

Geology of the Cove Mine, Lander County, Nevada, and a Genetic Model for the McCoy-Cove Hydrothermal System

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Abstract

The McCoy Au-Ag skarn and Cove Au-Ag deposits are located in the northern Fish Creek Mountains, Lander County, Nevada. Through the end of mining in 2001, large-scale open-pit and associated underground production at the two deposits yielded 3.3 million ounces (Moz) of Au and 108 Moz of Ag. Most production was from Cove, making it the fourth-largest Ag producer in the history of Nevada.

Cove is hosted by the middle to early Late Triassic Augusta Mountain Formation, which consists of limestone with lesser dolostone and clastic units. Ore also is present locally in Eocene porphyritic granodiorite dikes and sills. The deposit comprises two distinct ore types: a central core of polymetallic vein-type ore and an outer aureole of relatively Ag rich Carlin-style ore. Polymetallic veins consist of pyrite-sphalerite-galena-dominated Au- and Ag-bearing veins, veinlets, stockworks, crustifications, and disseminations in clastic and carbonate strata and locally in the intrusions. Carlin-style ore comprises disseminated Fe ± As sulfides with arsenian, argentiferous, and auriferous components ± native Au-electrum in silty to sandy carbonate strata. Polymetallic vein-type ore has Ag/Au ratios of >50/1, and Carlin-style ore has Ag/Au ratios that decrease from ~50/1 near the feeder faults to ~1/1 in one of the more distal ore zones. Both types of ore are associated with decarbonized, silicified, and illitized rocks. New structural and age data for fresh and altered intrusive rocks indicate that mineralization at Cove occurred during active extension and magmatism at ~39 Ma (⁴⁰Ar-³⁹Ar). Fluid inclusion and δD and δ¹⁸O data for polymetallic vein-type ore indicate that the mineralizing fluids had temperatures of 250° to 370°C and were magmatic in origin.

Cove is located 1.6 km northeast of McCoy, where Early Tertiary igneous activity occurred in two pulses. The first pulse consisted of relatively oxidized magnetite-series magma and formed the central stock at McCoy and related dikes that extend to the Cove deposit. This pulse occurred at ~41.5 Ma and produced subeconomic skarn at McCoy. The second pulse consisted of relatively reduced ilmenite-series magma and produced economic skarn ore at McCoy. Adularia from a mineralized skarn assemblage at McCoy was dated at ~39 Ma (K-Ar). The age data indicate that McCoy and Cove formed contemporaneously. The δ³⁴S data for ore-stage sulfides from skarn ore at McCoy, and polymetallic vein-type and Carlin-style ore at Cove indicate a common source for S for the three types of ore. This source is interpreted to have been the pulse of ilmenite-series magma.

Although the volume of the Carlin-style ore at Cove is substantially larger than that of the polymetallic vein-type ore, the relatively high concentrations of base metals and clear associations with igneous activity have made Cove difficult to classify. The new data indicate that Cove is a telescoped system consisting of polymetallic vein-type and porphyry-related, distal disseminated ores. The zonation for the McCoy-Cove system is nearly identical to zonations described by other workers for Au-enriched porphyry systems. In this case, the porphyry center and skarn ore at McCoy comprise the proximal component, and polymetallic vein-type and Carlin-style ores at Cove are the intermediate and distal components, respectively. Economic concentrations of Au occur in all three zones, which are separated from one another by subeconomic concentrations of Au.

The Carlin-style orebodies at Cove share several important similarities with ores in classic Carlin-type deposits, including ore characteristics, associated alteration styles, and host lithologic units. The late Eocene age of the McCoy-Cove system is also a typical age for Carlin-type deposits in the Great Basin. The proposed genetic model for McCoy-Cove may have important implications for the exploration potential of intrusion-related and Carlin-type deposits worldwide.

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Introduction

THE MCCOY Au-Ag skarn and Cove Au-Ag deposits are located in the northern Fish Creek Mountains, 48 km southwest of the town of Battle Mountain, Lander County, Nevada (Fig. 1). Through the end of production in 2001, large-scale open-pit and associated underground mining at the two deposits yielded 3.3 million ounces (Moz) of Au and 108 Moz of Ag. Most production was from Cove, making it the fourth largest Ag producer in the history of Nevada, behind the Comstock, Tonopah, and Rochester mines. Lesser amounts of Au and Ag continued to be recovered from the McCoy-Cove heap-leach operation through 2003, with later revenue in 2004 through 2005 derived from the refinery and carbon plant cleanup (E. Daniels, pers. commun., 2007). Exploration of the property continues to the present day.

Premining in situ reserves at Cove consisted of 3.6 Moz of Au, and 165 Moz of Ag (Emmons and Eng, 1995). Cove comprises two mineralogically distinct, but spatially related hypogene systems with a supergene overprint (Johnston, 2000a). The most obvious hypogene system consists of Au- and Ag-bearing, base metal-dominated veins, veinlets, crustifications,

stockworks, and disseminations that consist principally of pyrite, sphalerite, and galena. This type of ore is referred to as polymetallic vein-type ore in the following text. The second hypogene system is dominated by Fe sulfides with Au- and Ag-bearing arsenian rims that are similar, but not identical, to "Carlin-type" and "Carlin-like" deposits in Nevada and elsewhere (terminology based on Berger and Bagby, 1993) and is referred to here as "Carlin-style" ore to avoid any genetic implications. Fresh and altered dikes at Cove were both dated at around 40 Ma (K-Ar) by Emmons and Eng (1995), which they interpreted as the age of mineralization.

Cove is located 1.6 km northeast of the McCoy Au-Ag skarn. Ore at McCoy is genetically related to a comagmatic suite of Tertiary hypabyssal stocks and dikes of granodioritic composition and commonly monzonitic dikes and sills (Brooks, 1994). Brooks (1994) identified two intrusive episodes at McCoy. The first pulse consisted of relatively oxidized magnetite-series magma and formed the central stock at McCoy and related dikes that extend to the Cove deposit. This pulse occurred at ~41.5 Ma and produced subeconomic skarn at McCoy. The second pulse consisted of relatively reduced

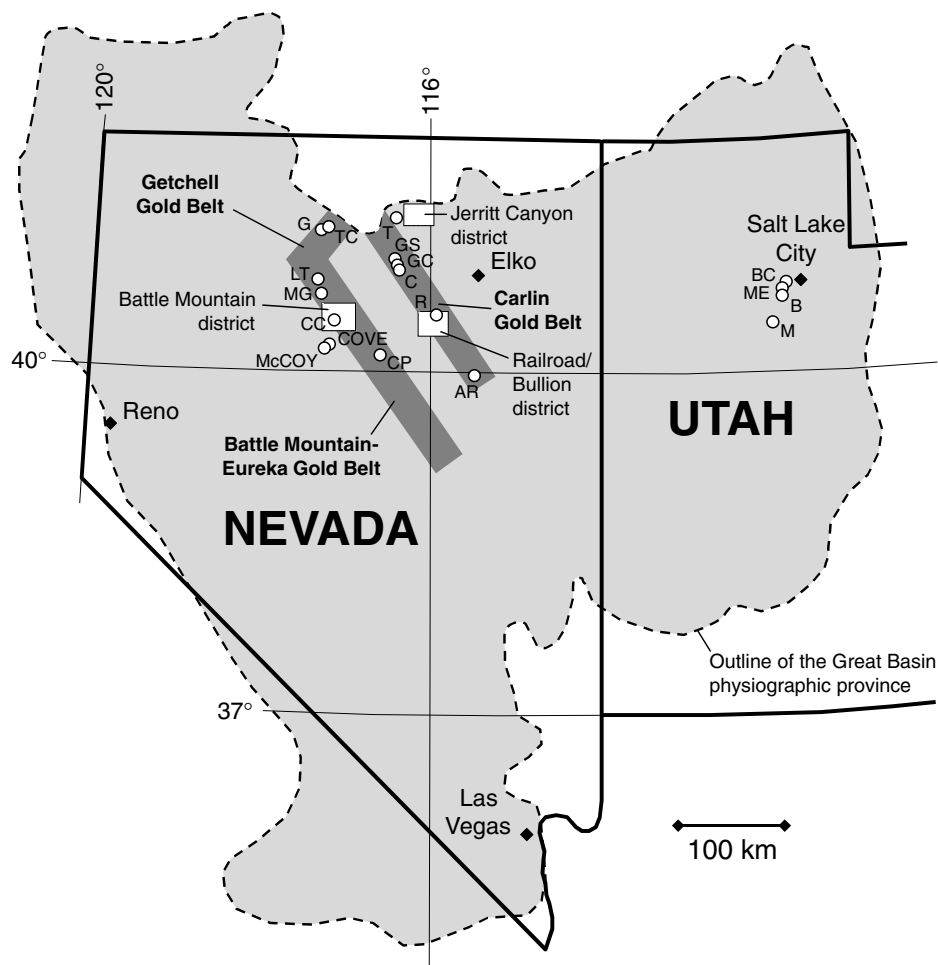


FIG. 1. Locations of the Cove and McCoy mines, gold belts, and major deposits in north-central Nevada (modified from Ressel et al., 2000). AR = Alligator Ridge, B = Bingham, BC = Barneys Canyon, C = Carlin (includes Carlin East), CC = Copper Canyon, CP = Cortez/Pipeline, G = Getchell, GC = Genesis complex (includes Beast, Deep Star, and Genesis), GS = Goldstrike (includes Betze-Post, Griffin, Meikle, and Rodeo), LT = Lone Tree, M = Mercur, ME = Melco, MG = Marigold, R = Rain, T = Tuscarora, and TC = Twin Creeks.

ilmenite-series magma and produced economic skarn ore at McCoy. Brooks (1994) dated adularia from a mineralized skarn assemblage at McCoy at ~39 Ma (K-Ar). Premining, in situ reserves at McCoy consisted of 880,000 oz of Au and 2.3 Moz of Ag (David L. Emmons, 2000, pers. commun.). Although the McCoy deposit was economic, based solely on its Au content, rocks with significant subeconomic Cu (800–1,000 ppm; Emmons and Eng, 1995) were also present.

Earlier workers suggested that Cove and McCoy may be parts of a single zoned system related to a large buried intrusion (Kuyper et al., 1991; Brooks, 1994; Emmons and Eng, 1995; Johnston, 2000a, b, 2001; Johnston et al., 2000). Kuyper et al. (1991) and Brooks (1994) cited five lines of evidence in support of this genetic link: (1) the two deposits are close to each other (1.6 km apart), (2) they are localized by the same northeast-striking fault zone, (3) they share identical host rocks, (4) they are spatially associated with similar to identical intrusive rocks, and (5) the intrusive rocks at both deposits were dated at about 40 Ma (K-Ar). While permissive of a genetic link, these observations do not prove that the deposits are related. This paper presents the latest mapping and petrological, microanalytical, fluid inclusion, stable isotope, and ^{40}Ar - ^{39}Ar data for the Cove deposit and compares these findings with details of the McCoy deposit from Brooks (1994) to elucidate the genetic relationships between the deposits. We also examine the role of magmatic fluids that contributed to the formation of the skarn, polymetallic, and Carlin-style Au-Ag deposits. Implications for other deposits are also discussed.

Sampling and Analytical Methods

The Cove open-pit and underground exposures were mapped at various scales between 1998 and 2001. More than 340 rock samples were collected for analysis from the Cove open pit, the Cove South Deep underground operation, drill core, the McCoy open pit, and dike exposures between the McCoy and Cove open pits. From these samples, 179 thin and polished sections were made and examined using standard petrographic and microscopic techniques. Standard X-ray diffraction analyses were performed on more than 30 samples of Cove intrusive rocks. Several of the samples were rerun to test for smectite group clay content following the ethylene glycol solvation technique described by Moore and Reynolds (1989). Eight samples were also submitted for standard X-ray fluorescence analyses. Standard scanning electron microscope analyses coupled with an energy dispersive X-ray detector and standard electron microprobe analyses were used as necessary to identify unknown mineral species.

Fluid inclusions

Fourteen samples were selected from polymetallic veins for fluid inclusion analyses. Standard reflected light petrographic analysis of ore-stage minerals was performed on the samples to fit them into a paragenetic scheme. Standard transmitted-light petrographic techniques were then used to map the hypogene quartz for suitable primary fluid inclusions based on criteria outlined by Roedder (1979). Measurements of homogenization temperatures (T_H) and final ice-melting temperatures (T_M) were performed on a FLUID

Inc.TM heating/freezing stage. T_M measurements were converted to equivalent salinities using the equations of Bodnar (1993).

Light stable isotopes

Eleven samples of altered intrusions were selected for $\delta^{18}\text{O}$ and δD analyses. These samples are from porphyritic intrusions that have been hydrothermally altered to a quartz-illite-pyrite assemblage. Each sample was physically disaggregated, ground, and sieved to collect the -60 mesh fraction. The powdered samples were processed by the Stable Isotope Laboratory at Washington State University, Pullman, WA. Conventional fluorination techniques (Clayton and Mayeda, 1963) were used to extract O_2 from the powdered samples. ClF_3 was used as an oxidizing agent (Borthwick and Harmon, 1982).

