1993

Alteration and mineralization of the Copper Cliff prospect Garnet Range Montana

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ALTERATION AND MINERALIZATION

of the

COPPER CLIFF PROSPECT

GARNET RANGE, MONTANA

by

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B.S., Montana State University, 1985

Presented in partial fulfillment of the requirements

for the degree of

Master of Science

University of Montana

1993

Approved by

Chairman, Board of Examiners

Dean, Graduate School

Nov. 29, 1993

Date

ABSTRACT

Ellsworth, Peter C., M.S., November 1993 Geology

Alteration and Mineralization of the Copper Cliff Prospect, Garnet Range, Montana (62 p.)

Director: Ian M. Lange

The Copper Cliff prospect in western Montana hosts gold-copper deposits in an altered porphyry stock, hydrothermal breccia pipes and carbonate replacement deposits. The recent recognition of quartz-alunite alteration sparked a renewed interest among explorationists.

Extensive faulting formed by thrusting of the Sapphire allochthon and movement along the Lewis and Clark line prepared structural conduits for acid sulfate-rich fluid migration during emplacement of Eocene quartz latite plutons and dikes. Post-mineral movement along the faults have offset altered and mineralized zones.

The Copper Cliff district has undergone multiple mineralizing events manifested by advanced argillic, phyllitic and propylitic alteration zones within Tertiary quartz latite plutons that intrude Late Proterozoic metasedimentary and Cambrian carbonate rocks. Anomalous gold concentrations occur within the phyllitic altered core zone, while higher gold and copper values occur within peripheral breccia pipes and carbonate replacement bodies.

Zonation of alteration minerals, the presence of enargite and hypogene alunite, and the style of mineralization suggest that the prospect is of the enargite-bearing quartz alunite gold-copper deposit type. The model was developed by geological, geochemical and mineral patterns observed at Goldfield, NV, Summitville, CO, El Indio, Chile, Pueblo Viejo, Dominican Republic and others. Several of these quartz-alunite gold deposits are underlain by gold-rich porphyry copper deposits. Patterns at the Copper Cliff district resemble both the quartz-alunite and porphyry copper deposit models. Late gold mineralization corresponds with sericite alteration zones. Observation of sericite overprinting alunite suggest that gold was mineralized from alkaline epithermal fluids.

ACKNOWLEDGEMENTS

The author acknowledges Newmont Exploration Ltd.'s financial support for this study, particularly Rich Harris who initiated the assistance and provided valuable data. Randy Vance of Newmont, Ian Lange and Don Winston, University of Montana provided integral editorial and technical assistance. Geologic maps prepared by Mike Thomas and Pavel Reichl of Newmont were the primary source for district geologic interpretations. Aaron and Tom Charlton, of Trans-Global Resources, N.L., owners of Copper Cliff, granted access to the property and data provided use of their office. Finally, Sid Williams' petrographic data and H. Roy Krouse's isotope analysis were integrated into this report.

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CHAPTER I

INTRODUCTION

The historic Copper Cliff mining district has been prospected for over 100 years, however Pederson's (1988) recognition of extensive quartz-alunite alteration sparked renewed interest among large-scale mining companies. Sillitoe's (1988) observation that porphyry copper deposits underlie quartz-alunite alteration, further enhances the district's potential to host world class gold-copper deposits. The district hosts gold-copper occurrences within an altered quartz latite porphyry stock, carbonate replacement bodies and hydrothermal breccia pipes, however large deposits remain undiscovered.

Eocene quartz latite volcanic plutons and dikes intrude Belt metasedimentary rocks and Cambrian carbonate rocks in the Copper Cliff district. Extensive faulting provided pathways for hydrothermal fluids which formed breccia pipes scattered throughout the district. The largest pipe, the Copper Cliff, earned its name from secondary copper minerals that decorate the cliff face with bright blue and green streaks. Chalcedonic quartz, alunite, clays and sulfides together with gold and copper were deposited within breccia pipes, a porphyritic stock and carbonate rocks.

This study analyzes the complex geology and geochemistry to determine the type of deposit present and the origin and timing of hydrothermal fluids responsible for the widespread alteration and unique mineralization of the mining district. The information generated by the study is used to test the hypothesis that the district hosts an epithermal quartz-alunite hydrothermal system.

Procedure

The study was launched by assembling and analyzing a data package from Newmont Exploration Limited. The data consists of geologic maps and cross-sections prepared by Pavel Reichl and Mike Thomas, soil geochemical maps, geophysical maps, rock sample geochemistry, drill hole assays, drill logs and drill samples. Pertinent data were selected for the study, and integrated with previous literature, whole rock geochemistry, absolute age dates, microprobe data, sulfur isotope analysis, x-ray mineralogy, drill sample logs and petrographic data generated by myself.

Study Objective

The primary goal is to categorize the Copper Cliff district into the proper hydrothermal precious metal model. To do this, the enormous database must be streamlined into a succinct summary in order to compare characteristics of the Copper Cliff district with the conceptual quartz-alunite gold deposit model presented by Ashley (1982), Bonham and Giles (1983), Bonham (1984, 1988), Walthier (1985) and Berger (1986). The model is based on world-class epithermal gold-copper deposits hosted in acid-sulfate altered volcanic rocks.

The research consolidates information generated over the years into a succinct summary, and integrates these findings with field and laboratory data. The results of the research clarifies the timing, chemistry, paragenesis and depth of gold and copper mineralizing events. These conclusions lead to additional exploration targets in the district, and will be useful for future exploration strategies in the northern Rockies.

Location

The Copper Cliff prospect is located 29 miles (47 km) east of Missoula in the western portion of the Garnet Range, Sec. 10-15, T 12 N, R 15 W, Missoula and Granite Counties,

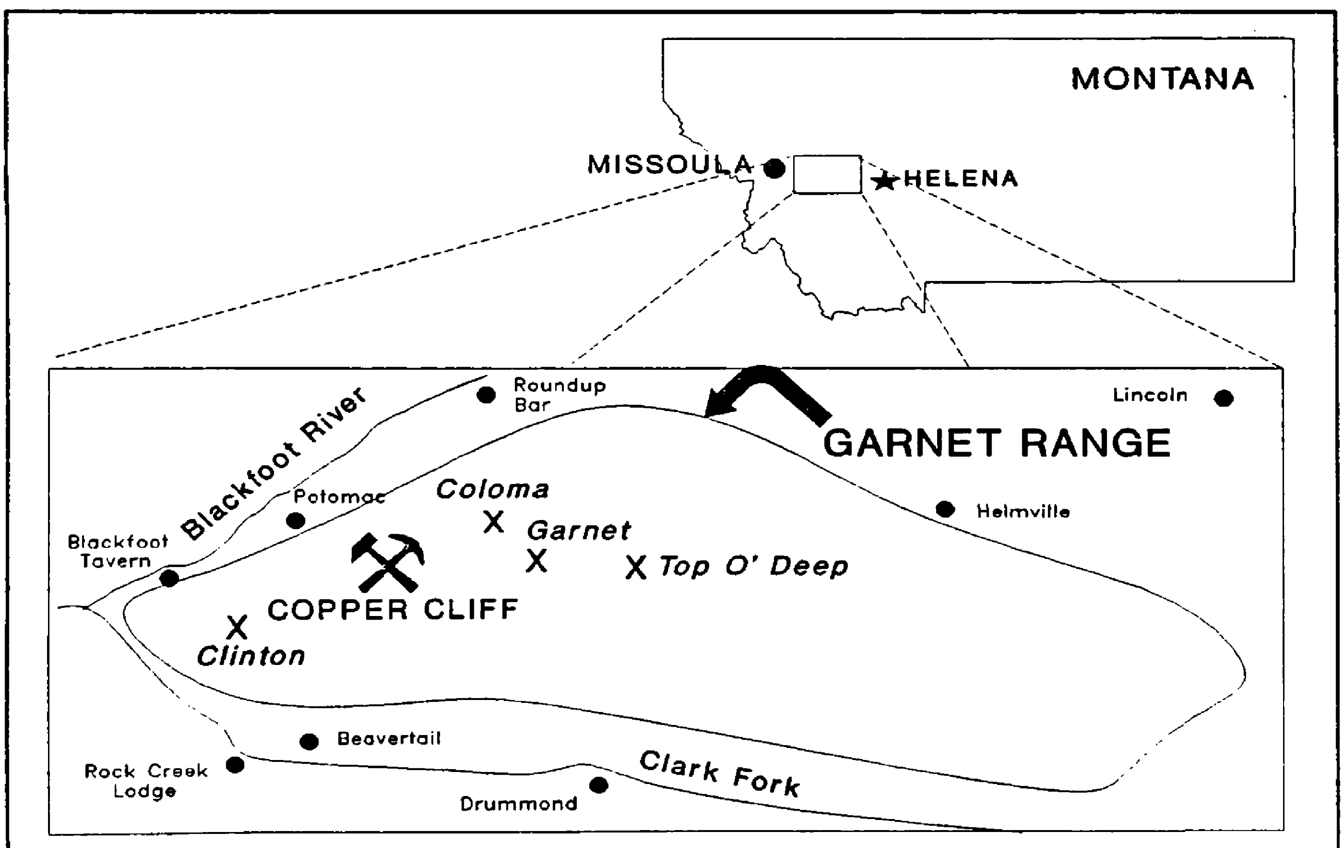


Figure 1. Location map of the Copper Cliff project and surrounding mining districts.

Montana (Fig. 1). The property is accessed via Interstate 90 at the Beavertail exit, 25 miles (40 km) east of Missoula, and northeast up the Cramer Creek Road approximately 15 miles (24 km). Research is concentrated in Sec. 11, which encompasses the Copper Cliff breccia pipe, the intensely altered Union Hill stock and the Klenzie and Leonard mines.

History and Previous Investigations

Gold in the western Garnet Range was first discovered within placer deposits along Bear and Elk Creeks in 1865 (Irving, 1963). Lode gold in the Garnet, Coloma and Top 'O Deep districts was discovered shortly thereafter. These mining districts, shown in figure 1, surround the Copper Cliff district, which was discovered in 1891 by W.P. Shipler (Irving, 1963). The Clinton mining district to the west was not discovered until 1899. Intermittent mining, development and exploration throughout the Garnet Range continued since that time, and exploration is presently active in the Garnet and Copper Cliff districts. Metallic lode production for the western Garnet Range through 1960 is summarized in Table 1.

Acquisition of the Copper Cliff property in 1900 by an English syndicate resulted in substantial development in the search for high grade ore. After mining several hundred tons of copper ore, the property was passed on to Bielenberg and Higgins in 1916, who shipped about 150 tons of 9% copper ore. The Potomac Copper Company was formed in 1918 to explore and develop low grade, large tonnage ore at depth within the

Table 1. Metal lode production through 1960 in the western Garnet Range.

District	Au (Oz.)	Ag (Oz.)	Cu (Lbs)	Pb (Lbs)	Zn(Lbs)
Clinton	212	31,774	226,545	36,642	3,200
Coloma	17,456	21,950	13,503	18,856	800
Copper Cliff	259	567	110,898		
Garnet	113,139	101,962	166,699	7,442	1,744
Blacktail		6,487	1,300	1,336,170	26,700
Top 'O Deep	2,575	N/A	N/A		
Total	133,641	162,740	518,945	1,399,110	32,444

Copper Cliff breccia pipe. Exploration was terminated after discovering that the pipe is truncated at shallow depth by a low angle fault.

The Bielenberg family maintained ownership until 1958, during which time, only minor, sporadic mining took place on the Copper Cliff face. Mr. James Charlton purchased the property and founded the American Mining Company in 1958. AMC explored the property through 1978 by compiling literature, mapping, surface sampling, geophysical surveying and drilling. The Charlton family still controls the Copper Cliff property, and numerous major exploration and mining companies examined the property since the mid 1970s.

Cities Service Mining Company leased Copper Cliff in 1977, however a decline in copper prices forced termination of the project in 1978 despite their 317 million ton potential ore estimate (Pederson, 1988). Anaconda Minerals Company initiated exploration at Copper Cliff in 1980 in conjunction with its Forest Products program in the western Garnet Range. Brannon et al. (1980) delineated three distinct targets along with resource potentials: 1) porphyry copper gold system with 340+ million tons of 0.01 oz/st gold and 1% copper; 2) mineralized breccia pipes with 2.5 million tons of 0.1 oz/st gold, 1.0 oz/st silver and 3% copper; 3) carbonate replacements with 20 million tons of 0.1 oz/st gold, 1.0 oz/st silver and 2% copper. Anaconda was unable to reach a lease agreement, and terminated exploration. Western Energy Company's purchase of Anaconda's Forest Product mineral holdings in 1985 prompted reconnaissance of the Copper Cliff district and subsequent recognition by Pederson (1988) of the quartz-alunite type system.

Newmont Exploration Limited reached an exploration agreement with Trans Global Resources N.L., controlled by the Charlton family, for the Copper Cliff district in 1991. The program entailed geologic mapping, geophysical surveying, geochemical sampling and drilling 17 holes. Newmont terminated the project in 1992, and contributed data and funding for this study. The property is presently under the control of Trans-Global Resources.

