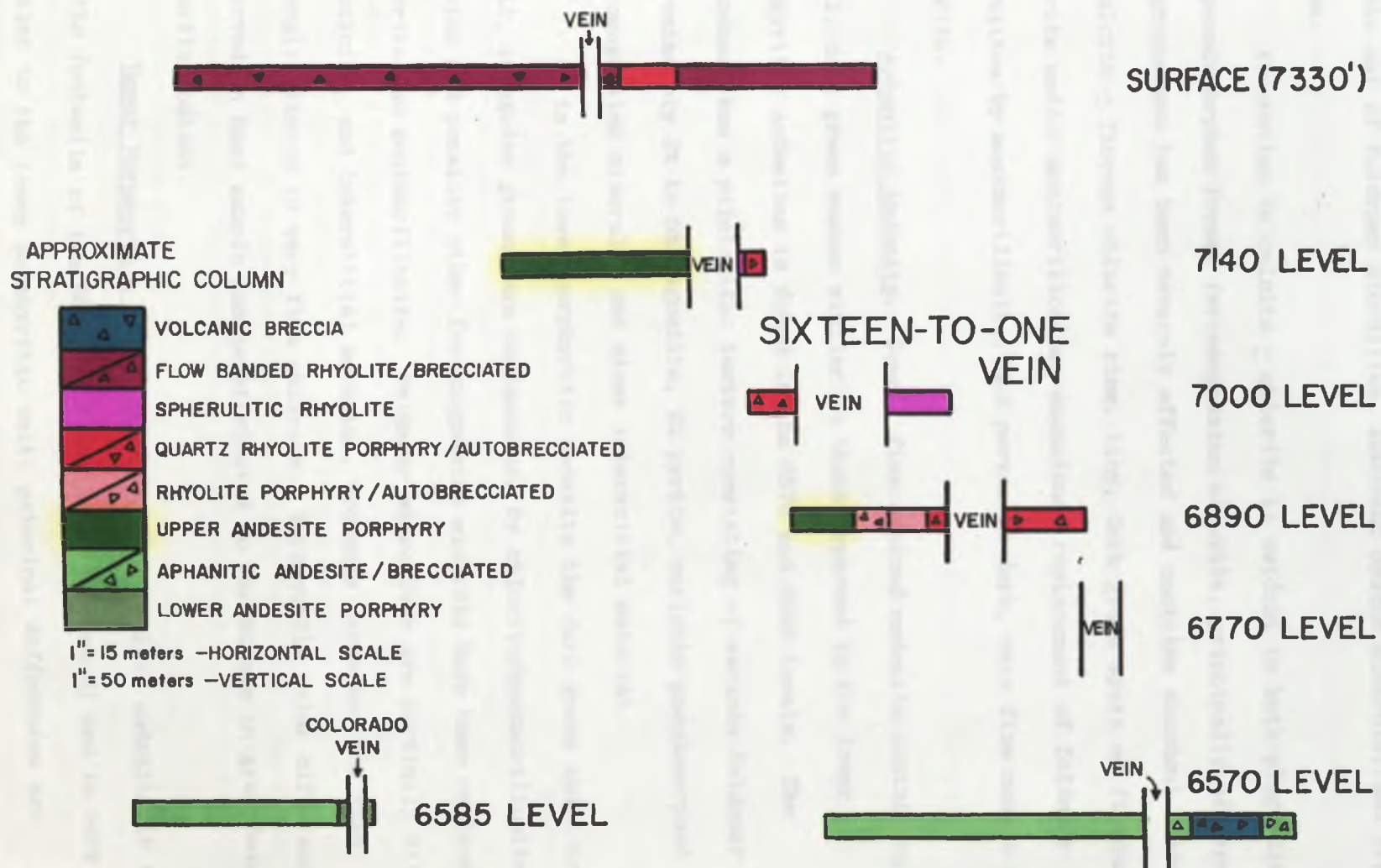


Figure 6. Cross Section Illustrating Lithologies Encountered During Sampling.

seriate mat of feldspar microlites, abundant opaque minerals, and trace zircon.

Alteration to calcite ± chlorite is evident in both plagioclase and pseudomorphed former ferromagnesian minerals, principally olivine. The groundmass has been severely affected and contains abundant masses of calcite ± fibrous chlorite rims, tiny, dark green spots of fibrous chlorite and/or montmorillonite, occasional replacement of feldspar microlites by montmorillonite, and pervasive dark, very fine masses of chlorite.

Aphanitic Andesite. Dense, fine grained andesite containing small, dark green masses similar to those observed in the lower porphyritic andesites is found in the 6570 and 6585 levels. The groundmass has a pilotaxitic texture consisting of seriate feldspar with approximately 2% to 5% magnetite, 2% pyrite, variably pseudomorphed ferromagnesian minerals, and minor interstitial material.

As in the lower porphyritic andesite the dark green spots are small, irregular groundmass replacements by chlorite/montmorillonite. Olivine and possibly other ferromagnesian minerals have been replaced by chlorite and montmorillonite. Feldspar microlites are partially altered to calcite, and interstitial material, probably pyroxene, has been strongly altered to very fine chlorite. Very subtle color differences observed in hand sample can be attributed to variations in groundmass chlorite content.

Upper Porphyritic Andesite. Upper porphyritic andesite is found in the footwalls of the 6890 and 7140 levels (Figure 6) and is very similar to the lower porphyritic unit; principal differences are

original ferromagnesian constituents. Phenocrysts include 10% to 15% plagioclase, commonly present in a glomerocrystic habit; 1 to 2% each of magnetite, former ferromagnesian minerals, and K-feldspar; and minor apatite. The groundmass consists of a pilotaxitic mat of feldspar, quartz, and opaque minerals.

The typically altered andesite contains very large, irregular masses of calcite ± fibrous chlorite rims. Plagioclase is moderately to nearly completely replaced by calcite ± very minor to minor chlorite, sericite, and quartz, and minor K-feldspar is altered to chlorite. Lath-shaped chlorite pseudomorphs indicate the former presence of ferromagnesian minerals, particularly hornblende. Approximately 1% former biotite has been replaced by muscovite and calcite ± minor chlorite, quartz, and opaque minerals. Fine masses and spicules of chlorite have replaced groundmass material to 50% locally.

Rhyolite

Rhyolite Porphyry. Fine grained rhyolite porphyry is found in the 6890 level footwall (Figure 6) and contains less than 10% phenocrysts: 2% to 5% K-feldspar, 0.5% to 2.0% plagioclase, less than 1% each of biotite, apatite, and magnetite, and trace amounts of zircon. Many plagioclase phenocrysts are rimmed by K-feldspar indicating an earlier episode of magmatic potassium metasomatism. The groundmass consists of 50% to 70% K-feldspar, ≤ 30% plagioclase, and ≤ 20% quartz, plus minor opaque minerals.

An autobrecciated rhyolite porphyry containing pale green clasts cemented by purple-gray matrix is found adjacent to the rhyolite porphyry. Thin sections show the clasts to be nearly identical in

composition to the porphyry. The breccia matrix consists of 93% groundmass and 7% phenocrysts; the phenocrysts duplicate those observed in the clasts in both identity and relative abundance. The matrix groundmass contains extremely fine grained feldspar, quartz, and minor magnetite.

Alteration in both rock types consists of minor calcite and chlorite replacement of feldspars, biotite, and groundmass.

Autobrecciated Quartz Rhyolite Porphyry. Quartz rhyolite porphyry is found in 6890 level hanging and footwalls, the 7000 level footwall, and the 7140 level and surface hanging walls (Figure 6), and is quite similar to the previously described unit. This porphyry additionally contains 1% to 5% moderately large, rounded primary anhedral quartz grains and minor to abundant clasts of strongly silicified, fine grained material. This unit commonly contains fragments of a more mafic rock, probably an andesite. Rock fragments vary from a few millimeters to less than a centimeter in diameter and contain abundant coarse plagioclase and completely altered ferromagnesian minerals set in a moderately coarse, pilotaxitic feldspar-rich groundmass. Fragment alteration is always strong and consists of abundant chlorite and moderate calcite; minor sericite and montmorillonite are almost always present. Rhyolite alteration consists of minor calcite and chlorite replacement of feldspar, biotite, and groundmass.

Spherulitic, Perlitic Rhyolite. Variable amounts of spherulites and oval perlitic fractures distinguish this rhyolite which is found in the 7000 level and 7140 level hanging walls (Figure 6).

Numerous rounded primary anhedral quartz grains, sparse corroded K-feldspar phenocrysts, and fragments of mafic rocks are also present. Opaque minerals include about 1/2% pyrite and magnetite.

Devitrification products contained within perlitic fractures include dirty brown feldspar and anhedral quartz. Groundmass consists of very fine, equigranular quartz and feldspar.

Alteration products, possibly related to devitrification, include minor chlorite replacing groundmass, and sparse calcite and montmorillonite replacing feldspar within perlitic fractures. Minor chlorite and calcite also replace groundmass and K-feldspar, respectively.

Flow Banded Rhyolite. Flow banded rhyolite is found in surface outcrop in both hanging and footwalls. Banding is a result of textural and compositional differences in the rhyolite. Bands contain various combinations of anhedral quartz grains, "snow-flake-like" devitrification quartz, coarse, cavity-filling quartz, chalcedony, and minor feldspar microlites and glass. Former cavities, both miarolitic openings and openings resulting from folding prior to solidification, commonly contain feldspar microlites and later coarse quartz. The rock has commonly been brecciated and cemented with clear quartz. Alteration products include silicification and veining and minor montmorillonite.

Volcanic Breccia

A matrix-supported breccia, probably correlative with Keith's volcanic breccia, is found in the 6570 level hanging wall. Clasts range in size from less than a millimeter to several centimeters and contain spherulitic and flow banded rhyolite and porphyritic andesite. The

matrix is an extremely fine, light gray material, probably devitrified glass. Fragments show variable degrees of alteration to calcite and chlorite; other than devitrification the matrix is essentially unaltered.

Alteration Assemblages - Descriptions

Petrographic work has led to the identification of two distinct but frequently superimposed alteration assemblages. These assemblages are distinguishable by their mineralogy, by the minerals which they replace, and by spatial relationships with each other and with the vein system. The assemblages are herein termed "regional" and "vein-controlled". A detailed discussion of the fluids responsible for each assemblage and the relationships between both assemblages and the vein system is presented in Chapter 5.

The regional assemblage is characterized by moderate to strong metasomatism of andesites and minor alteration of rhyolites to an assemblage containing primarily chlorite, calcite, and pyrite.

Vein-controlled alteration is evidenced in two forms: fracture filling and metasomatism. The major effect the hydrothermal system had upon the wall rocks of the Sixteen-to-One deposit, was the formation of abundant veins and veinlets. Very fine to coarse quartz veins commonly contain minor amounts of gangue minerals which formed as a result of interaction between fluids and wall rocks. These gangue minerals are concentrated adjacent to the quartz/wall rock contact. In this study, this type of veining is considered part of the wall rock alteration assemblage and alteration products are classified as either open space fillings or replacements.

Regional Alteration - Mineralogy

The regional assemblage is characterized by abundant chlorite and calcite, lesser pyrite, and trace amounts of montmorillonite and white micas (Table 2). Original textures are usually preserved, but many original minerals have been completely replaced. This assemblage is distinguished from vein-controlled alteration in samples collected from the spiral ramp system and from sample traverse sites located significant distances from the vein. A complete description of the regional assemblage is given in Appendix A.

Chlorite. Chlorite, probably penninite, commonly occurs in andesites in many forms. It most often replaces groundmass as both extremely fine masses (10% to 50%) (Figure 7A) and as coarser, fibrous oval and irregular masses. Thin to thick fibrous chlorite rims surrounding large irregular calcite masses are most abundant in upper andesite porphyry (Figure 8). Chlorite commonly pseudomorphs olivine (Figure 7), hornblende, and pyroxene, and is a minor replacement of feldspar.

Chlorite alteration in rhyolites is minor. Fine masses replacing groundmass and matrix rarely exceed 8%. Biotite replacement varies from minor to complete; alteration of feldspar is usually minor. Chlorite alteration is most apparent in mafic rock fragments in quartz rhyolite porphyry and spherulitic rhyolite.

Calcite. Calcite alteration is especially common in andesites where calcite frequently forms large masses associated with chlorite (Figure 8). Fine grained calcite replaces groundmass and 2% to 50% of

Table 2. Regional Alteration

<u>Alteration Mineral</u>	<u>Host Rock</u>	<u>Alteration Description</u>
Chlorite	Andesite	Abundant alteration product, strong association with mafic minerals. Complete replacement of olivine, hornblende, pyroxene, and biotite. Minor replacement of plagioclase. Very fine replacement of groundmass (10-50%). Minor to abundant replacement of groundmass by large, rounded and irregular fibrous masses.
	Rhyolite	Minor very fine grained alteration of groundmass. Minor to complete alteration of biotite. Trace to minor alteration of feldspar. Abundance increases as distance from andesite decreases.
Calcite	Andesite	Moderate to strong (15%) replacement of groundmass. Frequent replacement of plagioclase (to 50%). With chlorite replaces olivine, pyroxene, and biotite.
	Rhyolite	Rare; trace to minor replacement of groundmass and plagioclase.
Pyrite	Andesite	Nil to 2%; generally <0.5% to <1%. Locally associated with chlorite.
	Rhyolite	Nil to <1%; generally nil to <0.25%.
Nontronite	Andesite	Minor to moderate small fibrous masses ± chlorite replace groundmass. Local, moderate replacement of feldspar.
	Rhyolite	Rare; trace replacement of groundmass.

Table 2, Continued

White Micas	Andesite	Trace to moderate plagioclase replacement. Trace replacement of groundmass.
	Rhyolite	Trace to minor replacement of groundmass and matrix. Trace replacement of plagioclase.

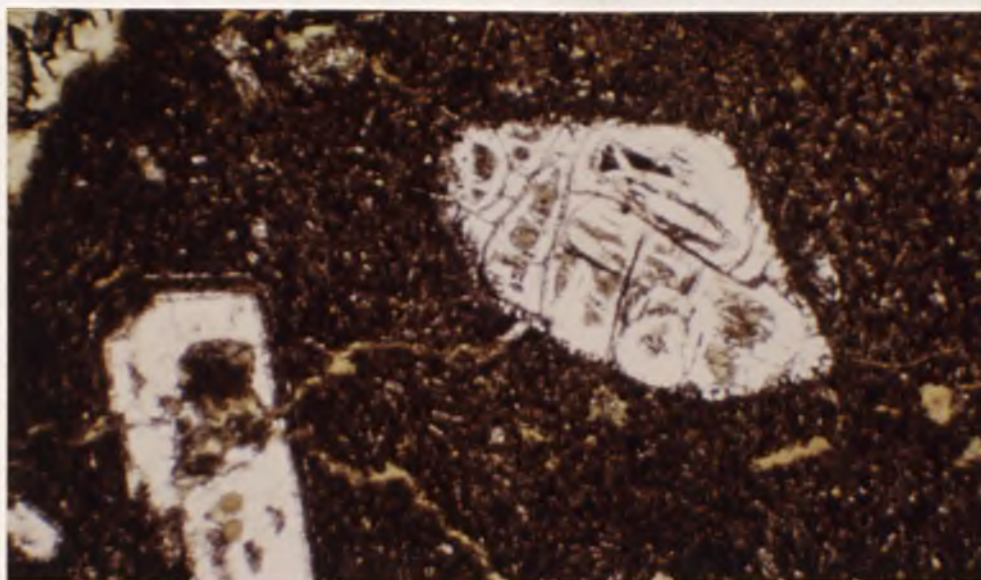


Figure 7A.