Splits from the samples used for $\delta^{18}\text{O}$ analyses were analyzed for whole-rock silicate δD . The sieved fractions were submersed in 10 percent HCl to dissolve calcite, which was present in each sample, then decanted twice in fresh water. After the samples were allowed to dry, the illite was isolated using bromoform density separation. The illite samples were sent to Oregon State University, Corvallis, OR, for δD analyses. Samples were analyzed for δD following the general procedure described by Bigeleisen et al. (1952). The H_2 yields were measured with a manometer (which allowed calculation of wt % water), then sent to Washington State University, Pullman, WA, for mass spectrometry.

Seven samples of polymetallic vein-type quartz and three samples of jasperoid from Cove were also processed and analyzed for $\delta^{18}\text{O}$ following the same general procedure described above, except that no heavy liquid separation was necessary.

Fifteen samples of coarse sulfides were chosen for $\delta^{34}\text{S}$ analyses. The samples were shipped to Geochron Laboratories in Cambridge, MA, for analysis.

^{40}Ar - ^{39}Ar dating

Five samples were selected for ^{40}Ar - ^{39}Ar analysis based on relative ages determined by mapping and petrographic study. Two of the samples contained macroscopically fresh and hydrothermally altered biotite grains, respectively. These samples were disaggregated, and the fresh and altered biotites were handpicked and cleaned. The other three samples contained significant amounts of microscopic illite intimately intergrown with quartz and sulfides. The illite-quartz-sulfide patches or coatings were pulverized and separated using an etching tool. All separates were placed in small glass vials and shipped to the Nevada Isotope Geochronology Laboratory at the University of Nevada, Las Vegas. Details of the analyses are given in the Appendix.

Stratigraphy and Igneous Rocks of the Cove Deposit

The stratigraphy of the McCoy mining district is well documented and has been described in detail by Emmons and Eng (1995) and Johnston (2000a). The stratigraphy in the vicinity of Cove is shown in Figure 2, and Figure 3 shows the generalized geology of the Cove-McCoy area. The oldest rocks recognized in the region belong to the Mississippian-Permian Havallah sequence, which consists of altered calcareous sandstone and siltstone (Emmons and Eng, 1995).

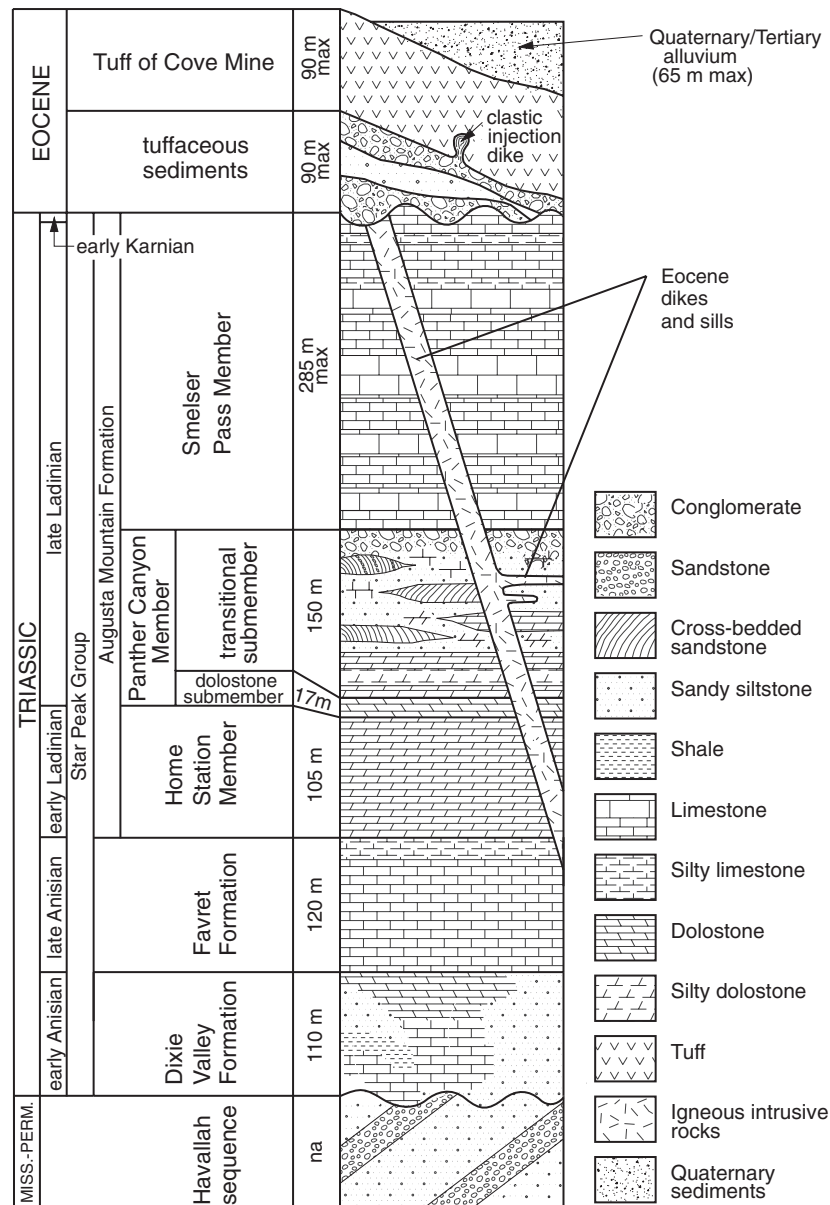


FIG. 2. Stratigraphy at the Cove deposit, modified from Kuyper et al. (1991) and Emmons and Eng (1995).

The Havallah sequence is unconformably overlain by strata of the Lower to middle-Upper Triassic Star Peak Group (nomenclature from Nichols and Silberling, 1977), a 1,220-m-thick section of marine platform limestone with lesser conglomerate, sandstone, siltstone, and dolostone. The Star Peak Group hosts nearly all the ore at Cove and most of the ore at McCoy. At McCoy, the Star Peak Group is conformably overlain by the Upper Triassic Cane Spring Formation, which consists of lower clastic and upper limestone members. The Cane Spring Formation is a lesser host at McCoy.

Discontinuous dikes and related sills are abundant at Cove and can typically be traced southwest to the Brown stock at McCoy (Fig. 3). The Cove dikes occupy the Lighthouse, Cay, Blasthole, Bay, 110, and Gold Dome faults (Fig. 4) and occur as the large, irregularly shaped West, Northeast, Southeast, and South intrusions. All of the intrusions are nearly identical

in composition and consist of 0.5- to 5.0-mm-long phenocrysts in a microcrystalline matrix. Phenocrysts average about 20 vol percent of the rock. In decreasing order of abundance, the phenocrysts are zoned plagioclase, biotite, hornblende, and resorbed quartz "eyes," with trace apatite, zircon, and monazite. The groundmass consists of aphanitic grains of phenocryst minerals with K-feldspar. Hydrothermal alteration is pervasive in these intrusive bodies.

Table 1 summarizes the XRF data from selected samples of intrusive rocks and is augmented by data from Emmons and Eng (1995) for the Brown stock at McCoy and feldspar porphyry dikes between the McCoy and Cove open pits. Although the primary mineralogy of the Cove intrusions was modified by hydrothermal alteration, petrological and geochemical data indicate that their original compositions were monzonitic to granodioritic. Emmons and Eng (1995) published five K-Ar

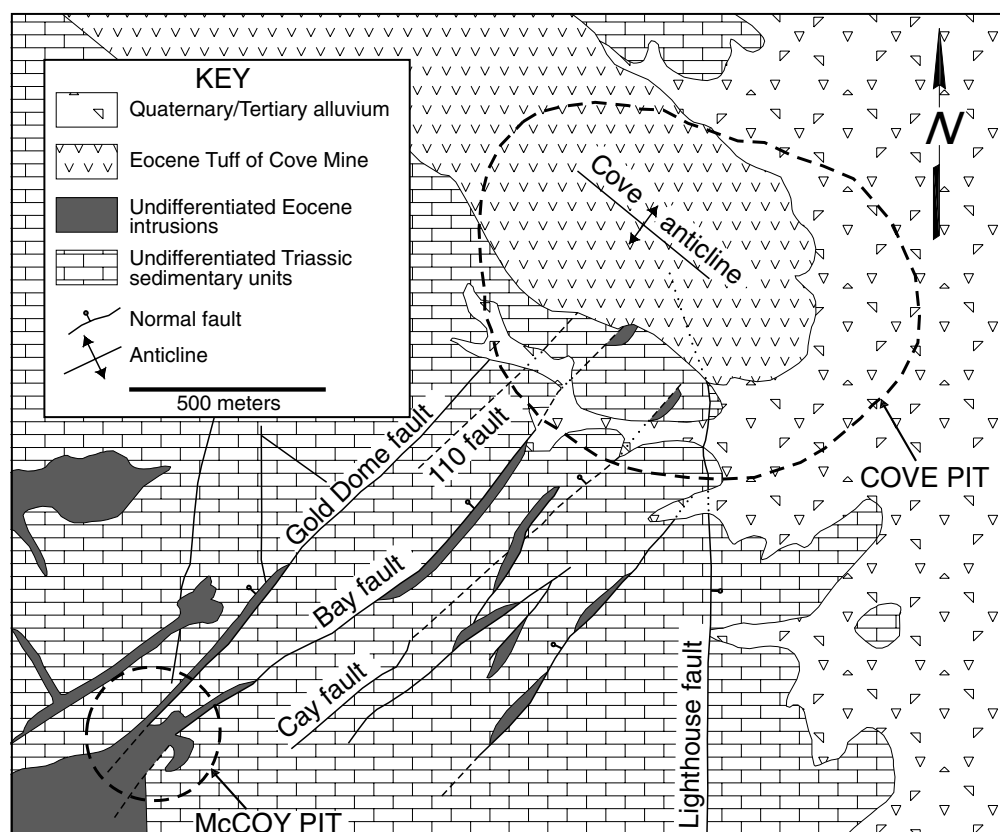


FIG. 3. Simplified premining geologic map of the Cove-McCoy area (modified from Emmons and Eng, 1995).

dates for intrusive rocks at Cove (Table 2), indicating a late Eocene age of intrusion. New ^{40}Ar - ^{39}Ar age data are presented later in this paper.

At Cove, the Cane Spring Formation has been removed by erosion, and the Star Peak Group is unconformably overlain by the 34.2 Ma, postore Tuff of Cove mine, a crystal-rich rhyolitic ash-flow tuff. The Tuff of Cove mine was formerly correlated with, but is now considered distinct from, the 33.8 Ma Caetano tuff (Stewart and McKee, 1977; John et al., 2008). Emmons and Eng (1995) divided the Quaternary surficial units in the McCoy mining district into alluvium, talus, and colluvium. Quaternary sediments exposed in the Cove open pit were not differentiated in this study. These sediments include unconsolidated sand and gravel and are less than ~65 m thick.

Structural Geology of the Cove Deposit

Figure 4 is the simplified pit map for the Cove deposit, and Figure 5 shows a west-east geologic cross section. Cove is centered on a broad, gently southeast-plunging anticline that was modified by normal faults. Folding probably occurred in the Mesozoic and definitely predated the intrusion of Eocene dikes and sills (Emmons and Eng, 1995). The Cove anticline hingeline trends S 44° E and plunges 18° SE, with limbs dipping approximately 25° SW and 40° NE, based on measured exposures in the open pit.

Brittle deformation is expressed as joints and faults related to both the development of the Cove anticline and other episodes of faulting. Flexural slip during folding produced

bedding-parallel reverse faults along bedding contacts and within less competent beds. These faults are characterized by continuous zones of fault gouge that parallel bedding and commonly are mineralized in the vicinity of the hinge zone of the anticline. The Cove anticline is cut by a series of steeply dipping (>60°) normal faults. The major faults (>1 m offset and continuous) can be separated into three principal groups: ~north-striking faults, ~northeast-striking faults, and ~northwest-striking faults.

The north-striking group consists of the Lighthouse fault and subordinate splays. The Lighthouse fault is a complex of multiple normal fault planes that contain discontinuous dikes and minor polymetallic veins. In many cases, veins and dike margins are brecciated by postmineral movement along the fault and/or dike complex.

