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Geology of the Cove Mine, Lander County, Nevada, with Emphasis on Structural, Lithologic, and Stratigraphic Controls on Ore Distribution and Characteristics

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Introduction

Purpose

Cove is a unique deposit in Nevada, as it contains associations of Ag + Au + Mn sulfides in an oxide orebody, and Ag + Au + base metal sulfides + tin sulfides + sulfosalts in sulfide orebodies. The purpose of the current study is to construct a 3-dimensional geologic framework for the Cove system, which is then compared to mineralization and alteration characteristics to establish spatial relationships relative to structures, lithologies, and stratigraphy. This framework is designed for use in conjunction with future studies regarding stable isotopes, geochemistry, mineralogy, fluid inclusions, and age dates to develop a genetic model for Cove.

Although the ideas expressed in this paper are intended to represent the original results and conclusions of this study, many of the relationships described were recognized in previous works, especially unpublished in-house reports. To address this issue, appropriate authors are referenced to provide due credit. Because most of the deposit has been excavated, however, it is necessary to rely heavily on data from previous studies regarding structures, ore characteristics, mineralogy, and controls on ore distribution in the mined-out portion to complete the geologic framework and its individual components.

Geologic Setting

The Cove Mine is a sedimentary rock-hosted gold-silver deposit located in the northern Fish Creek Mountains, 50 kilometers southwest of Battle Mountain, Nevada (Figure 1). The deposit was discovered in early 1986 as a Au anomaly revealed by a stream sediment

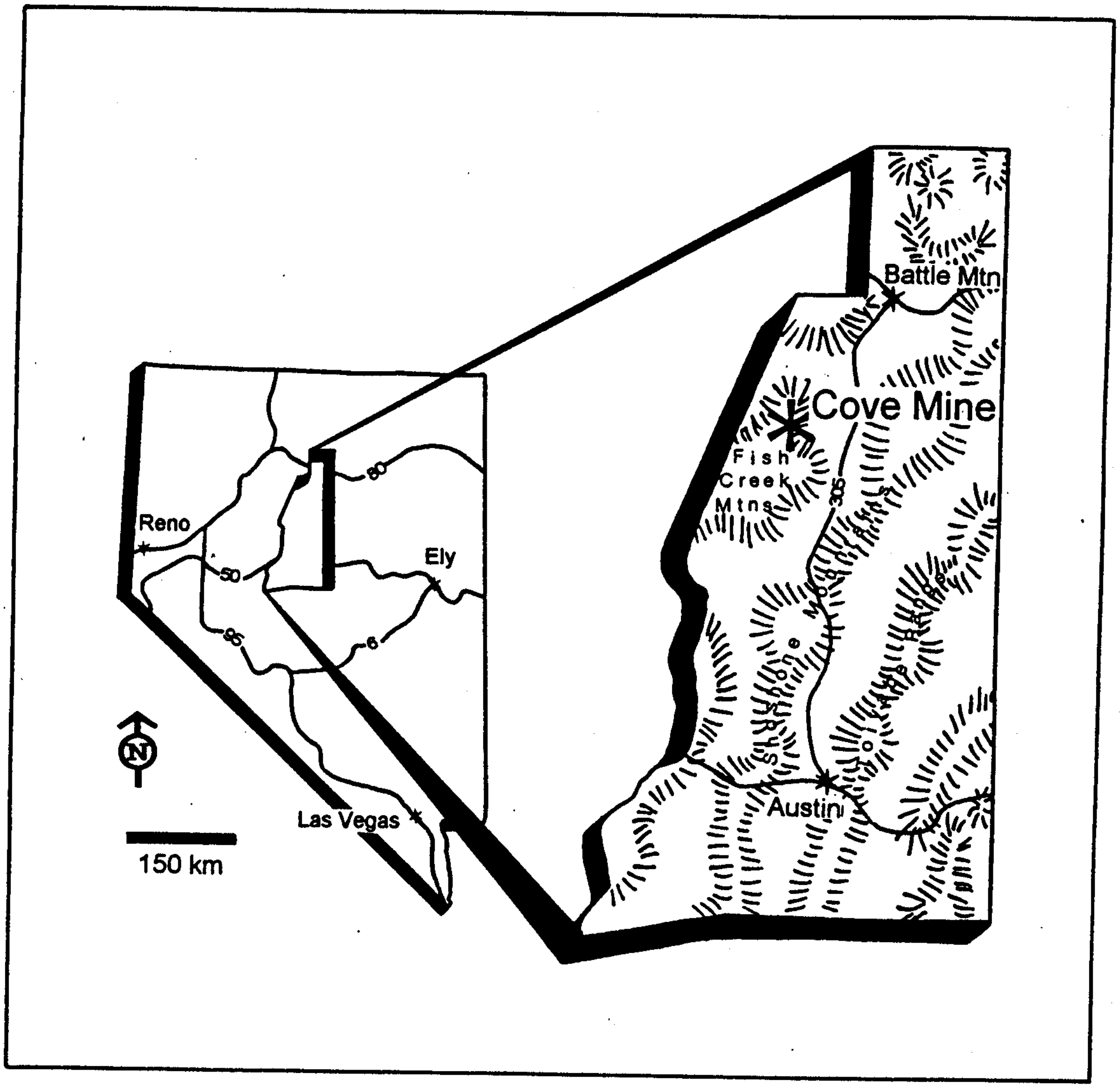


Figure 1. Location of the Cove Mine.

survey, and was put into production in early 1988. Pre-mining in situ reserves consisted of 3.6 million ounces Au, and 164.3 million ounces Ag (Emmons and Eng, 1995). The deposit consists of three economic orebodies: 1) a mined-out oxide orebody, 2) a mined-out upper high-grade sulfide orebody, and 3) a lower high-grade sulfide orebody currently in production. A fourth potential orebody was recently discovered at depth during exploratory drilling, but is currently uneconomic (Dieter A. Krewedl, 1998, personal communication). The upper high-grade sulfide orebody typically graded 0.25 ounces per standard ton Au and 10 ounces per standard ton Ag. The lower high-grade sulfide orebody grades 0.045 ounces per standard ton Au and 2.5 ounces per standard ton Ag (Emmons and Eng, 1995).

Cove is located in the McCoy Mining District, where gold was first discovered in 1914. The stratigraphy of the McCoy Mining district is shown in Figure 2, and Figure 3 shows the generalized geology of the Cove area. The deepest unit recognized in the region is the Mississippian-Permian Havallah Formation, consisting of altered calcareous sandstone and siltstone (Emmons and Eng, 1995). The Havallah sequence is unconformably overlain by the early to middle-late Triassic Star Peak Group (nomenclature from Nichols and Silberling, 1977), a 4000 foot thick section of marine platform limestone with lesser conglomerate, sandstone, siltstone, and dolomite.

Mineralization at Cove is hosted by the Augusta Mountain Formation in the Star Peak Group, which was first described by Muller et al. (1951). The Augusta Mountain Formation is subdivided into three members (see Emmons and Eng, 1995): 1) the early Ladinian Home Station Member, consisting primarily of massively bedded limestone with diagenetic dolomite, 2) the late Ladinian Panther Canyon Member, consisting of a lower primary dolomite submember and an upper clastic submember, and 3) the late Ladinian to early Karnian Smelser Pass Member, consisting of medium to thickly bedded limestone. The Star Peak Group here is unconformably overlain by the unmineralized Oligocene tuff sediments and main mass of the Caetano Tuff, a crystal rich quartz latite porphyry named by Gilluly and Masurky (1965).