Information on Copper Cliff mineralization was first published by Pardee (1917) just after the peak mining activity in the Garnet Range. Sahinen (1957) summarized the geology, mineralization and production for the western Garnet Range mining districts. A condensed summary of this thesis was published by Ellsworth (1993). Additional publications are available for the western Garnet Range. Numerous private company reports were made available for this study, which include reports by Billingsley (1916), Rozenkranz (1919), Weed and Gow (1919), Higgens (1919), Irving (1963, 1969), Johnson (1972), Hawe (1974), Michel (1976), Shell (1977), Sherry (1983), Brannon and Korzendorfer (1982), Brannon et al. (1982), Pederson (1988), Childs and Mulholland (1988) and Vance (1988). Geologic maps, geochemical data, geophysical data and historical information of the Copper Cliff district are presented in these reports.

Methods of Study

This study integrates data generated by myself with information provided by previous workers in order to develop a coherent deposit model. K-Ar age determinations from biotite in unaltered quartz latite intrusive rock, and from alunite obtained from core recovered in the altered Union Hill stock establish their timing. Magma-chem whole rock geochemical analyses of samples collected from unaltered quartz latite stocks and dikes, as well as volcanic flows on Union Peak and Tenmile Creek east of the district indicate their compositional relationship. More than 35 thin and polished sections of igneous phases, alteration and mineralization were examined. Three samples from drill core in the Union Creek stock were prepared for fluid inclusions analysis, however none were found. Information obtained from previous studies of the regional and local geology, and the quartz-alunite deposit model is condensed into this report.

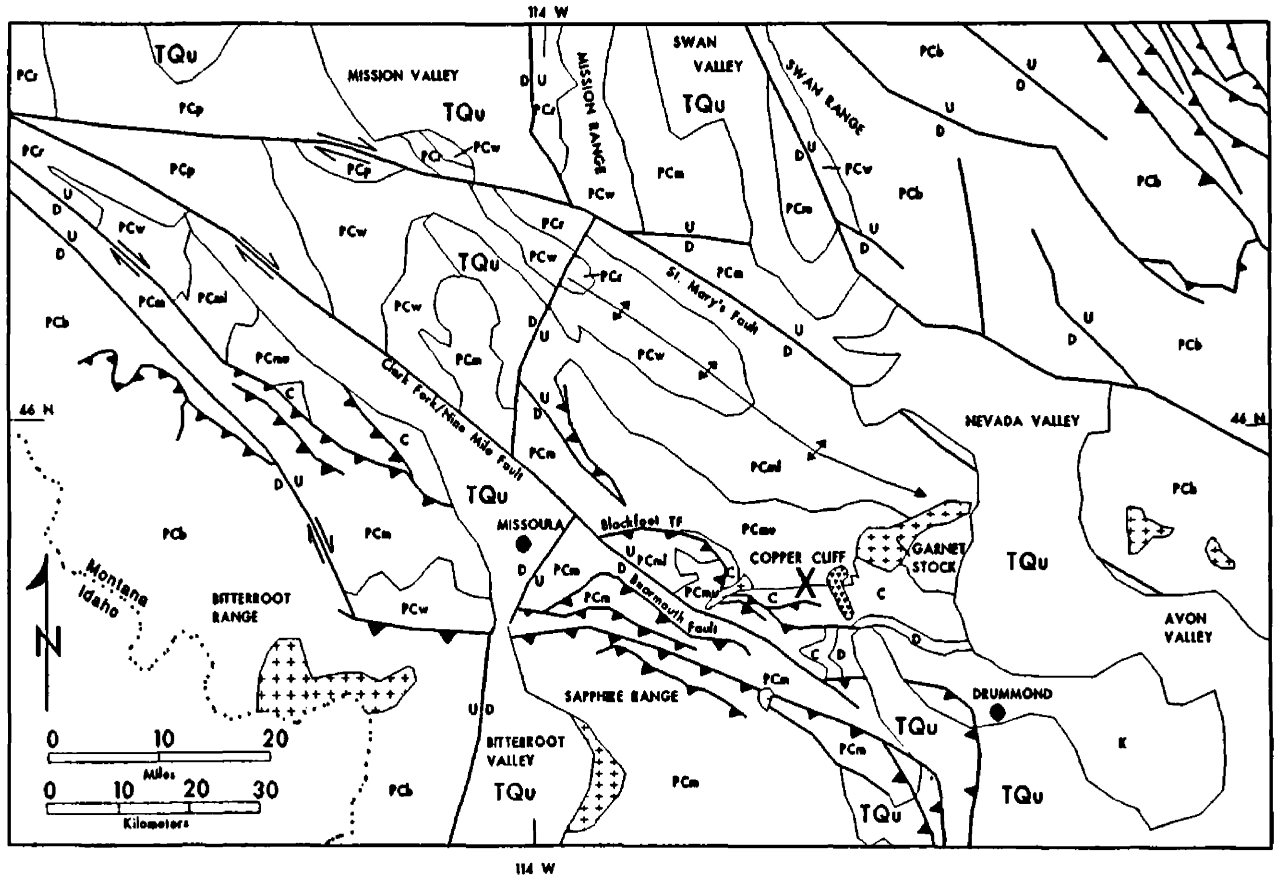
CHAPTER II

GEOLOGY

The Copper Cliff mining district is located on the southwest limb of a broad southeast-plunging anticline shown in figure 2. Late Proterozoic Belt Supergroup quartzite and argillite, Cambrian carbonates and shale, and Eocene hypabyssal quartz latite plutons and dikes crop out in the area surrounding mineralization. Tectonic effects along the Lewis and Clark line (tectonic zone) and thrusting of the Sapphire allochthon are expressed as a complex fault pattern that may be responsible for igneous activity, hydrothermal fluid migration, emplacement of hydrothermal breccia pipes and displacement of mineralized zones within the district. The complicated fault patterns and poor outcrop exposure obscures clear interpretations of structures and the geologic history of the area.

Lewis and Clark Line

The Lewis and Clark line is a broad structural zone that extends from Couer d'Alene, Idaho, southeast to the Helena area, and possibly as far east as the Lake Basin fault zone north of Billings, Montana (Harrison et al., 1974). It is represented by a series of steep faults that exhibit strike-slip, dip-slip and oblique-slip motion (Vice, 1989; Wallace et al., 1990). Reynolds (1979) suggested that movement recurred along the line since Proterozoic time. Harrison et al. (1974) observed that the line truncates the Libby trough and the



TQu Undifferentiated Quaternery and Tertiary

Eocene Volcanics

Tertiary & Cretaceous Intrusive Igneous Rocks

K Jurassic-Cretaceous Sedimentary Rocks

D Devonian Sedimentary Rocks

C Cambrian Sedimentary Rocks

PCb Undifferentiated Belt Supergroup

PCmu Upper Missoula Group

PCml Lower Missoula Group

PCm Undifferentiated Missoula Group

PCw Wallace & Helena Formations

PCr Ravalli Group

PCp Prichard Formation

Thrust Fault

Normal Fault

Lithologic Contact

Figure 2. Regional geologic map of the Garnet Range and surrounding areas. Modified after Sears et al. (1989) and Vice (1989).

Rocky Mountain trench to the north. These observations, along with aeromagnetic and gravity data suggest that the line forms a deep crustal feature that influenced Mesozoic and Cenozoic igneous activity. The recurrent activity along the line may also be responsible for channeling hydrothermal fluids and subsequent mineral deposition in the western Garnet Range.

Sapphire Allochthon

The Sapphire allochthon in western Montana constitutes the western segment of two principal thrust plates within the Cordilleran overthrust belt (Reynolds, 1991). Late Cretaceous eastward thrusting of the Sapphire allochthon accompanied emplacement of numerous plutons such as the Garnet stock, the Boulder, Philipsburg and Pioneer batholiths. These large sill-like bodies were emplaced along active thrust faults to form an arcuate pattern that extends from Paradise to Drummond, and south to Bannock (Sears, 1988; Hyndman et al., 1988; Winston, 1986). Hyndman (1980) proposed that the Sapphire allochthon represents a regional gravity slide tectonic block that detached from the Idaho batholith along the Bitteroot mylonite zone. Sears (1988) suggested that the Sapphire plate was then carried piggy-back eastward by the eastern slab over the southern portion of the Montana Disturbed Belt during Paleocene time.

The northern edge of the Sapphire allochthon is expressed as the Blackfoot and Bearmouth thrust faults in the western Garnet Range (Sears et al., 1989) as shown on figure 2. These faults are exposed along Cramer Creek within 8 miles (13 km) south of the Copper Cliff property. Here, the Bearmouth thrust places Proterozoic upper Missoula Group of the Belt Supergroup over the Cambrian Hasmark Dolomite. Further north near the Linton (Blacktail) mine, the Blackfoot thrust places Proterozoic McNamara Formation over a series of horses composed of the Pilcher Quartzite, Garnet Range Formation, the Hasmark Dolomite and the Devonian Jefferson Dolomite (Sears et al., 1989).

District Geology

The Copper Cliff district is hosted by the Late Proterozoic Belt Supergroup unconformably overlain by the Middle Cambrian Silver Hill and Hasmark formations. Early Eocene quartz latite porphyry plutons and dikes intrude the sedimentary rocks within the central mining district, and middle Eocene quartz latite volcanic flows cap Union Peak two miles (3 km) east (Fig. 2). All rock types in the central district have undergone propylitic, silicic or advanced argillic alteration.

Sedimentary rocks consist of the McNamara Formation in the northern areas, ascending south stratigraphically to the Garnet Range Formation, the Silver Hill Formation, the Hasmark Dolomite and the Red Lion Formation. Bedding planes dip 10° to 40° to the south (Fig. 3). The Flathead Quartzite, which typically underlies the Silver Hill Formation, is absent in this area. Evidently, the Copper Cliff district was located

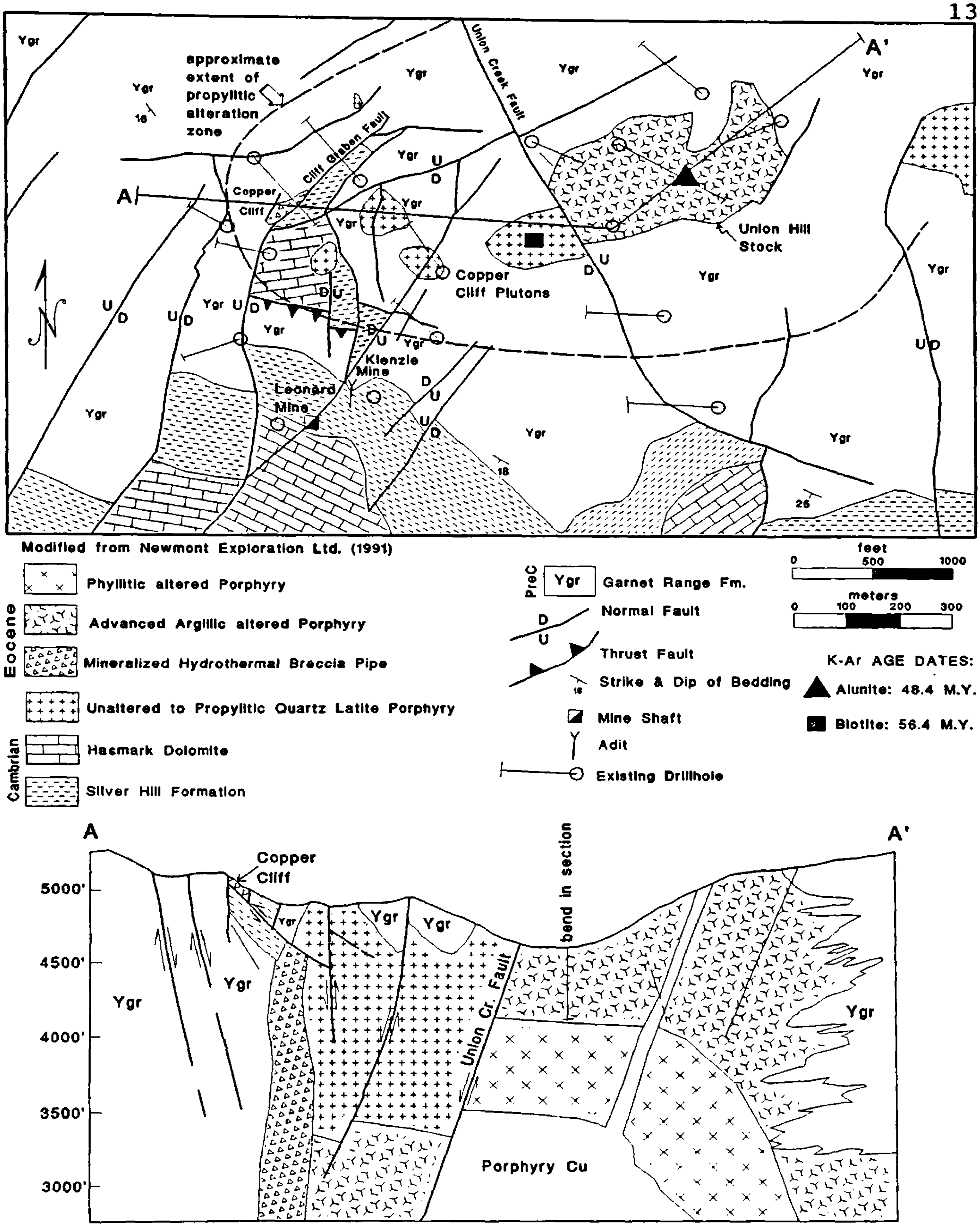


Figure 3. Geologic map (3a) and conceptual cross-section (3b) of the Copper Cliff mining district.

on a topographic high during the Middle Cambrian marine transgression and the near shore sand of the Flathead did not bury it. The mine area and primary alteration are concentrated just north of the Garnet Range/Silver Hill unconformity, which is exposed at the Klenzie mine portal (Fig. 3).