The northeast-striking, northwest-dipping normal faults are the most common faults in the Cove open pit (Fig. 4) and can be divided into two distinct subgroups. The major faults in subgroup I are the Cay, Bay, Musky, 110, and Gold Dome faults. These faults have strikes ranging from N 52° E to N 65° E and dips ranging from 60° NW to 80° NW. Within the open pit, the Cay, Bay, Musky, and 110 faults steepen with increasing depth, from dips of less than 65° to dips greater than 80°. Measured displacements along these faults range from 10 m or less (along the Cay fault) to as much as 80 m (along the Bay fault). Discontinuous dikes occupy the Cay, Bay, and Gold Dome faults. The Cay and Bay dikes commonly have polymetallic vein-type ore localized in their footwalls, and base metal veins cut the Bay dike in the hinge zone of the

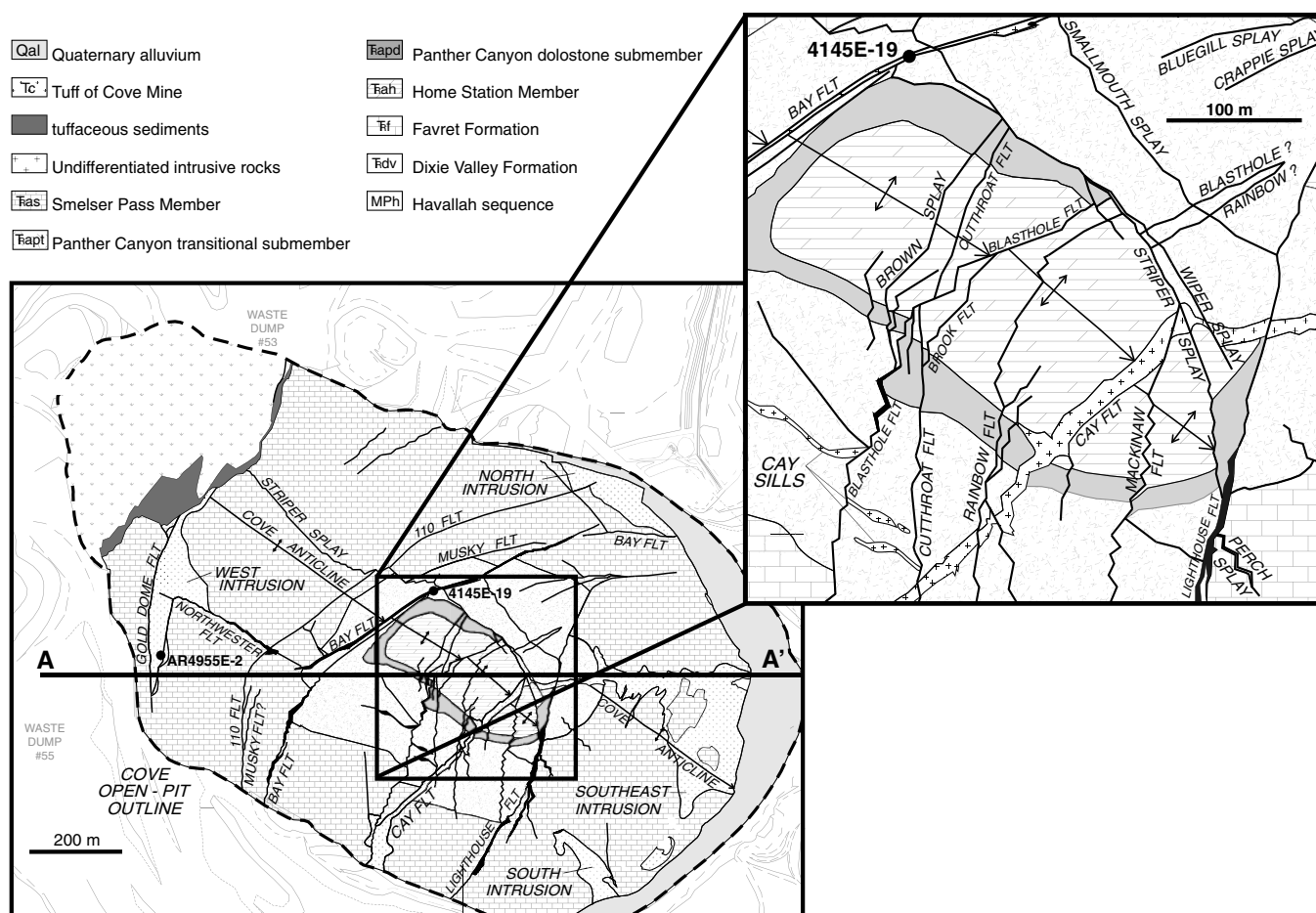


FIG. 4. Simplified geologic map of the Cove mine open pit. Cross section A-A' is shown in Figure 5. Sample numbers AR4955-1 and AR4145-19 show the locations of the samples analyzed for ^{40}Ar - ^{39}Ar age data. Favret Formation, Dixie Valley Formation, and Havallah sequence rocks do not occur in the open pit.

Cove anticline. These relationships indicate that these fault-dike complexes predate the mineralizing event(s).

Major faults in subgroup II are the Mackinaw, Rainbow, Cutthroat, Blasthole, and Brook faults, and the Brown splay. These faults generally have more northerly strikes than subgroup I, ranging from N 25° E to N 58° E, with dips ranging from 62° NW to 80° NW. Unlike many of the faults in subgroup I, the faults in subgroup II do not clearly steepen with depth. Also, the faults in subgroup II are much thinner, with widths of less than 1 m. Only one of the faults in subgroup II has an associated dike; the Blasthole fault contains a discontinuous dike that is less than 0.5 m wide where present. The Rainbow, Cutthroat, and Blasthole faults cut and offset the Cay fault-dike. The faults of subgroup II are all the loci of intense quartz-illite-pyrite alteration (including the Blasthole dike) and commonly contain polymetallic veins.

Major faults in the ~northwest-striking fault group are the Northwest fault and the Striper, Wiper, and Smallmouth splays (Fig. 4). The Northwest fault strikes N 60° W and dips 77° NE. It is up to 3 m wide and contains a discontinuous altered dike. The margins of the dike are brecciated and contain fragments of altered dike and polymetallic veins.

The Striper, Wiper, and Smallmouth faults generally strike N 27° W to N 30° W and dip 70° NW to 83° NW. The widths

of these faults are generally less than 1.5 m, and none contain associated intrusive rocks. They do, however, contain brecciated fragments of polymetallic vein-type ore derived from the rocks they cut. It is also clear that the Striper fault displaces hypogene ore (Johnston, 2000a), indicating that these are postmineral faults.

Alteration Styles at Cove

Figure 6 is a schematic alteration overlay for the west-east cross section (refer to Fig. 5), showing the distribution of alteration relative to structures and stratigraphic units. Each of the sedimentary host units at Cove has been altered to varying degrees of intensity. Hypogene alteration in sedimentary units at Cove is described in detail by Johnston (2000a) and comprises dolomitization, decarbonatization, silicification, illitization, and carbon enrichment. Silicification and illitization are described in detail here because quartz and illite are both used for light stable isotope analyses, and because illite was used to date the timing of mineralization.

Silicification and illitization

Silicification and illitization are intimately associated with both polymetallic vein-type and Carlin-style orebodies. In all of the sedimentary host units, silicification, with or without

TABLE 1. Whole-Rock X-Ray Fluorescence Analyses of Selected Intrusive Rocks from Cove and McCoy

Sample no.	Description	Alteration intensity
4725-4	From the east side of the Northeast intrusion at Cove	Weak
4205-23	From the Southeast intrusion at Cove	Moderate
4285-11	From the Cay sills at Cove	Moderate-strong
AR-8	From the Lighthouse fault and dike complex at Cove	Moderate-strong
4205-5	From the Bay fault and dike complex at Cove	Strong
4205-7	From the Bay fault and dike complex at Cove	Complete
4405-2	From the 110 and Striper intersection at Cove	Very strong
HS-6	From the Cay dike at Cove	Very strong
143108	Feldspar porphyry dikes of Emmons and Eng (1995)	Some alteration
143111	Feldspar porphyry dikes of Emmons and Eng (1995)	Some alteration
143114	Feldspar porphyry dikes of Emmons and Eng (1995)	Some alteration
320507	Brown stock at McCoy	No data
R85-85 625	Brown stock at McCoy	No data
R26-86 335	Brown stock at McCoy	No data
R28-86 225	Brown stock at McCoy	No data

Sample no.	Al ₂ O ₃	CaO	Cr ₂ O ₃	Fe ₂ O ₃	K ₂ O	MgO	MnO	Na ₂ O	P ₂ O ₅	SiO ₂	TiO ₂	LOI	Total
4725-4	16.21	3.54	<0.01	4.51	2.78	1.44	0.05	2.50	0.22	63.10	0.66	4.09	99.10
4205-23	14.64	2.91	<0.01	2.73	3.03	2.04	0.06	1.81	0.12	64.34	0.38	6.70	98.76
4285-11	14.35	4.88	<0.01	2.97	3.32	1.54	0.16	0.60	0.15	61.34	0.40	9.32	99.03
AR-8	16.25	4.94	<0.01	3.55	2.62	1.69	0.05	0.99	0.25	57.71	0.63	10.51	99.19
4205-5	16.11	0.37	<0.01	4.92	5.13	0.62	0.02	<0.01	0.18	65.05	0.63	6.35	99.36
4205-7	17.33	0.42	<0.01	8.10	4.37	0.58	0.01	0.12	0.20	59.25	0.79	7.87	99.04
4405-2	16.47	4.12	<0.01	3.85	3.43	0.61	0.04	0.23	0.25	60.75	0.71	8.48	98.94
HS-6	16.48	0.32	<0.01	2.87	2.61	0.50	<0.01	<0.01	0.16	69.81	0.48	6.40	99.63
143108	18.06	0.24	No data	0.70	1.24	0.28	<0.01	6.62	0.20	71.73	0.18	1.68	100.92
143111	16.17	0.61	No data	0.78	2.25	0.24	<0.01	7.50	0.06	72.09	0.20	1.34	101.23
143114	18.39	1.50	No data	0.99	3.34	0.40	<0.01	4.42	0.09	70.71	0.27	2.89	102.99
320507	15.43	5.32	No data	1.45	0.76	1.89	<0.01	4.48	0.16	68.50	0.41	1.57	99.96
R85-85 625	16.47	4.96	No data	5.30	2.82	2.53	<0.01	3.00	0.23	63.14	0.65	3.41	102.50
R26-86 335	15.97	4.04	No data	4.19	3.30	1.67	<0.01	3.16	0.20	64.49	0.50	2.06	99.57
R28-86 225	15.86	6.31	No data	2.23	5.60	1.52	<0.01	1.34	0.18	64.76	0.51	2.14	100.44

Notes: All data reported in percentages; Brown stock and feldspar porphyry dike sample data from Emmons and Eng (1995)

illitization, is most pronounced near major faults. However, the relatively high permeabilities in the secondary dolostone of the Home Station Member and the porous clastic strata in the Panther Canyon Member allowed widespread fluid access and ubiquitous development of these alteration styles.

In the Home Station Member and carbonate-dominated units in the Panther Canyon Member, silicification occurs as crustiform and cockscomb quartz in polymetallic veins and in dissolution-related pore spaces. The walls of the veins contain disseminated sulfides and small anhedral masses of quartz that are commonly intergrown with illite and pyrite. Further away from the veins, silicification occurs as irregular patches of recrystallized quartz. In the clastic-dominated units of the Panther Canyon Member, silicification occurs as crustiform and cockscomb quartz along polymetallic veins and in intergranular pore spaces. In the hinge zone of the Cove anticline, these pores are typically filled with intergrown quartz, illite, and sulfides.

Silicification is most obviously expressed as jasperoid bodies in the Smelser Pass Member. These jasperoids are auriferous, commonly manganiferous, and occur with breccias along large faults. They are best developed in the hanging

wall of the Lighthouse fault and adjacent to the Southeast intrusion.

Illitization is most pronounced in the late Eocene intrusions that cut the sedimentary units. The dikes, and lesser sills, are strongly altered to quartz-illite-pyrite in the immediate vicinity of both polymetallic vein-type and Carlin-style orebodies. In most cases, it is clear that the dikes predate the precious metal mineralization, which is temporally related to the quartz-illite-pyrite alteration based on the common occurrence of ore minerals intergrown with quartz and illite. Polymetallic veins and pods commonly occur in the footwalls of the altered intrusions and also cut them. Carlin-style ore also shows the same relationships with the intrusions, which apparently acted as aquitards to the ascending hydrothermal fluids.

Supergene alteration and mineralization

Because this study is focused on the hypogene genesis of the Cove deposit, supergene alteration and mineralization were not examined in detail. Exposed strata in the upper part of the Cove deposit have an orange to red coloration, due principally to the supergene oxidation of Fe sulfides. The principal products of supergene processes are illite, smectite,

TABLE 2. K-Ar Age Determinations in the McCoy Mining District

Rock unit	Age (Ma)	Material dated	Comments
Brown stock	40.0 ± 1.6	Sericite	Biotite quartz monzonite
Brown stock	40.9 ± 1.6	Sericite	quartz monzonite
Brown stock	41.6 ± 1.6	Biotite	Biotite quartz monzonite
Brown stock	42.9 ± 1.9	Sericite	Altered quartz monzonite
"Mafic dike"	48.6 ± 2.0	Biotite	North of McCoy deposit
"Dike"	64.5 ± 3.1	Hornblende	Dike near NW Brown zone
Feldspar porphyry	37.0 ± 2.2	Hornblende	McCoy decline
Feldspar porphyry	39.9 ± 1.6	Biotite	Drill cuttings, pediment area
Bay dike	40.3 ± 1.2	Biotite	Bay dike at Cove deposit
Bay dike	39.5 ± 1.5	Biotite	Bay dike at Cove deposit
Cay dike	39.4 ± 1.2	Biotite	Cay dike at Cove deposit
Southeast intrusion	38.8 ± 1.1	Biotite	Southeast intrusion at Cove
Southeast intrusion	40.0 ± 1.2	Biotite	Southeast intrusion at Cove
Adularia vein	39.1 ± 1.5	Adularia	McCoy gold deposit
Adularia vein	38.7 ± 1.1	Adularia	McCoy gold deposit
Flow-dome complex	34.1 ± 0.9	Biotite	Pinnacle Mountain
Flow-dome complex	32.9 ± 0.9	Biotite	Pinnacle Mountain
McCoy pluton	140 ± 6	Whole rock	Drill cuttings
McCoy pluton	139 ± 7	Whole rock	Drill cuttings

Data from Emmons and Eng (1995)

and kaolinite clays, Fe and Mn oxides and/or hydroxides, and late carbonates. Supergene alteration affects much of the Smelser Pass Member and the upper parts of the transitional submember of the Panther Canyon Member.