Mapping, Sampling, and Analytical Methods

This study was begun in May, 1998, and is focused on developing a geological framework for the Cove deposit. To this end, 63 field days were spent mapping the Cove pit. Eighteen benches for a total of 50625 bench feet were mapped for lithology, structure, alteration, and ore characteristics. Control points were surveyed in at appropriate intervals to ensure map accuracy. Because much of the pit highwall is inaccessible, three field days were used in whole or part to photograph unmapped portions using a zoom lens. The photographs were used to extrapolate the features mapped via direct observation, producing a finalized field map. This map was then correlated to a pre-

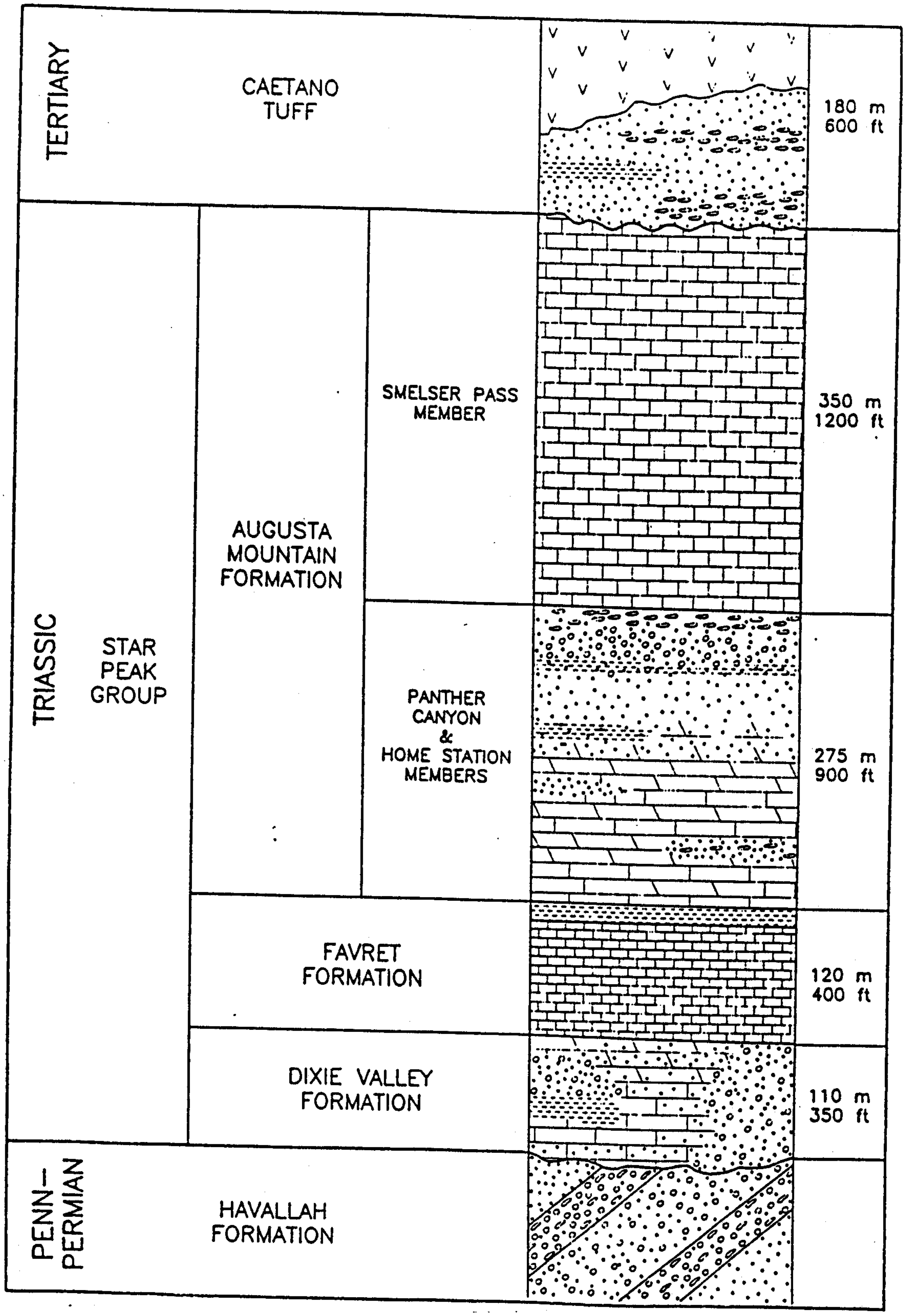


Figure 2. Generalized stratigraphic section of the Cove area (reproduced from Kuyper et al., 1991).

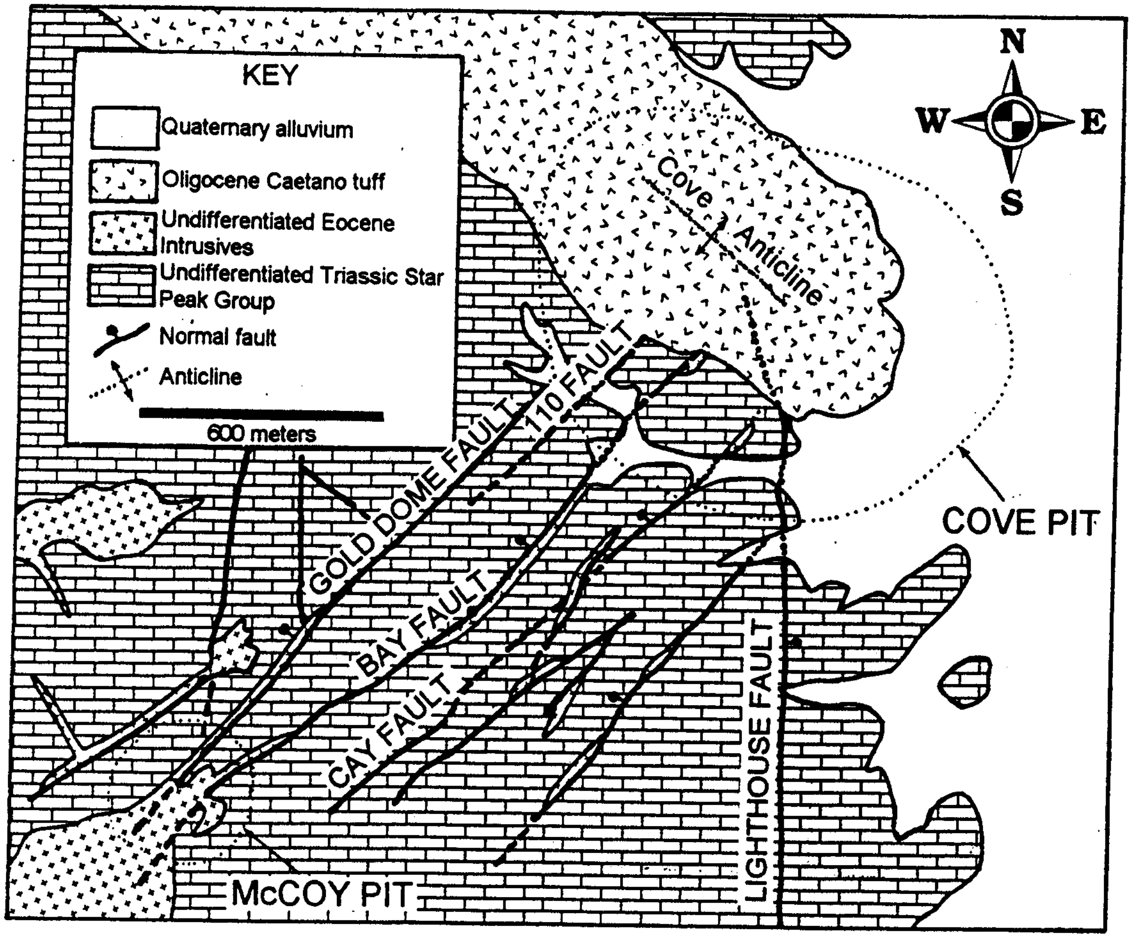


Figure 3. Simplified geologic map of the Cove vicinity (modified from Emmons and Eng, 1995).

existing core log database, published studies, and unpublished in-house reports to produce four cross-sections.

During mapping, more than 600 attitudes of bedding , faults, and joints were collected to characterize structures and structural paragenesis relative to the mineralizing event. More than 200 selective rock samples were collected for detailed analytical work. To date, 58 thin-sections, 52 polished-sections, and 6 doubly-polished plates have been produced for petrologic analyses. They have been examined for lithology, alteration, and ore-type (vein/veinlet versus disseminations) characteristics. X-ray diffraction analyses were used as necessary to clarify mineral and alteration assemblages. The data produced were compared to the map-generated framework to establish spatial patterns relative to structures, lithologies, and stratigraphy.

Results and Observations

Figure 4 shows the simplified geologic map of the Cove pit, and Figure 5 shows cross-sections developed from this geologic map and Echo Bay's core log database. The scale of these figures prohibits showing much of the information collected regarding structures, alteration, and ore characteristics. Therefore, these features, together with stratigraphy and mineralogy, are discussed in detail individually.

Stratigraphy

The stratigraphy at Cove comprises the Triassic Star Peak Group passive margin sequence (refer to Figure 2 for nomenclature). This sequence was intruded by Eocene dikes and sills, and blanketed by the Oligocene Caetano tuff. The following observations are based primarily on observations made in the Cove pit during the 1998 field season, and are supported by thin-section analyses.