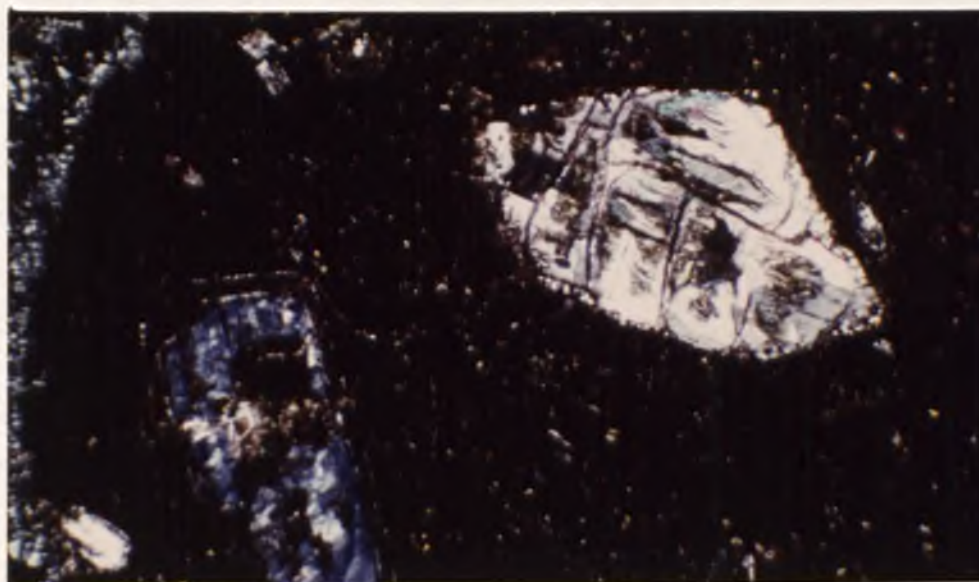


Figure 7B.

Figure 7. Propylitic Alteration of Groundmass and Olivine by Chlorite, and Calcite with Lesser Chlorite, Respectively.

Horizontal field of view is 3.0 mm. A. Plain polarized light. B. Crossed polarized light.

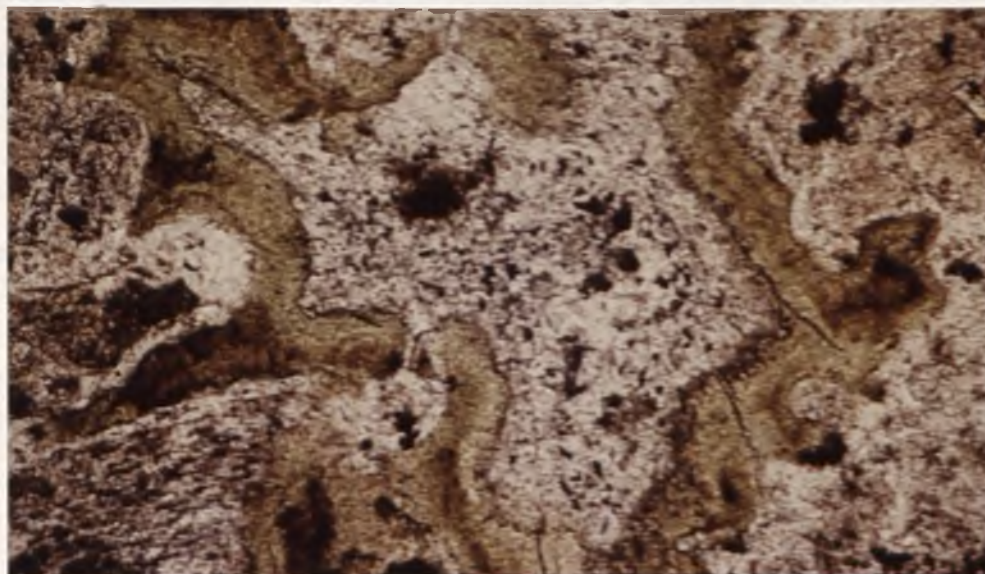


Figure 8A.



Figure 8B.

Figure 8. Irregular Calcite Masses Rimmed by Fibrous Chlorite.

Horizontal field of view is 0.75 mm. A. Plain polarized light. B. Crossed polarized light.

plagioclase phenocrysts. Olivine is commonly pseudomorphed (Figure 7B) and calcite may accompany chlorite alteration of biotite.

Calcite alteration in rhyolites is quite rare. Trace to minor amounts of calcite are found as rare replacements in plagioclase and may also be found in mafic rock fragments.

Pyrite. Disseminated pyrite ranges from nil to 2% in andesites and commonly varies from <0.5% to <1%. Sparse pyrite in rhyolites ranges from nil to <1% and averages <0.25%. It generally forms sparse, fairly coarse cubes, locally associated with chlorite.

Montmorillonite. Montmorillonite, probably nontronite, commonly forms small fibrous masses in andesite groundmass and is often accompanied by chlorite. Plagioclase phenocrysts and groundmass microlites are also replaced.

Nontronite rarely replaces rhyolite porphyry groundmass and is spatially related to oxidized opaque minerals. Moderate nontronite occurs in mafic rock fragments in some rhyolites.

White Micas. Sparse mica abundances did not permit detection by X-ray diffraction and they have been identified only by petrographic methods. Optical methods generally cannot be used to distinguish between talc, pyrophyllite, paragonite, vermiculite, muscovite, and possibly illite. Very fine grained white phyllosilicates observed to have the form and birefringence of sericite will be referred to as white micas.

White micas are rarely associated with the regional assemblage. Trace amounts in andesites form small, scattered flakes in plagioclase, and small, shreddy masses in groundmass. Rhyolites contain trace to

minor white micas in groundmass and matrix, and rare micas replacing plagioclase.

Vein-Controlled Alteration - Fracture Filling and Metasomatism

Fracturing and fracture filling are the most important vein-controlled features observed in wall rocks; metasomatism is much less abundant and never extends more than 2mm from a fracture. The location and amount of both open space and metasomatic alteration minerals are dictated, in part, by the abundance, intensity, and locations of fractures; areas which are most thoroughly brecciated are also the most strongly metasomatized. Highly fractured areas in wall rocks may be separated from the vein by unfractured areas leading to a pattern in which metasomatically altered rocks are separated from the vein by rocks unaffected by mineralizing fluids.

Since mineral abundances are, in part, controlled by fracture abundances, it is important to consider the degree of fracturing at any given sample location when determining the significance of alteration minerals present. Rhyolite is, in general, more brittle than andesite and, at the Sixteen-to-One deposit, shattered more readily leading to more abundant veining and metasomatism in rhyolite host rocks. Wall rock fracturing and brecciation are strongest in rhyolites on the 6890 and 7000 levels where the Sixteen-to-One vein attains its greatest width, and in andesite in the 7140 level footwall.

Vein-Controlled Alteration - Mineralogy

Vein-controlled alteration minerals include, in decreasing abundance, quartz, calcite, chlorite, pyrite, adularia, epidote,

nontronite, and white micas (Table 3) and their occurrences are summarized below. Complete descriptions are given in Appendix B.

Quartz. Quartz veining and breccia-filling comprise more than 95% of the vein-controlled wall rock alteration; quartz replacements are minor, but locally important. Veins thin to veinlets which, in areas of strong brecciation, show a web-like texture (Figure 9). Quartz veins contain minor calcite, adularia, chlorite, epidote, and sulfides. Chlorite and epidote commonly concentrate along the vein/wall rock contacts indicating interaction between fluids and wall rocks. Vugs are common and may be partially filled with later calcite.

Small, oval to circular masses of anhedral quartz grains disseminated in wall rocks are a second form of open-space-filling quartz. These masses are generally less than 0.75mm in diameter and commonly increase in concentration with increasing proximity of a vein or veinlet. As concentration increases, masses become connected at one or more points and grade to a web-like vein texture (Figure 10). The "discrete" masses are in fact flow channels which are connected in a plane other than the one viewed in thin section. Further evidence that these masses were originally open cavities is provided by the occasional presence of clusters of euhedral zoisite crystals which are attached to the wall of the cavity and extend into the former opening. Quartz masses also contain minor fine spicules or spicule masses of chlorite and radial clusters of epidote, generally concentrated around the outer edges of the quartz mass. Anhedral quartz masses are spatially related to those areas which have been most strongly fractured.

Table 3. Vein-Controlled Alteration.

<u>Alteration Mineral</u>	<u>Host Rock</u>	<u>Alteration Description</u>
Quartz	Andesite	Principally fracture filling; metasomatism minor. Veining, minor to abundant; frequently vuggy; vugs may contain younger calcite. Anhedral quartz masses, minor to moderate; may contain chlorite, rare epidote. Silicification very minor to minor.
	Rhyolite	Principally fracture filling; metasomatism minor to locally abundant. Veining, minor to strong; brecciation common; veins frequently vuggy, frequently contain younger calcite. Anhedral quartz masses, minor to abundant; frequently contain minor epidote, chlorite, + nontronite. Silicification, minor to locally abundant, especially around anhedral quartz masses.
Calcite	Andesite	Principally fracture filling; metasomatism minor. Partially or completely fills vuggy quartz vein centers; occasionally as bladed calcite. Trace to minor fine replacements of groundmass and occasionally plagioclase, generally with chlorite. Close proximity to vein.
	Rhyolite	Principally fracture filling; metasomatism minor. Partially or completely fills vuggy quartz vein centers; occasionally as bladed calcite. Local, moderately abundant anhedral calcite masses adjacent to vein. Trace to moderately strong replacement of feldspars close to vein. Trace to minor replacement of groundmass and matrix.

Table 3, Continued

Chlorite	Andesite	Principally fracture filling; metasomatism rare. Minor to locally abundant in veinlets and anhedral quartz masses, forms large wispy spicules. Rare replacement of groundmass.
	Rhyolite	Principally as fracture filling; metasomatism very minor. Minor to moderate wispy masses in veinlets and anhedral quartz masses. Abundance increases as distance to andesites decreases. Replaces biotite. Trace to very minor alteration of feldspar and groundmass.
Pyrite	Andesite	Both fracture fillings and replacements. Nil to 6%; generally nil to <1%. Decreases away from vein; concentrations in wall rocks frequently > concentrations in vein.
	Rhyolite	Both fracture fillings and replacements. Nil to 1%; generally <0.5%. Slight increase near veins. Locally associated with epidote.
Adularia	Andesite and Rhyolite	Only as fracture fillings. Minor occurrences within veins associated with chlorite/nontronite and minor sulfides.
Epidote	Andesite	Only as fracture fillings. Minor, but common in veinlets and anhedral quartz masses. Located \leq 1 meter from vein.
	Rhyolite	Principally fracture filling; metasomatism minor. Minor to locally abundant in veinlets and anhedral quartz masses; at greater lateral distances from vein than when in andesite. Rarely replaces feldspars. Local associations with adularia and chlorite.

Table 3, Continued

Nontronite	Andesite	Rarely replaces plagioclase and groundmass.
	Rhyolite	Principally as a replacement; rarely as fracture filling. Minor, but common replacement of groundmass and feldspar. Spatially related to quartz veining and anomolous precious metal values. Forms high in system.
White Micas	Andesite	Trace replacement of groundmass adjacent to quartz veinlets.
	Rhyolite	Trace replacement of feldspars, groundmass, and matrix. Trace amounts in veinlets.

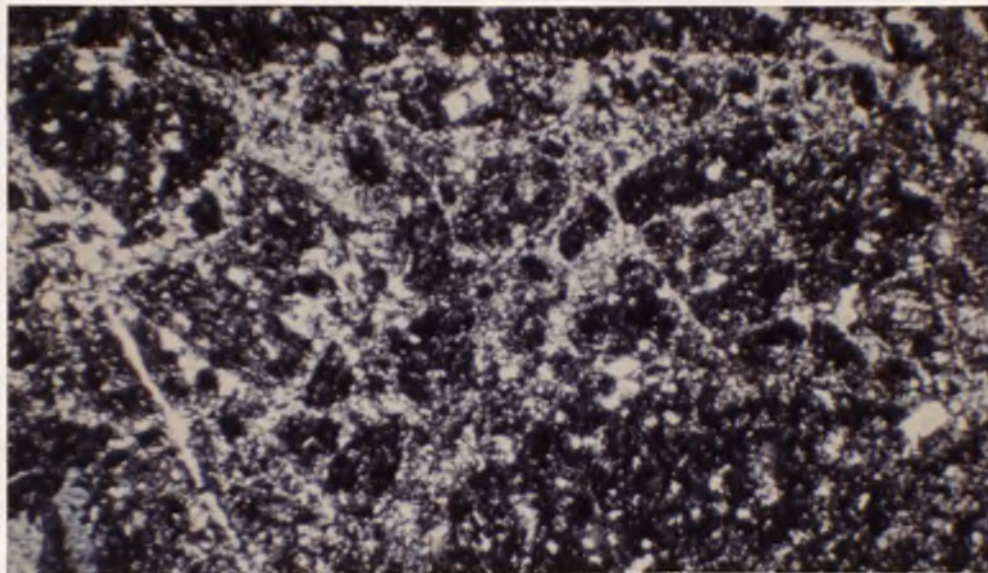


Figure 9. Web-like Vein Texture.

Horizontal field of view is 3.0 mm. Crossed polarized light.

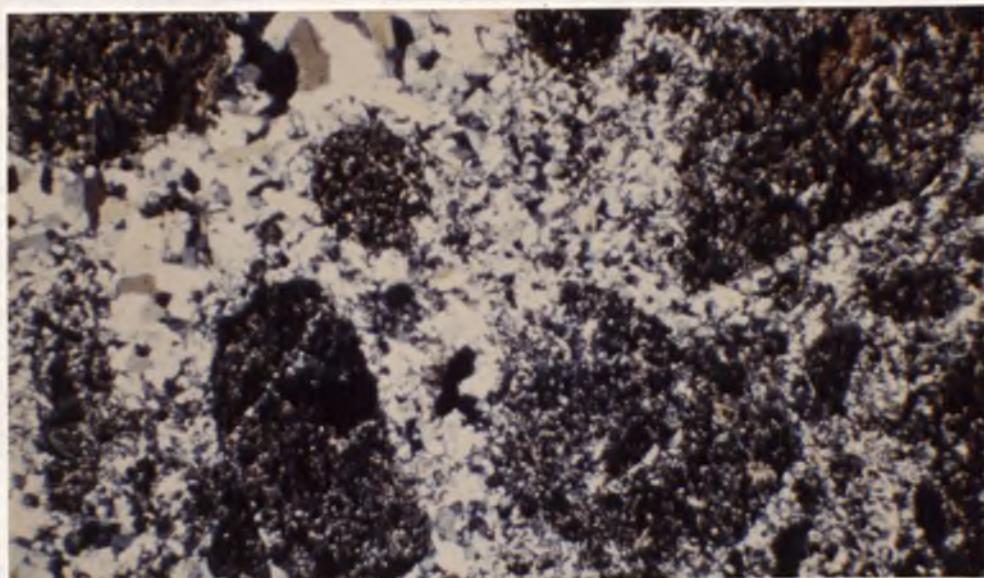


Figure 10. Clear Anhedral Quartz Masses Grading to a Web-like Vein Texture.

Horizontal field of view is 3.0 mm. Crossed polarized light.

Quartz metasomatism composes less than 5% of the vein-controlled, quartz alteration. Silicified rims around anhedral quartz masses occur in highly fractured rocks. The rims rarely extend more than 0.5mm beyond the quartz mass (Figure 11). Silicification adjacent to quartz veins and veinlets is rarely present. Optically continuous quartz coronas may rim primary anhedral quartz grains. Small rounded areas within groundmass are occasionally silicified. The fuzzy borders and contained groundmass give the quartz masses a "snowflake-like" appearance (Figure 12) under crossed polarized light. These masses are frequently disseminated among anhedral quartz masses and probably formed adjacent to other anhedral quartz masses not present in the plane of the thin section.

The entire pattern suggests hydrothermal fluids travelled through numerous once-connected flow channels, now preserved as anhedral quartz masses, and occasionally diffused through and replaced adjacent wall rock for very small distances.

Calcite. Minor calcite commonly fills or partially fills vuggy vein quartz centers, generally close to the vein or within strongly fractured areas. Calcite rarely occurs in anhedral quartz masses, however analogous calcite masses are found in one area within 0.5 meters of the vein. Grain size varies from medium to coarse and calcite occasionally exhibits a coarse bladed habit. Blades may separate later quartz crystals indicating minor quartz is later than calcite.