General Characteristics of Polymetallic Vein-Type and Carlin-Style Ore

Polymetallic vein-type ore

Figure 7 summarizes the characteristics of polymetallic vein-type ore for each sedimentary host unit and shows the mapped vertical zonation of ore styles. In many cases, polymetallic veins appear to have formed in single episodes and

are concentrically banded with single centerlines, indicating their development during a discrete episode of fracturing and precipitation of ore and gangue minerals. Multiple-episode veins, large ore pods, and sulfide-cemented crackle breccias typically show more complicated development with common overprinting relationships. These have multiple concentrically banded veins and centerlines, which locally parallel one another and cut one another elsewhere. The multiple-episode veins occur adjacent to or within the principal conduits related to polymetallic vein-type fluid flow and in the footwalls of the premineral dikes and sills.

The principal vein conduits include subgroup II of the north-east-striking faults, such as the Blasthole fault. Subordinate

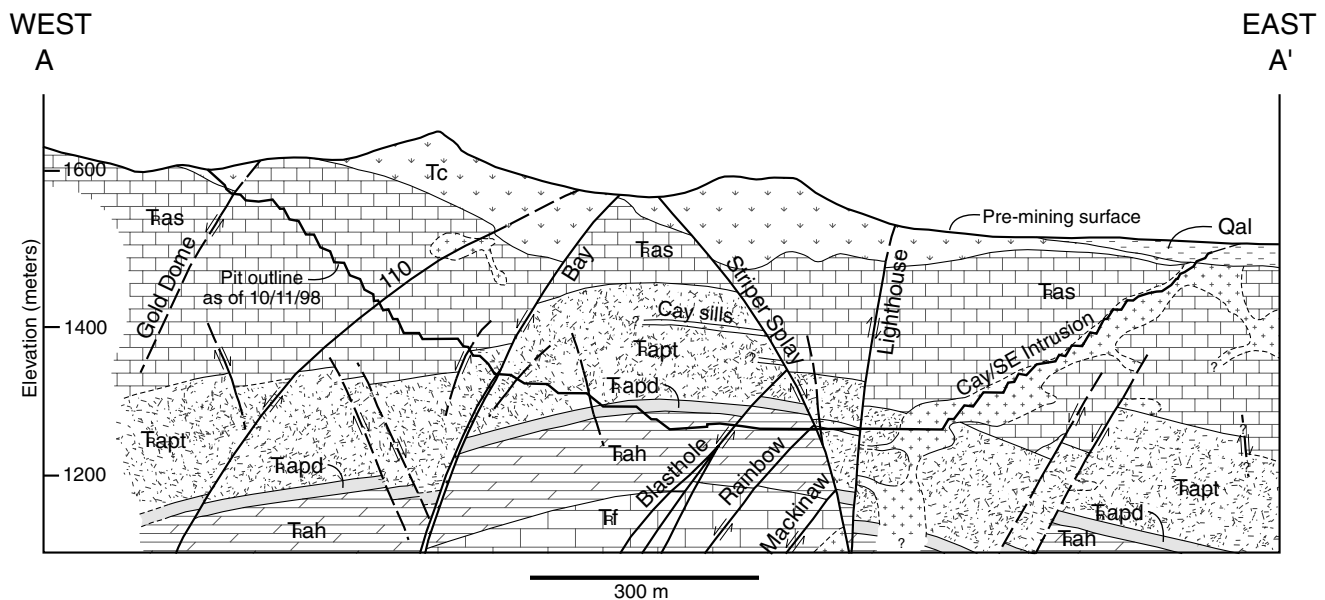


FIG. 5. East-west cross section of the Cove deposit, modified from Johnston (2000a). Refer to Figure 4 for location and lithologic key.

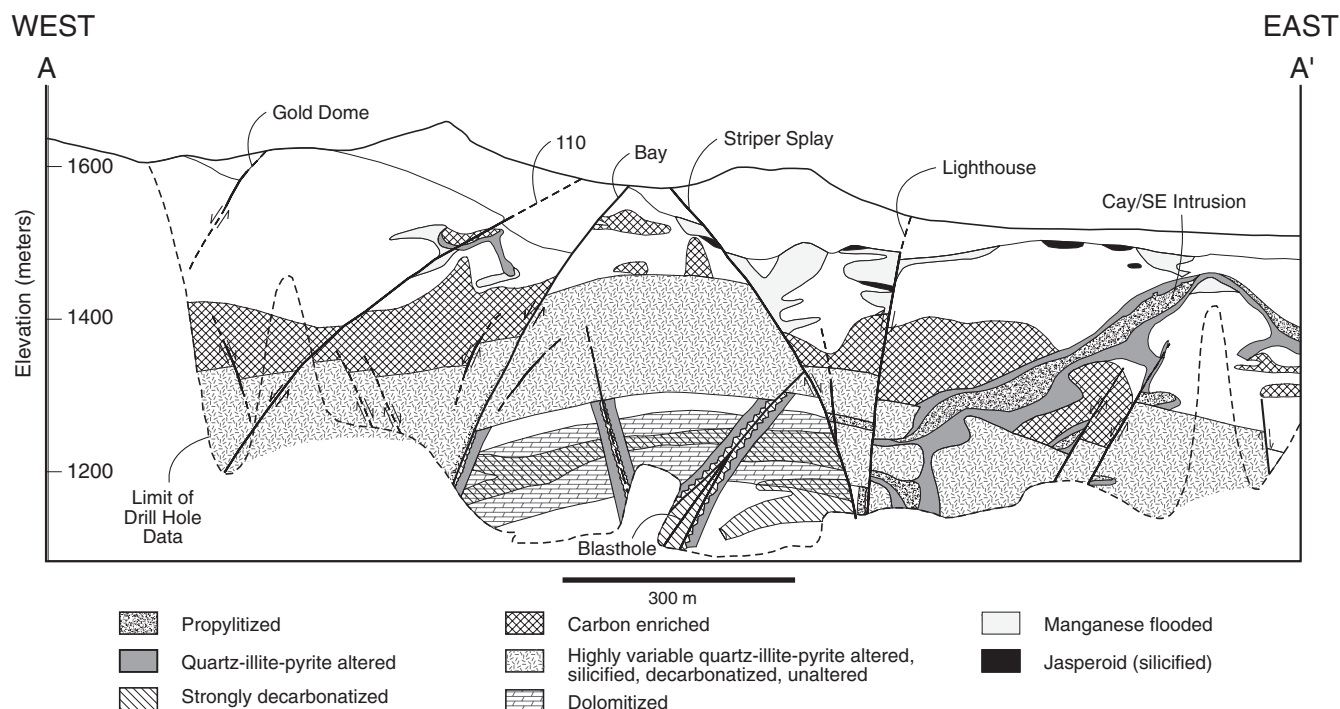


FIG. 6. Hypogene alteration overlay for the east-west cross section (Fig. 5), modified from Johnston (2000a).

conduits include the Lighthouse fault and flexural-slip faults and radial joints occurring in the hinge zone of the Cove anticline in the Home Station Member, dolostone submember of the Panther Canyon Member, and the lower carbonate component of the transitional submember of the Panther

Canyon Member. Several large veins (>10 cm width) displaying multiple episodes of dilation-precipitation were traced through all three of these host units. The multiple-episode veins are generally restricted to the axis of the Cove anticline, between the Bay and Cay fault-dike complexes.

Hypogene polymetallic vein-type ore at Cove is a complicated assemblage of sulfides, sulfosalts, native metals, oxides, and carbonates that fit into a deposit-scale paragenetic scheme (Fig. 8; Johnston, 2000a). The polymetallic vein-type paragenesis can be summarized as an Fe sulfide-quartz pre-ore stage, an iterative vein stage equivalent to the main ore stage, and a supergene stage. The main polymetallic vein-type ore stage developed in a dynamic environment of fracturing, dilation, and episodic hydrothermal fluid release and mineralization that produced single veins, veins related to episodic dilation and precipitation, vein breccias, sulfide-cemented crackle breccias, crustiform pore-lining sulfides, and widespread disseminations (Johnston, 2000a).

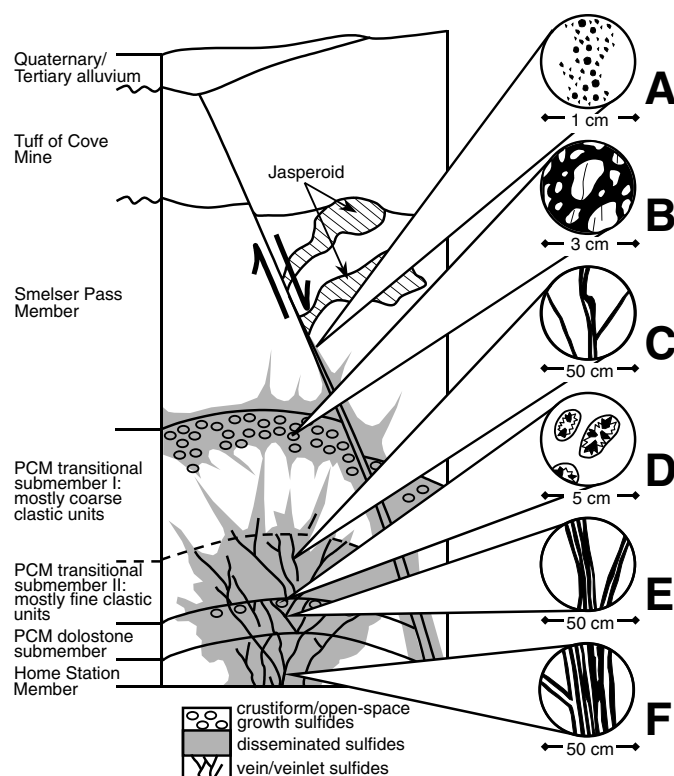


FIG. 7. Schematic diagram of macroscopic characteristics of polymetallic vein-type ore. For (A) through (F), sulfides are shown in black. A. Disseminated sulfides in the Smelser Pass Member. B. Crustiform sulfides in the clastic-dominated portion of the transitional submember of the Panther Canyon Member (transitional submember I of the PCM). C. Vein-veinlet sulfides in the carbonate-dominated portion of the transitional submember of the Panther Canyon Member (transitional submember II of the PCM). D. Open-space growth sulfides in dissolution holes in the uppermost bed of the dolostone submember of the Panther Canyon Member. E. Vein sulfides exhibiting multiple episodes of deposition in the dolostone submember of the Panther Canyon Member. F. Vein sulfides exhibiting multiple episodes of deposition in the Home Station Member. Note that the distribution of Carlin-style disseminated sulfide ore is not shown. Modified from Johnston (2000a).

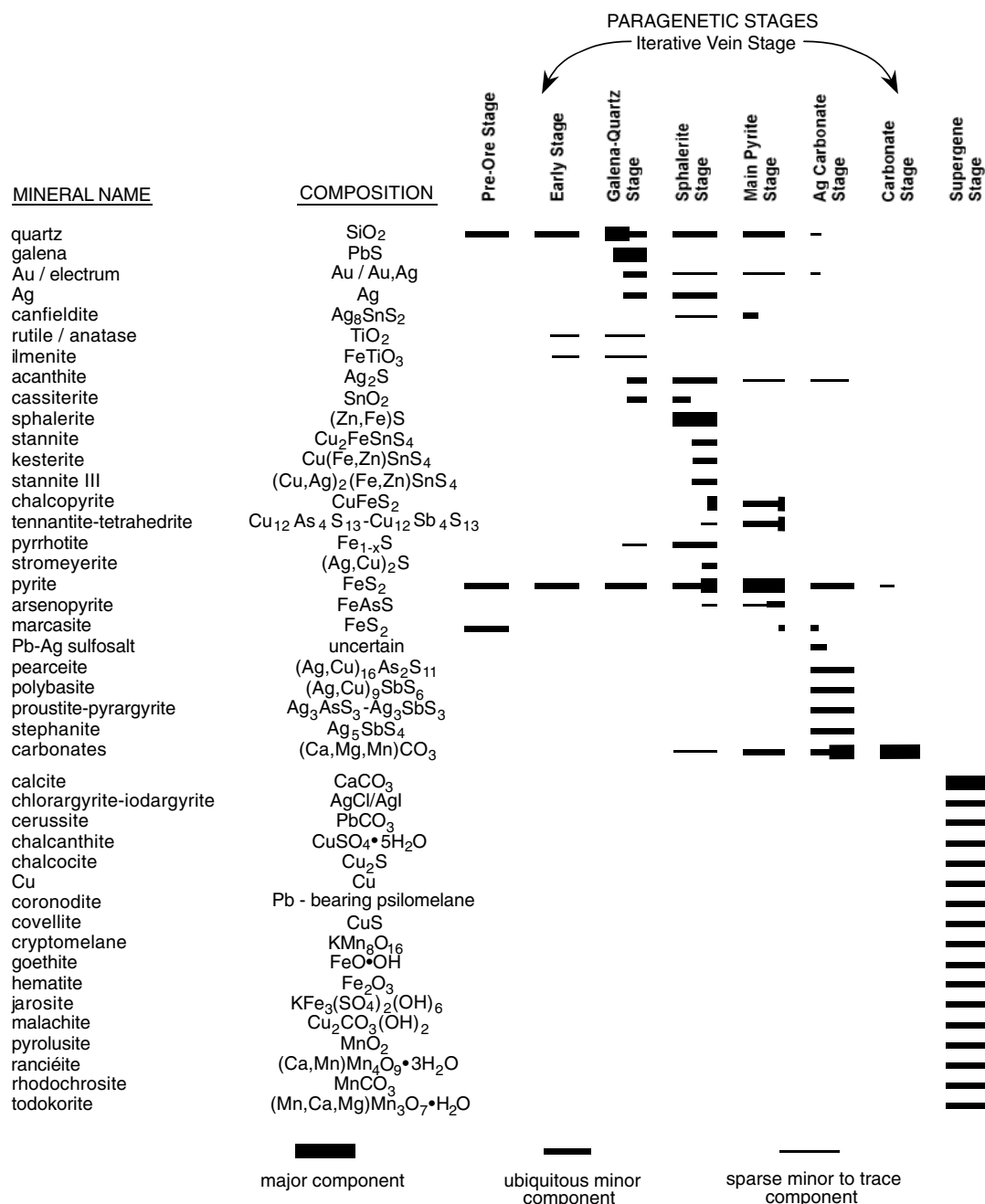


FIG. 8. Mineralogy and paragenesis for the hypogene polymetallic vein-type ore system and supergene alteration. Note that the spatial gaps between stages do not indicate temporal gaps. Modified from Johnston (2000a).