The McNamara Formation consists of maroon and light green argillite interbedded with cross-bedded quartzite. It grades up into Garnet Range Formation (within Missoula Group), which is composed of green to pink hummocky, cross-stratified quartzite with fewer argillite interbeds. Detrital muscovite is aligned along bedding planes, and up to 10% microcline and interstitial chlorite is common (Brannon et al., 1982). Ripple marks, mud cracks and shaly partings characterize the upper 50 feet (15 m) of the unit. Apparent thickness is about 3000 feet (915 m) in the district (Brannon et al., 1982), however Reynolds (1991) reports a 2500 foot (760 m) section in Cramer Creek to the south. North of the Copper Cliff breccia the Garnet Range Formation may be thickened by concealed bedding-plane thrust faults.

The Silver Hill Formation is divided into two units on plate I. The lower unit includes 50 feet (15 m) of olive green fissile shale; the upper portion contains 100 feet (30 m) of dark grey mottled limestone and minor shale that forms prominent outcrops just south of the mineralized area. The Hasmark Dolomite is a massive, micritic, dark gray, ridge forming unit. The Red Lion Formation, exposed south of the study area, encompasses 500 feet (150 m) of gray, nodular micritic limestone and red-brown siltstone and shale.

Early Eocene quartz latite and quartz trachyte porphyritic plutons and dikes intrude Belt and Cambrian strata throughout the Copper Cliff district. Plagioclase and sanidine phenocrysts are within a matrix of biotite, hornblende and quartz in unaltered plutons that crop out several hundred feet east of the Copper Cliff breccia pipe. These plutons are cylindrical in shape, measuring 300 to 400 feet (90 to 120 m) in diameter. Biotite from the largest unaltered pluton yields a K-Ar age of 56.4 +/- 1.5 ma (Fig. 3). The intensely altered Union Hill stock, located northeast of the Union Creek fault (Fig. 3), is texturally similar to these porphyritic plutons.

Union Hill Stock

The Union Hill stock measures 1500 feet (457 m) by 900 feet (274 m) and is truncated by the Union Creek fault on its southwest margin (Fig 3a). It appears that the Union Hill stock was uplifted relative to the Copper Cliff plutons after its alteration and mineralization (Fig. 3b). Relict porphyritic textures are preserved within quartz-alunite and quartz-sericite replacements in the stock. Alteration patterns described in Chapter III suggest that this stock is central to the mineralizing source.

Volcanism

Latite porphyry volcanic flows that cap Union Peak two miles (3 km) east of the Copper Cliff district are described in detail by Carter (1982). Age dates indicate that regional volcanism was active from 47.7 to 43.7 ma. Carter (1982) reports that the oldest flows from Union Peak yield 47.4 ma. The Copper Cliff plutons were emplaced 8 million years before the volcanic flows, and therefore cannot be their feeders. This volcanic event however, was the source for mineralization and alteration at Copper Cliff, dated at 48.4 ma. Paragenesis of volcanism and alteration is discussed in detail in the Geochronology section of this report.

Structural Geology

The Copper Cliff district is located about 5 miles (8 km) north of the Clark Fork/Nine Mile fault zone (Fig. 2), a major component of the Lewis and Clark line that experienced Tertiary right-lateral strike-slip motion (Sears, 1988). This fault however, has a normal component along Cramer Creek several miles south of the deposit, which places the Copper Cliff district on the upthrown footwall (Sears et al., 1989). The St. Mary's fault, 15 miles (24 km) north of the Copper Cliff district, forms the northeast margin of the Lewis and Clark line. This fault experienced both normal and right-lateral strike-slip motion.

The Union Creek fault is the only northwest-trending fault that parallels the Lewis and Clark line in the Copper

Cliff district (Fig. 3 and plate I). At least 1500 feet (460 m) of normal offset along this fault caused the emplacement of a deep level hydrothermal alteration zone to the northeast in contact with upper level shallow alteration on the southwest. In addition, numerous northeasterly-striking faults dominate the structural fabric in the Copper Cliff district (Fig. 3). This fault pattern is probably related to the Lewis and Clark line as large-scale dilational fault jogs that are commonly sandwiched between two strike-slip faults (Sibson, 1986). This style of extensional faulting can create implosion breccias, which induce boiling of hydrothermal fluids originating from igneous magmas at depth (Sibson, 1986). Boiling is induced by a sudden loss of lithostatic pressure, which subsequently precipitates hydrothermal minerals within breccia pipes (Sibson, 1986). This process may have formed the Copper Cliff breccia pipe, and its mineralization. Extension in the western Garnet Range correlates regionally with a mid-Eocene metallogenic epoch that ranges from the Toroda and Republic grabens in north-central Washington to the Custer and Panther grabens in south-central Idaho and into western Montana.

The Copper Cliff district is north of the Blackfoot fault, the major north-bounding fault of the Sapphire allochthon (Reynolds, 1991), but effects of the Sapphire detachment are not prominent in the Copper Cliff district. Evidence of only one thrust fault is mappable, located about

600 feet (183 m) south of the Copper Cliff breccia, which brought the Garnet Range Formation on the south over the Hasmark Dolomite (Fig. 3a) during Late Cretaceous time. Additional thrust faults may be present in the district, but poor outcrop and lithologic uniformity of the Garnet Range Formation obscure their traces. Altered and mineralized zones are likely offset by low angle or bedding plane faults formed by Tertiary extensional detachments.

Copper Cliff Breccia

The Copper Cliff breccia pipe forms a prominent cliff in the center of the district. It measures 330 feet (100 m) by 75 feet (23 m) in plan and 100 feet (30 m) in height (Figs. 3 & 4). Brecciated clasts of quartzite, argillite, limestone and quartz latite are suspended within a chalcedonic quartz matrix. All the clasts are intensely silicified, and contain alunite, rutile, pyrite and chenevixite (Williams, 1988). Typically, pyrite, famatinite and enargite are disseminated within the matrix. The breccia pipe is bounded by a graben fault (Fig. 4), which was probably responsible for channelling the pressurized fluids that brecciated the underlying rocks.

Post-mineral faults, not exposed at the surface but mapped in early underground workings, overprint the breccias and were reactivated along syn-mineral/breccia structures. Joint mapping along the face of the Copper Cliff breccia pipe did not indicate a strong preferred structural orientation, shown by the large scatter of poles to joints in figure 5.

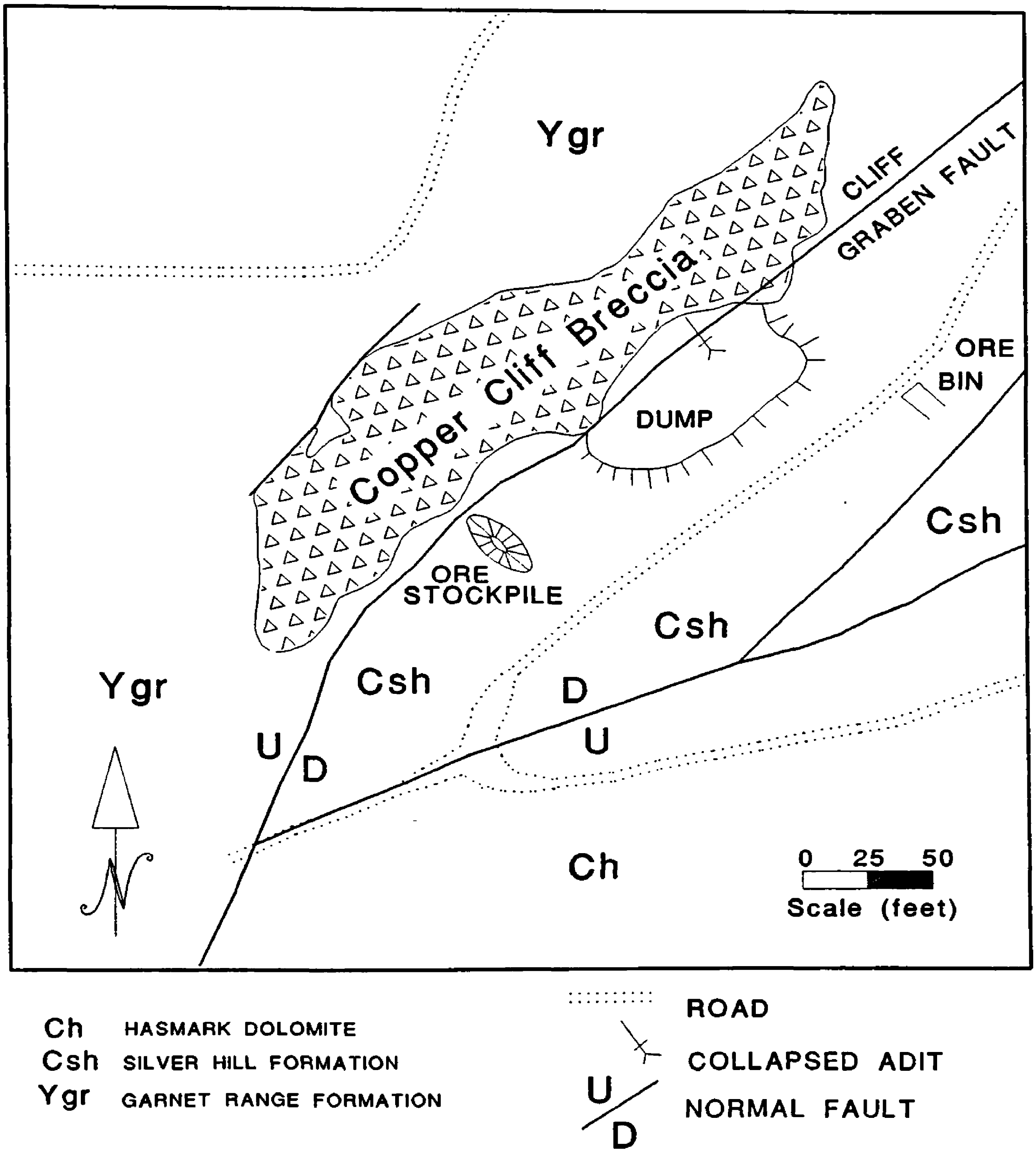


Figure 4. Detailed geologic map of the Copper Cliff breccia. Joints and slickenside measured along the southeast face are shown in Figure 5.

A low-angle post-mineralization fault underlying the breccia pipe at 30 feet (10 m) depth was discovered during early underground development, and truncates the roots of the pipe (Pardee, 1917 and Irving, 1963). This northeast-striking fault dips 45° to 50° to the southeast, and is not exposed at the surface (Irving, 1963). The extension of the Copper Cliff breccia pipe at depth remains undiscovered. Underground mapping and Newmont drilling indicate that the breccia pipe roots are offset to the southeast, as speculated in cross-section (Fig. 3b).

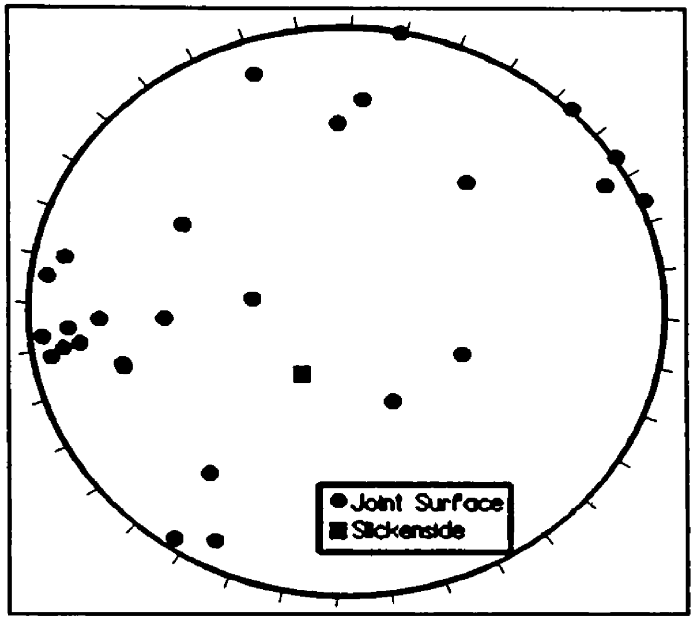


Figure 5. Stereonet plot of poles to joints and slickenside mapped on southeast face of Copper Cliff.