Calcite metasomatism is much less common, but can be locally abundant. Trace to minor fine calcite replaces rhyolite and andesite groundmass. Calcite replacement of feldspars varies from trace to minor

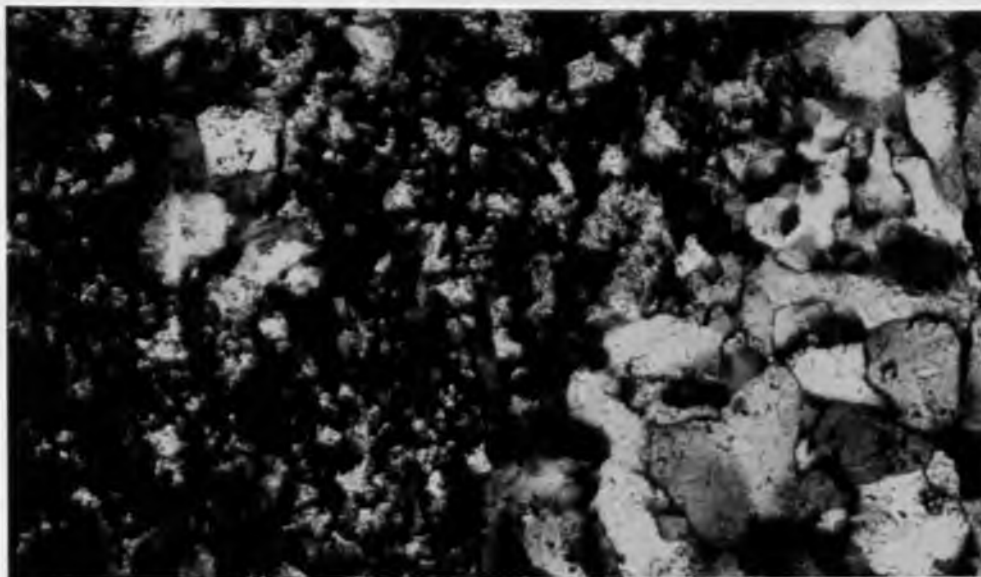


Figure 11. Anhedral Quartz Mass With Silicified Rim.

Part of a clear, anhedral quartz mass is located on the right-hand-side of the photo. Adjacent groundmass has been replaced by "snowflake" quartz. Horizontal field of view is 0.75 mm. Crossed polarized light.

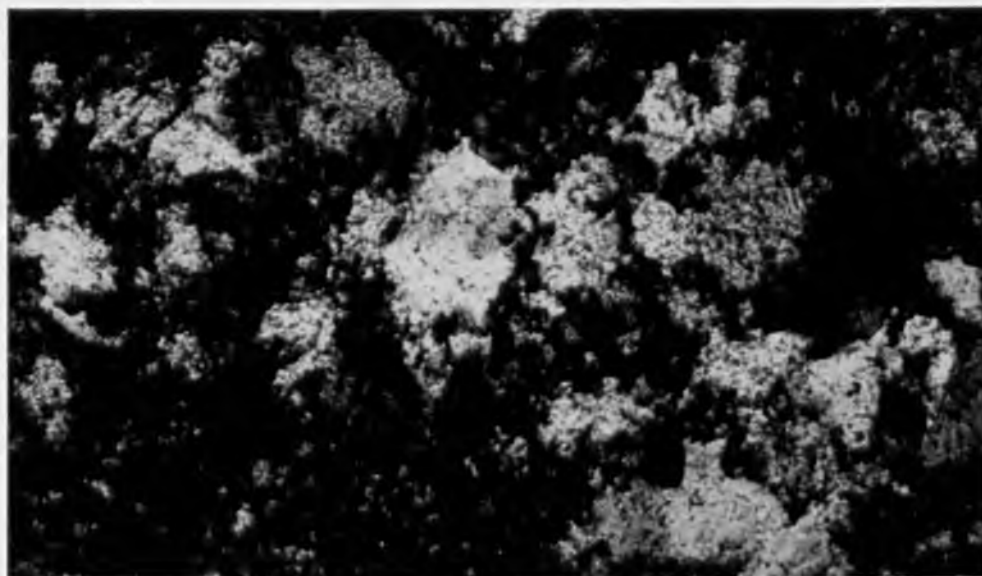


Figure 12. "Snowflake" Quartz.

Silicification of groundmass results in fuzzy borders and mottled appearance under crossed polarized light. Horizontal field of view is 0.75 mm.

in andesite, and from minor to abundant in rhyolite. Metasomatic calcite is restricted to within a close proximity of the vein system and strongly fractured areas. Total calcite content decreases in upper levels.

Chlorite. Vein-controlled chlorite occurs most frequently as an open space, fracture filling mineral. It is locally abundant in quartz veins and anhedral quartz masses as spicules and wispy masses (Figure 13), concentrated near quartz/wall rock contacts; chlorite occasionally replaces plagioclase (Figure 14). It is most abundant in lower and mid-mine levels; only trace amounts are present in upper level rhyolites. Chlorite replacement of andesite and rhyolite groundmass is rare.

Pyrite. Pyrite varies from nil to 6% and is generally more abundant in andesites. In rhyolite, abundances reach 1% locally, but commonly show no or only trace increases over regional alteration amounts.

Pyrite is often more concentrated in wall rock adjacent to the vein contact, than within the vein. It may be present in anhedral quartz masses and is sometimes associated with chlorite. Pyrite is locally accompanied by sphalerite and galena.

Adularia. Selected thin sections and section slabs were stained to determine the presence of adularia. The small number of stained sections precludes a quantitative estimate of adularia abundance, however, it appears to be a moderately common, though minor vein constituent. Adularia is locally associated with chlorite/nontronite bands and minor sulfides.

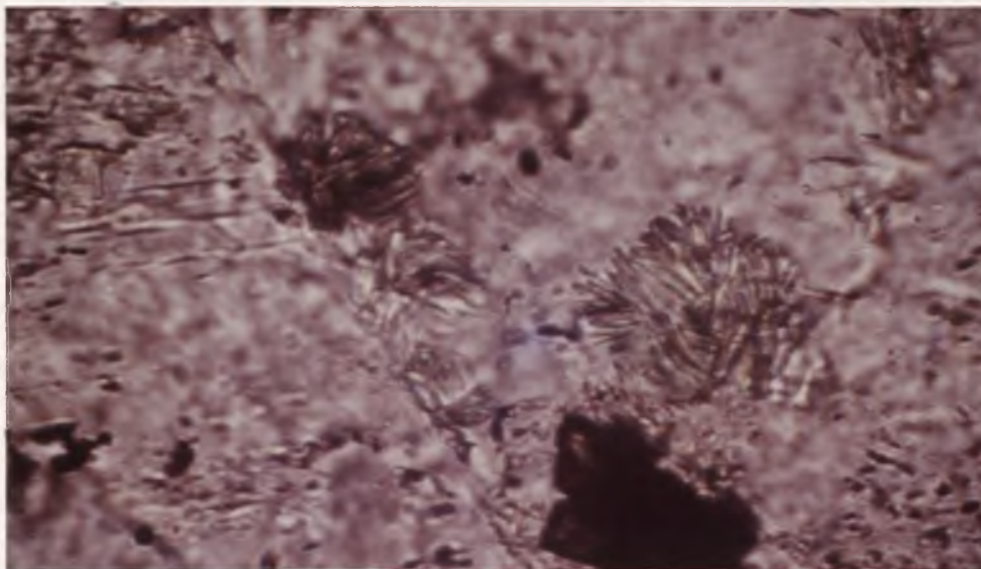


Figure 13. Chlorite Spicules in Anhedral Quartz Mass.
Horizontal field of view is 0.15 mm. Plain polarized light.

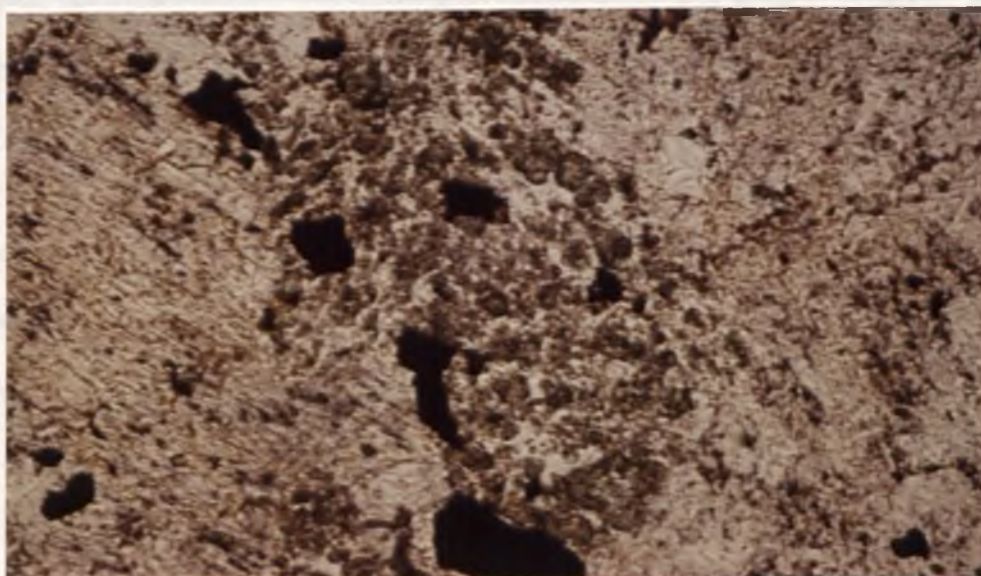


Figure 14. Masses of Chlorite Spicules Replacing Plagioclase.
Horizontal field of view is 0.75 mm. Plain polarized light.

Epidote. Epidote and zoisite occur as minor open-space-filling minerals, closely restricted to the vein in andesites, and more widespread laterally in rhyolites. Minor amounts are common within anhedral quartz masses and veinlets, sometimes near quartz/wall rock contacts and sometimes within quartz vein interiors. Zoisite forms 0.08mm crystals which extend from outer walls of anhedral quartz masses into former openings (Figure 15). Trace epidote replaces minor feldspars close to quartz veins or veinlets and is locally associated with oxidized ferromagnesian minerals, adularia, and chlorite.

Montmorillonite. Nontronite occurs most commonly as a replacement in rhyolites. It is most abundant in surface outcrops where it forms ropy masses and irregular patches along quartz veinlets; it displays a strong spatial relationship with quartz veining and anomalous precious metal values. Plagioclase replacement is minor (Figure 16). Rare open-space-filling nontronite occurs in anhedral quartz masses and quartz veins within two meters of the vein system.

White Micas. Trace white micas are found in silicified andesite groundmass adjacent to quartz veinlets, and in rhyolites as replacements of plagioclase, K-feldspar, groundmass, and matrix. Trace amounts occur in veinlets and breccia zones.

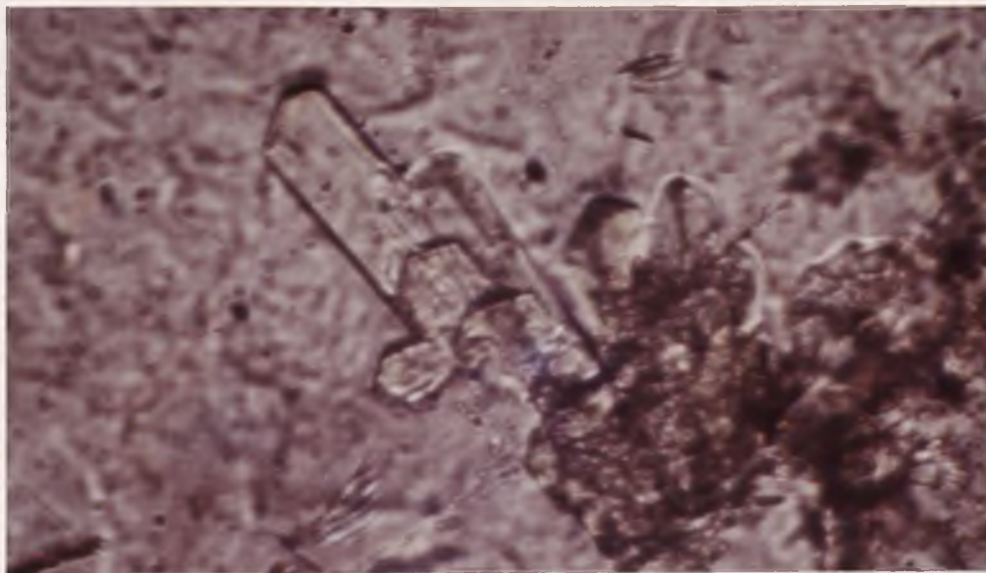


Figure 15A.

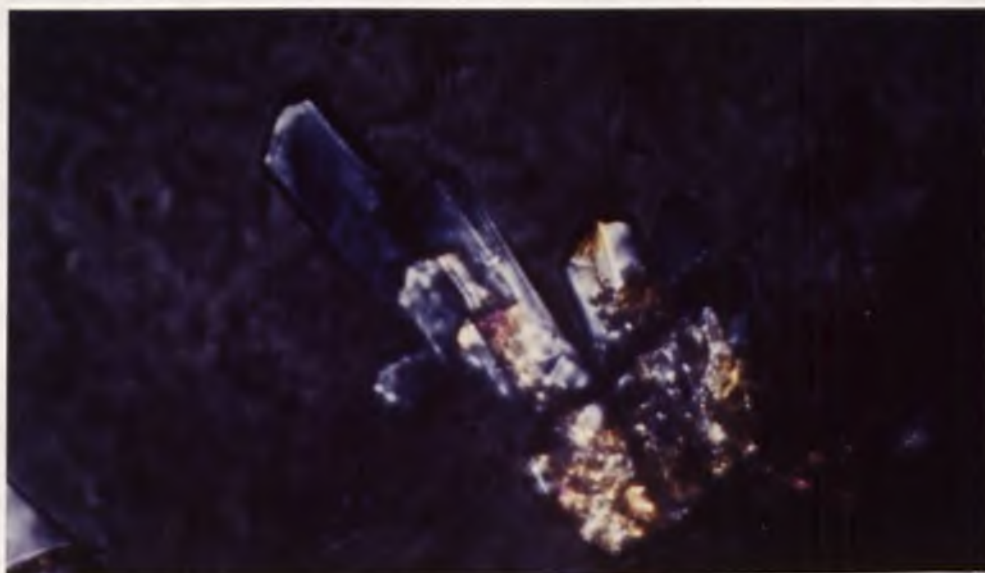


Figure 15B.

Figure 15. Zoisite Crystals in Anhedral Quartz Mass.

Horizontal field of view is 0.4 mm. A. Plain polarized light. B. Crossed polarized light. Note anomalous blue interference colors.

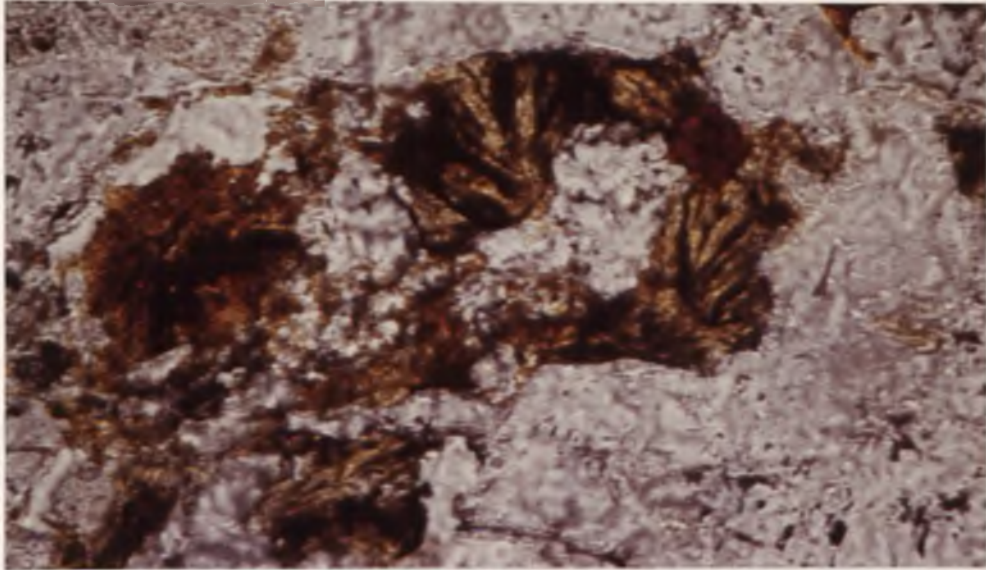


Figure 16A.