In Figure 8, each iteration of veining is broken down into six substages: (1) an early stage consisting of cockscomb quartz, Fe ± Ti oxides, and Fe sulfides, (2) a galena-quartz stage consisting dominantly of galena and quartz, with lesser Fe sulfides, and minor rutile, cassiterite, and Au/Ag-bearing phases, (3) a sphalerite stage consisting of sphalerite with lesser pyrite, and minor chalcocopyrite, quartz, Au- and Ag-bearing phases, Sn-bearing phases (canfieldite, cassiterite, kesterite, stannite), tennantite-tetrahedrite, pyrrhotite, arsenopyrite, and carbonates, (4) a main pyrite stage consisting dominantly of pyrite with lesser chalcocopyrite and tennantite-tetrahedrite,

and minor quartz, acanthite, canfieldite, arsenian pyrite, arsenopyrite, and carbonates, (5) a Ag carbonate stage consisting of acanthite, pearceite-polybasite, proustite-pyrargyrite, stephanite, pyrite, a Pb-Ag sulfosalt, and carbonates, and (6) a "carbonate" stage consisting of essentially calcite and manganocalcite ± rhodochrosite (Johnston, 2000a).

Carlin-style ore

The Carlin-style mineral assemblage consists principally of disseminated pyrite with lesser disseminated arsenopyrite, veins and/or veinlets of pyrite and/or marcasite, and veins

and/or veinlets and pods of realgar $\pm$ stibnite $\pm$ orpiment, typically with void-filling calcite that is paragenetically late. Disseminated pyrite was observed during mapping of the open pit, and during tours of the underground workings, in all of the reduced rocks in the Home Station Member, in the dolostone-dominated portions of the Panther Canyon Member, and in the Smelser Pass Member. Thin (3- to 10-cm-wide) veins lined by botryoidal marcasite and filled with calcite and disseminated arsenopyrite were observed in the Smelser Pass Member, principally in proximity to the Bay dike, Cay dike and/or Southeast intrusion, and Lighthouse fault. Several veins and pods of realgar with stibnite were also observed in the Smelser Pass Member. The largest of the pods occurs in the hanging wall of the Cay dike and/or Southeast intrusion, in the east wall of the open pit. Another pod was observed in the vicinity of the Northwester fault in the west wall of the pit. Realgar was also found in exploration drill holes on the margins of the Cove system (D. Ryan, 1998, pers. commun.).

Spatially coincident Carlin-style and polymetallic vein-type ore assemblages were not observed during the mapping portion of this study nor was this coincidence found in any of the thin or polished sections examined or reported by earlier workers. In all cases, the Carlin-style assemblages were observed peripheral to or above the central core of polymetallic vein-type ore.

An erratically distributed assemblage consisting of realgar-stibnite-calcite was observed during mapping in the Smelser Pass Member. A more regularly defined realgar $\pm$ orpiment assemblage was observed in the underground workings as realgar-dominated veins developed at the contact between the Home Station Member and overlying dolostone submember of the Panther Canyon. These assemblages are the only readily mappable manifestations of the Carlin-style mineralization besides decarbonatization $\pm$ silicification.

The mineral paragenesis in the Smelser Pass Member is clear, with early stibnite, mid-stage realgar, and late carbonate pore filling. No stibnite was observed in samples from the underground realgar occurrences, in which a clearly defined sequence of early realgar coated with, or cut by, later orpiment has been observed. Barite was observed in two samples associated with thin pyrite veinlets, but its association with either the polymetallic vein-type or Carlin-style assemblages is unclear. The paragenetic association of Au-bearing, Carlin-style Fe $\pm$ As sulfides with the orpiment, realgar, and stibnite is also unclear.

Hypogene precious metals associations

The Au-bearing phases at Cove are electrum and native Au in polymetallic vein-type ore, and arsenian pyrite and arsenopyrite in Carlin-style ore (Johnston, 2000a). Paragenetically, electrum and/or native Au (referred to as electrum for simplicity in the following text) belongs to the early galena-quartz and possibly to main pyrite polymetallic vein-type ore stages, coprecipitated with early quartz and galena $\pm$ intermediate sphalerite and pyrite.

Carlin-style, disseminated arsenian pyrite and arsenopyrite contain Au and account for most of the refractory portion of the Cove ore (Johnston, 2000a). Gold concentrations are generally highest in the microcrystalline pyrite and arsenopyrite,

with decreasing values in fine-grained pyrite, and lowest values in the coarse-grained pyrite.

Ag-bearing minerals at Cove are more diverse and typically more complex than those carrying Au. They were deposited in a clear paragenetic sequence during all stages of polymetallic vein-type hypogene mineralization, during Carlin-style mineralization, and during supergene alteration and/or mineralization as native Ag and Ag halides. Although the Ag-bearing galena has relatively low Ag concentrations (0.26 wt % Ag) compared to other phases such as tennantite-tetrahedrite (var. freibergite: 10.8 wt % Ag), electrum (up to 42.10 wt % Ag), and native Ag, the relative abundance of galena makes it the most important Ag host in the polymetallic vein-type system (Johnston, 2000a).

In Carlin-style pyrite crystals examined by Chrysosoulis et al. (1997), there is a direct positive correlation between Ag and Au concentrations, which indicates that both Au and Ag are associated with arsenian pyrite in Carlin-style ore (Johnston, 2000a).

Spatial relationships between polymetallic vein-type and Carlin-style ore

The distribution of ore types at Cove includes centrally located polymetallic vein-type ore with a wide halo of Carlin-style ore (Fig. 9). Probably the best place to observe the spatial relationship between polymetallic vein-type and Carlin-style ore is in the large, zoned orebody that comprises the Lower High-Grade Sulfide and Cove South Deep orebodies (Fig. 10). The following focuses on the polymetallic vein-type ore in the Lower High-Grade Sulfide orebody and the Carlin-style ore in the lower zone of the Cove South Deep orebody.

The observed distribution of Ag and Au in Figure 10 has three important implications. First, the elevated concentration of Ag between the Lower High-Grade Sulfide feeder (the Mackinaw fault in Fig. 10) and the Cove South Deep orebody shows a southeasterly trend. This is interpreted to indicate that the hydrothermal fluid flowed toward the southeast and suggests that another control exists that was not observed during mapping of the open pit. This may be structural, reflecting either folding or, perhaps more likely, the location of a northwest-striking fault parallel to the Northwester fault mapped in the pit.

Secondly, the Carlin-style ore in the lower zone of the Cove South Deep orebody shows an increase in grade toward the southwest. The highest grades occur along the northwestern margin of the Omega dike. The grades gradually decrease toward the feeder faults to the northwest but drop off dramatically in the hanging wall of the Lighthouse fault and footwall of the Omega dike. The zonation between the polymetallic vein-type and Carlin-style ores, lack of grade in the hanging wall of the Lighthouse fault, and lack of grade in the footwall of the Omega dike suggest that neither the Lighthouse fault nor the Omega fault served as a principal feeder to this orebody. Instead, the increase in grade toward the southwest is interpreted to indicate a secondary direction of fluid flow, where the fluids flowed laterally along the Omega dike (Fig. 10).

The third, and perhaps most important, implication is that the Carlin-style ore in the lower zone of the Cove South Deep

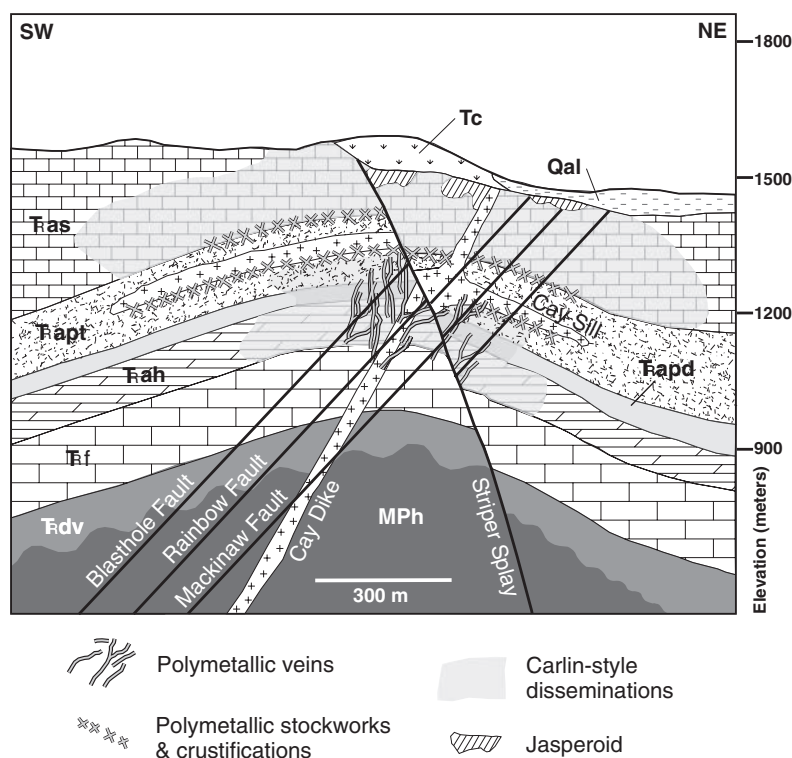


FIG. 9. Schematic cross section showing the generalized distribution of polymetallic vein-type and Carlin-style ore at Cove. See Figure 4 for lithologic key.

orebody is clearly zoned from higher Ag/Au ratios in the northeast to lower Ag/Au ratios in the southwest. These ratios range systematically from $>50/1$ in the vicinity of the Mackinaw fault and in the nonore grade zone separating the polymetallic vein-type and Carlin-style ore, to $<1/1$ in the highest grade portions of the Cove South Deep orebody. This relationship has important implications for classic Carlin-type deposits in Nevada and elsewhere, as they are dominated by Au, not Ag (see Discussion).

Fluid inclusions in polymetallic vein-type quartz from the Cove deposit

Of fourteen doubly polished plates prepared for fluid inclusion analyses, only seven contained fluid inclusions that were large enough to analyze. Each sample comprises a single episode of polymetallic vein-type ore precipitation and therefore lacks overprinting. Many of the quartz crystals analyzed contained sparse to minor inclusions of galena, sphalerite, pyrite and/or other minerals that could not be positively identified under the microscope.

Care was taken to avoid obvious secondary fluid inclusions based on the criteria described by Roedder (1979, 1984), Shepherd et al. (1985), and Goldstein and Reynolds (1994). Although primary inclusions are best identified by their occurrence in growth zones that mimic the crystal morphology (Goldstein and Reynolds, 1994), the inclusions in growth zones of the Cove samples were generally too small to analyze. The inclusions analyzed were typically larger, isolated, and randomly distributed, and commonly displayed negative crystal shapes. Although such inclusions were interpreted by

Goldstein and Reynolds (1994) to have ambiguous origins, they showed no evidence of being secondary.

Consideration was also given to the possibility that the inclusions analyzed may have experienced necking down, which could lead to erroneous interpretations of hypogene fluid characteristics. The inclusions studied have fairly consistent liquid/vapor (L/V) ratios (see below), and closely spaced inclusions with variable temperatures of homogenization (T_H) also have variable salinities. Regular L/V ratios suggest that none of the inclusions analyzed experienced the degree of necking that would influence the interpretation of hypogene fluid data. Also, because necked inclusions retain the salinity of the parent inclusion, the variability in salinities a likely primary origin.

Table 3 summarizes measured homogenization temperatures (T_H), ice-melting temperatures (T_M), and equivalent salinities for the fluid inclusions analyzed in this study. All of the fluid inclusions observed were liquid + vapor types with apparent L/V ratios ranging from 1/1 to 5/1. The variation in ratios, however, is due to the generally cylindrical shape of the inclusions and their orientations with respect to the plane of observation. In the planes of the doubly polished plates, the fluid inclusions were typically elongate, and less commonly equant in apparent outline, and had long dimensions that ranged from ~ 2 to $\sim 34 \mu\text{m}$. True L/V ratios probably have a tighter range of 4/1 to 5/1. No daughter products were observed in any of the inclusions. In all cases but one, the inclusions homogenized to liquid. For the single exception, the vapor bubble expanded as it homogenized with the liquid until it filled the vacuole.