Whole Rock Geochemistry

Whole rock geochemistry of 12 igneous and volcanic rock samples were used to characterize the composition of the volcanic activity that dominated the area during Eocene time. Unaltered Copper Cliff plutons and Union Peak volcanic flows were sampled for the study. The raw whole rock geochemical data are presented in Appendix A, and sample locations are shown on Plate I. The purpose for obtaining the whole rock geochemical data was to compare compositions of the Copper

Cliff plutons with the Union Peak flows, two miles east. The oxide chemicals, excluding LOI were normalized to 100%, and CIPW norms were calculated using GPP computer software. These results are also tabulated in Appendix A.

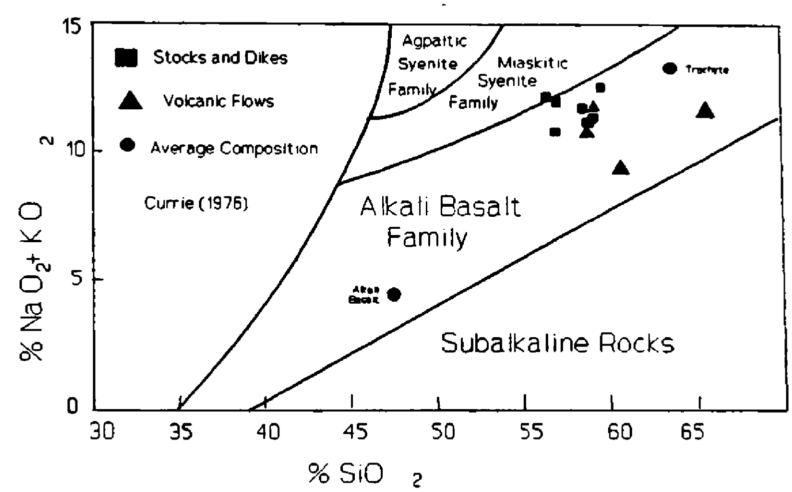


Figure 6. Alkaline-silica diagram with Copper Cliff data plotted. Squares show plutonic samples, and triangles volcanic flows from Union Peak.

The whole rock samples are chemically similar, and exhibit an alkaline affinity. The compositions lie mostly in the alkali basalt family of the Currie alkali-silica diagram (Fig. 6). The data were also plotted on an IUGS classification chart using the Le Maitre method of calculating alkali feldspar and plagioclase from normative minerals (Fig. 7). The results show that the plutons lie within the quartz trachyte and quartz latite fields, while the more siliceous flows lie within the rhyolite

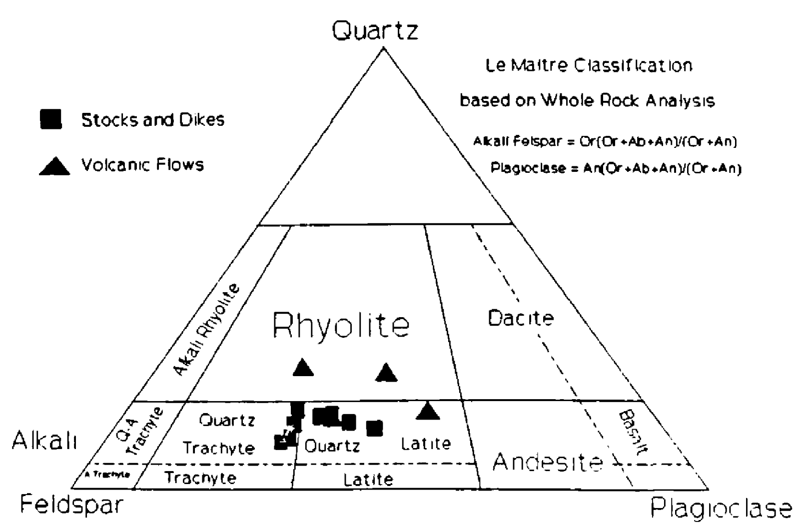


Figure 7. Le Maitre classification based on whole rock geochemical analyses of unaltered samples.

field. Slight secondary silicification was noted in a few of the pluton samples (shown as square symbols), so their original composition could have been latite and trachyte. Although whole rock composition between the Copper Cliff plutons and the Union Peak volcanic flows is similar, their 8 million year difference in age precludes the possibility that the Copper Cliff plutons fed the flows, but suggest a common magma source.

CHAPTER III

ALTERATION & MINERALIZATION

The Copper Cliff mining district exhibits silicic, advanced argillic, phyllitic and propylitic alteration types, and hosts enargite, chalcopyrite and pyrite along with tetrahedrite and other precious metal minerals. Three primary altered and mineralized occurrences within the mining district are discussed in this chapter. The most widespread, intensely altered and mineralized occurrence is within the Union Hill stock (Fig. 3). It is dominated by an advanced argillic alteration assemblage of quartz-alunite (+/- kaolinite-diaspore), and contains anomalously high levels of disseminated gold and copper. The second occurrence is the Copper Cliff breccia, which is a faulted fragment of a silicified pipe that hosts ore-grade gold and copper, and was the principal focus for historic mining and development in the district (Fig. 4). The third mineralized area, comprising the Leonard and Klenzie mines (Fig. 3), contain sub-ore grade gold and copper within silicified carbonates and breccias of the Silver Hill Formation.

Zonation of Hydrothermal Alteration

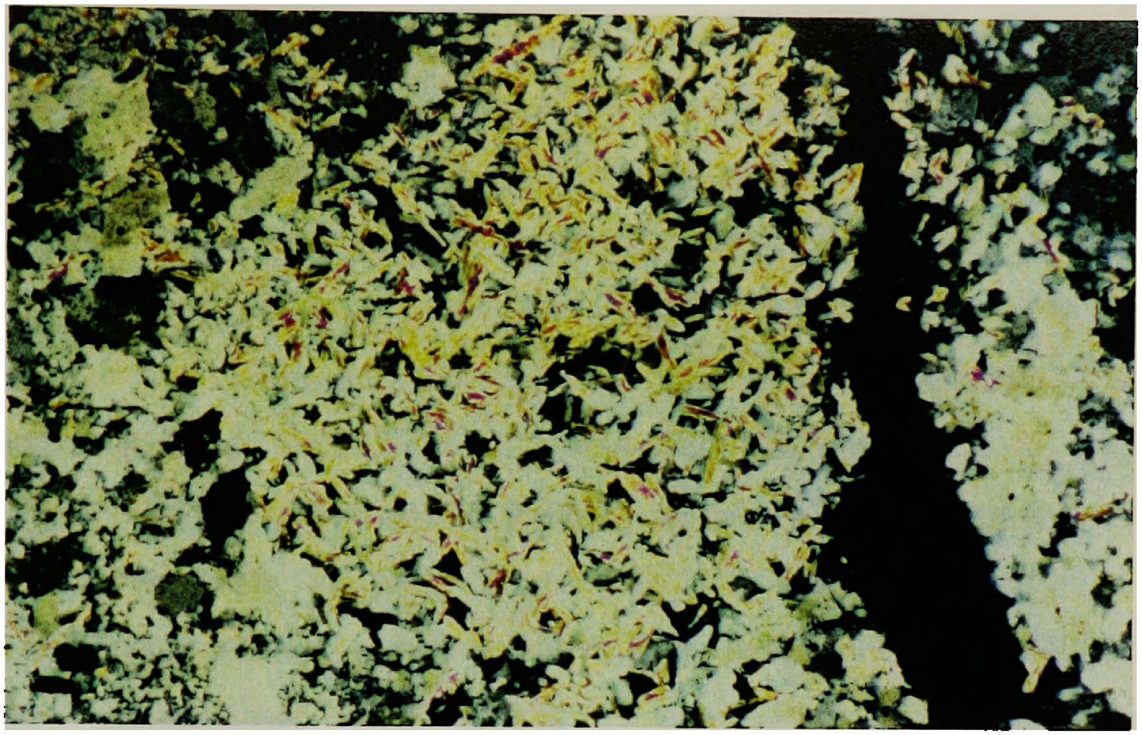
Alteration zones form a crude, district-wide bullseye pattern centered on the Union Hill stock (Fig. 3a). A peripheral propylitic zone is developed within the Copper Cliff plutons. The lack of chemical reactivity of the Garnet Range Formation precluded the development of propylitic alteration minerals. The Union Hill stock contains an advanced argillic shell at shallow depths, and a phyllitic core at deeper levels, based on drill hole data and conceptualized in cross-section (Fig. 3b). This pattern suggests that the hydrothermal fluid source was centered beneath the Union Hill stock.

The propylitic mineral assemblage consists of quartz, chlorite, epidote, kaolinite, magnetite, pyrite and sulfosalt minerals. The advanced argillic alteration zone in the Union Hill stock is an acid-sulfate assemblage that contains quartz, alunite, kaolinite, diaspore, hematite, sulfosalts and native sulfur. The central phyllitic zone within the stock contains quartz, sericite, kaolinite, chlorite, phlogopite, anhydrite, magnetite, pyrite and chalcopyrite along with elevated gold and copper values.

Alteration of the Union Hill Stock

The Union Hill stock, located in the northeast portion of the district, exhibits the most intense and extensive alteration in the district, as well as the highest gold intercepts encountered during Newmont's 1991 drill program. The original, unaltered stock was a chilled porphyry consisting of plagioclase, biotite and hornblende within an aphanitic quartz and plagioclase matrix (Williams, 1988).

Strong hydrothermal alteration subsequently destroyed most of the primary minerals but not the primary texture. Acid-sulfate alteration dominates shallow levels of the stock, 8a.



8b.

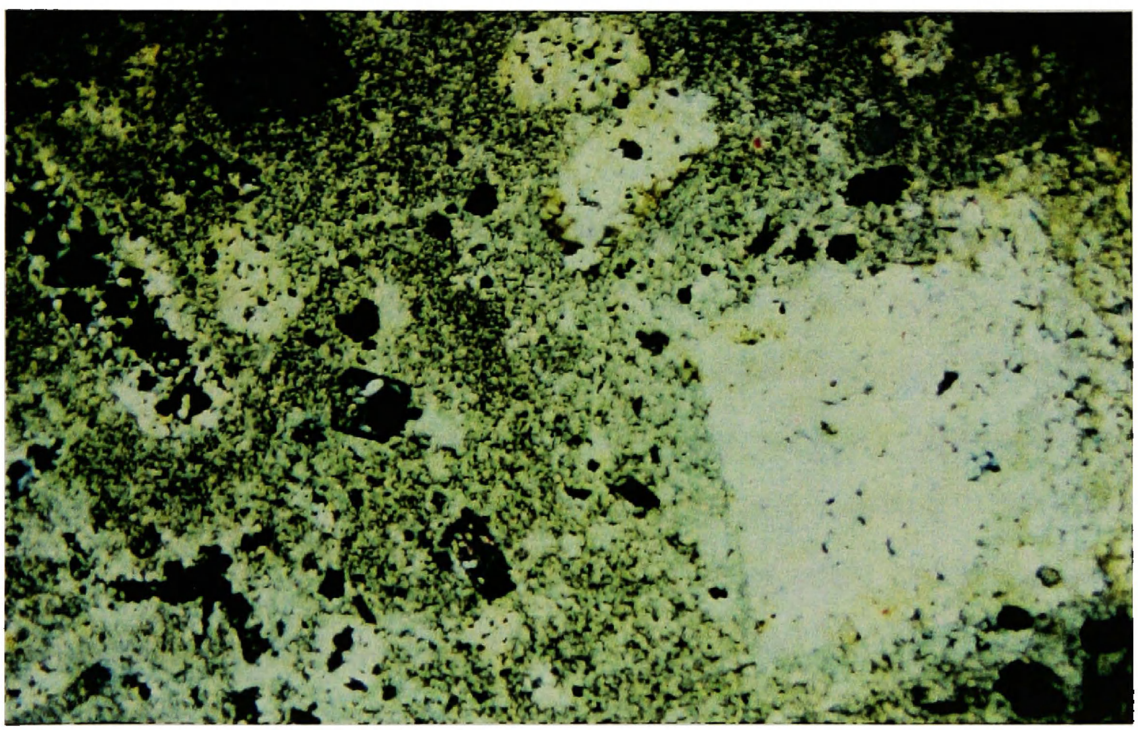


Figure 8. Photomicrograph images under transmitted polarized light of samples collected from the Union Hill stock. **8a** is a surface sample that shows alunite and quartz formed within a relict feldspar phenocryst, and quartz in the surrounding matrix under 20x magnification. **8b** is from core at 236 feet (72 m) depth under 8x magnification, and shows sericite and quartz in the matrix and sericite cross-cutting alunite in relict phenocrysts. Opaque minerals are magnetite developed in relict biotite crystals and disseminated hematite.

but grades into quartz-sericite with depth (Ellsworth, 1993).