Triassic Home Station Member: The upper 30 feet of this unit were exposed just prior to the end of the field season, and only hand-samples are available for the current study. This portion of the unit is medium dark gray and massive, consisting of 0.01 millimeter diameter quartz grains in a dolomitic matrix. Therefore, this unit is tentatively classified as a silty dolomite or dolomite cemented fine-grained siltstone, pending further exposure and quantitative petrologic analyses. Localized 1 to 3 centimeter patches of white recrystallized dolomite are typically kidney-shaped, suggesting that they may have originally been bioclasts.

Triassic Panther Canyon dolomite submember: This unit is uniformly 55 feet thick, consisting of a massively bedded, medium gray dolostone. No allochemical fragments were observed, but 0.025 millimeter diameter (medium silt) quartz grains locally constituted up to 20 percent of the samples examined. Minor stylolites occur, and disseminated pyrite is widely distributed. The uppermost bed contains 1 to 3 centimeter diameter dissolution holes. In a sample from the Cove anticline axis, these dissolution holes consist of a recrystallized dolomite rind lined with crustiform prismatic quartz and euhedral sulfide open-space growths.

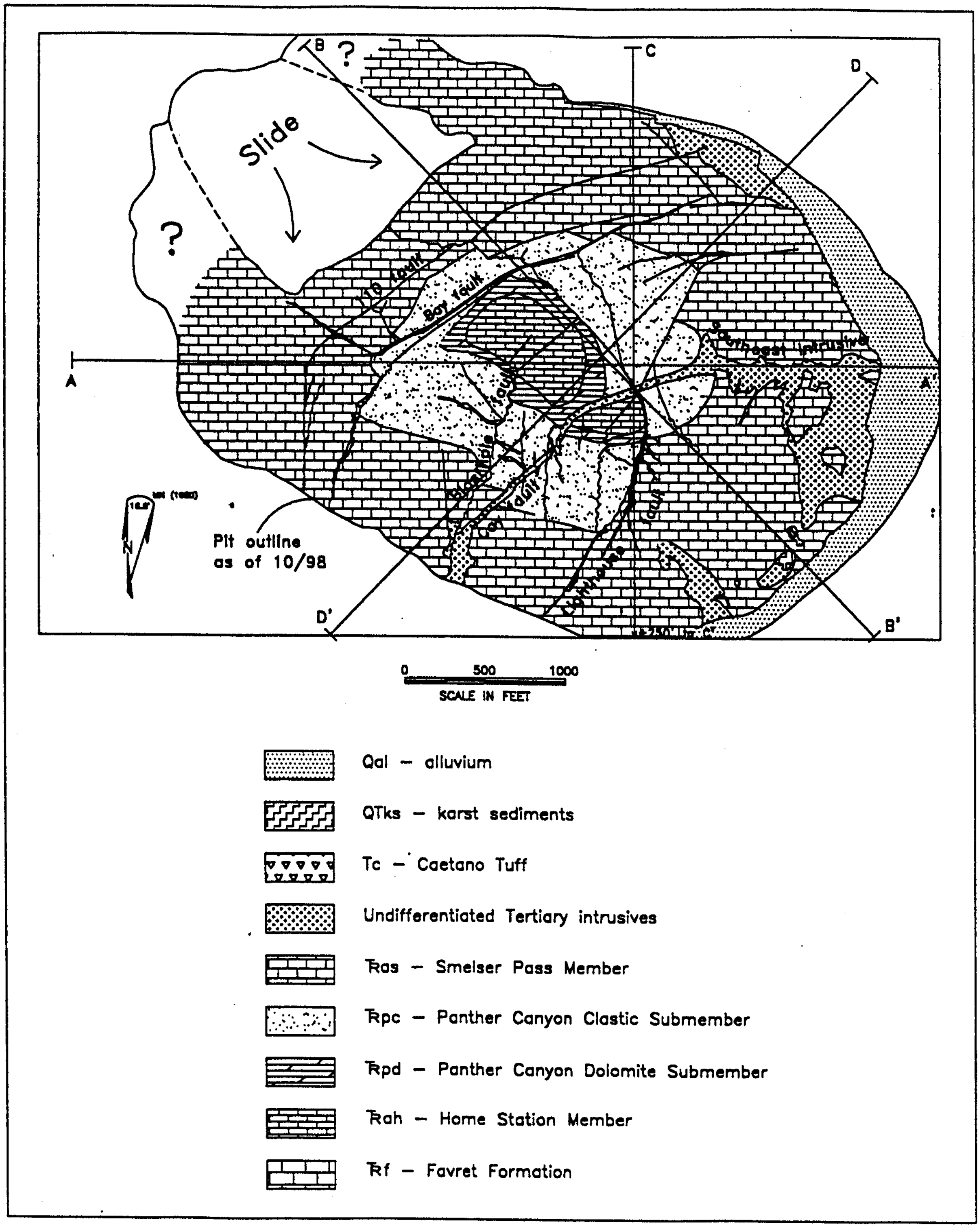
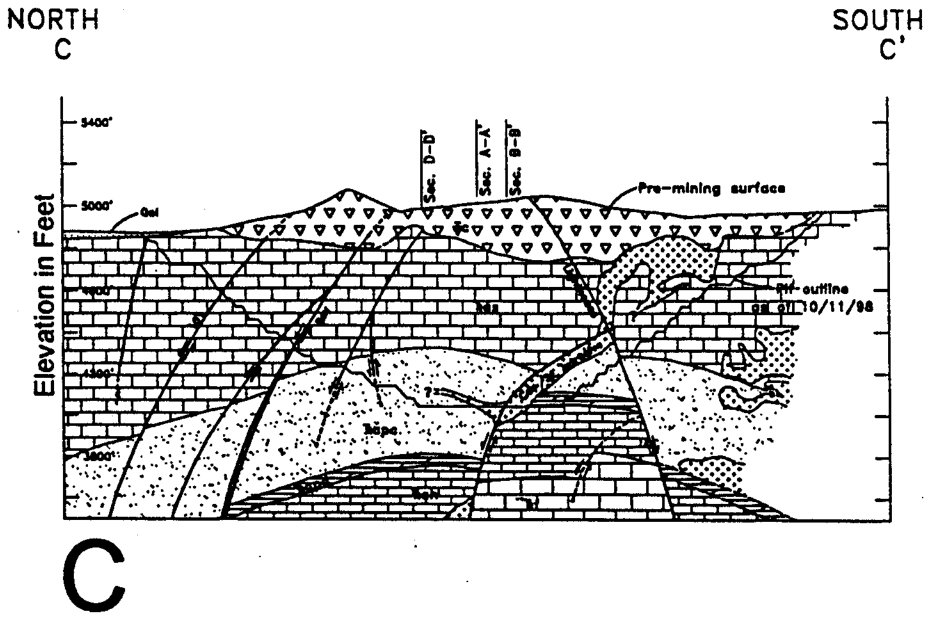


Figure 4. Geologic map of the Cove Mine open pit.