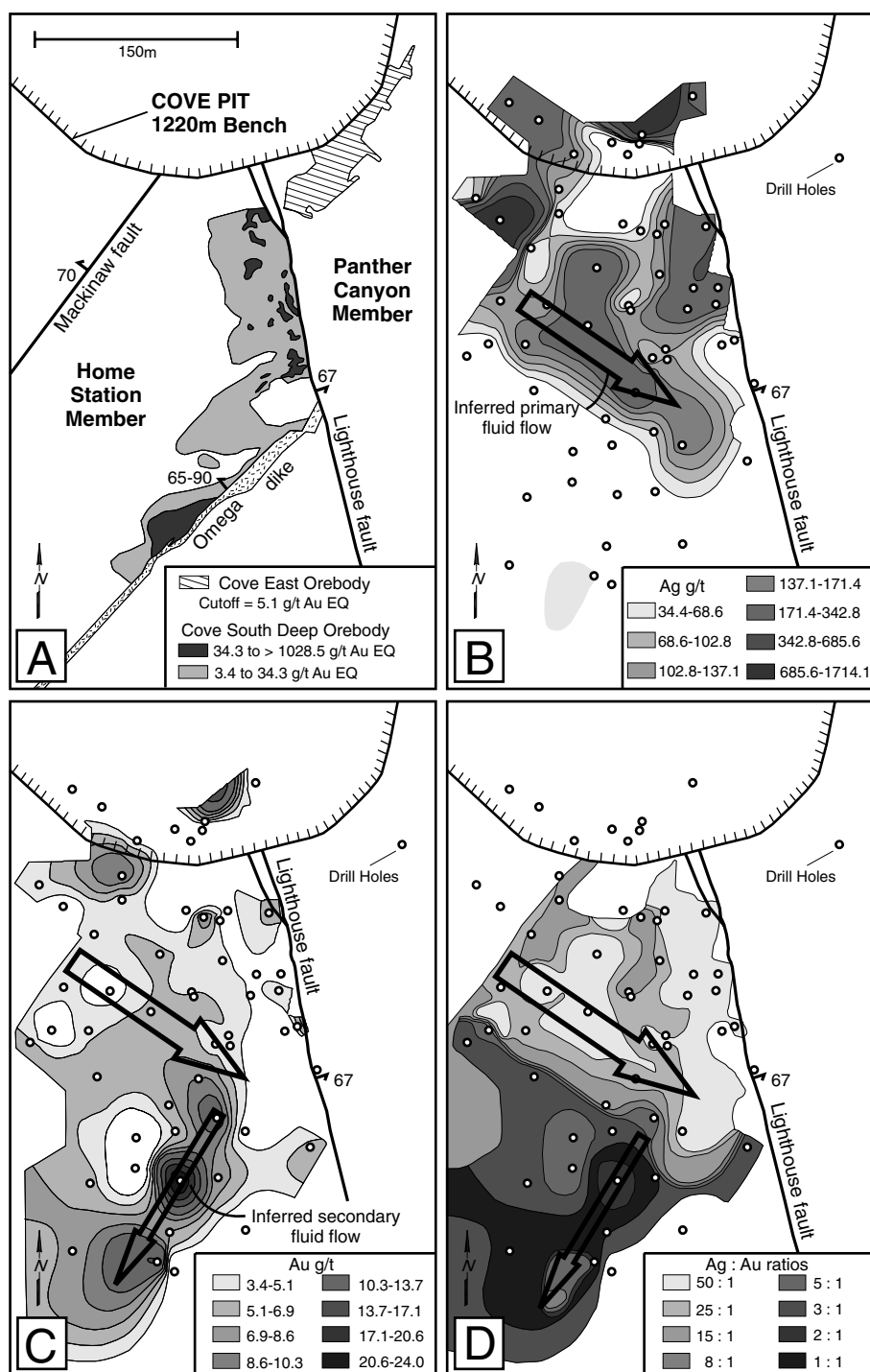


FIG. 10. Spatial relationships and zonations between polymetallic vein-type and Carlin-style ore. A. Locations of the polymetallic vein-type Cove East orebody and the Carlin-style upper zone of the Cove South Deep orebody. A large polymetallic vein, which is part of the Lower High-Grade Sulfide orebody occurs along the Mackinaw fault (shown partially by the high Ag values in (B)). B. and C. Contoured Ag and Au grade-thickness in the Lower High-Grade Sulfide and Carlin-style lower zone of the Cove South Deep orebody. D. Ag/Au in the Lower High-Grade Sulfide and lower zone of the Cove South Deep orebody. (B) through (D) are based on assay data from the drill holes shown.

Figures 11 and 12 show the T_H and T_M (salinity) data. The 90 T_H measurements range between $\sim 208^\circ$ and $\sim 371^\circ\text{C}$ and average $\sim 304^\circ\text{C}$ (Table 3, Fig. 11). The T_H range is variable for a given sample. For the entire population of fluid inclusions, T_M

ranged from -1.3° to -4.8°C (-2.7°C avg), and calculated salinities ranged from 2.2 to 7.6 (4.5 avg) wt percent NaCl equiv.

Based on stratigraphic reconstruction and current erosional levels, Cove may have formed at depths as shallow as 1 km

TABLE 3. Fluid Inclusion Data for Quartz in Polymetallic Vein-Type Ore from Cove

Sample no.	T homogenization	T melting (actual)	Salinity (wt % NaCl equiv)	Sample no.	T homogenization	T melting (actual)	Salinity (wt % NaCl equiv)
1	BOTTOMA-1	327.7	-4.3	6.88	46	4145E-9	295.9
2	BOTTOMA-1	326.3	-3.4	5.56	47	4145E-9	342.7
3	BOTTOMA-1	321.6	-3.7	6.01	48	4145E-9	341.9
4	BOTTOMA-1	298.6	-4.0	6.45	49	4145E-9	286.6
5	BOTTOMA-1	329.1	-4.8	7.59	50	BOTTOMA-2	296.5
6	BOTTOMA-1	330.3	-3.5	5.71	51	BOTTOMA-2	299.2
7	BOTTOMA-1	330.4	-4.2	6.74	52	BOTTOMA-2	333.5
8	BOTTOMA-1	330.2	na	na	53	BOTTOMA-2	315.9
9	BOTTOMA-1	323.5	na	na	54	BOTTOMA-2	283.8
10	BOTTOMA-1	328.9	-3.8	6.16	55	BOTTOMA-2	281.3
11	BOTTOMA-1	323.3	-3.4	5.56	56	BOTTOMA-2	281.4
12	BOTTOMA-1	321.6	-3.8	6.16	57	BOTTOMA-2	306.0
13	BOTTOMA-1	301.4	-2.4	4.03	58	BOTTOMA-2	297.3
14	BOTTOMA-1	279.7	-3.7	6.01	59	BOTTOMA-2	298.2
15	BOTTOMA-1	302.7	-2.0	3.39	60	BOTTOMA-2	299.2
16	BOTTOMA-1	292.7	na	na	61	BOTTOMA-2	301.6
17	7/26/98-2B	290.5	-2.1	3.55	62	BOTTOMA-2	300.2
18	7/26/98-2B	277.6	-2.1	3.55	63	BOTTOMA-2	299.9
19	7/26/98-2B	280.8	-2.0	3.39	64	BOTTOMA-2	297.1
20	7/26/98-2B	301.2	na	na	65	CVC-8-1705	339.4
21	7/26/98-2B	320.3	-1.7	2.90	66	CVC-8-1705	207.5
22	7/26/98-2B	296.0	na	na	67	CVC-8-1705	273.8
23	7/26/98-2B	284.9	na	na	68	CVC-8-1705	288.0
24	7/26/98-2B	319.4	na	na	69	CVC-8-1705	287.4
25	7/26/98-2B	304.7	na	na	70	CVC-8-2180.5	294.7
26	7/26/98-2B	309.8	na	na	71	CVC-8-2180.5	351.9
27	7/26/98-2B	305.0	na	na	72	CVC-8-2180.5	294.7
28	7/26/98-2B	249.6	-3.0	4.96	73	CVC-8-2180.5	285.5
29	7/26/98-2B	270.0	na	na	74	CVC-8-2180.5	286.8
30	7/26/98-2B	327.0	na	na	75	CVC-8-2180.5	296.5
31	7/26/98-2B	272.4	na	na	76	CVC-8-2180.5	305.5
32	7/26/98-2B	278.0	na	na	77	CVC-8-2180.5	294.8
33	4145E-9	310.5	na	na	78	CVC-8-2180.5	254.7
34	4145E-9	282.7	na	na	79	CVC-8-2180.5	311.3
35	4145E-9	290.4	na	na	80	CVC-8-2180.5	330.5
36	4145E-9	300.9	na	na	81	CVC-8-2180.5	363.9
37	4145E-9	333.3	na	na	82	CVC-8-2470.5	327.1
38	4145E-9	299.5	na	na	83	CVC-8-2470.5	325.7
39	4145E-9	312.3	-2.0	3.39	84	CVC-8-2470.5	357.0
40	4145E-9	252.5	-1.9	3.23	85	CVC-8-2470.5	315.7
41	4145E-9	303.3	-1.3	2.24	86	CVC-8-2470.5	329.1
42	4145E-9	281.6	-1.5	2.57	87	CVC-8-2470.5	313.4
43	4145E-9	255.5	-1.7	2.90	88	CVC-8-2470.5	313.4
44	4145E-9	258.0	-2.2	3.71	89	CVC-8-2470.5	370.9
45	4145E-9	293.9	-2.0	3.39	90	CVC-8-2470.5	346.0
Averages						303.9	-2.7
							4.48

(D. L. Emmons, pers. commun., 1998–2001). However, these observations are inconclusive and cannot be used for pressure corrections. Therefore, the T_H should be considered as minimum temperatures for the mineralizing fluid(s).

Light Stable Isotope Studies of the Cove and McCoy Deposits

δD and $\delta^{18}O$ values of quartz-illite-pyrite-altered intrusive rocks, jasperoid and polymetallic vein-type quartz from Cove

Table 4 summarizes the δD and $\delta^{18}O$ results for illite from quartz-illite-pyrite-altered intrusive rocks from the Cove deposit. The δD values range from -51 to -102 per mil, with a majority of the values between -72 and -51 per mil. The $\delta^{18}O$

values have a range of 10.0 to 18.5 per mil. Because the temperatures of homogenization for fluid inclusions in ore-stage quartz in polymetallic veins generally range from 250° to 350°C (not corrected for pressure), and these veins are clearly associated with quartz-illite-pyrite alteration of intrusive and sedimentary host rocks, the δD and $\delta^{18}O$ of fluids in equilibrium with the hydrothermal illite were calculated at 250°, 300°, and 350°C (Fig. 13). For the nine samples analyzed, seven cluster fairly tightly and two appear to be outliers. For the temperature range considered, the cluster lies within or just to the right of the magmatic water box (Fig. 13). Based on these results and the close temporal relationship between magmatism and mineralization at Cove, the source for the mineralizing fluid(s) is interpreted to be magmatic. The trend toward slightly higher $\delta^{18}O$ values may

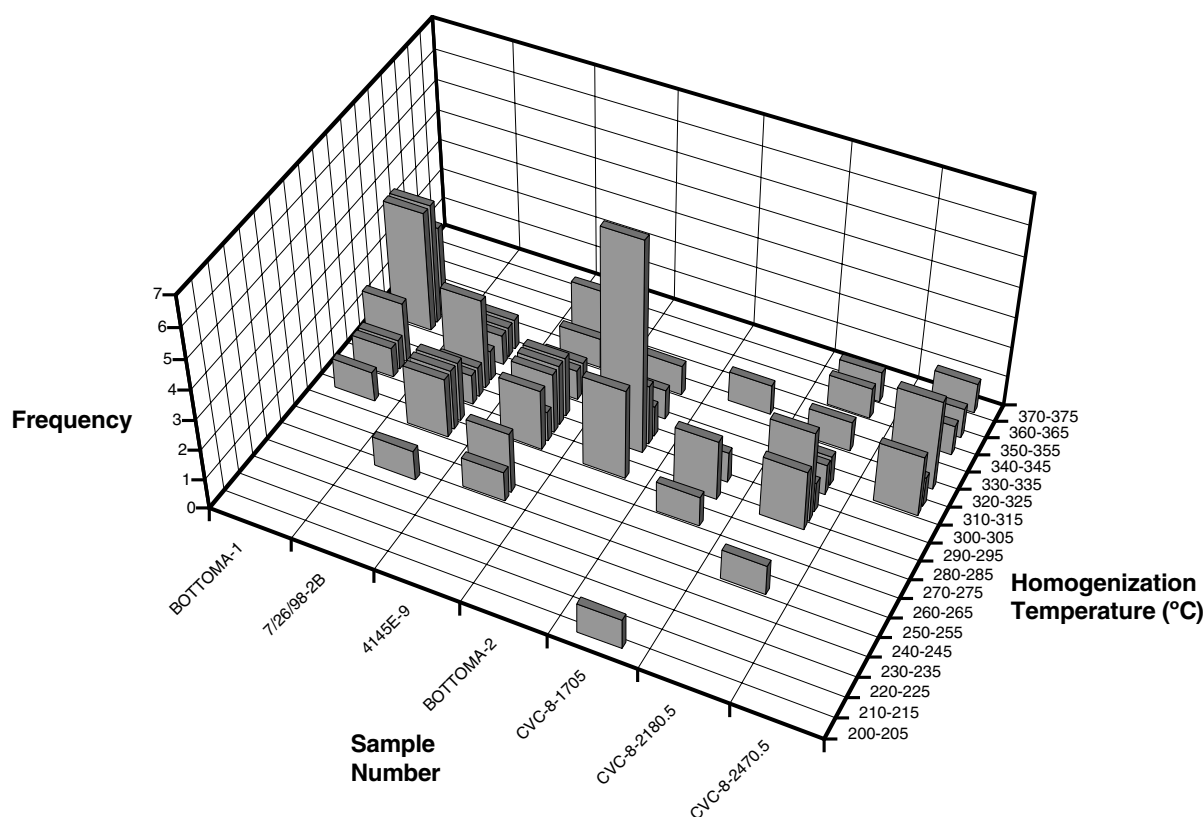


FIG. 11. Frequency distribution of fluid inclusion homogenization temperatures for Cove mine polymetallic vein-type quartz.

indicate contamination of the magma chamber by assimilation of country rocks during its ascent. The two outliers may indicate some dilution of the magmatic fluid(s) by meteoric or exchanged meteoric water, but the cause for this shift is unclear.