Alunite and clay minerals replaced feldspar phenocrysts, and quartz replaced the groundmass of the original porphyry in the shallow advanced argillic zone. Thin section petrography indicates that quartz-sericite type alteration (phyllitic) dominates at deeper levels. Figures 8a and 8b are photomicrographs of alunite from the surface, and sericite from core that replaced feldspar phenocrysts, respectively. Petrographic work by Matter (1993) on deep sericite-altered drill samples shows progressive alteration of hornblende to biotite, chlorite, and finally sericite. These samples contain high levels of gold and copper, and their paragenetic frameworks are typical of porphyry copper systems (Beane, 1993).

Mineralization of the Union Hill Stock

Anomalously high gold and copper values occur throughout the Union Hill stock. Drill hole assays typically range from 50 to 200 ppb gold and 100 to 1000 ppm copper across 100's of feet, and yield isolated ore-grade intercepts. Mineralogic studies of ore-grade drill samples from the Union Hill stock characterize gold distribution, and the alteration minerals that accompanied its mineralization.

Whole rock X-ray diffraction analyses of ore-grade intercept drill samples, located 700 feet (213 m) beneath the surface near the northeast margin of the Union Hill stock, yielded the following mineral assemblage:

quartz	kaolinite	sericite
chlorite-smectite	phlogopite	anhydrite
albite	biotite	magnetite
pyrite	hematite	chalcopyrite
tetrahedrite	tennantite	Au-telluride?

A panned concentrate sample of the same drill sample was analyzed by automated microprobe scanning, and revealed the following mineral assemblage (Brosnahan, 1993):

quartz	barite	sericite
chlorite	phlogopite	apatite
woodhouseite	anhydrite	TiO_2
pyrite	chalcopyrite	sphalerite
galena	bornite	chalcocite
gold	krennerite	electrum

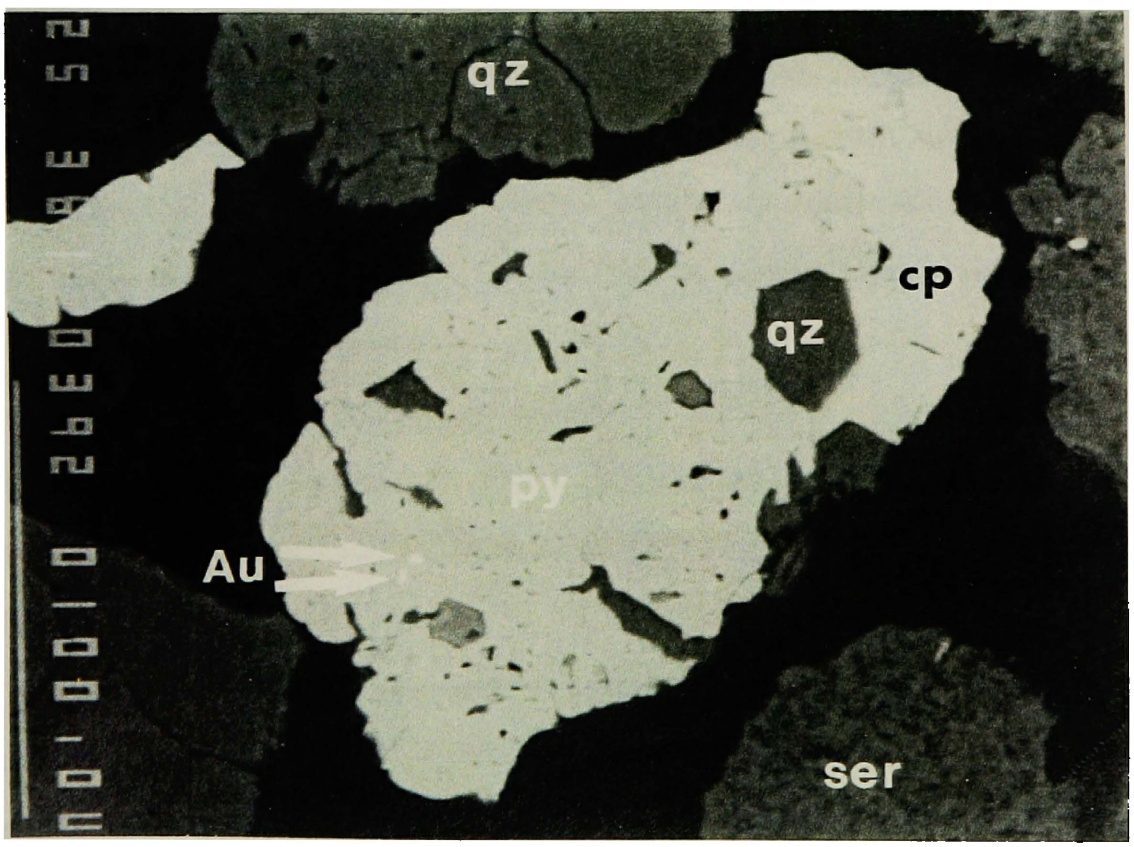


Figure 9. backscatter electron image of pyrite (**py**) particle with chalcopyrite (**cp**) and quartz (**qz**). Arrows show gold grains (**Au**) encapsulated in pyrite. Quartz and sericite (**ser**) occur in mounting medium. Scale Bar = 100 microns.

Most of the gold detected by the microprobe scan is encapsulated in pyrite crystals, as shown in the backscatter electron image in figure 9. Gold occurs as end-member native gold, with minor silver substitution, and ranges between 1.3 to 5.0 microns in diameter, averaging 2.1 microns. Brosnahan (1993) also reported that gold occurs as a gold-silver telluride (krennerite), is attached to pyrite and occurs as free gold with chlorite and quartz.

Copper Cliff Breccia Pipe

Historic production, development and exploration of the district concentrated on the Copper Cliff breccia pipe. Early shipping records report copper grades as high as 12% (Irving, 1963), and gold grades over 0.1 oz/st (Gow and Weed, 1919). Ore shipments to the Anaconda smelter between 1917 and 1944 from the Copper Cliff mine totalled 146 tons with the following average grades: 9.8% Cu, 2.18 oz/st Ag, 0.11 oz/st Au (Childs and Mulholland, 1988). Johnson (1972) collected 14 channel samples around the perimeter of the Copper Cliff breccia pipe, and obtained a weighted average of 0.061 oz/st gold, 0.20 oz/st silver and 0.17% copper.

Higher grade zones are reported from underground workings beneath the Copper Cliff breccia pipe, which are developed within unconsolidated fault breccias. These zones are referred to as either "black ore" or "red ore". The "black ore" contains pyrite, enargite, chalcocite and covellite. The "red ore" contains malachite, azurite, chrysocolla and native copper, and is probably oxidized "black ore".

Irving (1963) reported that enargite, famatinite, covellite and auriferous pyrite are microscopically disseminated within the silica matrix. In addition, petrographic work by Williams (1988) indicated trace amounts of alunite, rutile, pyrite and chenevixite disseminated in the matrix. Deep red hematite staining of the matrix is due to leaching of microscopic pyrite cubes on matrix grain boundaries. Secondary copper minerals stain the cliff face in the form of copper phosphate (Pardee, 1917), probably the turquoise variety.

The Copper Cliff breccia was probably formed by highly pressurized magmatic (+/- meteoric?) fluids that fractured the country rock, mobilized the fragments and deposited quartz, gold and copper. The matrix-supported breccia clasts vary in lithology and texture. Their rounded to angular shape, coupled with the variety of fragment rock types, suggests the clasts were transported vertically and experienced milling. In addition, older breccia clasts are encased within younger breccia clasts. Such characteristics demonstrate that the Copper Cliff breccia originated from repeated explosions and introduction of hydrothermal fluids. Micrographic textures indicate that at least two brecciation and mineralization events occurred (Williams, 1988). The fluids intensely silicified all the clasts, and deposited chalcedony in the matrix. Chemical analyses of the Copper Cliff breccia average

80% average SiO_2.

Numerous other small breccia bodies scattered throughout the district contain comparable grades and minerals (Plate I). These satellite breccias were likely formed temporally with the Copper Cliff breccia.

Leonard and Klenzie Mines

The Leonard and Klenzie mines are aligned along a northeast-trending fault within the Silver Hill Formation. They contain sub-ore grade gold and copper within silicified carbonates and breccias of the Silver Hill Formation (Fig. 3). The known replacement bodies are not extensive, and appear to be controlled by a northeasterly fault that channelled hydrothermal fluids. A jasperoid breccia, measuring 100 feet by 30 feet (30 x 10 m) is exposed by the Klenzie mine workings. It cuts the Garnet Range/Silver Hill formation unconformity.

The Klenzie breccia is similar to the Copper Cliff breccia, however clasts are predominately silicified limestone. Pardee (1917) reported enargite, famatinite and pyrite are finely disseminated within the matrix; malachite and azurite form coatings and veinlets. Silicified carbonate lenses extend 5 to 10 feet (1.5 to 3 m) laterally beyond the breccia, and contain low-grade gold and copper. Three channel samples yield 0.011 oz/st gold across 14 feet (4.3 m) of jasperoid along the Klenzie adit (Childs and Mulholland, 1988). The limited size and grade of the Leonard and Klenzie mines precluded extensive development of these deposits.

Trace Element Geochemistry

A total of 442 surface rock samples collected from the Copper Cliff prospect were analyzed for various trace elements, and compiled into a single database (Table 2).

Table 2. Basic statistics for surface rock sample geochemical data. Gold is listed in units of ppb, and all other elements in ppm. Values half the detection limit were assigned to undetected results.

Element	mean	#	maximum
Au	198	442	6900
Ag	1	442	>50
Cu	1072	442	>20000
Pb	96	442	1466
Zn	38	442	645
Mo	5	420	109
Bi	7	442	157
As	447	442	>10000
Sb	41	442	2120
Hg	1	258	47
W	3	273	15
Te	5	423	>100
Tl	2	169	20
Ba	831	239	3900
Se	2	147	15

Scatter diagrams of gold versus selected elements are plotted on log-log scales to evaluate correlations (Fig. 10). The plots show that gold correlates well with copper, arsenic, antimony and tellurium; silver and mercury show a weak correlation with gold. These relationships probably reflect a spatial and temporal relationship of gold with enargite (copper arsenic sulfosalt), tetrahedrite (copper antimony sulfosalt), chalcopyrite and telluride minerals. The weak gold-silver correlation may be the result of supergene surface leaching of silver. Silver to gold ratios average 2:1 in these rock samples. Mercury shows very high levels (1 ppm average) in the district, but correlates weakly with gold.

Sulfur Isotope Geochemistry

A single sulfur-isotope analysis of alunite from core at 660 feet depth within the Union Hill stock yields $\delta^{34}S$ of 21.4 +/- 0.2 ‰. While only one analysis of anything should be treated with extreme caution, the result is compatible with disproportionation of magmatic SO_2 into H_2S and $SO_4^{=}$. This results in the formation of isotopically heavy alunite and isotopically light pyrite. This datum suggests a magmatic source for at least the sulfur, and rules out a supergene origin of the alunite.

Alunite, a potassium-aluminum-sulfate-hydroxide mineral is formed by acid meteoric water and acid hydrothermal fluids that react with primary potassium-bearing minerals. Hypogene alunite typically occupies advanced argillic alteration assemblages associated with epithermal precious metal deposits, or high-level porphyry copper deposits.