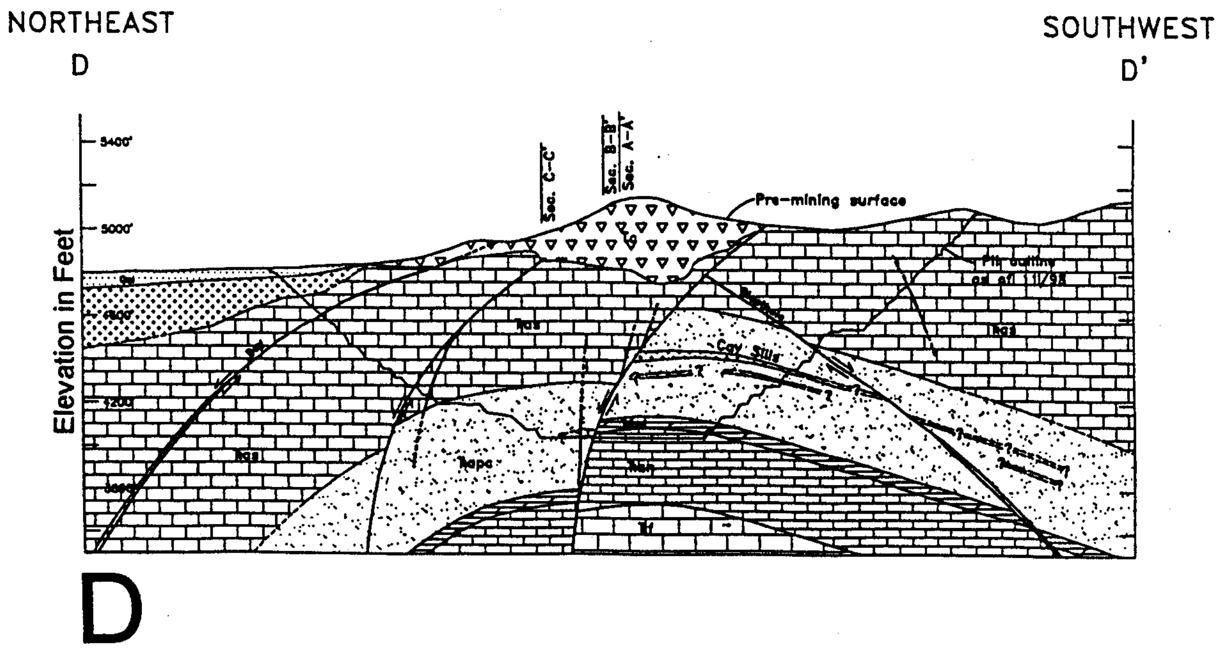


Figure 5. Continued.

Triassic Panther Canyon clastic submember: This unit coarsens upward, from a basal carbonate cemented siltstone to conglomerates near the top, where the coarsening trend reverses and sandstone occurs. The general transition is not smooth, however, as contrasting lithologies are interspersed throughout the unit at all levels, typically as lensoid bodies. In order to simplify the following synopsis, the 500 foot thick clastic submember is arbitrarily broken down into a lower finer-grained package and upper coarser-grained package.

Lithologies in the lower package are highly variable. Although the strata are primarily carbonate cemented siltstones and very fine-grained sandstones, lenses and beds of pure to sandy micrite, coarser sandstones, and conglomerates are abundant. The typical strata consist of 0.025 (medium silt) to 0.08 millimeter diameter (very fine sand), subrounded, moderately sorted quartz grains. The diagenetic cement is calcite, but has been replaced by smectite-group clays and/or sericite where hydrothermally altered.

The upper clastic package generally consists of fine-grained sandstones to cobble conglomerates. Chert, quartzite, and quartz grains comprise the clastic component. These grains are rounded to subrounded and moderately sorted. Primary porosity was high, but has been greatly reduced by deposition of hypogene sulfides, smectite-group clays, and silica. In one sample, argillization and subsequent calcite veining have obliterated primary textures and reduced porosity to ~0 percent. Current porosity in some samples, however, ranges up to 15 to 20 percent.

Triassic Smelser Pass Member: With 940 feet maximum thickness, this unit is volumetrically the largest at Cove. The unit is predominantly a micrite with abundant recrystallized bioclasts, but the upper 500+ feet contains very minor, 5 to 30 centimeter thick, interlaminated carbonate shales. Macro-allochemical remains consists of partial to complete brachiopods, pelecypods, gastropods, crinoids, corals, sponges (tentative identification), and ammonites, in decreasing order of abundance. The bioclasts usually display random packing of mostly partial fragments, indicating a thanatocoenosis. However, a few beds contain larger, complete, articulated brachiopods and/or corals in oriented positions, suggesting a biocoenosis or deposition resulting from a short-term, higher energy event. The lowermost beds contain up to 15 percent 0.015 millimeter individual domain can be seen cutting the other two. These ambiguous relations probably reflect reactivation of earlier faults during subsequent events. It is more prudent, therefore, to establish paragenesis using individual faults and fault complexes.

Although the scale of the map in Figure 4 precludes showing most of the faults mapped, the following relationships were observed. The ~N-striking faults may represent either the earliest extensional event or an incipient event related to the development of the ~NE-striking faults. The Lighthouse fault is the most prominent visible feature in the Cove pit, and strikes ~N10°E. It shows multiple episodes of activation: mineralization of a discontinuous dike within the Lighthouse boundaries indicates pre-mineral faulting, but brecciation of mineralized zones at the fault core indicates post-mineral reactivation.

The ~NE-striking faults are the most common brittle deformation features, and include the Cay, Blasthole, Bay, and 110 faults. Discontinuous dikes occupy the Cay, Blasthole, and Bay faults. The Blasthole and Bay dikes are commonly conspicuously mineralized. In the Bay dike, mineralization occurs as veins and veinlets, indicating pre-mineral development of this fault/dike complex. Ponding of ore fluids beneath the Cay dike and Cay-related sills will be discussed later, lending evidence to support of the pre-mineral development of these systems.

A clearer paragenetic picture is seen for the ~NW-striking faults. Although some show pre- or syn-mineralization development, such as mineralization of the Northwest fault, others clearly show post-mineral development. The best examples of this post-mineral episode are ~NW-striking, steeply dipping faults offsetting the Cay dike, and more importantly, the NW-striking splay off the Lighthouse fault. This splay is clearly late in the paragenetic sequence, as it offsets both mineralization and the Bay dike in the northwest corner of the pit, and offsets the Cay/ Southeast Intrusive dike in the west-central pit bottom. This splay probably represents a late, southwesterly directed extensional episode that reactivated a portion of the original Lighthouse fault and splayed where the extensional forces exceeded the inherited structural anisotropy.

Alteration

Alteration at Cove is highly convoluted for several reasons: 1) hypogene alteration consisted of multiple overlapping episodes produced by the evolving hydrothermal system; 2) this alteration is generally controlled by lithology, and contrasting and alternating lithologies are common in the stratigraphic column; and 3) hypogene alteration in the upper portion of the deposit has been modified by supergene alteration and enrichment. However, the effects of the following post-diagenetic alteration styles are clearly discernable: decarbonatization, carbon enrichment, bleaching (loss of organic components), sulfidation, propylitization, sericitization, argillization, silicification, Mn-enrichment, and oxidation.

Hydrothermal alteration at Cove is examined in the context of oxide versus sulfide orebodies. The oxide orebody exhibited five alteration styles, all of which can still be found locally in the pit highwall: 1) propylitic alteration of the intrusive porphyries characterized by chlorite + calcite + pyrite; 2) argillic alteration consisting of illite ± mixed-layer smectite/mica ± montmorillonite ± kaolinite (Baum, 1990, personal communication in Kuyper et al., 1991) in the Smelser Pass limestone and overprinting propylitization in the porphyries; 3) Mn alteration in the Smelser Pass limestone characterized by psilomelane-group minerals and pyrolusite (Schurer and Fuchs, 1988; Honea, 1988; and Kuyper et al., 1991); 4) decarbonatization; and 5) silicification of the Smelser Pass limestone (Kuyper et al., 1991; Emmons and Eng, 1995), most obvious in the form of jasperoid and manganiferous jasperoid. Mn alteration and silicification were well developed in the hanging wall of the Lighthouse fault and adjacent to the Southeast Intrusive. The jasperoids were generally controlled by stratigraphy and faults. Sulfidation occurs primarily as disseminated sulfides in the Smelser Pass Member, and as crustiform, disseminated, and veinlet mineralization in the upper Panther Canyon clastic submember.

Kuyper et al. (1991) observed two alteration styles in the sulfide orebodies: 1) propylitic alteration consiting of remnant chlorite + calcite + pyrite cores surrounded by 2) sericitic alteration characterized by sericite ± quartz ± pyrite ± chlorite. Emmons and Eng (1995) also described silicification and sulfidation within the sulfide orebodies, with chlorite, potassic alteration, and hornfels present deeper. Brooks (1990, personal communication in Kuyper et al., 1991) found the chlorite in the deeper parts of Cove to be widely distributed and to commonly occur as intergrowths with sericite and quartz.

Decarbonatization, bleaching, carbon enrichment, sulfidation, silicification, and argillization are also associated with the sulfide orebodies. Decarbonatization affects the carbonate component of the lower Panther Canyon clastic submember carbonate-cemented siltstones and fine-grained sandstones, Panther Canyon dolomite submember, and Home Station Member silty dolomite. The results of this dissolution are discussed in the Ore Characteristics, Ground Preparation, and Controls on Hypogene Mineralization sections of this paper. Bleaching and carbon enrichment occurred in the Smelser Pass Member. These effects are most obvious in the vicinity of large faults/dikes. Between the Lighthouse fault/dike and the Southeast Intrusive, for example, bleaching was most intense proximal to these structures, giving the limestone a purplish-gray hue. Bleaching decreases and gives way to carbon enrichment in the central portion between the two structures, giving the limestone a sooty black appearance. The bleaching is probably due to mobilization of the organic component of the carbonaceous limestone during intrusive and/or hydrothermal events. The carbon component of these organics was then concentrated in more distal rocks.