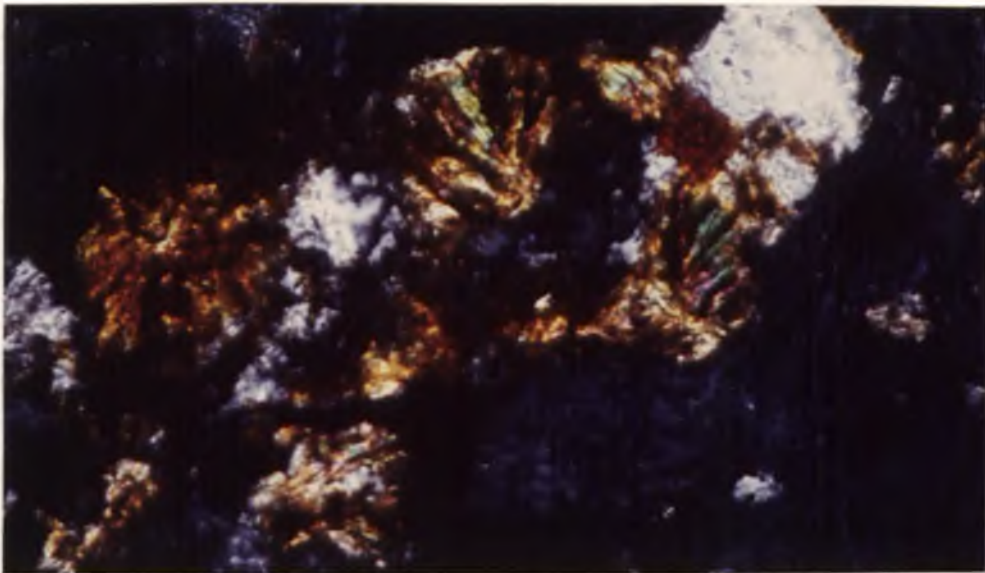


Figure 16B.

Figure 16. Nontronite with Quartz Replacing Feldspar.

Horizontal field of view is 0.4 mm. A. Plain polarized light. B. Crossed polarized light.

CHAPTER 4

FLUID INCLUSION STUDY

A fluid inclusion study was undertaken to determine fluid temperatures and salinities within the system and potential precious metal precipitation mechanisms. Methods employed included standard thermometric heating and melting techniques, crushing experiments to obtain qualitative estimates of inclusion CO₂ contents, and construction of homogenization temperature versus melting temperature diagrams to distinguish relative importances of boiling and fluid mixing within the system.

In an earlier fluid inclusion study of the Sixteen-to-One system (Nelson 1984), five doubly polished sections, one each from the 7000, 6890, and 6770 levels, and two from the 6600 level, were examined. One hundred, seventeen homogenization temperatures were obtained from 80 primary and 37 secondary inclusions; 37 melting temperatures were obtained from 28 primary and 9 secondary inclusions. Homogenization temperatures in primary inclusions ranged from 170° to 220°C and salinities varied from 5 to 12 wt.% NaCl equivalent. No inclusions with variable fluid to gas ratios were observed. Nelson's homogenization temperatures indicate a bimodal distribution with modes at 180° to 185° and 205° to 210°C. He concluded that deposition resulted from two separate events.

Method of Study

Doubly polished sections were subjected to heating and freezing on an SGE, Inc. gas-flow stage under a magnification of 500x. Homogenization temperatures (T_h) were measured in 5°C increments. Melting temperatures (T_m) were observed by freezing inclusions to -60°C, heating, and observing the temperature of last ice melt. These temperatures were measured in 0.1°C increments. Selected inclusions were crushed under glycerine; the activity of the vapor bubble when intersected by a fracture was observed.

Nine doubly polished sections were prepared; six were found to contain primary inclusions suitable for analysis. Three of the examined sections contained Sixteen-to-One vein material collected from the 7000, 6890, and 6570 levels. A fourth section was prepared from high grade drill core which intersected the Sixteen-to-One vein at an elevation of 6835 feet. Two samples were collected from the Colorado vein on the 6770 and 6585 levels. All samples contained vein quartz and sulfides ± other gangue minerals; the 6570 and 6585 level samples were especially rich in base metals.

The vuggy nature of the vein suggests pressures were near hydrostatic during much or all of vein formation. Stratigraphic reconstructions indicate not more than 600 meters of volcanic rocks and sediments were likely to have overlain the vein system during mineralization and therefore pressures probably did not exceed 60 bars (Nelson 1984). Corrections for pressure would change homogenization temperatures less than 10°C (Potter 1977) and have not been applied.

Inclusion Descriptions

Inclusions in quartz yielded most of the data; sphalerite inclusions were analyzed in samples from the two deepest levels. All inclusions are liquid-rich, two-phase inclusions and contain no immiscible liquids or daughter salts. The vapor phase occupies 5 to 15 volume percent of the inclusions and all inclusions homogenize to the liquid phase. Secondary inclusions, aligned along fracture planes, are present in great abundances indicating much fracturing following quartz deposition. Primary inclusions are rare and were identified as primary or pseudosecondary based on criteria by Roedder (1984). Quartz inclusion sizes varied from <10 to 65 microns; most analyzed inclusions ranged from 10 to 35 microns. Sphalerite inclusions varied from <10 to 150 microns and averaged about 40 microns. Homogenization temperatures were obtained for 51 primary and 6 secondary inclusions; paired melting temperatures were obtained for 41 primary and 3 secondary inclusions. Fluid inclusion data are presented in Appendix C. No two-phase inclusions with variable vapor/liquid ratios, confirming boiling in the system, were observed.

Observations

Homogenization Temperatures

Temperatures varied consistently with elevation (Figure 17, Table 4). High temperatures (205° to 225°C) were observed on all except the 7000 level, however, the general pattern of decreasing lowest temperatures in successively higher levels suggests fluids were being cooled as they approach the surface.

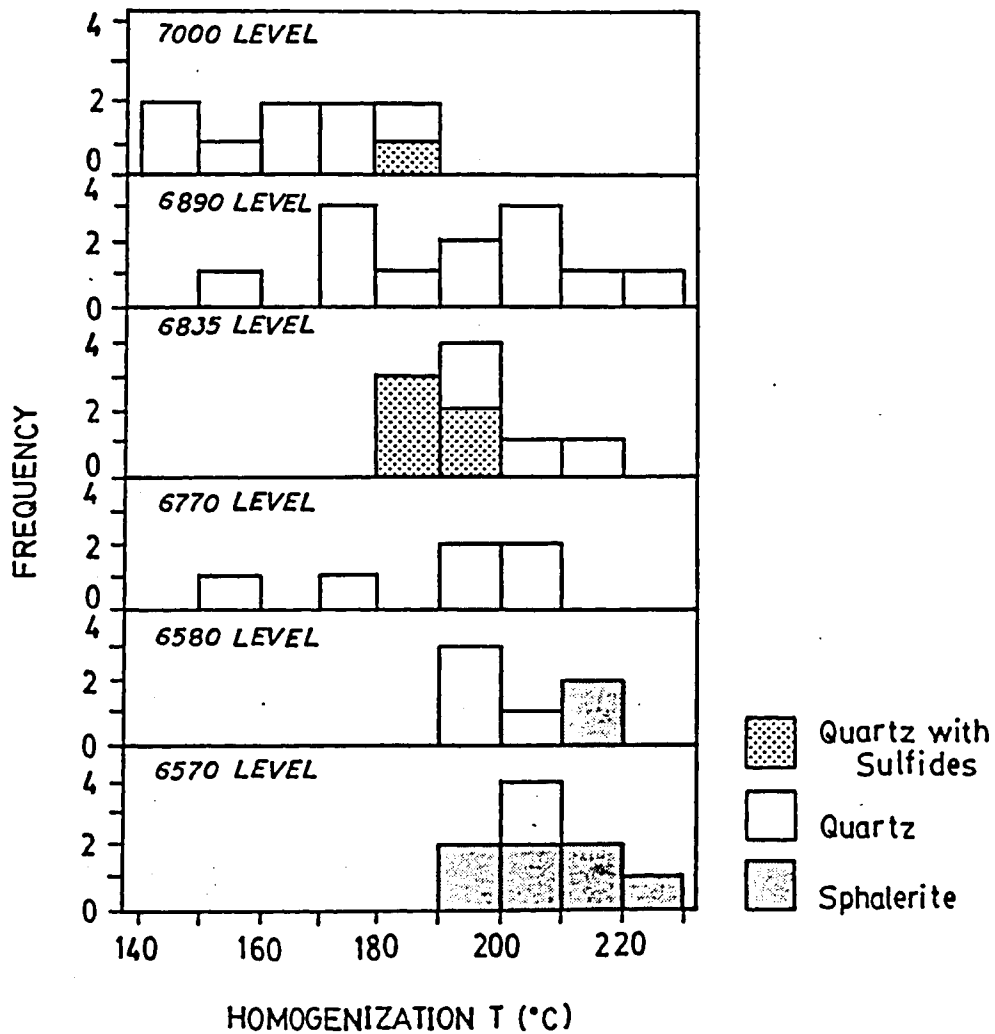


Figure 17. Histogram of Primary Fluid Inclusion Homogenization Temperatures for Each Level.

Note temperature decrease with increasing elevation. "Quartz with Sulfides" refers to inclusions in quartz crystals that are adjacent to sulfides.

Table 4. Fluid Inclusion Data.

<u>LEVEL</u>	<u>AVE. Th</u>	<u>(no. meas.)</u>	<u>Th RANGE</u>	<u>AVE. Tm</u>	<u>(no. meas)</u>	<u>Tm RANGE</u>	<u>AVE. SALIN.</u>	<u>SALIN. RANGE</u>
6570	209	9	190-205	-6.7	9	-2.9-7.8	10.0	4.8-11.5
6585	205	6	190-215	-3.5	3	-2.2-5.9	5.6	3.7-9.2
6770	192	6	155-205	-7.0	5	-6.1-7.4	10.5	9.3-11.0
6835	199	9	185-220	-6.1	6	-5.4-7.1	9.4	8.4-10.6
6890	195	12	150-225	-5.8	11	-4.2-7.5	8.9	6.7-11.1
7000	169	9	145-190	-5.7	7	-2.1-7.5	8.6	3.5-11.1

Homogenization temperatures measured on the 7000 level varied from 145° to 190°C and are considerably lower than the range of 190° to 225°C measured in the sample from the deepest 6570 level (Table 4). The average temperature decreased 40°C over a vertical distance of 130 meters.

Sphalerite homogenization temperatures varied from 190° to 230°C (Figure 17) and fall within the upper bounds of measured temperatures. Quartz inclusions spatially associated with sulfides are found in samples from the 6835 and 7000 levels and range from 180° to 200°C (Figure 17). Inclusions in coarse, clear quartz, commonly part of the last local episode of quartz deposition varied from 145° to 225°C. A histogram of all primary homogenization temperatures (Figure 18) shows a skewed temperature distribution with a mode at 200°C. The bimodal distribution observed by Nelson (1984) is not present, although small peaks do exist.

Homogenization Temperatures Versus Melting Temperatures

T_h versus $T_{m(ice)}$ diagrams (Figure 19) reveal clustering of data points on all but the 6890 level. All but two data points on the 6570 and 6770 levels fall within a homogenization temperature range of 190° to 225°C and a melting temperature range of -6.6° to -7.8°C. Only three melting temperatures were obtained from the 6585 Colorado vein sample; homogenization temperatures fall into the above range but salinities are lower. Homogenization temperatures measured in the 6835 sample have decreased to a range of 185° to 200°C; salinities have dropped also and their range has widened slightly.

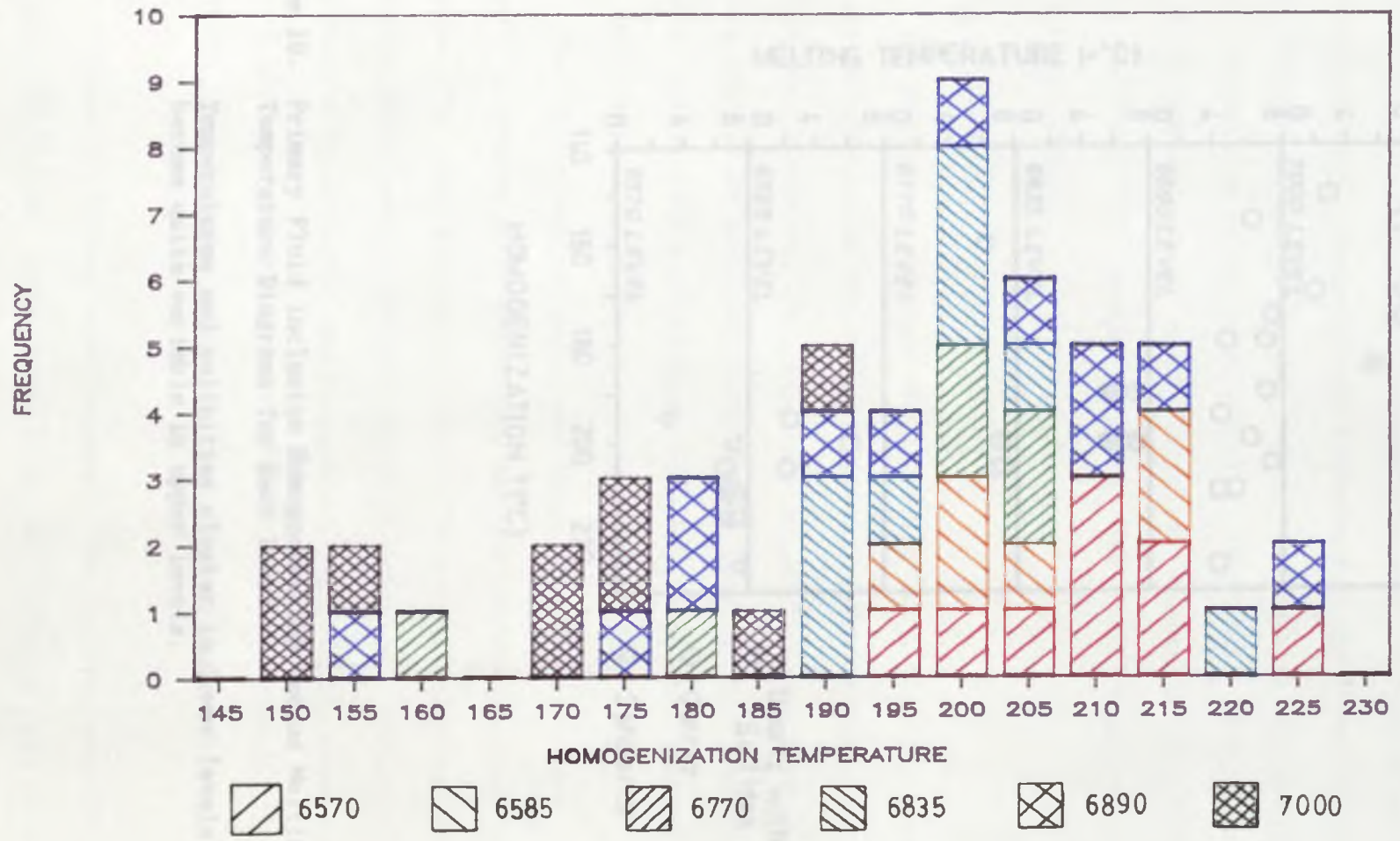


Figure 18. Histogram of Primary Fluid Inclusion Homogenization Temperatures.