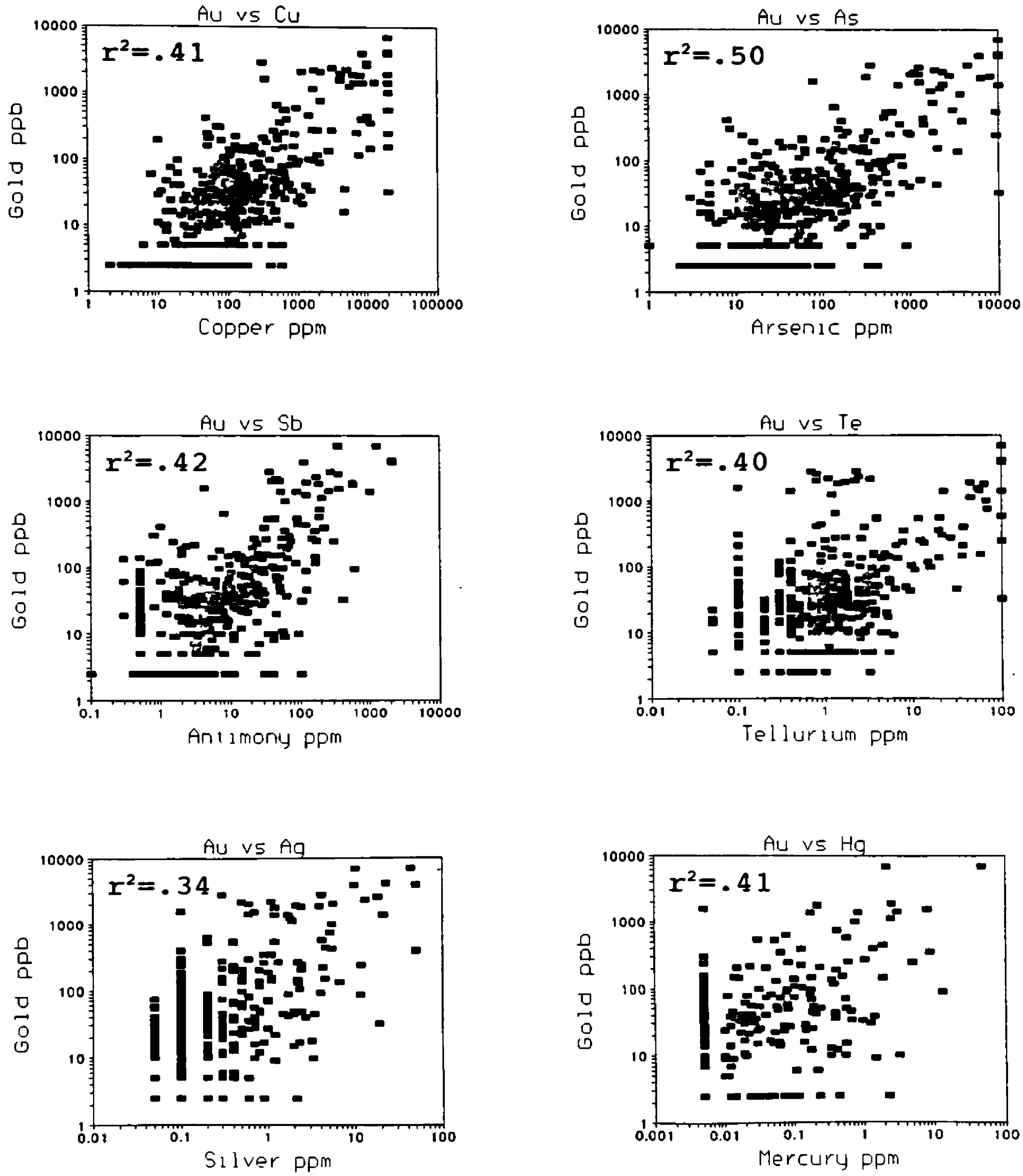


Figure 10. Rock sample geochemistry of district-wide database, presented as scatter diagrams of gold against various trace elements. Note gold is plotted in units of parts per billion, while trace elements in units of parts per million on logarithmic scales. Effects of upper and lower detection limits from various analytical methods and labs align data points. Data outside detection limits were disregarded for r^2 calculation (r=correlation coefficient).

CHAPTER IV

GEOCHRONOLOGY

Age dates were obtained from rock samples at the Copper Cliff district in order to constrain interpretations of geochronologic events that led to the alteration and mineralization patterns within the district. Copper Cliff district age dates are compared with earlier obtained dates from the western Garnet Range (Table 3).

Copper Cliff Age Dates

A potassium-argon determination on biotite from the easternmost unaltered Copper Cliff pluton yields an age of 56.4 +/- 1.5 Ma (Fig. 3a). This age does not correlate with other igneous dates obtained in the western Garnet Range (Fig. 11), but correlates regionally with igneous activity in the central Montana alkalic belt, the Idaho batholith and various isolated volcanic eruptions in western Montana. Alunite from core recovered at 660 feet (201 m) down the hole (467 feet beneath surface) in the Union Hill stock yields a K-Ar date of 48.4 +/- 1.3 Ma. These age dates indicate that alunite formed eight million years after emplacement of the Copper Cliff pluton. Age date sample locations are shown in figure 3a.

Western Garnet Range Age Dates

The alunite age from the Union Hill stock correlates temporally with latite volcanic flows located 2 miles (3 km) east on Union Peak, and the Clinton stock 5 miles (8 km) west. The age also correlates with the Challis and Lowland Creek volcanic rock ages. Carter (1982) reported that the composition of volcanic flows in the Union Peak and Bearmouth area progressively change with age. Forty-seven Ma flows are hornblende-biotite andesite, whereas 44 Ma flows shift to biotite-pyroxene andesite.

Table 3. Age dates in the western Garnet Range.

Location & Rock Type	Age	Method	Reference
Bearmouth: rhyolite porphyry flow	44.5+/- 2.0 Ma	K-Ar sanidine	Carter (1982)
Bearmouth: olivine basalt flow	44.9+/- 2.0 Ma	K-Ar whole rock	Carter (1982)
Union Peak: Latite porphyry flows	47.4+/- 1.6 Ma	K-Ar biotite	Carter (1982)
Clinton stock: granite	48.0+/- 2.0 Ma	Pb-isotope	Reynolds (1991)
Union Hill stock: altered porphyry	48.4+/- 1.3 Ma	K-Ar alunite	Geochron Lab (1993)
Copper Cliff pluton: quartz latite porphyry	56.4+/- 1.5 Ma	K-Ar biotite	Geochron Lab (1993)
Garnet stock: granodiorite	78.7+/- 3.9 Ma	K-Ar biotite	Carter (1982)
Garnet stock: granodiorite	82 Ma	K-Ar hornblende	Sears et al. (1989)

These age dates suggest that the Union Hill stock was altered 8 million years following its emplacement. The acidic fluid source was apparently a pluton at depth which may have vented the Union Peak volcanic flows 2 miles (3 km) east.

Interpretation

Alunite-forming fluids were derived from a hypothetical gold-rich porphyry copper system which typically underlie quartz-alunite type epithermal gold deposits (Ashley, 1982;

Sillitoe, 1988; Walthier et al., 1985; Sillitoe, 1990). The quartz-alunite alteration was either overprinted by late sericite from a separate magmatic event that introduced gold and copper, or was immediately followed by the sericite alteration. A sericite date would clarify their chronologic relationship.

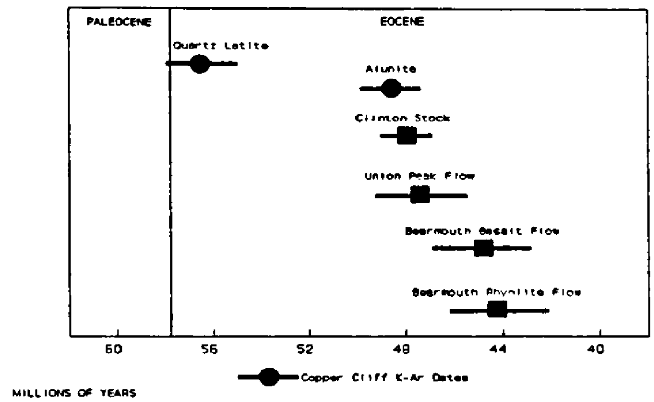


Figure 11. Age dates from the Copper Cliff prospect and western Garnet Range.

<u>**Geologic History**</u>

A summary of the geologic history of events that led to mineralization in the district begins with Late Cretaceous thrusting of the Sapphire allochthon and emplacement of the Garnet stock (Fig. 2). The western Garnet Range then experienced Early Eocene east-west extension due to right-lateral pull-apart motion from the St. Mary's and Clark Fork/Nine Mile faults of the Lewis and Clark line. The extension formed graben faults and induced emplacement of the Copper Cliff plutons and the Union Hill stock at 56.4 Ma (Fig. 11). Middle Eocene time marked the intrusion of an inferred buried porphyry copper stock, the likely source of acid fluids that formed alunite in the Union Hill stock at 48.4 Ma. This intrusion is apparently related to the Copper Cliff breccias and the Union Peak volcanic flows. A third magmatic event (porphyry Cu-Au?) introduced alkaline fluids and gold into the

Union Hill stock that formed the gold-bearing sericite zone (Fig. 3), and continued development of the breccias. This mineralizing epoch accompanied eruption of the Bearmouth volcanic flows 8 miles (13 km) to the southeast. This event deposited gold in the Union Hill stock, which correlates with sericite and not alunite. Continued Tertiary displacement along the Lewis and Clark line subsequently offset mineralized and altered zones and formed the complex fault structures at the Copper Cliff district.

CHAPTER V

DISCUSSION AND CONCLUSIONS

In order to understand the genesis and structure of hydrothermal ore deposits in complex districts, such as Copper Cliff, deposit models are developed for exploration and development of ore deposits. Models are formulated from well known and understood deposits. Six possible scenarios can explain the co-existence of alunite and sericite alteration in the Union Hill stock. They include:

1) Fluids lie along acid/alkaline Eh-pH phase boundary.
2) Late sill or dike introduced sericite without gold.
3) Porphyry copper system with acid meteoric water mixing.
4) Metal-bearing solutions evolved from an alkaline to an acid system.
5) Porphyry copper with alunite cap (e.g. Red Mountain)
6) Acid-sulfate alunite assemblage overprinted by sericite (e.g. El Indio)

Scenarios 1) and 2) are discounted since they cannot account for the zonation of shallow alunite and deep sericite, or the spatial association of gold within the sericite zone. Scenario 3) can explain the zonation but the sulfur isotope value indicates a magmatic rather than supergene origin of the sulfur. In scenario 4) the magmatic fluids would initially be acid, however wall rock buffering raises the solution pH at depth forming alunite, and sericite forms late as the wall rocks lose their buffering capacity. This mechanism would result with a sericite zone overlying an alunite zone. This scenario cannot explain the gold-copper affinity to the sericite alteration zone, or the dominance of alunite in the upper levels of the Union Hill stock. Scenarios 5) and 6) best explain the alteration and mineralization within the Union Hill stock.

The Copper Cliff district resembles Berger's (1986) epithermal quartz-alunite Au descriptive model in which the deposit forms near the surface and is associated with deep gold-rich porphyry copper systems. However, drilling revealed similarities of Copper Cliff mineralization to the acid-sulfate capped gold-rich porphyry copper type deposit which form at greater depths (Beane, 1993). Both models are described and discussed in relation to the Copper Cliff district in this chapter.

Quartz-Alunite Deposit Model

Enargite-bearing quartz-alunite epithermal systems host large gold deposits within intermediate-composition intrusive complexes in a variety of geologic settings throughout the world. They commonly are associated with porphyry copper systems, and are characterized by the presence of advanced argillic alteration and enargite group minerals. Most of these deposits lie along the Pacific rim, including the majority of world class gold deposits of the central Chilean Andes.

The epithermal ore deposit type known as enargite-bearing quartz-alunite gold systems were classified in recent years by Ashley (1982), Bonham and Giles (1983), Heald et al. (1987), Bonham (1984, 1988) and Walthier (1985). The term is synonymous with acid-sulfate, high-sulfur, high-sulfidation and enargite-gold. Berger (1986) lists deposit sizes ranging from 0.24 million to 12 million short tons with grades ranging from 0.11 to 0.53 oz/st gold. Many of the deposits contain one to 5 million ounces of gold, and may host 300,000 to one million tons of copper. Sillitoe (1991) describes the majority of precious metal districts in the Andean Cordillera of Chile as the world's premier high-sulfidation epithermal province.

Bonham (1988) proposed the "general occurrence quartz-alunite model", which is volcanic hosted, sulfur-rich and shows no evidence of venting. Examples include El Indio, Chile; Lepanto, Philippines; Goldfield, Nevada; Summitville, Colorado; Chinkuashih, Taiwan; Pueblo Viejo, Dominican Republic; Cerro de Pasco, Cuahuarso and Julcani, Peru. An idealized cross-section of the general occurrence quartz-alunite model is illustrated in figure 12.