It is important to point out that carbon enrichment is also seen in core-sections nearly everywhere in the system above the Panther Canyon/Smelser Pass contact. This enrichment is interpreted to be the effect of hydrothermal alteration alone, as acidic fluids ponded in the upper portions of the Panther Canyon clastic submember beneath the physiochemical barrier of the Smelser Pass Member. Some fluid must have penetrated the limestone along fractures and inter- and intragranular boundaries, driving off the organic components and concentrating them above.

Sulfidation in the sulfide orebodies occurs as veins/veinlets and disseminations of predominantly base-metal sulfides. In the Panther Canyon Member, sulfidation is usually associated with argillization of the clastic components. Argillization also overprints propylitization along intrusive margins. The argillization is typically most intense in the footwall boundaries, indicating that the intrusive bodies served as physical barriers to ascending hydrothermal fluids. In a few noteworthy cases, feldspars in the argillized porphyries had sericite selvages.

Supergene oxidation and enrichment was controlled by the paleo-water table (Emmons and Eng, 1995) and by the Panther Canyon clastic submember lithology; the massive and lensoid conglomerates were oxidized, but the sandstones and siltstones were not (Streiff, 1994). This control produced alternating oxidation/reduction in the conglomerate - sandstone - siltstone of the mixed middle clastic submember as an overprint on hypogene mineralization. The resultant mixed oxide/sulfide zone contained a thin blanket of secondary native Ag, especially around minor structures.

Ore Characteristics

Hypogene mineralization at Cove occurs as joint fracture linings. veins/veinlets, pods, disseminations, and crustiform linings in primary and secondary pore spaces. The types of mineralization are grouped here by lithology/unit. In the silty dolostone of the Home Station Member, mineralization consists of: 1) 5 to 20 centimeter wide veins radiating from the axial plane of the Cove anticline; 2) 0.5 to 5 centimeter wide irregular, non-radial discordant veins in the anticline axis; 3) 0.5 to 5 centimeter wide concordant veins that thin and pinch-out away from the anticline axis; and 4) pods associated with ~N- and ~NE-striking faults with or without associated dikes. The radial, irregular discordant, and concordant veins form a dense stockwork in the anticline axis, and typically show multiple episodes of mineralization within single veins. Each episode consists of irregularly banded base-metal sulfides with calcite gangue, and is separated from successive episodes by a thin layer of medium gray clay. The largest pod of mineralization visible in the Cove highwall is hosted by the Home Station Member at the footwall contact with the Cay dike, and consists of a 4 meter wide mass of sooty, friable base-metal sulfides.

In the Panther Canyon dolomite submember, mineralization occurs as: 1) 3 to 10 centimeter wide continuations of the radial veins seen in the Home Station Member; 2) 3 to 10 centimeter wide non-radial discordant veins; 3) 1 to 5 centimeter wide concordant veins; 4) 20 to 30 centimeter diameter pods; and 5) euhedral open-space growths in quartz lined dissolution holes in the 1 meter thick uppermost dolomite bed. The veins seen here differ from those in the Home Station Member in that they are thinner, more widely spaced, and do not show as many episodes of development. Pods consist of sooty, friable base-metal sulfides at intersections and splays of non-radial discordant veins. The dissolution holes in the uppermost bed range from 1 to 3 centimeters in diameter, and form an excellent marker horizon. The crustiform quartz linings and euhedral base-metal sulfides, however, are only found in the general region of the anticline axis.

Mineralization of the Panther Canyon clastic submember must be broken down into two stratigraphic packages: 1) the lower carbonate cemented siltstones and fine-grained sandstones versus 2) the upper coarse-grained sandstones and conglomerates. In the lower package, mineralization occurs in veins similar to those in the Panther Canyon dolomite submember, and also as thin Fe-sulfide linings of anticline-related radial joints. Vein/veinlet density increases dramatically in the proximal footwall of the Bay dike, locally grading into small pods of crackle breccia at the dike contact. In the upper package, mineralization is more variable and widely dispersed than in the units described thus far. In general, the veins seen in the lower units dissipate and disappear into the coarser-grained clastic strata. The style of mineralization transforms to crustiform linings in intergranular pore spaces, dissemination, and thin (<1 millimeter wide) intragranular veinlets. The thin pyrite/marcasite linings of radial joints do persist into this zone, but are not as well developed as those in the lower clastic package.

In the Smelser Pass Member limestone, mineralization occurs as disseminations generally restricted to the immediate hanging walls of the Lighthouse and other faults, and in manganiferous jasperoid replacement bodies. The overlying tuff sediments and main mass of the Caetano tuff, Tertiary/Quaternary karst sediments, and Quaternary alluvial sediments are all unmineralized. Figure 9 summarizes the ore characteristics listed for each of the units above in schematic form.

Mineralogy

The oxide orebody typically graded across a mixed oxide/sulfide zone into the sulfide orebodies. Each of these zones contained its own mineral assemblage, which may be