Fluid temperatures varied from 145°C to 225°C.

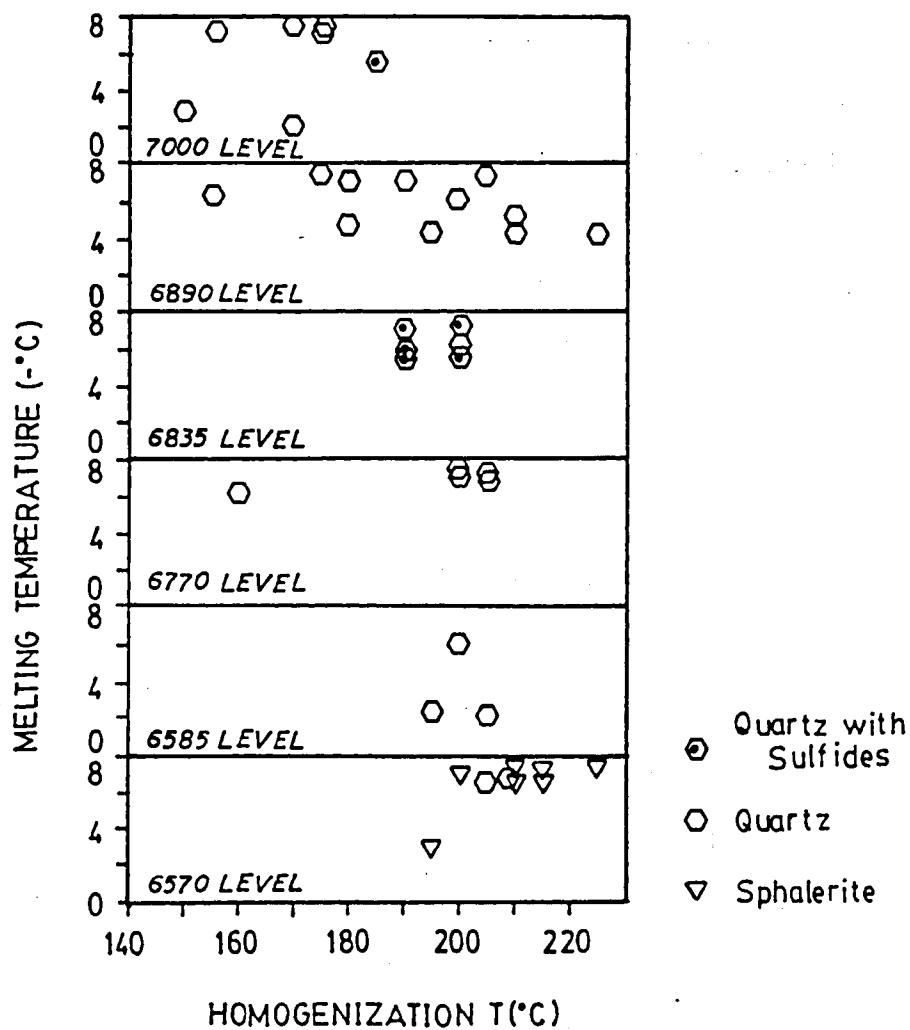


Figure 19. Primary Fluid Inclusion Homogenization Versus Melting Temperature Diagrams for Each Level.

Temperatures and salinities cluster in lower levels, but become quite variable in upper levels.

Homogenization and melting temperatures in the 6890 level sample are quite variable. Inclusions observed in clear, coarse quartz revealed a pattern of decreasing temperature with increasing salinity. Seven thousand level homogenization temperatures are significantly reduced compared to deeper levels; variable salinities are indicated by melting temperatures which vary from -2.1° to -7.5°C . Homogenization and melting temperatures in quartz inclusions spatially associated with sulfides (6835 and 7000 levels) vary from 180° to 200°C and -5.4° to -7.1°C , respectively.

Crushing Experiments

The presence or absence of CO_2 in inclusion fluids provides important information on the boiling history of the hydrothermal fluids. Under boiling conditions, gas components are partitioned into the vapor phase and lost while unboiled fluids retain their gases. The CO_2 content of fluids within inclusions reflects the boiling history of the parent hydrothermal fluid (Roedder 1984, Barton et al. 1977).

Four inclusions in quartz and three in sphalerite were successfully crushed under glycerine, and qualitative CO_2 observations were made. The vapor bubbles in four of the seven inclusions shrank and disappeared indicating an absence of contained gases. Intersection of fractures with three inclusions resulted in vapor bubble expansion to about $1/2$ the bubble diameter or slightly less indicating CO_2 was present and trapped under relatively low pressure (approximately 2 to 3 bars).

Crushed inclusions were located in samples from the 6570, 6585, 6770, and 7000 levels. Vapor bubbles in one inclusion from each level

contracted on fracturing indicating an absence of CO₂; hydrothermal fluids either originally contained no CO₂ or boiling led to loss of fluid gases to the vapor phase.

Vapor bubble expansion indicating the presence of CO₂ was observed in two sphalerite inclusions from the 6570 level and one quartz inclusion from the 7000 level. Prior boiling had not removed the contained gases.

CHAPTER 5

DISCUSSION AND INTERPRETATIONS

Discussion of Alteration Assemblages

The two alteration assemblages - regional and vein-controlled - are characterized by different mineralogical assemblages, different alteration styles, and different spatial relationships with the vein system. Regional alteration is typified by moderate to complete replacement of primary minerals; vein-controlled alteration is evidenced as open space, fracture filling and minor, locally important, metasomatism. Vein-controlled alteration is observed superimposed upon regional alteration in andesites. This superposition is probably present in rhyolites also, but is less apparent as regional alteration is much more subtly expressed in these rocks. The assemblages have formed in response to two temporally discrete events.

Regional Alteration

This assemblage principally consists of chlorite, calcite, and pyrite and fits the classic definition of propylitic alteration (Coats 1940, Meyer and Hemley 1969, Beane and Titley 1981). The chemical composition of the original rocks has not been extensively changed; alteration is the result of minor hydrogen metasomatism and the addition of water, CO₂, and sulfur to the original system.

Chlorite. Penninite is much more abundant in andesites than in rhyolites, indicating the importance of iron and magnesium contributions

from mafic rocks. Chlorite alteration of rhyolite groundmass is most common on the 6890 level and rare in upper levels, apparently owing to proximity to andesite as a source for iron and magnesium. Plagioclase replacement by chlorite requires stronger magnesium metasomatism and is minor. The formation of chlorite probably requires the addition of only water to the system.

Calcite. "Regional calcite" parallels chlorite in its distribution in andesite and rhyolite, reflecting in this case the availability of calcium. Groundmass plagioclase concentrations in andesite are often replaced by large, irregular masses of calcite. Addition of CO₂ to the system may be required for calcite formation.

Pyrite. Pyrite abundances also vary between andesites and rhyolites reflecting distribution of available iron. Local pyrite association with chlorite and with calcite/chlorite pseudomorphs after olivine reflects mutual iron requirements. The formation of pyrite may require an increase in the system's sulfur content.

Nontronite. Minor nontronite occurs most often in andesite as an alteration product of mafic minerals and plagioclase. A frequent spatial relationship with chlorite suggests some nontronite resulted from chlorite hydration and incorporation of locally available calcium and iron. Nontronite's spatial relationship with opaque minerals and rarity within rhyolites reflects its dependency on available iron. The addition of water and possibly silica to the system may be necessary in order for nontronite to form.

White Micas. Trace amounts of white micas may indicate minor K-metasomatism within the system; the necessary potassium may be provided by altering biotite and groundmass. Mica formation requires hydration.

Vein-Controlled Alteration

Vein alteration consists primarily of quartz veining and minor silicification, plus the formation of minor chlorite, epidote, and montmorillonite as a result of fluid interaction with wall rocks, and minor calcite, adularia, and epidote deposition owing to boiling.

Quartz. Hydrothermal fluids provided large volumes of silica to the system and quartz is primarily found filling formerly open spaces. The great abundance of anhedral quartz masses in the Sixteen-to-One deposit, particularly in areas of strong fracturing, is evidence of numerous flow channels which provided fluid access to large volumes of wall rock. The mineralogy of these flow channels indicates only minor fluid/rock interaction producing minor chlorite or epidote or, more commonly, precipitation of only quartz. Anhedral quartz masses provide no evidence of hydrolytic alteration leading to the formation of clays or micas. Quartz most likely precipitated in response to decreasing temperature (Holland and Malinin 1979), and probably sealed wall rocks from further reaction with hydrothermal fluids. Vuggy veins and veinlets indicate near hydrostatic pressures during much and possibly all of vein formation.

Calcite. Calcite distribution within the system is somewhat complex. Regionally altered rocks unaffected by vein-controlled fractures or fluids contain abundant calcite replacements. Calcite is absent or sparse, even though other regional alteration minerals are

present, in areas containing minor to moderate fracturing and evidence of the passage of vein-controlled fluids. Calcite reappears in areas of strong fracturing or brecciation, generally close to the vein, and always displays textural features indicating it formed late in the vein paragenetic sequence. This pattern suggests "regional" calcite was not in equilibrium with early vein-controlled fluids and was removed.

Hydrothermal calcite is clearly one of the latest minerals to form. Its near absence in anhedral quartz masses indicates these flow channels were sealed prior to calcite precipitation. Sudden losses of CO_2 can override calcite's increased solubility at reduced temperatures (Holland and Malinin 1979). A very late fracturing event could have caused a sudden pressure drop and boiling; partitioning of CO_2 to the vapor phase would have increased pH and precipitated calcite. The occasional bladed habit indicates some late calcite deposited as a result of local boiling (Browne 1978). Alternatively, if circulating ground water entering the vein system was heated beyond its calcite saturation point, calcite precipitation may have resulted. The presence of minor quartz within calcite blades indicates some quartz precipitated after calcite deposition.

Minor, but locally abundant calcite replacement of groundmass and feldspar is found only in areas of strong fracturing and may indicate local areas of increased $a_{\text{Ca}^{++}}/a_{\text{H}^+}$.

Chlorite. Vein-controlled chlorite occurs most frequently as masses of spicules precipitated within anhedral quartz masses or quartz veinlets. The concentration of these spicules along wall rock contacts suggests wall rock influence in stabilizing chlorite. Abundance of

chlorite in lower and mid andesite levels, and paucity in upper rhyolite levels supports this interpretation. Magnesium metasomatism is only rarely observed.

Pyrite. Pyrite distribution is partly controlled by wall rock composition; fracture density appears to be unimportant. The poorly fractured 6570 footwall contains vein-controlled pyrite reaching 6%. Pyrite is notably less abundant in the hanging wall where fluids encountered iron poor volcanic breccia matrix. Pyrite abundances are locally greater in wall rocks adjacent to veinlets than within veinlets.

It is unclear why hydrothermal pyrite is less important in andesites on the 6585 level or why it preferentially formed in rhyolites in the 7000 level hanging wall. Association with epidote in rhyolite suggests iron availability in rhyolites is partly responsible for pyrite formation.

Adularia. Adularia is probably present in at least minor abundances in all levels. Chlorite associations with adularia suggest a relatively early formation; its presence within quartz veinlets suggests formation may extend over the length of time required to form and fill a vein.

Adularia precipitation in geothermal systems is a response to boiling of hot fluids in upflow channels (Keith, White, and Beeson 1978). Fluid boiling causes a decrease in CO_2 and an increase in pH and in $a_{\text{K}^+}/a_{\text{H}^+}$; the fluid shifts from the muscovite stability field into the K-feldspar stability field and adularia may precipitate (Figures 21A, 21B).

Epidote. Epidote occurs both as concentrations in fracture filling quartz adjacent to wall rock/quartz contacts, and within quartz veinlets. Concentrations adjacent to wall rocks suggest, as do similar chlorite occurrences, formation as a result of interaction between hydrothermal fluids and wall rocks. Zoisite occurs attached to anhedral quartz mass walls indicating it formed very early in the paragenetic sequence. The presence of epidote dispersed through veins suggests it may also precipitate from hydrothermal fluids, possibly as a result of boiling, similarly to adularia. pH increase can also lead to increased $a_{Ca^{++}}/a_{H^+}$ and increased epidote stability (Figures 21A, 21B). Epidote appears to increase somewhat in upper level rhyolites, perhaps as a result of increased fracture density and increased area of fluid/rock interaction.

Nontronite. Nontronite forms high in the system, primarily in rhyolite, probably owing to lower temperatures higher in the system (Browne and Ellis 1970). Its precipitation in open space is consistent with its formation in geothermal systems. Strong correlation with vein quartz and anomalous precious metal values suggests nontronite responds to precipitation mechanisms in a manner similar to precious metals.

White Micas. The sparse presence of white micas indicates minor hydrogen metasomatism in more highly fractured areas. Extremely minor amounts of white micas found in vein quartz may have precipitated from hydrothermal fluids.

Relationships Between Alteration Assemblages and the Vein System

Epithermal models have been proposed which suggest propylitic alteration is genetically related to vein-controlled alteration and mineralization (Buchanan 1981). Genetically related assemblages form from a single, or possibly evolving hydrothermal fluid. Deep fluids pass up and out through the system, diffusing into the wall and producing alteration assemblages spatially related to the vein system.

A spatial relationship between the regional propylitic and vein-controlled assemblages should exist if a single fluid of reasonably constant composition was responsible for creation of both assemblages (Meyer and Hemley 1969). A single fluid would lead to simultaneous growth of all alteration zones, with individual zones advancing at their outer edge while being overprinted at their veinward edge by subsequent zones. Alteration zones could vary in thickness, but relative to one another, thicknesses should be constant.

No such relationship exists between regional and vein alteration assemblages at the Sixteen-To-One deposit. Vein-controlled metasomatism is never observed more than a few millimeters from a fracture, yet propylitically altered rocks extend many hundreds of meters beyond the vein system and the propylitically altered region is geometrically unrelated to the vein configuration (Keith 1972). The lack of spatial relationship between the two alteration zones indicates it is unlikely that one fluid was responsible for both alteration assemblages.

On a regional scale, both a single, unchanging fluid and an evolving fluid which undergoes chemical changes should create a spatial relationship between resulting alteration assemblages and the vein.

Keith (1972) observes that propylitic alteration in the district shows no spatial relationship with the mineralized vein systems. Earnest (private communication 1985) concurs and notes the regional nature of the propylitic alteration. It seems unlikely that all fluids responsible for propylitically altering an irregular area of regional extent, gained access through the Sixteen-to-One fracture system. It is more reasonable that the deep heat source responsible for both volcanism and epithermal mineralization, generated abundant early hydrothermal fluids which regionally permeated and extensively altered the volcanic rocks (Table 1). This interpretation is consistent with interpretations by Coats (1940) for alteration around the Comstock Lode and by Burbank and Leudtke (1969) for the Eureka District in the San Juan Mountains.

Interpretation of Fluid Inclusion Observations

Fluid temperatures within hydrothermal systems are decreased principally by three mechanisms: fluid boiling, frequently as a result of pressure decreases; fluid dilution, owing to mixing with surface waters; and conduction of heat into surrounding wall rocks (Henley, 1984). Conduction is probably unimportant in most epithermal systems as fluid residence time is generally too short for significant amounts of heat to be lost to the wall rocks (Henley and Ellis 1983, Fournier 1979). Boiling and mixing are probably responsible for nearly all temperature reduction and salinity variations within these systems.

Homogenization Versus Melting Temperature Patterns

Homogenization temperature versus melting temperature diagrams can reveal mechanisms responsible for fluid temperature reduction

(Hedenquist and Henley 1985). Inclusions formed from hydrothermal fluids which have mixed with surface waters of low temperature and salinity, will define a linear pattern indicating regularly decreasing temperature and salinity as mixing progresses. Fluid boiling results in two linear patterns. Extensive boiling will reduce the amount of volatiles present and concentrate salts; the resulting trend is one of decreasing temperature and increasing salinity. A second trend is related to freezing point depression due to CO₂ content of fluids. Inclusions with salinities similar to those encountered in this study, can contain up to 0.85 molal CO₂, undetectably dissolved within an inclusion fluid. This amount of CO₂ can depress the melting temperature as much as 2.0°C. During boiling gases are partitioned into the vapor phase and most CO₂ in the system is lost. Variable boiling of fluids containing up to 0.85 molal CO₂ will result in decreased CO₂ and will be evidenced by T_m variations to as much as 2.0°C. A T_h versus T_m pattern of very minor or no homogenization temperature decrease with melting temperature variations of 2.0°C may result from fluid boiling and decreased CO₂ abundances rather than salinity variations.