Most of these deposit types located along the Pacific rim are of Tertiary age. However several deposits lie inboard of plate margins. All the deposits require significant structural preparation to provide plumbing for ascending hydrothermal fluids and mineral deposition. Berger (1986) emphasized that through-going fracture systems are critical, including keystone graben structures, ring fracture zones, normal faults, dome-related fractures and joints. Heald et al. (1987) noted that nine of 16 deposits studied are

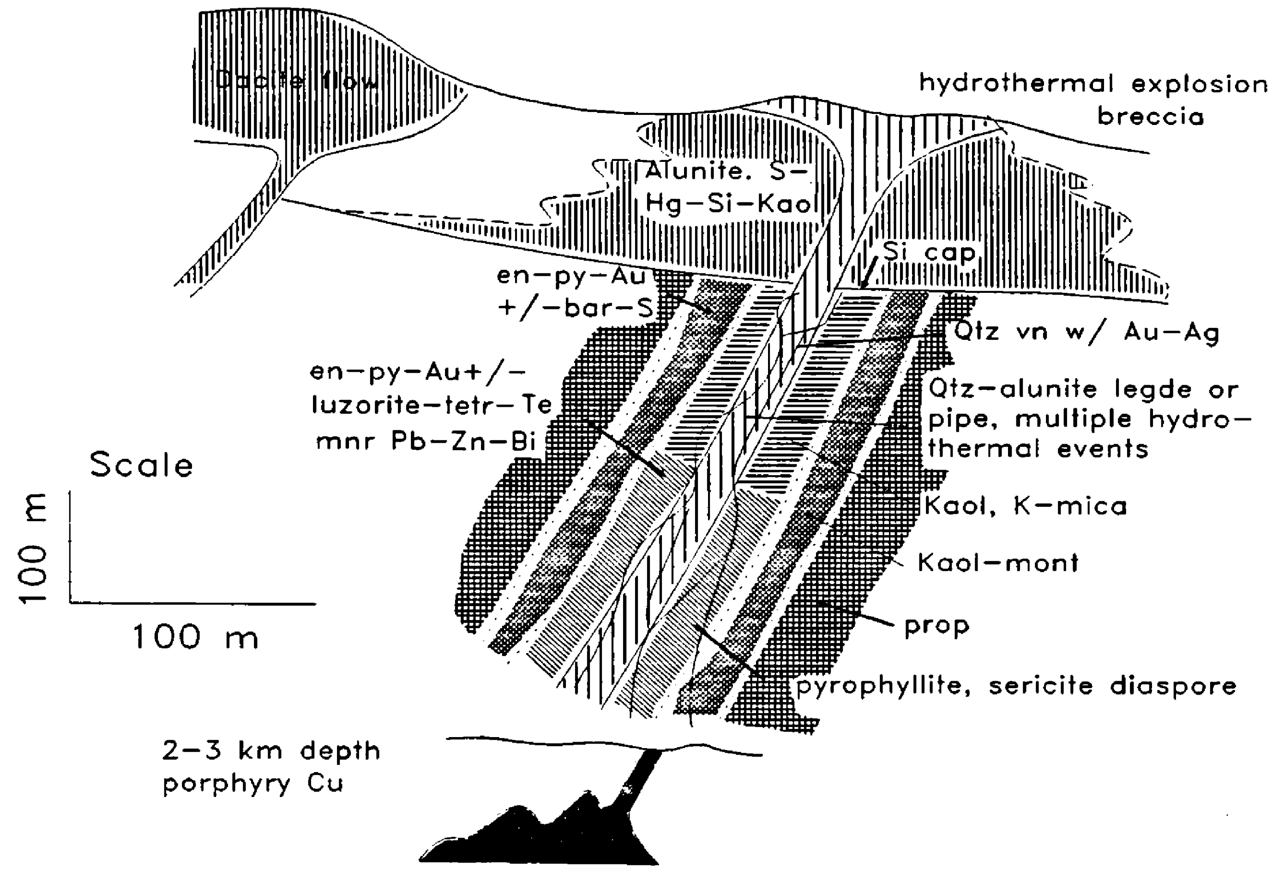


Figure 12. Schematic cross-section of an epithermal enargite-precious metal deposit associated with granodiorite-dacite magmatism (Bonham, 1988). Refer to Appendix B for abbreviations.

spatially related to calderas, making this geologic setting most common. The deposit morphology varies depending on structures and host rock. Deposits range from complex vein systems (e.g. El Indio) to irregular pod or pipe-like bodies associated with silicified hydrothermal breccias (Sillitoe, 1988). Most deposits have pyrite-enargite and associated sulfides as massive or semi-massive replacements within advanced argillic alteration zones, composed of vuggy chalcedonic silica, alunite and clays.

The origin of contemporaneous alunite-bearing acid-sulfate alteration is due to disproportionation of magmatic SO_2 to H_2S and $SO_4^=$, in magmatic water or mixed magmatic-meteoric water systems at less than 400°C (Rye et al., 1989). Bonham (1988) suggests that the acid sulfate chloride solutions are derived from depth and deposit gold during boiling. Alteration is dominated by intermediate argillic assemblages such as quartz-kaolinite-Kmica, quartz-illite-montmorillinite and quartz-kaolinite that surround the advanced argillic zone. The advanced argillic zone of minerals, which form under very acid-oxidizing conditions, envelops the main hydrothermal feeders, and forms alteration mineral assemblages such as: quartz-alunite-kaolinite, quartz-alunite-native sulfur, quartz-diaspore, quartz-pyrophyllite-diaspore, quartz-alunite-pyrophyllite-diaspore, quartz-alunite-sericite (Ashley, 1982).

Several districts are vertically zoned; intermediate argillic zones grade into a phyllic assemblage with depth (Fig. 10). Gold mineralization is primarily restricted to the advanced argillic zone along with vuggy chalcedonic silica. Large volumes of pyrite-bearing propylitized zones commonly surround the advanced argillic zones.

Quartz-alunite gold ore is dominated by sulfosalt minerals, specifically the enargite-luzonite and tetrahedrite-tennantite series. Silver sulfosalt minerals, bismuthinite and gold-silver tellurides occur in some deposits; pyrite is ubiquitous (Ashley, 1982). Base-metal sulfides occur around and beneath gold mineralization. Berger (1986) indicated that some deposits may contain a hypogene oxidation phase with chalcocite, covellite, luzonite and late stage native sulfur. The ore assemblage displays vertical zonation as shown in figure 12. The central enargite-luzonite zone tends to grade both vertically downward and laterally outward into tetrahedrite-tennantite, chalcopyrite and bismuthinite, and finally into base-metal sulfides where gold values decrease. Gold is primarily hosted in the enargite zone, while the highest silver values occur in the tetrahedrite zone (Bonham, 1988).

Sillitoe (1988) suggested that gold deposition post-dates enargite mineralization. He proposed that gold, re-mobilized from early gold-rich porphyry copper at depth, was transported upward into the epithermal system during late-stage alteration (e.g. El Indio, Jannas and Araneda, 1985).

Quartz, the most abundant gangue mineral in the ore zone, forms matrix comb structures. Barite, alunite and kaolinite occur as breccia fillings and barite is widespread in all deposits.

Recent discoveries at El Indio, Chile, and Goldfield, Nevada, disclose that enargite, chalcopyrite and alunite were introduced early. They were overprinted by late-stage gold-bearing sericite mineralization. The pre-existing alunite causes gold to precipitate from late-stage alkaline fluids by dropping the pH and oxidizing the fluids as they encounter the acidic-sulfate assemblage (Richard Beane, pers. comm., 1993).

Porphyry copper-gold Systems

Most quartz-alunite gold deposits are spatially associated with gold-rich porphyry copper deposits, strongly suggesting a genetic association exists. Some quartz-alunite deposits appear to represent the epithermal upper expression of deeper mesothermal porphyry copper systems (Fig. 12). In other systems barren quartz-alunite alteration zones are known to cap porphyry copper deposits (e.g. Red Mountain, Arizona, Bodnar and Beane, 1980). At Red Mountain propylitic alteration forms an outer zone to alunite, which gives way to sericite at a shallow depth.

Gold-rich porphyry copper systems are centered on high-level stocks with pervasive alteration and mineralization. Retrograde boiling mineralizes potassic, propylitic, argillic and sericitic zones, forming spatial and timing patterns (Sillitoe, 1990). Extensive intermediate argillic alteration often overprints potassic alteration, and predominates in the upper levels of the system. Quartz-sericite-pyrite alteration masks primary rock textures, and may form around potassic cores. Gold porphyries commonly are capped by advanced argillic zones which post-date other alteration, and are formed during degeneration of the porphyry system (Sillitoe, 1990).

According to Sillitoe's (1990) model, gold is found in quartz veinlet stockwork within the potassic alteration zone.

This zone typically contains phlogopite, K-feldspar or amphibole. Intermediate argillic alteration zones are also known to host gold ore where they overprint pre-existing gold-bearing potassic zones. Porphyry gold occurs as electrum, mainly in association with chalcopyrite, pyrite and bornite (Sillitoe, 1988). Some porphyry gold occurs in the high-fineness native state and is fine-grained (< 60 microns).

Copper Cliff District Model

Both the quartz-alunite and the gold-rich porphyry copper-type deposits are genetically related to breccia pipes and the porphyry mineralizers (Fig. 12). The Copper Cliff breccia pipe and the Union Hill stock porphyry are probably no exception. The Union Hill stock represents the deepest exposed part of the mineralizing system; the Copper Cliff breccia pipe represents the shallowest zone of the same system. The difference between their depths of mineralization depends on the throw of the Union Creek fault, which was not determined. Application of models to the geologic situation in the district narrowed the classification of alteration and mineralization in the Union Hill stock to two possibilities: 1) gold-rich porphyry copper-type with an acid-sulfate cap, and 2) quartz-alunite type overlying a deep copper-gold porphyry. Regardless which model applies, the Copper Cliff breccia pipe formed high in the system.

In general, geological, geochemical and mineral patterns within the Copper Cliff district are similar to those of quartz-alunite deposit systems which overlie porphyry systems at depth. Both the Copper Cliff district and the model contain quartz, alunite, sericite, enargite, tetrahedrite, clays and additional accessory minerals, and are hosted in intermediate composition, hypabyssal plutonic rocks and hydrothermal breccias, as shown in Table 4.

Table 4. Comparison of selected quartz-alunite gold deposits. See Appendix B for abbreviations.

Deposit	Oz Au	Host Rock	Ore Mineral	Alteration
El Indio Chile	7 M	Dacite-Rhyolite	tn-py-en-tl	al-kaol-ser-pyr-qtz-chl
Pueblo Viejo Dom. Rep.	21 M	Spillite	py-sp-en-tn-tt	pyr-al-qtz-clay
Summitville Colorado	N/A	Qtz Latite	cv-lz-cp-tn-en	qtz-al-kaol
Copper Cliff Montana	?	Qtz Latite	py-cpy-tl-en-cc-sp-gl	al-kaol-ser-qtz-chl

Table 5 compares characteristics of the Copper Cliff district with the quartz-alunite deposit model. The Copper Cliff district differs from the quartz-alunite deposit model by lacking near-surface high sulfide mineral-rich zones and metallized quartz veins and near-surface, large gold deposits. Gold at Copper Cliff either was not abundant in hydrothermal fluids, or erosion has not cut down to the mineralized horizon, typically corresponding with boiling levels (Richard Beane, pers. comm., 1993). Absence of placer gold deposits downstream in Union Creek suggest there was no gold horizon above the present erosional level.

Table 5. Copper Cliff district characteristics compared to the quartz-alunite deposit model. Refer to Appendix B for abbreviations. Model characteristics from Ashley (1982) and Berger (1986).

Observation	Copper Cliff	Model
host rock	qtz-latite, trachyte	trachyandesite, qtz latite, rhyodacite
age	Eocene (Cenozoic)	Cenozoic
timing: volcanism w/alteration	close (?): alunite w/Union Pk. flows	close association
alteration	qtz-al, ser-chl-phl-anh, kaol; advanced argillic	qtz-al, qtz-kaol, pyr-ser; advanced argillic
alteration texture	replacement (relict phenocrysts)	replacement
gangue minerals	qtz-al-clays-ba-ap-hm	qtz-al-ba-kaol
sulfides	en-tt-py-cp-sp-gl-bn-cc	en-luz-tt-tn-py-cp
structures	grabens, hydrothermal breccias	grabens, breccia pipes
sulfur isotopes	$\delta^{34}S$ = 21.4	magmatic?-enriched $\delta^{34}S$

Alternatively, the petrographic and microprobe mineralogical information, generated from the Union Hill stock drill samples, are compatible with an acid-sulfate capped gold-rich porphyry copper deposit that formed at much greater depths than the epithermal quartz-alunite type. Beane (1993) concluded that the alteration sequence (hornblende→biotite→ chlorite→sericite), and the fine-grained nature of the pyrite-encapsulated gold are more typical of ore zones in high-level porphyry copper deposits of southwestern North America. Beane (1993) suggested progressively increasing acid fluids formed early sericite followed by alunitization and finally silicification. Red Mountain, Arizona, described by Bodnar and Beane (1980), was classified as a high-level gold-rich porphyry copper deposit that shows similar zonation patterns to the Copper Cliff district. Beane (1993) concluded that alunite formed immediately above the porphyry copper zone in the Union Hill stock.

If the Union Hill stock is, indeed a porphyry copper deposit with a quartz-alunite cap, displacement along the Union Creek fault is great. This is due to the fact that the near surface-forming Copper Cliff breccia pipe, containing sulfosalt minerals and alunite, is exposed on the other side of the fault.

The textural observations of the Copper Cliff breccia pipe (see Chapter III), and the presence of relatively shallow alunite and deep sericite in the Union Hill stock support either several hydrothermal pulses, or a single, long-lived evolving hydrothermal system. Unaltered, post-mineralization dikes in core from the Union Hill stock indicate a possible second or third magmatic event (depending on the above scenarios), a potential source for late-stage sericite-forming fluids. Furthermore, the x-ray, microprobe and petrographic data (Chapter III) indicate that gold in the Union Hill stock precipitated from alkaline fluids associated with late sericite and pyrite formation, and not from earlier acid fluids that deposited alunite and enargite group minerals.