Table 5 shows the $\delta^{18}\text{O}$ results for hydrothermal quartz from polymetallic veins and jasperoid at Cove. The seven

samples of polymetallic vein-type quartz share a restricted range of $\delta^{18}\text{O}$ values from 17.0 to 18.2 per mil. The $\delta^{18}\text{O}$ values for the jasperoid samples range from 14.8 to 21.1 per mil. These values are similar to the raw $\delta^{18}\text{O}$ values from the illite from quartz-illite-pyrite-altered intrusive rocks (Table 4), which suggests a common source for oxygen in these various silicate and/or siliceous phases.

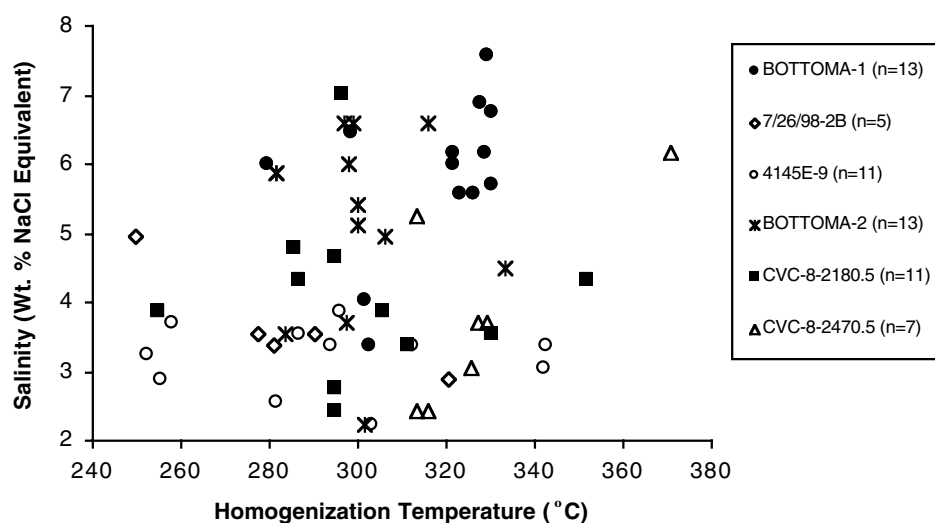


FIG. 12. Homogenization temperatures and salinity data for fluid inclusions from polymetallic vein-type quartz.

TABLE 4. δD and $\delta^{18}O$ Results for Quartz-Illite-Pyrite-Altered Intrusive Rocks at Cove

Sample no.	δD (‰)	$\delta^{18}O$ (‰)
4405E-2	-51.3	13.7
CVC218-857.5	Sample lost	18.5
4145E-46	-63.4	15.7
4145E-19	Sample lost	14.3
4205E-19	-93.0	10.0
4405E-1	-70.6	16.0, 16.1 (avg 16.0)
4145E-17C	-61.7	15.4
4205E-7	-72.2	15.3
25-50-1	-99.0, -104.8 (avg -102 $\pm$ 4)	10.6
4205E-5	-68.4	13.5
4145E-29	-63.0	14.2
Misasa Ser ¹	-61.9	-
Misasa Ser ¹	-65.3	-
Misasa Ser ¹	-57.8	-
Misasa Ser ¹	-60.4	-

δD and $\delta^{18}O$ reported relative to V-SMOW; the lost samples in the δD vs. $\delta^{18}O$ column (CVC218-857.5 and 4145E-19) were consumed during laboratory analyses, but no data were produced

¹ Sample Misasa Ser is a laboratory standard with a value of -60 ± 1 per mil

$\delta^{34}S$ values of sulfides from skarn ore from McCoy, and polymetallic vein-type and Carlin-style ore from Cove

The $\delta^{34}S$ values for sulfides from McCoy and Cove are shown in Table 6. All of the values cluster tightly between 1.6 and 4.5 per mil. The polymetallic sulfides from Cove and pyrite from skarn ore at McCoy share a particularly tight range of 2.2 to 3.3 per mil. These results indicate a common source for S in the various types of ore from the two deposits and support the proposed link between the skarn, polymetallic vein-type, and Carlin-style ores.

Age of the Intrusions, Alteration, and Mineralization

The ^{40}Ar - ^{39}Ar age data from this study, coupled with preexisting K-Ar ages for Cove and McCoy (Table 2) and observed relationships between intrusions, ore, and alteration are the

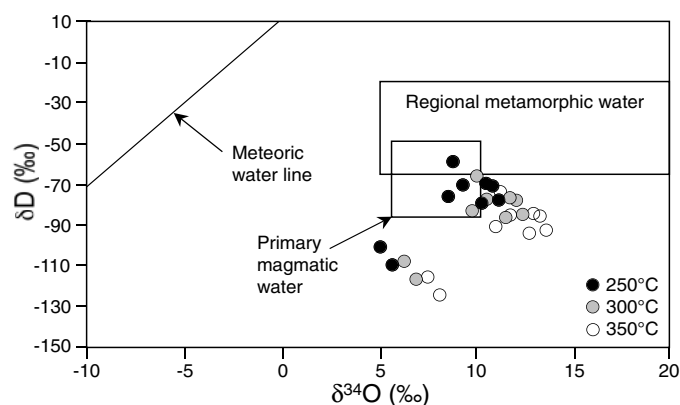


FIG. 13. Calculated $\delta^{18}O$ and δD values of waters in equilibrium with the hydrothermal illite at 350°, 300°, and 250°C. The fractionation factor for $\delta^{18}O$ was determined from the fractionation equation of Sheppard and Gilg (1996). The fractionation factor for δD was determined from the fractionation equation of Capuano (1992) and Girard and Fouillac (1995). Primary magmatic, metamorphic, and meteoric water values are from Taylor (1997).

TABLE 5. $\delta^{18}O$ Results for Jasperoid and Polymetallic Vein-Type Quartz from the Cove Deposit

Sample source	Sample no.	$\delta^{18}O$ (‰)
Hydrothermal jasperoid	4725E-3	15.5
	DW-12-1	14.8
	4835E-2	21.1
Hydrothermal polymetallic vein-type quartz	4145E-24	18.2
	STOPE 5	17.3
	7/26/98-2	18.0
	ARPB-1	17.0
	TC4MID+66'	17.6
	UK-3	18.1
	AUK-1	17.7

Notes: The precision for the analyses is better than ± 0.1 per mil

basis for interpretation of the age of alteration and mineralization at Cove. Five samples from the Cove deposit were selected for ^{40}Ar - ^{39}Ar analyses (Fig. 4). Two of the samples submitted for analyses were individual minerals selected from samples 4145E-19 and AR44955E-2 and produced analytically and geologically acceptable ages (data from T. Spell at the Nevada Isotope Geochronology Laboratory at the University of Nevada, Las Vegas). Three additional samples produced unreliable age data, which are not used here.

^{40}Ar - ^{39}Ar data for sample 4145E-19

Sample 4145E-19 was collected from a quartz-illite-pyrite-altered part of the Bay dike. Coarse polymetallic vein-type sulfides occurred in veins and as crustifications in intergranular pores immediately beneath the altered dike. The highwall from which this sample was collected was subsequently mined out.

More than 98 vol percent of sample 4145E-19 consists of alteration products. In decreasing order of abundance, the sample consists of illite, quartz, opaques (chiefly pyrite with lesser sphalerite and galena), pore space, and calcite. Coarser illite, quartz, and sulfides are intergrown in phenocryst sites, and finer illite, quartz, and sulfides are intergrown in the altered groundmass. A 1-mm-wide polymetallic veinlet cuts this sample (Fig. 14A). This veinlet is filled with polymetallic sulfides and later calcite. Relict biotite crystals are preserved as coarse intergrowths of illite, quartz, and pyrite (Fig. 14B).

The age spectrum produced for the illitized biotite grains from sample 4145E-19 (Fig. 15) exhibits decreasing ages from an initial step of ~ 51 Ma to a plateau segment (steps 7–12) that yields an age of 39.37 ± 0.23 Ma and comprises 58 percent of the gas released. A valid isochron defined by steps 5 through 11, comprising 69 percent of released gas, yields an age of 39.12 ± 0.30 Ma, which is indistinguishable from the plateau age. Because the sample is an illite replacement of primary igneous biotite, the age represents the timing of replacement of biotite by hypogene illite. The intimate association of the illite with polymetallic vein-type sulfides in sample 4145E-19 indicates that this is also the age of polymetallic vein-type mineralization.

^{40}Ar - ^{39}Ar data for sample AR44955E-2

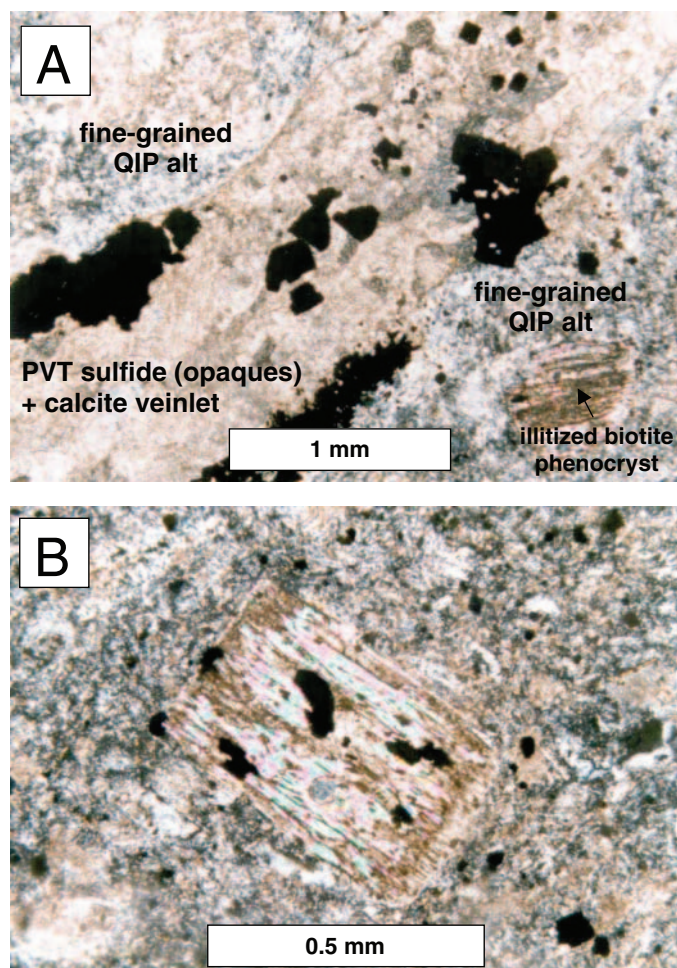
Sample AR44955E-2 was collected from an apparently fresh exposure of the West intrusion. In thin section, however, it is

TABLE 6. $\delta^{34}\text{S}$ Results for Polymetallic Vein-Type and Carlin-Style Sulfides from the Cove and McCoy Mines

Sample no.	Source	Mineral analyzed	$\delta^{34}\text{S}$ (‰)
ARPB-2	Cove polymetallic vein	Sphalerite	2.4
ARPB-2	Cove polymetallic vein	Pyrite	2.6
CUBM-59	Cove polymetallic vein	Galena	2.4
CUBM-59	Cove polymetallic vein	Pyrite	2.2
CUBM-59	Cove polymetallic vein	Sphalerite	2.8
10/10-1B	Cove polymetallic vein	Sphalerite	2.8, 2.9 (avg 2.8)
10/10-1B	Cove polymetallic vein	Pyrite	2.8
10/10-1A	Cove polymetallic vein	Pyrite	3.3
CVC-218-808	Cove Carlin-style ore	Stibnite	1.6
CSD-4	Cove Carlin-style ore	Realgar	3.7
CSD-A1	Cove Carlin-style ore	Realgar	4.0
REALGARC	Cove Carlin-style ore	Realgar	4.5
CSD31	McCoy skarn ore	Pyrite	3.1, 3.2 (avg 3.2)
P-1PY	McCoy skarn ore	Pyrite	2.2
P-2PY	McCoy skarn ore	Pyrite	2.8

Notes: Analytical methods: 10 to 15 Mg of material were loaded into quartz tubing and secured with quartz wool plugs; the material was combusted at approximately 1,100°C in a stream of pure O_2 (see Thode et al., 1961); the resulting SO_2 and other gases were passed through a series of cryogenic traps to condense the SO_2 and pump away the contaminants (excess O_2 and any other gases of combustion); the purified sample SO_2 was transferred to a sample flask for mass spectrometric analysis.