Sixteen-to-One Trends

Examination of data reveals trends both within levels and between levels. The clustering of points in deep levels (Figure 19) suggests that homogenization temperatures and salinities are not changing significantly and neither mixing nor boiling are important at these depths. Minor local mixing or boiling may be responsible for the two lower temperature and salinity points on the 6570 and 6770 levels.

Temperatures in the 6835 sample are reduced compared to lower levels. Within the sample homogenization temperatures cluster; melting temperatures vary 1.7°C. The rather tight homogenization range accompanied by more variable salinities may reflect minor boiling and decreasing CO₂ contents. Mixing may also have contributed to decreased temperatures and salinities.

Wide homogenization temperature and salinity variations on the 6890 level suggest fluids are being cooled by several mechanisms. The pattern of decreasing homogenization temperature and increasing salinity suggests boiling extensive enough to reduce liquid volume and concentrate salts. Some decreased temperature and salinity points may indicate mixing; a few high temperature, high salinity points indicate the presence of unmixed, unboiled fluids.

7000 level data points range in homogenization temperature from 145° to 190°C and indicate significant cooling of essentially all fluids. High salinity fluids probably result from boiling and salt concentration; low temperature, low salinity inclusions represent mixed fluids.

Overall Pattern

The resulting pattern reveals a system with very minimal temperature and salinity variations in lower levels, suggesting little or no boiling or mixing at these locations. The variable homogenization temperatures and salinities observed on the 6890 level may be explained by two hypotheses. The first possibility assumes deep hydrothermal fluids were homogeneous and suggests minor, but locally important, episodes of boiling contributed to salinity variations. Boiling may

have been important at the 6835 elevation where somewhat decreased temperatures and salinities might indicate a combination of minor boiling and resultant CO₂ loss, and minor mixing. Both mixing and boiling may have been important mechanisms in the two upper levels examined, leading to the highly variable salinities observed. These variations could alternatively result from a combination of the initial presence of fluids of various stages having different salinities, and fluid mixing. The clustering of temperatures and salinities in deeper levels makes the first hypothesis preferable. The presence of high temperature, high salinity fluids on the 6890 level indicates at least minor amounts of unmixed, unboiled fluids did reach this elevation; essentially all fluids underwent mixing or boiling prior to reaching the 7000 level.

Sphalerite precipitation appears to be enhanced at temperatures above 190°C and the mineral is most abundant where higher temperatures prevailed. Inclusions in quartz spatially related to sulfides are found in 6835 and 7000 level samples and formed within a temperature range of 180° to 200°C.

The bimodal temperature distribution observed by Nelson (1984) was not found in this study. The relation of observed temperature with elevation suggests the small peaks are an artifact of limited sampling access. Samples located between levels, particularly between upper levels where temperature reduction is greatest, would probably reveal more continuous temperature variations.

The small number of successfully crushed inclusions permits only qualitative observations and in no way constrains the extent to which

boiling occurred at any level. Crushing suggests at least minor boiling occurred throughout the examined portion of the system; it further indicates unboiled fluids reached the 7000 level.

Enthalpy Versus Salinity

The degree to which fluids in geothermal systems have boiled or been diluted by surface waters is often estimated with the aid of enthalpy-chloride diagrams (Fournier 1979). Diagram construction requires the conversion of temperature to enthalpy, an extensive rather than intensive parameter, subject to heat conservation laws within a system. Since heat loss by conduction is unimportant in epithermal systems, fluid mixing and boiling are the only feasible mechanisms for heat loss. Application of the restriction of heat conservation allows estimation of the temperature of surface fluids which, when mixed with hydrothermal fluids, could have produced the temperature and salinity variations observed within the system.

An enthalpy-salinity diagram for the Sixteen-to-One system (Figure 20) includes data points representing average enthalpies and salinities for each level and two end members which represent the highest temperature obtained from the 6570 level and the lowest temperature obtained from the 7000 level. Calculations are based on enthalpy data from Haas (1976) which incorporate the salinity contribution to the enthalpy value. The majority of points defines a line which intersects the Y axis at an enthalpy of approximately 395 J/gm. This theoretical mixing line suggests that if 6570 level fluids are taken to represent "pristine" hydrothermal fluids which mixed with surface waters of low salinity and enthalpy (0 wt. % NaCl and 395 J/gm,

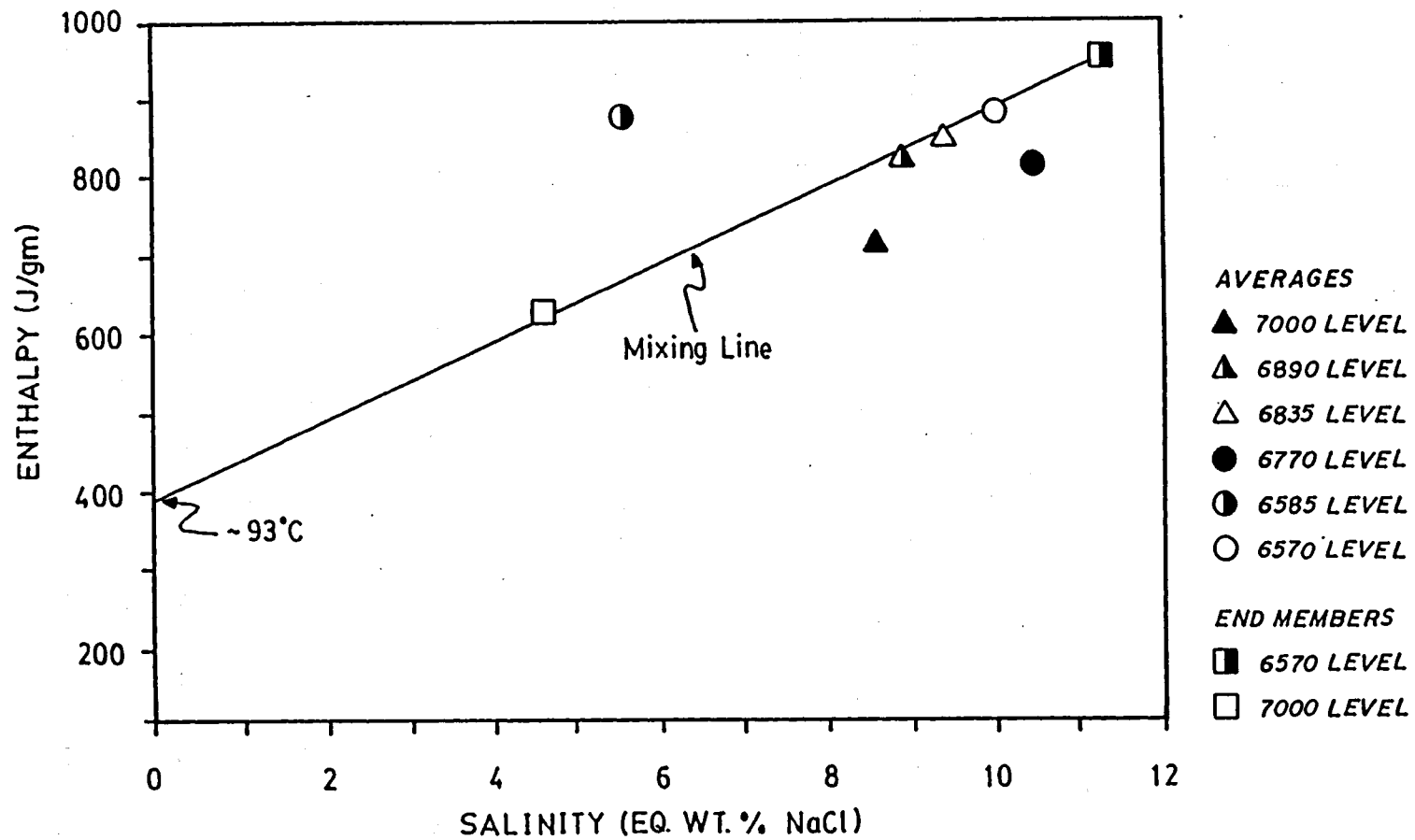


Figure 20. Enthalpy Versus Salinity Diagram.

See text for explanation.

respectively), they could have produced most of the enthalpy-salinity variations observed in the system. The "pristine" samples are from the deepest mine level. The diagram suggests that "average" fluids in higher levels could have formed by mixing of saline, deep level hydrothermal fluids with non-saline, surface fluids with an enthalpy of about 400 J/gm. The diagram further indicates that mixing with $\leq 25\%$ groundwater would produce most observed changes; mixing with 60% groundwater is necessary to produce the low temperature, 7000 level fluid. Three hundred, ninety-five J/gm converts to a temperature of 93°C, within surface temperatures of a convecting hydrothermal system (Henley 1984). Boiling causes a loss of enthalpy and gain in salinity and data points which plot below the line reflect fluid temperatures and salinities which resulted from either boiling or a combination of mixing and boiling.

In analyzing the entire system this diagram must be applied cautiously. Most plotted data points are level averages; plotting of raw data would result in much scatter, particularly in upper levels. Also, in order for the mixing line to be accurate, it must be drawn through a data point representing previously unmixed fluid, and it cannot be clearly established that 6570 level fluids truly represent deep, unmixed fluids. Finally, and perhaps most importantly, this diagram accounts for mixing of hydrothermal fluids and surface fluids of only one composition and temperature. This simplification ignores the possible presence of several distinct surface waters and hydrothermal fluids and the likely change in fluid character during the life of the

hydrothermal system. Such complications may be responsible for data points such as the one which plots above the mixing line.

Nevertheless, this diagram effectively illustrates the relationships between different fluids within the system and, more importantly, indicates which processes may have been responsible for creating these differences. The number of data points which plot along or near the mixing line suggests mixing was the most important temperature reduction mechanism in the system. The importance of local boiling on the 6770 and 7000 levels is suggested by the location of data points below the mixing line. The lack of points well below the mixing line indicates boiling did not contribute significantly to changes in fluid character.

Comparisons With Geothermal Systems

Epithermal deposits may be fossil analogues of active geothermal systems (Henley and Ellis 1983, White 1981). Geothermal studies permit examination of complete hydrothermal systems, including the fluid phase, and have provided increased knowledge of equilibrium relationships between fluids and wall rocks. Extensive studies, particularly at Broadlands, New Zealand, have led to improved understanding of alteration zoning within moderate to low temperature hydrothermal systems. An important result of these studies is that permeability and temperature have been identified as the two most important factors in determining which alteration products will form in many systems. Fluid composition is a third important parameter and the influence of parent material is important in systems with temperatures lower than 280°C (Brown 1978).

The Broadlands geothermal system formed within a series of volcanic rocks very similar to those containing the Sixteen-to-One deposit. Alteration mineralogy at Broadlands also conforms closely to that observed at the Sixteen-to-One mine. Similarities between the two systems in both original volcanic rocks and alteration products suggests hydrothermal fluids were probably similar. Deep Broadlands fluids are dilute, chloride bicarbonate waters with temperatures of 260°C, pH = 6.0 to 6.2 (neutral = 5.7 at 260°C), and $m_{CO_2} = 0.15$. Oxygen isotopes indicate fluids are primarily recirculating meteoric waters (Henley and Ellis 1983). Fluids are in near equilibrium with K-mica, K-feldspar, albite, chlorite, calcite, quartz, and minor wairakite (calcium zeolite). Minor variations in temperature and fluid composition will shift the fluid between the various mineral stability fields resulting in precipitation of any of these phases.

Additional influences on several minerals have been noted. Illite-montmorillonite forms high in the system in response to decreasing temperatures (130° to 230°C). The formation of chlorite is unusual in that it is related to original iron concentrations and is independent of depth, permeability, and temperature. Pyrite is also independent of temperature and forms in areas of increased sulfur or iron concentrations (Browne and Ellis 1970). Silica precipitation in response to decreasing temperature frequently seals walls from further reaction with hydrothermal fluids (Fournier 1979).

Boiling is an important mechanism leading to precipitation of calcite, adularia, and minor epidote. Bladed calcite precipitation in drill rods penetrating geothermal systems indicates this bladed form

often results from boiling in response to sudden pressure decreases. An activity diagram containing Broadland's potassium and calcium equilibrium assemblages and fluid composition, (Figure 21A, after Browne and Ellis 1970) illustrates how boiling and resultant pH increase can shift the fluid composition into the zoisite, K-feldspar, or calcite stability field. The relationship between P_{CO_2} and calcite precipitation is also illustrated (Figures 21B, 21C). At a particular carbon dioxide concentration, a horizontal line can be drawn representing the value at which calcite precipitates and forms a calcite "blind" beyond which $a_{Ca^{2+}}/a_{H^+}$ cannot increase; calcite precipitation prevents formation of minerals otherwise stable within this field. The two "calcite lines" represent Broadland's high initial fluid contents of 0.15m CO_2 , and fluid contents of 0.03m CO_2 after 3 to 4% boiling (Browne and Ellis 1970) and indicate the effect of CO_2 on equilibrium assemblages.

Zoning of vein-controlled alteration within the Sixteen-to-One system is very similar to alteration zoning at Broadlands. Chlorite, and to some degree pyrite, are spatially related to deep andesites. Epidote formation is in part related to available iron, and in part related to boiling and pH increase. Minor adularia and calcite precipitated in response to boiling throughout the system, and nontronite formed as a result of temperature decrease high in the system. Trace amounts of white micas formed in highly fractured areas indicating minor local hydrogen metasomatism. Quartz deposition, in response to decreasing temperature, sealed wall rocks from further reaction with hydrothermal fluids.

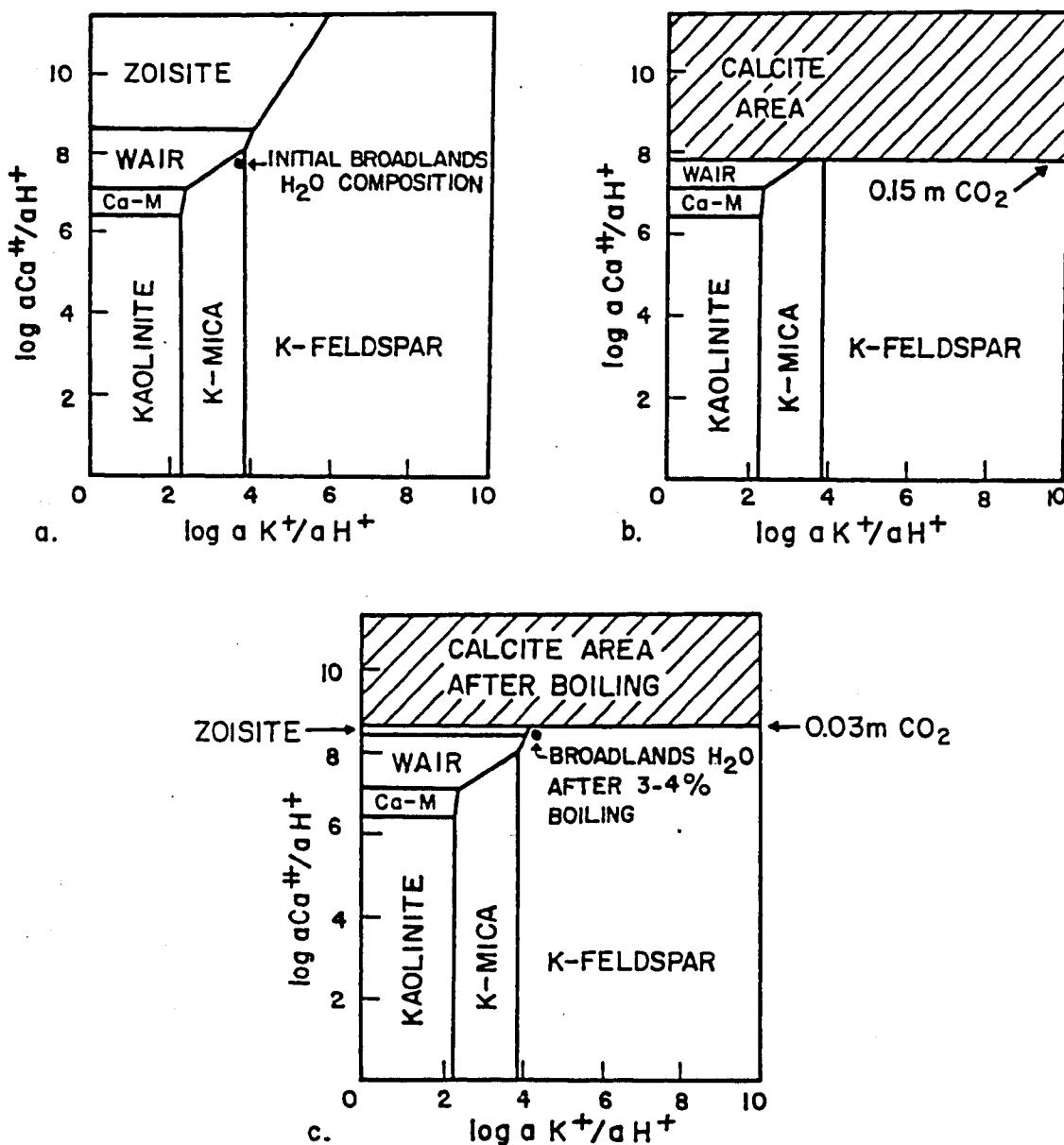


Figure 21. Mineral Stability Diagrams for Calcium and Potassium Minerals, Broadlands, New Zealand (from Browne and Ellis 1970).