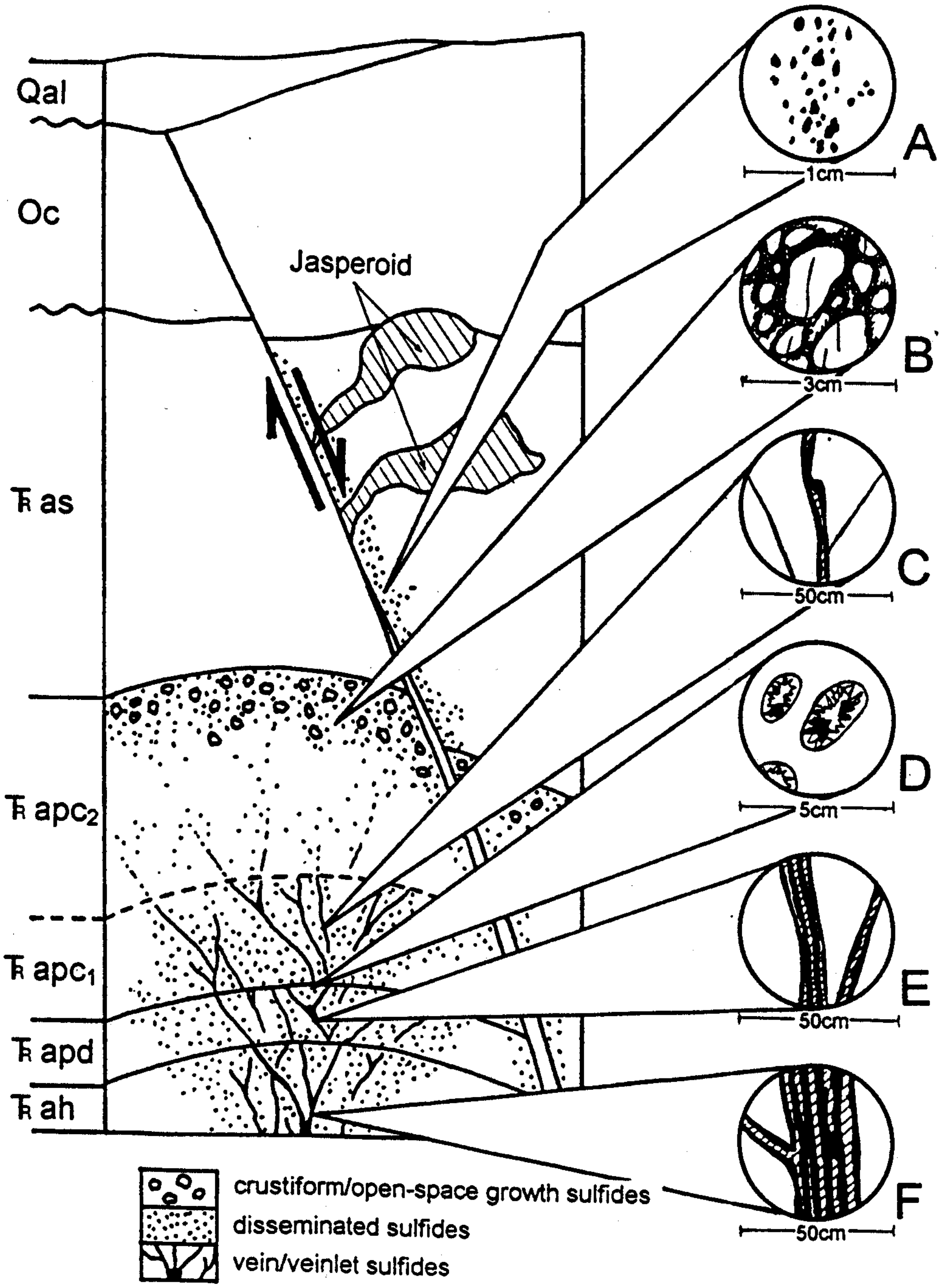


Figure 9. Schematic diagram of Cove ore characteristics. For A through F, sulfides are shown in black. A shows disseminated sulfides in the Smelser Pass Member, B shows crustiform/open-space growth sulfides in the upper Panther Canyon clastic submember, C shows vein/veinlet sulfides in the lower Panther Canyon clastic submember, D shows open-space growth sulfides in dissolution holes at the top of the Panther Canyon dolomite submember, E shows vein sulfides in the Panther Canyon dolomite submember exhibiting multiple episodes of deposition, and F shows vein sulfides in the Home Station member also exhibiting multiple episodes of deposition.

shared in part with one or both of the others. Only the sulfide assemblages can still be found in the pit highwall. Much of the following synopsis of Cove mineralogy is based on data collected from published and in-house metallurgical and mineralogical reports. Many observations are supported by hand-sample, thin-section, and polished-section analyses for the current study.

Table 1 shows the oxide orebody mineralogy. Drexler (1988) found the Ag in the oxide orebody to be associated primarily with the Mn-oxide phases, with Ag contents of 0.2 to 0.56 weight percent in cryptomelane (KMn_8O_{16}) and ranceite ($(Ca,Mn)Mn_4O_9 \cdot 3H_2O$). Although some samples also contained the Pb-bearing psilomelane group mineral coronadite, this phase was not found to contain Ag. Less commonly, Ag occurred as sulfosalts (stephanite (Ag_5SbS_4) - polybasite ($Ag_{16}Sb_2S_{11}$) - pearceite ($Ag_{16}As_2S_{11}$)), as electrum with variable Ag content, and as iodyrite (AgI). Emmons and Eng (1995) believed Ag to also occur as chlorargyrite (AgCl). Honea (1990a) found native Au in the oxide orebody, associated with a complex Mn-oxide assemblage of cryptnomelane, pyrolusite, todokorite ($(Mn,Ca,Mg)Mn_3O_7 \cdot H_2O$), and ranceite. Au also occurred as electrum in the oxide orebody (Drexler, 1988; Emmons and Eng, 1995). Accessory minerals in the oxide orebody included rutile, magnetite, ilmenite, and hematite (Honea, 1988).

In samples apparently collected from the oxide-sulfide "mixed zone," Honea (1990b) found a more exotic assemblage. He believed the native Au in the samples to be of primary hypogene origin. He thought the Ag to be a secondary product formed through the partial oxidation of argentiferous galena and tetrahedrite (freibergite?). The chalcocite found on the margins of some corroded galena aggregates was therefore interpreted to be a secondary enrichment product. Cerrusite and malachite were also found as supergene phases.

Ore minerals in the sulfide orebodies are much more diverse, and were probably deposited in several stages. Table 2 shows the combined mineralogy of the sulfide orebodies. Veins in the sulfide orebodies consist of complex intergrowths of sulfides and sulfosalts without appreciable gangue (Kuyper et al., 1991). Where present, gangue

Mineral Name	Chemical Composition	Abundance	Distribution
Cerrusite	$PbCO_3$	NA	NA
Chalcocite	Cu_2S	NA	NA
Cerargyrite	$AgCl$	NA	NA
Coronadite	Pb-bearing Psilomelane	NA	NA
Cryptomelane	KMn_8O_{16}	NA	NA
Electrum	Au,Ag (Ag≥20%)	NA	NA
Gold	Au	NA	NA
Hematite	Fe_2O_3	NA	NA
Ilmenite	$FeTiO_3$	NA	NA
Iodyrite	AgI	NA	NA
Magnetite	Fe_3O_4	NA	NA
Malachite	$Cu_2CO_3(OH)_2$	NA	NA
Pearceite	$(Ag,Cu)_{16}As_2S_{11}$	NA	NA
Polybasite	$(Ag,Cu)_9SbS_6$	NA	NA
Pyrolusite	MnO_2	NA	NA
Rancieite	$(Ca,Mn)Mn_4O_9 \cdot 3H_2O$	NA	NA
Rutile	TiO_2	NA	NA
Silver	Ag	NA	NA
Stephanite	Ag_5SbS_4	NA	NA
Todokorite	$(Mn,Ca,Mg)Mn_3O_7 \cdot H_2O$	NA	NA

Table 1. Ore mineralogy in the Cove Mine oxide orebody (Data compiled from Drexler (1988), Honea (1988,1990a, 1990b, 1991, and 1998), and Emmons and Eng (1995)). Note: no information on abundance or distribution available.

Mineral Name	Chemical Composition	Abundance	Distribution
Acanthite	Ag_2S	Trace	Rare
Anatase	TiO_2	Minor	Ubiquitous
Arsenopyrite	$FeAsS$	Minor	Common
Bravoite	$(Ni,Fe)S_2$	Trace	Rare
Canfieldite	Ag_8SnS_2	Trace	Rare
Cassiterite	SnO_2	Trace	Rare
Chalcocite	Cu_2S	Trace	Rare
Chalcopyrite	$CuFeS$	Minor	Ubiquitous
Chatkalite (tentative identification)	$Cu_6FeSn_2S_8$	Trace	Rare
Covellite	CuS	Trace	Rare
Digenite	Cu_9S_5	Trace	Rare
Electrum	Au,Ag (Ag≥20%)	Trace	Ubiquitous
Enargite[1]	Cu_3AsS_4	NA	NA
Freibergite (var. of Tetrahedrite)	$(Ag,Cu,Fe)_{12}(Sb,As)_4S_{13}$	Minor	Common
Galena	PbS	Abundant	Ubiquitous
Gersdorffite	$(Ni,Fe)AsS$	Trace	Rare
Goethite	$FeO(OH)$	Trace	Rare
Gold[1]	Au	NA	NA
Hematite	Fe_2O_3	Trace	Rare
Kesterite	$Cu(Zn,Fe)SnS_4$	Minor	Common
Kesterite-Stannite mix	$Cu_2(Fe,Zn)SnS_4$	Minor	Common
Marcasite	FeS_2	Abundant	Common
Miargyrite[2] (tentative identification)	$AgSbS_2$	NA	NA
Non-stoichiometric Stannite	-	Trace	Common
Non-stoichiometric Cu-Fe sulfide	-	Trace	Rare
Pearceite	$(Ag,Cu)_{16}As_2S_{11}$	Minor	Rare
Polybasite	$(Ag,Cu)_9SbS_6$	Minor	Rare
Proustite-Pyrargyrite	Ag_3AsS_3-Ag_3SbS_3	Minor	Rare
Pyrite	FeS_2	Abundant	Ubiquitous
Pyrrhotite	$Fe_{1-x}S$	Minor	Ubiquitous
Rutile	TiO_2	Minor	Ubiquitous
Shadlundite (tentative identification)	$(Pb,Cd)(Fe,Cu)_8S_8$	Trace	Rare
Silver	Ag	Minor	Ubiquitous
Sphalerite	$(Zn,Fe)S$	Abundant	Ubiquitous
Stannite	Cu_2FeSnS_4	Minor	Common
Stannite III	$(Cu,Ag)_2(Fe,Zn)SnS_4$	Trace	Rare
Stromeyerite[3]	$(Ag,Cu)_2S$	NA	NA
Tennantite-Tetrahedrite	$Cu_{12}(As,Sb)_4S_{13}$	Minor	Common

Table 2. Ore mineralogy in the Cove Mine sulfide orebodies (modified from Kuyper et al. (1991) using data from 1. Honea (1991), 2. Honea (1998), and 3. Schaffer and Kimbel (1994)). For abundance, Trace = 1 or 2 grains observed in polished section, Minor = <1% of vein mineralogy and not uncommonly visible in hand specimen, Abundant = >1% of vein mineralogy and commonly visible in hand specimen, and NA = data not available. For distribution, Rare = only one occurrence noted, Common = observed in 30-50% of polished sections studied, Ubiquitous = observed in >50% of polished sections studied, and NA = data not available.

consists of sericite ± clay minerals ± quartz, with rare late drusy quartz and manganocalcite (Emmons and Coyle, 1988; Kuyper et al., 1991). A sooty Mn gangue in the stockworks closest to the Cay and Blasthole faults/dikes was found by XRD methods to be rhodochrosite (Streiff, 1994).