Alteration in the Union Hill stock could have formed under deep mesothermal or shallow epithermal conditions. Occurrences southwest of the Union Creek fault, however are undoubtedly epithermal, and likely formed under acid-oxidizing conditions, as evidenced by sulfosalt minerals and alunite. Gold within breccia pipes and with enargite-group minerals are more typical of quartz-alunite epithermal deposits (Fig. 12). The Union Creek fault, could therefore represent a major normal fault that raised the deep alteration zone of the Union Hill stock to the same level as the shallow epithermal zone of the Copper Cliff breccia pipe, or more likely the system is a quartz-alunite type located over deep gold-rich porphyry copper system. At any rate, the Copper Cliff breccia pipe formed at a high level, and is genetically linked to deeper porphyry copper activity within or beneath the Union Hill stock.

Conclusions and Summary

In summary, at least two scenarios can explain the mineralization and alteration patterns seen in the Union Hill stock: 1) gold-rich porphyry style mineralization with a chronologic progression of alkaline to acid conditions, and 2) epithermal quartz-alunite acid-oxidizing alteration overprinted by late sericite-type alkaline gold mineralizing fluids. Fluid inclusion studies might resolve fluid temperatures, however no useable inclusions were found.

Scenario 1) is possible only if the assumption is made that the Union Hill stock was positioned well below the Copper Cliff breccia pipe during the mineralizing events. Later offset along the Union Creek fault placed the two zones at the same erosional level. Such major offset should be reflected in great stratigraphic offset across the Union Creek fault. Although difficult to document, the strata does not appear to be largely offset by the Union Creek fault. It therefore seems more logical that the offset along the Union Creek fault was not large enough to juxtapose a deep seated mesothermal system (Union Hill stock) against a shallow epithermal system (Copper Cliff breccia).

According to the quartz-alunite model (Scenario 2), Copper Cliff mineralizing fluids were likely similar to those that formed deposits at El Indio and Goldfield. Early acid fluids were followed by alkaline fluids in an evolving system or in two distinct hydrothermal events, forming the alunite and sericite alteration pattern conceptualized in cross-section (Fig. 3b). The late alkaline fluids did not reach the present erosional level, leaving alunite near the surface, and sericite at depth.

Compared with El Indio however, Copper Cliff fluids apparently lacked sufficient quantities of sulfur to form comparable quantities of alunite and sulfide minerals. Also, the areal extent of the alunite zone throughout the region is very limited. Sulfur-rich fluids enhance the gold transport capacity, and a high water/rock ratio along with host rock permeability are required to form large gold deposits.

Regardless of whether fluid conditions became more acidic or alkaline with time in the Copper Cliff district, the system was undoubtedly driven by a gold-rich porphyry copper magma at some depth. This proposal is supported by the Butte-type suite of copper minerals present in the district (e.g. enargite-group, bornite, chalcopyrite and chalcocite). Additionally, the mineral zonation pattern strongly resembles patterns at the Red Mountain porphyry copper, Arizona (Bodnar and Beane, 1980).

In summary, I believe the available evidence best supports early alunite formation, together with enargite, tetrahedrite and tennantite. Sericite formed later, accompanied by gold and some pyrite. Some copper formed chalcopyrite. The system was driven by a gold-rich porphyry copper pluton located about 1500 feet (460 m) beneath the present surface. This interpretation was first proposed by Anaconda geophysicists. The prospect shows similarities to El Indio, a world class gold deposit that hosts over 7 million ounces of gold within high grade bonanza quartz veins and gold tellurides. The Copper Cliff district lacks high sulfide zones, mineral rich zones and bonanza quartz veins within the reaches of present exploration. Therefore, large quantities of gold were either not abundant in the hydrothermal fluids, or were deposited at deeper levels. Accordingly, the primary exploration targets are structurally controlled, discrete veins beneath the Copper Cliff breccia pipe, porphyry copper targets northeast of the Union Creek fault and carbonate replacements or skarns associated with the porphyry copper deposit.

Ongoing gold and copper exploration of the Copper Cliff prospect will add to our understanding of the hydrothermal system that produced this intriguing mining district. Deposit modelling is an essential exploration tool in this district, and hopefully will lead to discovery of a world class gold-copper deposit. The model developed by this study may also prove useful for exploration of acid-sulfate and gold-rich porphyry systems in the northwest U.S.

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APPENDIX A

Raw Whole Rock Geochemical Data

and corresponding

Normalized Whole Rock Geochemical Data

with CIPW Normative Minerals

B:CUCLIFF.WRO - Page 1
12 samples, 20 elements, Date: 1/20/93

	PE-14	PE-19	PE-22	PE-37	PE-38	PE-39	PE-40	PE-41	PE-42	PE-43	PE-46	PE-48
SIO2	62.69	59.39	59.74	60.77	61.91	63.37	69.90	62.44	61.94	60.66	63.85	62.22
TIO2	0.51	0.82	0.84	0.36	0.61	0.62	0.40	0.59	0.59	0.60	0.56	0.60
AL2O3	17.29	15.62	15.79	18.97	16.70	16.45	14.84	15.71	15.54	16.50	15.67	15.51
FE2O3	3.41	3.09	3.25	1.78	2.30	3.58	2.11	3.26	2.74	3.17	2.45	2.88
FEO	0.71	1.42	1.42	0.64	1.29	0.71	0.71	0.90	1.35	1.48	1.80	1.29
MNO	0.06	0.06	0.06	0.03	0.04	0.07	0.03	0.07	0.06	0.07	0.08	0.06
MGO	2.73	3.26	3.32	1.36	2.27	2.56	1.16	3.53	3.77	4.11	2.86	3.83
CAO	3.62	4.32	4.83	4.72	3.80	3.81	2.37	3.58	3.63	4.38	3.16	3.09
NA2O	4.09	3.23	3.38	3.87	3.00	3.88	3.90	3.63	3.23	3.72	4.21	3.20
K2O	3.64	4.90	4.96	2.85	2.99	4.01	3.91	3.91	4.34	3.42	4.13	4.49
H2O+	1.42	1.64	2.10	5.46	4.24	1.32	0.56	2.39	2.88	2.14	1.32	2.60
H2O-	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
P2O5	0.27	0.59	0.60	0.10	0.23	0.28	0.17	0.38	0.38	0.28	0.29	0.40
TOTAL	100.44	98.34	100.29	100.91	99.38	100.66	100.06	100.39	100.45	100.53	100.38	100.17
Ba	2700	2700	2800	890	1500	2200	1800	2700	3000	2100	2100	2800
Nb	7.00	12.00	10.00	6.00	7.00	9.00	7.00	6.00	5.00	8.00	9.00	5.00
Rb	60.00	105.00	100.00	92.00	77.00	87.00	99.00	74.00	83.00	47.00	91.00	84.00
Sr	1406	1537	1570	1106	1522	1409	857	1648	1357	1200	1313	1360
Zr	193	312	290	153	207	231	155	183	186	185	189	184
Y	5.00	13.00	13.00	2.00	13.00	16.00	6.00	11.00	8.00	10.00	12.00	7.00

PE-14 - latite porphyry
PE-19 - latite porphyry
PE-22 - latite porphyry
PE-37 - latite flow Tenmile Cr.
PE-38 - latite flow Tenmile Cr.
PE-39 - Latite flow Union Pk.
PE-40 - latite flow Union Pk.
PE-41 - latite porphyry stock
PE-42 - latite stock (same 41)
PE-43 - latite porphyry stock
PE-46 - latite stock N. Union Cr.
PE-48 - duplicate of PE-42

B:CUCLFNRM.NRM - Page 1
13 samples, 32 elements, Date: 1/20/93

	PE-14	PE-19	PE-22	PE-37	PE-38	PE-39	PE-40	PE-41	PE-42	PE-43	PE-46	PE-48	MEAN
SIO2	58.36	56.84	56.26	58.65	60.59	59.03	65.41	58.84	58.67	56.76	59.41	58.95	58.98
TIO2	0.36	0.59	0.59	0.26	0.45	0.43	0.28	0.42	0.42	0.42	0.39	0.43	0.42
AL2O3	18.97	17.62	17.53	21.58	19.26	18.06	16.37	17.45	17.35	18.20	17.18	17.32	18.07
FE2O3	2.39	2.23	2.30	1.29	1.69	2.51	1.49	2.31	1.95	2.23	1.72	2.05	2.01
FEO	0.55	1.14	1.12	0.52	1.06	0.55	0.56	0.71	1.07	1.16	1.40	1.02	0.90
MNO	0.05	0.05	0.05	0.02	0.03	0.06	0.02	0.06	0.05	0.06	0.06	0.05	0.05
MGO	3.79	4.65	4.66	1.96	3.31	3.56	1.62	4.96	5.32	5.73	3.97	5.41	4.08
CAO	3.61	4.43	4.87	4.88	3.98	3.80	2.38	3.61	3.68	4.39	3.15	3.14	3.83
NA2O	7.38	5.99	6.17	7.24	5.69	7.01	7.08	6.63	5.93	6.75	7.59	5.88	6.61
K2O	4.32	5.98	5.96	3.51	3.73	4.77	4.67	4.70	5.24	4.08	4.90	5.43	4.77
H2O+	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
H2O-	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
P2O5	0.21	0.48	0.48	0.08	0.19	0.22	0.13	0.30	0.30	0.22	0.23	0.32	0.26
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Ap	.63578	1.42	1.42	.24426	.56360	.65716	.39830	.90415	.90816	.66359	.68257	.95596	.78838
Il	.98059	1.61	1.63	.71802	1.22	1.19	.76525	1.15	1.15	1.16	1.08	1.17	1.15
Mt	1.02	2.48	2.39	1.17	2.65	.72629	1.24	1.45	2.91	3.32	3.59	2.69	2.14
Or	21.71	29.93	29.83	17.64	18.56	23.84	23.21	23.57	26.28	20.53	24.63	27.19	23.91
Ab	34.95	28.26	29.12	34.30	26.68	33.04	33.16	31.34	28.01	31.99	35.96	27.75	31.21
An	16.36	14.11	13.51	23.85	18.23	15.73	10.70	15.33	15.46	18.52	11.77	13.03	15.55
Di	nd	3.17	5.39	nd	nd	1.14	nd	.20207	.35211	1.33	1.68	nd	1.89
Hy	6.85	6.91	5.91	3.54	5.92	5.87	2.89	8.85	9.43	9.76	6.90	9.75	6.88
C	.69398	nd	nd	1.23	2.28	nd	.29165	nd	nd	nd	nd	.74438	1.05
Q	14.06	10.61	9.13	16.25	23.29	14.69	26.08	14.87	14.68	11.78	13.71	15.62	15.40
Hm	2.75	1.49	1.67	1.06	.59211	3.11	1.27	2.33	.80529	.93976	nd	1.11	1.56
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
A	51.67	50.05	49.96	62.81	49.48	52.12	64.95	48.36	48.11	43.93	53.04	48.03	51.88
M	18.25	20.07	19.89	12.71	18.75	16.91	9.65	22.64	23.96	25.29	18.19	23.92	19.19
F	30.08	29.88	30.15	24.47	31.77	30.97	25.40	29.01	27.93	30.78	28.77	28.05	28.94
A FSPAR	41.65	49.13	49.88	32.22	32.02	43.75	45.91	42.56	43.91	37.35	48.96	45.94	42.77
PLAG	31.37	23.17	22.58	43.57	31.45	28.86	21.16	27.68	25.84	33.69	23.40	22.03	27.90
NA+K2	11.71	11.98	12.13	10.75	9.43	11.77	11.74	11.33	11.18	10.83	12.50	11.31	11.39

APPENDIX B

Mineral Abbreviations
and their
Chemical Formulas

Abbreviation	Mineral Name	Chemical Formula
al	alunite	$KAl_3(SO_4)_2(OH)_6$
anh	anhydrite	$CaSO_4$
ap	apatite	$Ca_5(PO_4)_3(F,PH,Cl)_3$
ba	barite	$BaSO_4$
bn	bornite	Cu_5FeS_4
cc	chalcocite	Cu_2S
cp	chalcopyrite	$CuFeS_2$
	chenevixite	$Cu_2Fe_2(AsO_4)_2(OH)_4 \bullet H_2O$
chl	chlorite	$(Mg,Fe)_5Al_2Si_3O_{10}(OH)_8$
cv	covellite	CuS
en	enargite	Cu_3AsS_4
	famatinite	Cu_3SbS_4
gl	galena	PbS
hm	hematite	Fe_2O_3
kaol	kaolinite	$Al_2Si_2O_5(OH)_4$
	krennerite	$(Au,Ag)Te_2$
lz, luz	luzonite	$Cu_3(As_{.64},Sb_{.36})S_4$
mont	montmorillinite	
s	native sulfur	S
phl	phlogopite	$K(Mg,Fe)_2(AlSi_3)O_{10}(F,OH)_2$
py	pyrite	FeS_2
pyr	pyrophyllite	$Al_2Si_4O_{10}(OH)_2$
qtz	quartz	SiO_2
ser	sericite	
sp	sphalerite	ZnS
tl	tellurides	
tn	tennantite	$Cu_{12}As_4S_{13}$
tt, tetr	tetrahedrite	$Cu_{12}Sb_4S_{13}$
	woodhouseite	$CaAl_3(SO_4)(PO_4)(OH)_6$