Figure 21A illustrates the stability fields for potassium and calcium minerals and initial Broadlands fluid composition. Fluid boiling increases Ca^{2+} and K^{+} relative to H^{+} and the fluid composition moves upward and right (Figure 21C). Figures 21B and 21C illustrate the effect CO_2 within a fluid has upon the equilibrium assemblage. See text for explanation.

WAIR = wairakite; Ca-M = calcium montmorillonite

Sixteen-to-One alteration studies suggest minor differences from Broadlands fluids; a slightly higher aK^+/aH^+ may have been responsible for increased fluid residence time in the K-feldspar stability field leading to the observed near lack of wall rock leaching prior to quartz precipitation.

Inclusion studies further constrain Sixteen-to-One fluid chemistry. Temperatures varied from 145° to at least 225°C. Salinities ranged from 3.5 to 11.5 wt % NaCl equivalent and are higher than salinities observed in most geothermal systems. CO₂, present in some inclusions, was trapped at pressures of approximately 2 to 3 bars; the lack of visible CO₂ indicates fluids contained less than 0.85m CO₂. The presence of zoisite within the system suggests CO₂ concentrations were locally low enough that the calcite "blind" did not totally preclude its formation (Figure 21C); the presence of both calcite and rare white micas, if they are an equilibrium assemblage, suggests CO₂ was locally abundant enough to permit calcite and K-mica stability fields to be in contact (Figure 21B).

Comparison with the Broadlands geothermal system, and fluid inclusion observations indicate Sixteen-to-One fluids were slightly alkaline, bicarbonate fluids with temperatures of at least 225°C, salinities reaching 11.5 wt % NaCl equivalent, and moderate CO₂ abundances. In all but salinity, Sixteen-to-One fluids closely resembled modern-day fluids at Broadlands.

Epithermal Silver Deposition

Silver solubility is enhanced by the formation of silver-chloride complexes, which are likely responsible for the increased

silver concentrations in moderately saline systems. Precipitation of silver sulfides occurs when physical and chemical changes in the system destabilize chloride complexes. Destabilization and silver precipitation can occur in response to increasing sulfur activity, increasing pH, decreasing temperature, and reduced oxygen fugacity (Barnes 1979).

Alteration and fluid inclusion studies indicate significant changes which occurred within the Sixteen-to-One system included temperature decrease resulting from fluid mixing and local boiling, and local pH increase in response to local boiling. Temperature reduction resulting from fluid mixing appears to have been the most widespread change within the system and was responsible for silver precipitation. Local boiling and related pH increase probably caused local precipitation.

Proposed Sixteen-to-One Model

The Silver Peak volcanic center resumed activity about 6 m.y. ago with eruption of rhyolite tuffs, structural foundering, and caldera formation. Volcanic eruptions continued, producing andesite, rhyolite, and latite tuffs and flows. Hydrothermal fluids, related to the magmatic system, permeated and propylitically altered the region adding minor amounts of sulfur, CO₂, and water to the existing volcanic stratigraphy. Tension fractures, related to caldera formation, formed east of the caldera margin.

About 1 m.y. after volcanism began, hydrothermal fluids locally traversed, altered, and mineralized steeply dipping fracture zones. Subsidiary fracturing and open space mineralization are the principal

hydrothermal effects in wall rocks; metasomatism is minor. Local reaction between hydrothermal fluids and wall rocks resulted in precipitation of minor chlorite, epidote, and pyrite, particularly in close proximity to andesites. Occasional fluid boiling led to partitioning of CO₂ to the vapor phase, pH increase, and precipitation of calcite, epidote, and adularia within quartz veins. Local nontronite alteration and precipitation occurred in low temperature environments high in the system. Trace amounts of white micas indicate local hydrogen metasomatism. Abundant quartz deposited in flow channels in response to decreasing temperature, and sealed walls from further reaction with fluids.

Fluids circulating through the vein system continued depositing abundant quartz, minor gangue minerals, and base and precious metals, principally in response to temperature reduction. Minor fluid mixing and boiling were responsible for slight temperature reduction and salinity variations in deep levels. Both mixing and boiling increased upwards leading to large and rapid temperature reductions in upper levels. Mixing was probably responsible for temperature reduction of most of the fluid volume; boiling was locally important in middle and upper levels. Nearly all fluid temperatures were reduced prior to fluids reaching the 7000 level.

Metal precipitation reflects temperature controls within the system. Sphalerite precipitated most readily at temperatures ranging from 190° to 230°C and occurs in greatest abundance in deepest mine levels. Precious metal precipitation was enhanced when fluid temperatures ranged from 180° to 200°C and salinities varied from 8.4 to

10.6 wt% NaCl equivalent. Increased precious metal abundances are coincident with locations of increased fluid mixing and boiling in middle and upper levels (Figure 22).

A late, large pressure drop, probably a result of fracturing, led to extensive boiling, and immediate precipitation of abundant calcite as a major gangue mineral throughout the system. Boiling concurrently destabilized silver-chloride complexes present in solution resulting in co-precipitation of sulfides. Reduced precious metal grades in calcite, compared to quartz, are a result of dilution within the vein by the abundant, rapidly precipitating calcite. Only minor quartz precipitation followed calcite deposition. Eventually the system sealed and fluid circulation ceased.

No intense acid leach alteration assemblage is observed in the Sixteen-to-One deposit. In some hydrothermal systems acidic fluids form when boiling causes gases containing hydrogen to partition into a vapor phase which quickly escapes towards the surface. Cooler, near-surface conditions lead to fluid condensation and oxidation of sulfur species resulting in formation of a low pH fluid capable of extensive hydrolytic alteration. This fluid may alter wall rocks during its rise to the surface; in many hydrothermal systems it recirculates both outward and down creating an intensely argillized assemblage which gradually decreases in volume and extent downward toward the top of the boiling zone. The absence of such an assemblage at the Sixteen-to-One deposit may be explained in three ways: the assemblage formed and was later removed by erosion, the assemblage was prevented from forming by sealing of the system, or, the appropriate acidic fluids did not form. The

Figure 22. Alteration, Fluid Inclusion, and Mineralization Summary Diagram.

Lithologies, vein widths, alteration, fluid inclusion temperatures and salinities, degrees of fluid mixing and boiling, productivities, and precious metal grades and ratios are listed for each level as data is available. Alteration minerals are schematic and intensity on diagram approximates observed abundances. Increases in fluid mixing and boiling are indicated by increased width between diagram lines. Productivity equals the weighted silver average across the vein times the vein width. Productive silver zones correlate well with those areas of greatest vein width, intense fracturing and silicification, mixing with low temperature, low salinity surface fluids, and local boiling.

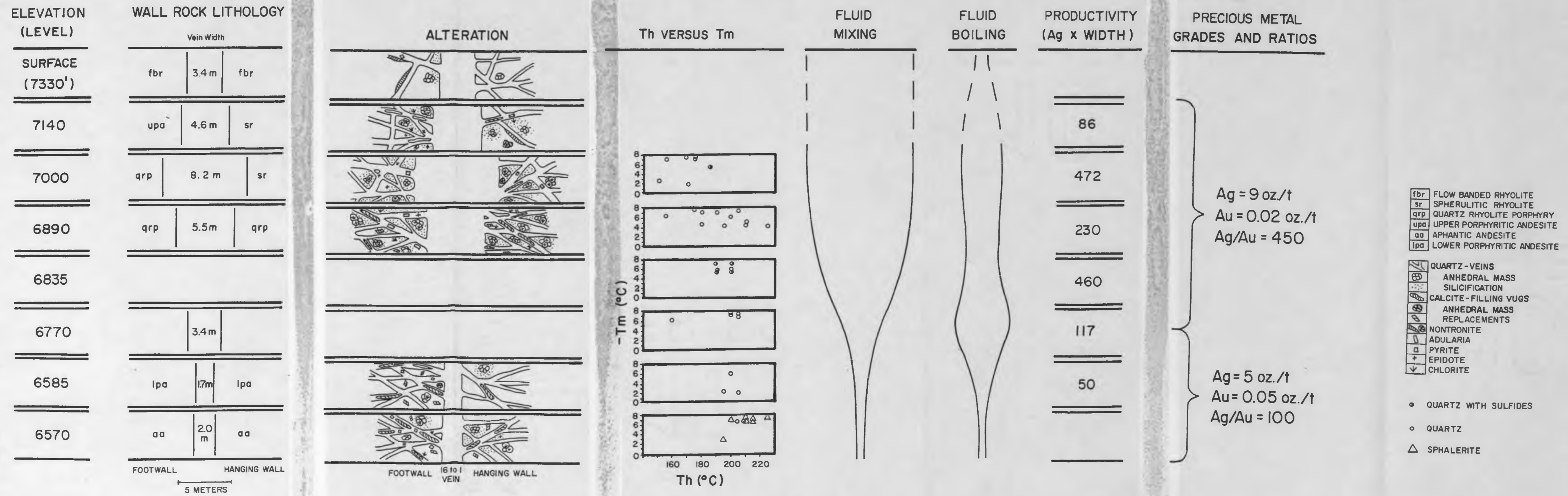


Figure 22. Alteration, Fluid Inclusion, and Mineralization Summary Diagram.

first alternative is rejected since minor evidence of boiling is observed throughout much of the system and enthalpy-salinity relationships indicate boiling was most important on the 6770 and 7000 levels, well below the current surface elevation. Lack of an acid leach assemblage is probably related to a combination of only minor formation of acidic fluids and system sealing. During most of the system life, boiling was relatively minor and the volume of gases partitioned into the vapor phase was minimal. Minor "sericite" alteration within highly fractured areas probably formed when minor amounts of these gases passed upward. The late fracturing event led to abundant boiling, calcite formation, and possible late formation of acidic fluids. Textural relationships indicate this boiling event was one of the last events in the life of the vein system. Sealing prevented any late-formed acidic solutions from penetrating the vein system.

CHAPTER 6

SUMMARY AND CONCLUSIONS

Alteration

Petrologic and alteration studies reveal a vein alteration pattern which is summarized as follows:

- * The only early mineral is Chlorite, precipitated deep within the system and controlled by Mg content of andesites and fluid access to wall rocks.

- * Minerals deposited throughout most of system's life include:
 - Quartz: deposition throughout system, probably in response to decreasing temperature.

 - Pyrite: deposition partially as a result of available Fe^{++} .

 - Adularia: deposition in response to pH increase probably as a result of boiling.

 - Epidote: perhaps increasing upward and possibly related to wallrock availability of Fe^{+++} . Formation, probably in response to boiling, continued after wall rocks were sealed from fluids by quartz precipitation.

 - Nontronite: replacement of rhyolites and precipitation high in system as a result of decreasing temperature and possibly availability of Fe^{+++} .

 - White micas: trace amounts in highly fractured middle levels and surface outcrops as a result of minor hydrogen metasomatism. Possibly very minor precipitation from hydrothermal fluids. Timing is uncertain.

- * The only late mineral is Calcite, deposited in response to boiling or possibly temperature increase. Minor calcite replacement.

Significance of Wall Rock Alteration

This study indicates the character of the hydrothermal fluids was essentially unchanged as a result of wall rock alteration and it is unlikely that fluid/wall rock interaction contributed toward precious metal precipitation. True replacement within the system is minor; extensive fracturing and vein formation are the major effects the hydrothermal system had upon the volcanic rocks containing the deposit. Most alteration minerals recognized in this study occurred as open space fillings which frequently formed as a result of interaction between wall rocks and hydrothermal fluids; wall rocks did, to varying degrees, control the presence and location of alteration minerals. Other than quartz, the volume of the alteration minerals formed is very small and the net effect their formation had upon fluid chemistry was local.

The presence of minor amounts of calcite, adularia, and epidote within quartz veins and veinlets is significant in that it indicates boiling did occur at least locally within the system. Boiling of fluids probably contributed to local metal precipitation.

Fluid Inclusions

Fluid inclusion data provided important information concerning fluid temperatures and salinities, and mechanisms responsible for fluid cooling and salinity variation at the Sixteen-to-One deposit.

1. Primary inclusion homogenization and melting temperatures varied from 145° to 225°C and -7.8° to -2.1°C. Melting temperatures translate to salinities of 11.5 to 3.5 Wt.% NaCl equivalent.

2. The complete pattern is one of decreasing temperature and salinity with increasing elevation. Fluid temperatures decreased an

average of 40°C over the 130 meter interval analyzed. Temperatures and salinities clustered on all but the 6890 level where they were highly variable. This variability coincides with widening of the vein and increased precious metal precipitation.

3. Th versus Tm diagrams indicate temperature reduction and salinity variation resulted from fluid mixing accompanied by minor boiling; both mechanisms increased in importance upward. Markedly increased mixing and boiling are coincident with the most productive portion of the deposit where vein widths reached 15 meters and silver locally reached values greater than 100 oz/t (3110 g/t).

4. Essentially all fluid temperatures were decreased at and above the 7000 level.

5. Inclusion CO₂ contents indicate at least some boiling occurred from the 6570 level to the 7000 level; some fluids reaching the 7000 level had not yet boiled.

6. An enthalpy-chloride diagram indicates mixing of hot, saline, deep level hydrothermal fluids with 93°C, low salinity, surface fluids was capable of producing temperature and salinity variations observed in the system. Boiling was locally important.

APPENDIX A

REGIONAL ALTERATION

The regional assemblage contains abundant chlorite and calcite, lesser pyrite, and trace amounts of montmorillonite and white micas. This assemblage is characterized by moderate to strong replacement of groundmass and feldspars and complete replacement of mafic minerals.

Chlorite. Chlorite is the most abundant regional alteration mineral present. It frequently displays an anomalous blue birefringence suggesting it is the variety penninite, a member of the amesite-antigorite series; an approximate composition would be $(Mg_5Al)(Si_3Al)O_{10}(OH)_8$. Ferrous iron usually substitutes for some of the magnesium.

Chlorite, in many habits, is commonly present in andesites. It occurs most abundantly as a very fine grained alteration product, frequently replacing 10% and locally replacing 50% of the groundmass. Replacement of groundmass is most pervasive in lower porphyritic and aphanitic andesites where chlorite is often associated with oxidized mafic minerals; less frequent associations were observed with montmorillonite and calcite.