Some marcasite and pyrite grains contain dark patches of material containing Cu and Ag, with less common Zn and Pb. These domains have been interpreted as non-stoichiometric mixtures deposited under non-equilibrium conditions, instead of separate mineral species (Schurer and Fuchs, 1988). Numerous minor, widely distributed sulfides and sulfosalts are also present. These include Sn-bearing phases: 1) stannite (Cu_2FeSnS_4), typically as blebs or inclusions in pyrite or more rarely in sphalerite and galena, 2) the stannite relatives stannite III ($(Cu,Ag)_2(Fe,Zn)SnS_4$), kesterite ($Cu(Zn,Fe)SnS_4$), and non-stoichiometric stannite, 3) canfieldite (Ag_8SnS_6), and 4) rare cassiterite.

Discussion

Ground Preparation

Of paramount importance to the genesis of the Cove deposit were the characteristics that enhanced permeability of the host rocks and facilitated precipitation of ore minerals from pregnant solutions moving through these permeable zones. These characteristics are examined in terms of primary traits of the host rocks, called "inherited characteristics" here, and in terms of secondary traits developed in the host following deposition, called "imposed characteristics" here.

Inherited Characteristics: Sorting, roundness, and sphericity of clastic grains all contribute to original porosity. Well-sorted, rounded, spherical grains can have 35 to 40+ percent porosity prior to compaction and cementation. Porosity in poorly-sorted, angular, pronouncedly prolate to oblate grains is greatly reduced. Although the different horizons in the Panther Canyon clastic submember have different size parameters, all horizons and lenses within these horizons are composed of moderately sorted, subrounded, somewhat oblate to spherical quartzose grains. Primary porosity in this unit moderately high, therefore, although subsequent compaction and cementation have diminished this favorable trait.

The massively bedded limestone and diagenetic dolomite of the Home Station Member, primary dolomite of the Panther Canyon dolomite submember, and carbonate cemented siltstones and fine-grained sandstones of the lower package in the Panther Canyon clastic submember all contain significant amounts of quartz silt and sand. This inherited composition allows these units to retain some or all of their original thickness following attack and dissolution of their carbonate components by acidic fluids. The amount of retained thickness depends on the percentage of clastic content and clast grain shape parameters. For example, a micrite containing 20 percent well-sorted, rounded, and spherical quartz grains would retain 20 percent of its original thickness in clast occupied space alone after dissolution, plus another 35 to 40 percent of this 20 percent, or 7 to 8 percent of the original thickness, in intergranular porosity.

The effects of these inherited characteristics at Cove are instrumental to development of crustiform and disseminated mineralization. In the Panther Canyon clastic submember, ore fluid transport and development of crustiform mineralization were directly related to the permeability and open-space framework related to the primary porosity. In the lower carbonate-cemented silt- and sandstones, and sandy carbonate units, porosity developed through dissolution of the carbonate component and retained unit thickness by the residual clastic grains generated the permeability necessary for disseminated mineralization.

Imposed Characteristics: Folding, faulting, dolomitization, decarbonatization, and magmatic intrusions along faults and bedding comprise the imposed characteristics at Cove. While faulting alone provided conduits for the mineralizing fluids, it is the combination of faulting and folding that produced the requisite geometry for the development of this large, bulk-mineable resource. This geometry is seen in Figure 5, and consists of a structural high formed by the Cove anticline and subsequent faulting. In this case, the anticline hinge formed an original structural high with increasing altitude from southeast to northwest. Later extension and development of the north-striking, steeply northeast-dipping Lighthouse fault and northeast-striking, steeply northwest-dipping Cay/Southeast Intrusive, Blasthole, Bay, and 110 faults have segmented the anticline.

This segmentation produced a horst block in the footwall of the Lighthouse fault between the Cay and Bay faults. This horst block is a principal host for the higher-grade ore zones at Cove (see Streiff, 1994, for ore zone descriptions).

Host rock permeability and composition play equally important roles with geometry to create a favorable setting for mineralization. At Cove, the most important host lithology is the highly porous, coarser-grained upper package of the Panther Canyon clastic submember. The permeability of this horizon is due to the inherited characteristics already described, but imposed dolomitization and decarbonatization contribute to permeability in other units. Dolomitization significantly increases permeability of a carbonate rock. Diagenetic dolomitization of the Home Station Member has therefore made this unit more susceptible to fluid/gas flow. Decarbonatization has been described above in its combination with inherited characteristics to facilitate disseminated mineralization. The dissolution holes in the uppermost bed of the Panther Canyon dolomite submember also fall into this category of imposed characteristics.

The most striking result of decarbonatization currently visible in the Cove highwall is the large pod of base-metal sulfides in the Home Station Member. Here, it is apparent that acidic fluids migrated up the footwall contact of the Cay dike. Dissolution of the Home Station carbonate component liberated the non-reactive sand grains, which were pushed to the footwall side of the enlarging megapore by continued fluid flow. The resultant void allowed for the deposition of the 4 meter wide pod. This pod could not have formed, though, without concentration of fluid flow in the dike footwall.

Igneous intrusions along faults and bedding have formed semi-permeable barriers to ascending hydrothermal fluids, concentrating fracturing, alteration, and mineralization in their footwalls. The most important intrusions relative to the development of the Cove orebody are the Bay dike and Cay dike with its related sills. The Cay sills were formed in the hanging wall of the Cay dike in conglomerate beds of the Panther Canyon clastic submember. They extend northwestward from the Cay approximately 250 meters, pinching-out in the Bay footwall. In his underground work at Cove, Streiff (1994) delineated 3 major ore zones within the upper high-grade orebody. By far the largest and most significant of these was the "Main Stratiform Zone," which was 600 meters long, 90 meters wide, and 3 to 20 meters thick. Much of this ore zone was formed immediately beneath one of the Cay sills, which probably served as a trap for ascending fluids, and pinched-out in the Bay dike footwall (Figure 10).

Controls on Hypogene Mineralization

The inherited and imposed characteristics at Cove can be grouped into 3 types of mineralization control. Spatial controls consist of features that served as conduits for the ascending fluids and accommodated depositional growth of ore and gangue phases. Physical controls comprise features that concentrated these fluids and the resultant ore precipitation. Chemical controls consist of features reactive to the mineralizing fluids, either limiting or enhancing their abilities to penetrate the host rocks. On an individual basis, most of the different ore types described were formed through combinations of these controls.