Oval and irregular masses of green and brown fibrous chlorite are fairly abundant in the lower two andesites. Other small irregular chlorite/montmorillonite masses replace groundmass or possibly mafic

minerals. Fibrous chlorite frequently rims irregular calcite masses; this style of alteration is present in all andesites, but is most abundant in the upper andesite porphyry where calcite/chlorite replacements reach 25% (Figure 7).

Chlorite often completely replaces mafic phenocrysts. Hexagonal pseudomorphs suggest the former presence of olivine in lower porphyritic andesite; laths indicate abundant former hornblende in upper porphyritic andesite; various rectangular, square, and octagonal shapes suggest pyroxenes were previously present in all andesite units. Chlorite also replaces minor feldspar.

Rhyolites contain significantly less regional chlorite. Very minor, fine green masses locally replace groundmass and matrix; abundances rarely exceed 8%. Minor chlorite is associated with montmorillonite and occurs within perlitic fractures in spherulitic rhyolite.

Biotite, plagioclase, and K-feldspar phenocrysts have been replaced by chlorite to varying degrees. Biotite replacement varies from minor to complete; chlorite is generally accompanied by opaques and quartz \pm calcite. Feldspar alteration is usually minor with plagioclase generally more affected than K-feldspar. Chlorite alteration is most evident in mafic fragments found within some rhyolite units and it parallels alteration described for andesitic rocks.

Calcite. Calcite alteration is especially common in andesite where large calcite masses reaching 5mm are frequently rimmed by fibrous chlorite. This habit is most common in porphyritic andesites where calcite/chlorite masses locally reach 25% (Figure 7). Fine grained

calcite replacements of groundmass are occasionally present and may be accompanied by chlorite and montmorillonite.

Calcite alteration of phenocrysts is strongly evident in porphyritic andesites. Plagioclase surfaces may be altered between 2% and 50%. Calcite and opaques \pm chlorite pseudomorphed olivine phenocrysts (Figure 8), and infrequently pseudomorphed orthopyroxene. Calcite frequently accompanies chlorite alteration of biotite.

Alteration in rhyolites is quite rare. Minor calcite accompanies chlorite in perlitic fractures in spherulitic rhyolite and trace to very minor calcite is rarely found altering plagioclase. Trace to minor amounts of calcite may be found in mafic fragments.

Pyrite. Disseminated pyrite ranges from nil to 2% in andesites; it commonly varies from <0.5% to <1%. It generally forms sparse, fairly coarse cubes. Minor pyrite replaces magnetite. Pyrite is locally associated with chlorite and also with calcite and chlorite pseudomorphs of olivine.

Sparse pyrite in rhyolites ranges from nil to <1%; common abundances vary from nil to <0.25%. Mafic rock fragments in several rhyolite units locally contain pyrite abundances to 5%. Magnetite has occasionally altered to pyrite and both pyrite and magnetite may be rimmed by goethite.

Montmorillonite. A bright green color identifies this montmorillonite as nontronite, $(1/2\text{Ca,Na})_{.67}\text{Fe}_4(\text{Si}_{7.33}\text{Al}_{.67})\text{O}_{20}(\text{OH})_4 \cdot n\text{H}_2\text{O}$. Nontronite masses are quite similar to chlorite but are distinguished by their higher birefringence.

In andesite, nontronite forms relatively small, bright green fibrous masses, frequently accompanied by chlorite. Masses appear in hand sample as dark green spots and are commonly found in the two lower andesitic units. Nontronite also commonly replaces plagioclase.

Regional nontronite is quite rare in rhyolites with the exception of a rhyolite tuff found only in the underground ramp system. Two to 5% nontronite appears as a coarse fibrous green mineral replacing groundmass adjacent to feldspar and quartz grains. Sparse nontronite replaces rhyolite porphyry groundmass and often appears to be spatially related to oxidized opaque minerals. It occurs rarely in perlitic fractures on the 7000 level with chlorite, calcite, and quartz. Moderate nontronite may be present in mafic fragments contained in some rhyolites.

White Micas. Micas have been identified only by petrographic methods; their very fine habit and sparse abundances did not permit identification by X-ray diffraction. Optical methods generally cannot be used to distinguish between talc, pyrophyllite, paragonite, vermiculite, and muscovite. Illite is optically very similar to muscovite, but has a slightly lower birefringence. Very fine grained white phyllosilicates having the form and birefringence of sericite are referred to as white micas.

White micas are found only rarely in this alteration assemblage. Trace amounts form small shreddy masses in the andesite groundmass; trace to moderate amounts are locally present as small scattered flakes in plagioclase. Very minor biotite has been completely altered to white

micas, calcite, and opaques ± quartz and chlorite in upper andesite porphyry.

Rhyolites contain trace to minor white micas in groundmass and matrix. Even rarer mica replaces plagioclase.

APPENDIX B

VEIN-CONTROLLED ALTERATION

Vein-controlled alteration minerals include, in decreasing abundance, quartz, calcite, chlorite, pyrite, adularia, epidote, nontronite and white micas.

Quartz. Quartz composes greater than 95% of the vein-controlled wall rock alteration minerals. It is most abundant in upper levels where the vein intersects the more extensively fractured rhyolite.

Veins frequently exhibit comb textures defined by several generations of variably sized quartz crystals. Vugs are common and may be partially filled with younger calcite. Quartz veins may also contain very minor amounts of adularia, chlorite, epidote, and sulfides. Chlorite and epidote are generally concentrated along the vein/wall rock contacts.

Small, oval to round masses of anhedral quartz grains comprise a second, common form of open-space-filling quartz. These masses are generally less than 0.75mm in diameter and frequently increase in density with increasing proximity of a vein or veinlet. As density increases, masses become connected at one or more points and grade to a web-like vein texture. The "discrete" masses are in fact flow channels which are connected in a plane other than the one viewed in thin section. Further evidence that these masses were originally open

cavities is provided by the occasional presence of clusters of euhedral zoisite crystals which are attached to the wall of the cavity and extend into the former opening (Figure 12). Quartz masses also contain minor fine spicules or spicule masses of chlorite and radial clusters of epidote, generally concentrated around the outer edges of the quartz mass. Anhedral quartz masses are spatially related to those areas which have been most strongly fractured.

Quartz metasomatism composes less than 5% of the vein-controlled quartz occurring in wall rocks. Silicification is observed in several forms within the system and its temporal relationship with veining is often ambiguous. Optically continuous quartz coronas occasionally form rims around primary anhedral quartz grains. In at least some cases the coronas appear to be related to veining. Vein-controlled silicification occurs in highly fractured rocks as silica rims around anhedral quartz masses. The rims rarely extend more than 0.5mm beyond the quartz mass. Silicification adjacent to quartz veins and veinlets is infrequently present.

Small rounded areas within groundmass are occasionally silicified. The fuzzy borders and contained groundmass give the quartz masses a "snowflake-like" appearance under crossed polarized light. These masses formed during several temporally discrete events. Rhyolite autobreccias contain clasts consisting primarily of these masses; clast boundaries frequently cut silicified masses indicating their formation prior to autobrecciation. Vein-controlled "snowflake-like" masses are found in areas containing abundant anhedral quartz masses and strong vein-controlled brecciation. These "snowflakes" are frequently

disseminated among anhedral quartz masses and probably formed adjacent to other anhedral masses not present in the plane of the thin section. The overall pattern suggests that hydrothermal fluids travelled through numerous once-connected flow channels, now preserved as anhedral quartz masses, and occasionally diffused through and replaced adjacent wall rock for very small distances.

Calcite. Calcite is commonly found in minor amounts filling or partially filling the center of vuggy quartz veins. Open space calcite is somewhat more restricted than quartz in the distances it occurs from the main vein; it is however, found at significant distances in areas of abundant fracturing. Calcite only rarely occurs in anhedral quartz masses, however analogous anhedral calcite masses are present on the 7140 level within 0.5 meters of the vein. Calcite is generally medium grained, but occasionally occurs as very coarse (greater than 4mm) grains or exhibits a coarse bladed habit. These blades may separate quartz crystals indicating at least minor quartz is later than calcite. Total calcite content decreases in the upper levels of the system.

Metasomatic calcite is much less abundant than open space filling calcite, but is locally important. Trace to minor amounts of fine calcite \pm chlorite are found in rhyolite and andesite groundmass, generally close to the Sixteen-to-One vein. Calcite replacement of plagioclase is accompanied by chlorite and quartz and varies from trace to minor amounts in andesite, and from minor amounts to 50% in rhyolite. Replacement of K-feldspar in rhyolite varies from trace amounts to 70% in the strongly fractured 6890 level hanging wall. Metasomatic calcite is quite restricted to close proximity of the vein.

Chlorite. Vein-controlled chlorite exhibits habits quite different from those observed in the propylitic assemblage and it occurs principally as an open space, fracture filling mineral. Chlorite is present in quartz veins and anhedral quartz masses where it forms spicules and wispy masses of spicules (Figure 11) concentrated near quartz/wall rock contacts. It is most abundant in lower mine levels and on the 6890 level; only trace amounts occur within vein quartz and anhedral masses on the 7000 and 7140 levels and chlorite is not observed in surface samples.

Rare vein-controlled chlorite replacement of andesite groundmass is distinguished from propylitic chlorite by local concentration increases in wall rocks along vein contacts. A similar occurrence in rhyolite is accompanied by nontronite. Trace chlorite replaced matrix, plagioclase, K-feldspar, and biotite in rhyolite, but it is difficult to be certain this chlorite was not part of the earlier propylitic event. The alteration has been interpreted as vein-controlled because of the coarse wispy chlorite habit and proximity to vein quartz.

Pyrite. Pyrite is identified as vein-controlled by the presence of local increases adjacent to veins, decreasing pyrite abundances in samples located greater distances from veins, and presence of pyrite within veins. Pyrite concentrations are frequently greater in wall rocks adjacent to the vein contact, than within the vein. Pyrite occasionally occurs in anhedral quartz masses and is sometimes associated with chlorite. Abundances vary from nil to 6% and are generally greater in andesites. Pyrite reaches 6% locally in the 6570

footwall where it is accompanied by sphalerite and galena. Pyrite does not exceed 2% in other andesite wall rocks.

The 7000 level hanging wall is the only area in which rhyolite contains a significant amount of vein-controlled pyrite. Pyrite locally reaches 1%; it exhibits slight increases near veins and is locally associated with epidote within veins. Other levels show nil to very minor pyrite increases over propylitic abundances.

Adularia. Selected thin sections and thin section slabs were stained to determine the presence of K-feldspar within vein quartz. As the number of sections stained was small, an accurate quantitative estimate of adularia abundance is not possible. At least small amounts of adularia were found within vein material on all but the 7000 levels. Abundances appear to be minor except locally on the 6890 and 7140 levels. In one 6890 level sample adularia composes 50% to 70% of the central third of a small veinlet. In another sample staining indicates a K-feldspar increase in the rhyolite wall rock adjacent to a small vein. A vein sample from the 7140 level contains abundant adularia bands. Adularia exhibits local spatial relationships with chlorite/nontronite and minor sulfides.

Epidote. Epidote and zoisite occur most frequently as open-space-filling minerals. They are generally minor and, in andesite, are not observed more than one meter from the Sixteen-to-One vein. Minor amounts are common within anhedral quartz masses and veinlets.

Epidote is present in the upper level rhyolites at greater lateral distances from the vein, but still occurs in only minor amounts. Zoisite is most frequently observed in 6890 level samples where it forms

0.08mm crystals with anomalous blue birefringence; the crystals extend from the walls of anhedral quartz masses into former openings (Figure 12).

Epidote very rarely replaces minor plagioclase and K-feldspar, generally when very close to a quartz vein or veinlet. It exhibits local strong associations with oxidized mafic minerals, and is occasionally associated with adularia and chlorite.

Montmorillonite. Vein montmorillonite displays the characteristic green color suggesting it also is nontronite. It occurs rarely as an open-space-filling mineral on the 6890 and 7000 levels in anhedral quartz masses and veins within two meters of the main vein system. It is also present in quartz veinlets in surface outcrops. Surface abundances are minor but nontronite is locally common and displays a strong spatial relationship with quartz veining and precious metal values.

Nontronite occurs more commonly as a replacement, generally in rhyolites. Fine masses are found in andesite in only one area of the 6585 level where they replace plagioclase and groundmass in a block of wall rock caught up within the vein. Nontronite is most commonly found in surface outcrops where it is a minor replacement of spherulitic material and forms abundant ropy masses and irregular patches along quartz veinlets. Groundmass replacement of rhyolites in other levels is minor but common and shows a frequent spatial relationship with both fracture filling and metasomatic quartz. Nontronite rarely replaces plagioclase on the 6890 level.

White Micas. White micas were found in andesite, in only one area, where groundmass adjacent to quartz veinlets had been silicified. Former biotite had been replaced by very pale brown mica, opaques, and minor quartz. The micas are most likely vermiculite, which forms when ferrous Fe in biotite is oxidized, leached, and replaced by Mg.

Trace white micas in rhyolites formed in plagioclase, K-feldspar, groundmass, and matrix, particularly on the 6890 level. Surface and 6890 level rhyolites contain trace amounts of white micas in veinlets and breccia zones.

APPENDIX C

FLUID INCLUSION DATA

Abbreviations: sph - sphalerite
 qtz - quartz
 P - Primary
 S - Secondary
 PS - Pseudosecondary

<u>Mineral</u>	<u>Type Inclusion</u>	<u>Homogenization Temperature (°C)</u>	<u>Freezing Temperature (°C)</u>	<u>Salinity (Wt% NaCl)</u>
<u>6570 Level</u>				
sph	P	220-225	-7.7	11.4
sph	P	195-200	-6.9	10.4
sph	P	205-210	-7.5	11.1
sph	P	190-195	-2.9	4.8
sph	P	210-215	-7.1	10.6
qtz	P	200-205	-6.6	10.0
sph	P	210-215	-6.8	10.2
qtz	P	205-210	-6.7	10.1
sph	P	205-210	-7.8	11.5
<u>6585 Level</u>				
sph	P	210-215		
qtz	S?	185-190		
qtz	P	190-195	-2.4	4.0
qtz	P?	195-200		
qtz	P	195-200	-5.9	9.1
qtz	S	120-125		
qtz	P	200-205	-2.2	3.7
sph	P	210-215		
qtz	S?	150-155	-0.7	1.2

6770 Level

qtz	P	155-160	-6.1	9.3
qtz	P	175-180		
qtz	P	200-205	-7.2	10.7
qtz	P	195-200	-7.3	10.9
qtz	P	195-200	-7.4	11.0
qtz	P	200-205	-7.1	10.6

6835 Level

qtz	P	190-195		
qtz	S	150-155	-5.3	8.3
qtz	P	185-190	-6.9	10.4
qtz	PS?	195-200	-6.1	9.3
qtz	PS?	215-220		
qtz	P	185-190	-5.8	8.9
qtz	P	185-190	-5.4	8.4
qtz	PS?	200-205		
qtz	P	195-200	-7.1	10.6
qtz	P	195-200	-5.5	8.5

6890 Level

qtz	P	200-205	-7.5	11.1
qtz	P	185-190	-7.1	10.6
qtz	P?	150-155	-6.3	9.6
qtz	P	210-215		
qtz	S	140-145		
qtz	P?	205-210	-4.3	6.9
qtz	P	205-210	-5.2	8.1
qtz	PS	170-175	-7.4	11.0
qtz	P?	175-180	-4.7	7.4
qtz	PS?	220-225	-4.2	6.7
qtz	P	175-180	-7.1	10.6
qtz	P	190-195	-4.3	6.9
qtz	P	195-200	-6.1	9.3
qtz	S	210-215	-3.7	6.0

7000 Level

qtz	PS	180-185	-5.5	8.5
qtz	PS?	185-190		
qtz	P	165-170	-2.1	3.5
qtz	P	165-170	-7.5	11.1
qtz	P	145-150	-2.8	4.6
qtz	P	170-175	-7.3	10.9
qtz	P	170-175	-7.4	11.0
qtz	P	150-155	-7.1	10.6
qtz	P?	145-150		

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