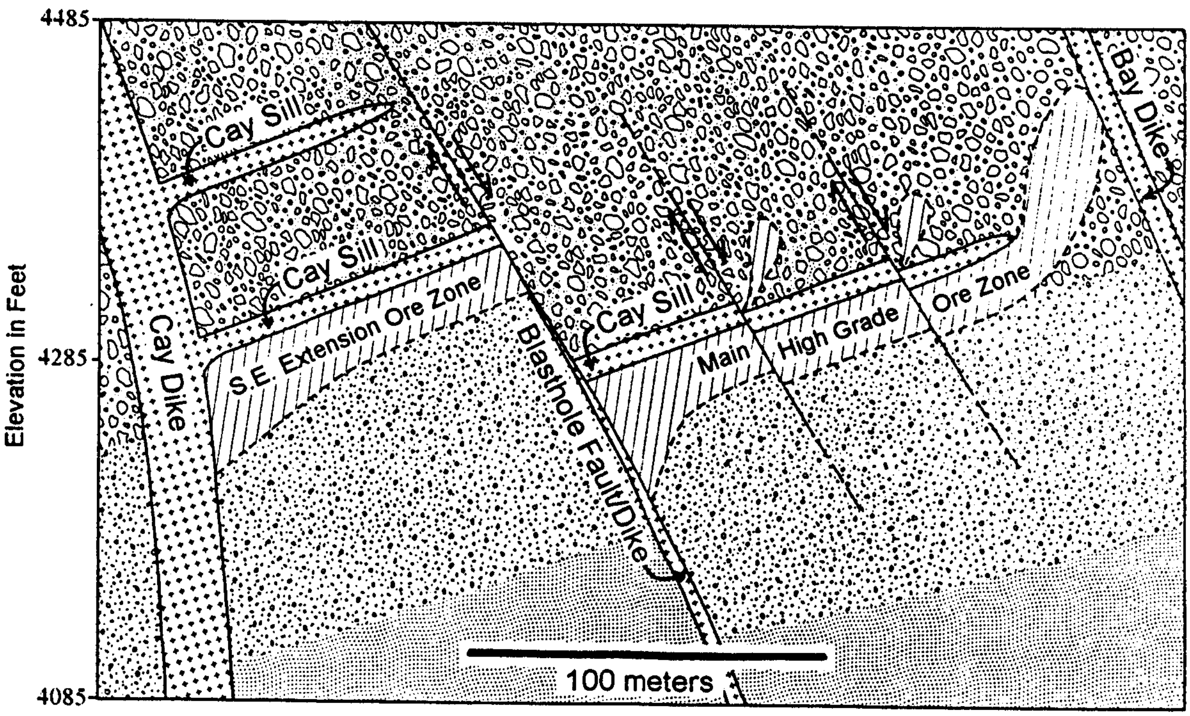


Figure 10. The Southeast Extension and Main High Grade components of the Main Stratiform Ore Zone, showing their intimate association with one of the Cay sills (modified from Streiff, 1994).

Spatial controls comprise faults, joints, and permeabilities of different host rocks. These controls provided conduits for ascending fluids and space for ore deposition. Base-metal sulfide stockwork veins/veinlets are the most important and obvious mineralization style, followed closely by disseminations and crustiform deposition. Stockworks typically occupy faults, radial joints, non-radial discordant fractures, conformable flexural-slip faults, and bedding planes. They also occur as dense networks that can grade into localized crackle breccias in the footwalls of the Cay sills and Bay dike. Such networks are interpreted to have formed through increasing hydrostatic pressures and resultant fracturing during the hydrothermal event(s). The episodic dilation and precipitation in the veins of the Home Station Member and Panther Canyon dolomite submember may also be caused by increasing hydrostatic pressures, or may reflect subtle doming caused by a deeper, as yet unrecognized intrusive body ultimately responsible for the genesis of the Cove system.

Physical controls consist of the Cove anticline, extensional horst, semi-permeable intrusive bodies, and possibly elevation/depth of the host rocks during mineralization. The horst developed perpendicular to the anticline axis, providing a structural high to localize fluid migration. Fluids were trapped and concentrated in the footwalls of intrusive bodies, and perhaps more importantly, they were also trapped by a chemical boundary.

Chemical controls comprise reactive carbonate rocks that either yield to acidic fluid attack and dissolution to increase permeability, or buffer these acidic fluids to prevent further invasion. The base of the Smelser Pass Member limestone served as such a chemical buffer to fluids migrating upward through the permeable Panther Canyon clastic submember. Buffering formed a physiochemical boundary that trapped the ascending fluids. The ponding effect was responsible for the development of the widely dispersed, bulk-mineable crustiform, disseminated, and veinlet ore in the upper portions of the clastic unit, as earlier mineralizing fluids were forced to spread out laterally and downward from the anticline hinge zone to accommodate later fluids. Some fluids, however, were able to escape this trap along the Lighthouse fault and other faults, forming the disseminated mineralization and manganiferous jasperoid bodies that are the uppermost expression of the mineralized Cove system.

Summary and Conclusion

This study produced a geologic framework for the Cove Au-Ag deposit based on structures, lithologies, and stratigraphy. The principal host is the Triassic Augusta Mountain Formation passive margin sequence, consisting of limestones, conglomerates, sandstones, siltstones, and dolomites. These rocks were gently folded, producing a broad, shallowly plunging anticline on which the deposit is centered. Multiple episodes of extensional faulting have segmented the anticline. Although the fault paragenesis is convoluted, a general sequence was recognized: early development of ~N-striking faults was overprinted by subsequent ~NE-striking faults and later ~NW-striking faults.

Ore consists of stockwork veins/veinlets, disseminations, and crustiform/open-space growth sulfides. The ore type(s) is generally lithology dependent, with veins more common in the Home Station Member, Panther Canyon dolomite submember, and lower Panther Canyon clastic submember. Crustiform/open-space growths occur in the upper Panther Canyon clastic submember, and disseminated sulfides and auriferous jasperoid bodies occur in the Smelser Pass Member. Most of the intrusive bodies are also mineralized.

Ore minerals in the mined-out oxide orebody were associated with Mn-oxides and sulfosalts. Ore minerals in the sulfide orebodies are associated with veins/veinlets, disseminations, and crustiform/open-space growths. Although this mineralization is dominated by base-metal sulfides, 38 sulfides, sulfosalts, oxides, and native metals have been recognized in these complex assemblages.

A broad spectrum of hydrothermal alteration is associated with the generation of the Cove deposit: 1) propylitization and/or argillization are seen nearly everywhere in the intrusive bodies; 2) decarbonatization, bleaching, carbon enrichment, argillization, silicification, and sulfidation are associated with carbonate rocks; and 3) argillization, silicification, and sulfidation are associated with the clastic rocks.

Controls on hypogene mineralization were examined in terms of inherited and imposed characteristics that enhanced permeability in the host. These characteristics were then broken down into spatial, physical, and chemical controls that localized and/or concentrated the mineralizing fluid(s). Spatial controls consisted of faults that served as conduits and porosity that facilitated deposition. Physical controls comprised the structural high formed by extension of the Cove anticline and intrusive bodies that concentrated the ore fluid(s) in their footwalls. The most important chemical control was the base of the Smelser Pass Member, which served as a physiochemical barrier to ascending fluids, concentrating them in the upper Panther Canyon clastic submember.

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REFERENCES

Drexler, J.W., 1988, Mineralogical report for Echo Bay Minerals Company: unpublished report, Echo Bay Minerals Co., 20 p.

Emmons, D.L., and Coyle, R.D., 1988, Echo Bay details exploration activities at its Cove gold deposit in Nevada: Mining Engineering, v. 40, no. 8, p. 791-794.

Emmons, D.L., and Eng, T.L., 1995, Geology and mineral resources of the McCoy Mining District, Lander County, Nevada: text to accompany Nevada Bureau of Mines Map 103, 12 p.

Gilluly, J., and Masurky, H., 1965, Geology of the Cortez quadrangle, Nevada: United States Geological Survey Bulletin 1175, 117 p.

Honea, R.M., 1988, Upper Cove samples: unpublished report, Echo Bay Minerals Co., 41 p.

Honea, R.M., 1990a, Preg-robbing character of samples: unpublished report, Echo Bay Minerals Co., 19 p.

Honea, R.M., 1990b, High-grade stope sample: unpublished report, Echo Bay Minerals Co., 10 p.

Honea, R.M., 1991, Analysis of samples from the flotation concentrate, leached concentrate residue, and leached oxide tailings of the Cove deposit: unpublished report, Echo Bay Minerals Co., 35 p.

Honea, R.M., 1998, Polished section examination of 4105 bench, Cove samples 1 and 2: unpublished report, Echo Bay Minerals, 18 p.

Kuyper, B.A., Mach, L.E., Streiff, R.E., and Brown, W.A., 1991, Geology of the Cove gold-silver deposit: 1991 SME Annual Meeting, 20 p.

Muller, S.W., Ferguson, H.G., and Roberts, R.J., 1951, Geology of the Mount Tobin quadrangle, Nevada: United States Geological Survey Geologic Quadrangle Map GQ-7.

Nichols, K.M., and Silberling, N.J., 1977, Stratigraphy and depositional history of the Star Peak Group (Triassic), northwestern Nevada: Geological Society of America Special Paper 108, 73 p.

Schaffer, M., and Kimbel, D., 1994, Sulfide recoveries: unpublished report, Echo Bay Minerals Co., 37 p.

Schurer, V., and Fuchs, W.A., 1988, Ore microscopy and electron microprobe analysis results for a selected suite of metallugical samples from the Cove deposit, Nevada: unpublished report, Echo Bay Minerals Co., 145 p.

Streiff, R.E., 1994(?), Geology and mineralization of the Panther Canyon Clastic Member at the Cove Mine, Nevada: unpublished report, Echo Bay Minerals Co., 20 p.