SO_2 samples were analyzed on a VG micromass 903 mass spectrometer; samples were run in comparison to the inhouse reference gas prepared from SR-0010 (Geochron sulfur flowers) that have been calibrated relative to the Cañon Diablo Troilite; results were calibrated by analyzing a number of internationally accepted standards interspersed among the unknown samples; one duplicate was also run; the precision of this method of analysis is about ± 0.3 per mil.



apparent that the unit has been slightly propylitized. Calcite comprises about 10 vol percent of the sample and occurs as a replacement phase on the margins of plagioclase grains and in the groundmass (Fig. 16). Minor secondary quartz is also present in the plagioclase sites and in the groundmass. The biotite crystals, however, generally appear fresh in both hand sample and thin section. The biotite contains no secondary illite, quartz, or calcite, but very minor (<1 vol %) pyrite was observed along cleavage planes in a few of the biotite grains. The age spectrum produced for the biotite crystals yielded a nearly ideal, flat age spectrum, with steps 4 through 12 comprising 97.5 percent of the gas released and defining a plateau age of 39.01 ± 0.22 Ma (Fig. 17). Steps 2 through 6 also define a valid isochron age of 38.68 ± 0.21 Ma but account for only 22 percent of the gas released.

Normally, an isochron age would be preferable, as it is not subject to assumptions regarding the isotopic composition of the trapped (nonradiogenic) Ar; ages are calculated assuming ^{40}Ar - ^{39}Ar of 295.5 for trapped Ar (air value) and are thus “apparent” age spectra. For this sample, the isochron indicates the presence of trapped atmospheric Ar for which the ^{40}Ar - ^{39}Ar is indistinguishable from the air value of 295.5. Because the isochron is defined by a much smaller percentage of the gas than the plateau, the plateau age is preferred for the timing of crystallization of the igneous biotite in this sample.

FIG. 14. Transmitted light photomicrographs of sample 4145E-19 (crossed polars). A. A sulfide-lined, calcite-filled polymetallic veinlet cutting the quartz-illite-pyrite-altered intrusive rock. B. Close-up of illite with pyrite which is pseudomorphous after a biotite phenocryst. The groundmass in (B) consists of a fine-grained quartz-illite-pyrite assemblage.

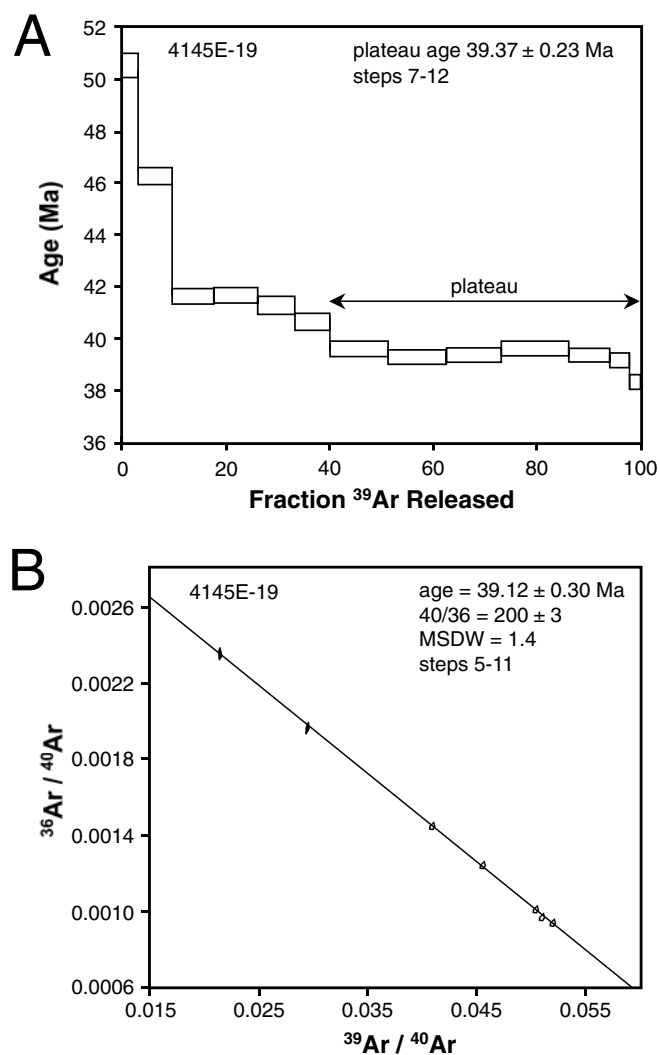


FIG. 15. Age data for sample 4145E-19. A. Incremental heating ^{40}Ar - ^{39}Ar age spectrum. B. Isochron plot.

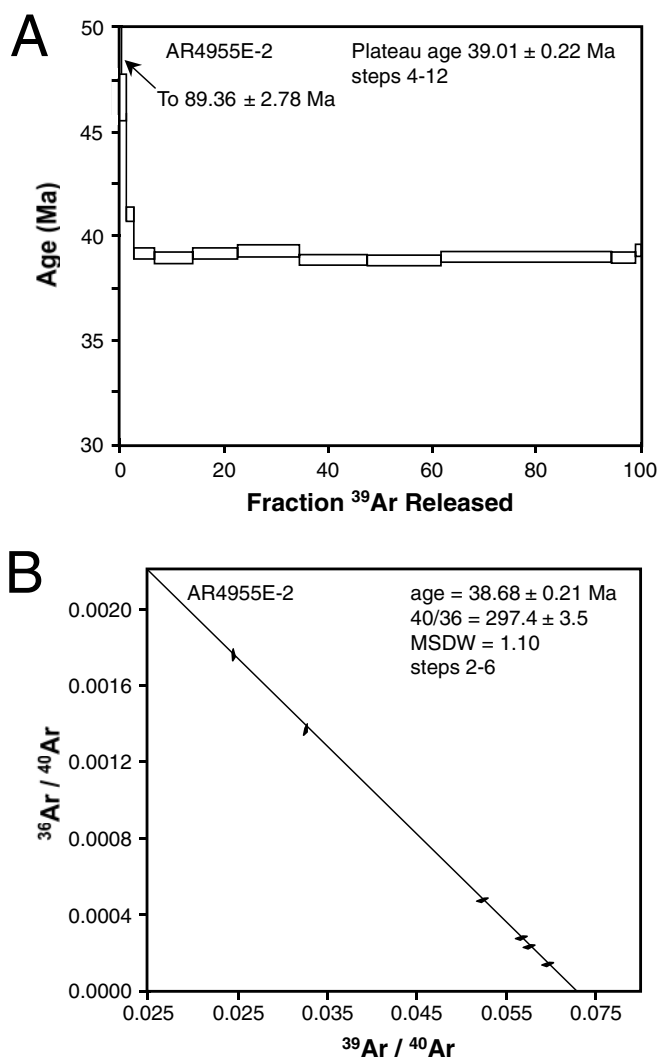


FIG. 17. Age data for sample AR4955E-2. A. Incremental heating ^{40}Ar - ^{39}Ar age spectrum. B. Isochron plot.

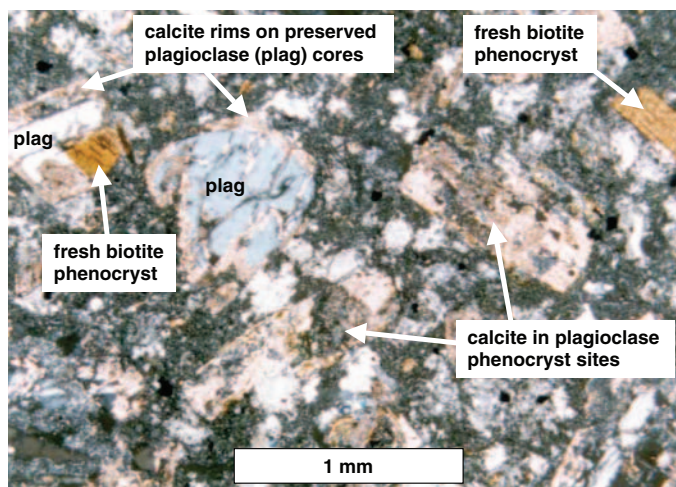


FIG. 16. Transmitted light photomicrograph of sample AR4955E-2 (crossed polars). Although the sample is moderately propylitized, as indicated by the alteration of much of the plagioclase to calcite, the biotite crystals are generally very fresh.

Discussion

The proposed genetic link between the various ore styles at the Cove and McCoy deposits is supported by a number of results of this study.

1. ~41.5 Ma granodioritic intrusions are present at both deposits. These rocks are preore and partly controlled the distribution of skarn, polymetallic vein-type, and Carlin-style ores.
2. Skarn ore at McCoy and polymetallic vein-type ore at Cove formed simultaneously at ~39 Ma, coeval with magmatism and overprinting the ~41.5 Ma intrusions at both deposits.
3. At Cove, δD and $\delta^{18}\text{O}$ values for polymetallic vein-type illite fall within to just outside the composition of magmatic water. Overlapping values for $\delta^{18}\text{O}$ from the polymetallic vein-type illite, polymetallic vein-type quartz, and Carlin-style jasperoids indicate a similar or identical source of magmatic fluid(s). The genetic associations between skarn ore at McCoy

and coeval, magmatic-hydrothermal activity also has been documented by previous workers.

4. Finally, $\delta^{34}\text{S}$ values indicate a common source for S in all three McCoy-Cove ore styles. The absence of sulfate minerals at McCoy and near absence of sulfate minerals at Cove suggest that the ratio of reduced S to oxidized S was high during mineralization at both deposits. Therefore, the $\delta^{34}\text{S}$ values for sulfides should approximate actual S values of the mineralizing fluids. The $\delta^{34}\text{S}$ values that are most likely to be indicative of the magmatic fluids are from pyrite from the skarn ore at McCoy, and overlap between these values and the $\delta^{34}\text{S}$ of both polymetallic vein-type and Carlin-style sulfides from Cove further supports a magmatic source for the S at Cove.

These observations support the findings of earlier workers that Cove and McCoy are spatially, temporally, chemically, and ultimately genetically related to a single, large, zoned, magmatic-hydrothermal system. The details of the structural and stratigraphic framework, timing of intrusion, timing of mineralization, and the spatial distribution of the various ore styles provide the basis for a genetic model for the McCoy-Cove system.

A descriptive genetic model for the McCoy-Cove system

The descriptive model is separated into three principal stages: (1) late Eocene extension in the McCoy mining district, emplacement of an early stage of the Brown stock with associated dikes and sills, and the development of early subeconomic skarn at McCoy; (2) evolution of the Brown stock porphyry system concurrent with continued extensional faulting and related economic mineralization at McCoy and Cove; and (3) postore tectonic and supergene and/or diagenetic effects on the two systems.

Figure 18A shows the middle to late Eocene, preore framework for McCoy and Cove. The results of stage 1 are shown in Figure 18B. Emplacement of a magnetite-bearing phase of the Brown stock occurred at about 41.5 Ma (Brooks, 1994; Emmons and Eng, 1995). The stock was localized by a series of faults belonging to subgroup I of the ~northeast-striking fault group at Cove. Related dikes and sills were emplaced along these faults and extended from the Brown stock at McCoy to Cove in the northeast. At McCoy, hydrothermal activity related to the early stage of the Brown stock produced proximal hornfels and skarn in sedimentary rocks and pyroxene- and amphibole-bearing assemblages in the intrusive rocks (Brooks, 1994). Subeconomic concentrations of Au were also deposited with these early assemblages (Brooks, 1994).

Figure 18C depicts stage 2. At about 39 Ma, a second pulse of magma and magmatically derived hydrothermal fluid(s) ascended along the same paths as the earlier Brown stock and related dikes. This pulse of magma contained appreciable Ti, which Brooks (1994) attributed to magma mixing at a deeper level of the system. The Ti was precipitated as ilmenite, which distinguishes the second pulse of magma from the earlier, magnetite-bearing one (Brooks, 1994). Hydrothermal activity associated with the later stage of the Brown stock produced an economic Au (-Cu) skarn at McCoy, which overprinted the earlier subeconomic skarn (Brooks, 1994). At Cove, mineralizing fluids ascended along subgroup II of the ~northeast-striking fault group, which developed after the emplacement

of the ~41.5 Ma dikes and sills at Cove. The distribution of polymetallic vein-type and Carlin-style ore was controlled in part by the earlier dikes and sills, and associated alteration overprinted the primary igneous and sedimentary assemblages. Adularia from mineralized quartz-pyrite $\pm$ adularia assemblages at McCoy, illite from an ore-related quartz-illite-pyrite alteration assemblage at Cove, and fresh biotite from a weakly altered portion of the Gold Dome dike at Cove all yielded ages of ~39 Ma.

Figure 18D shows the postore effects on the McCoy-Cove system. These effects were produced by volcanic, tectonic, sedimentary, diagenetic, and supergene processes. The deposition of the postmineral Tuff of Cove mine at about 34.2 Ma provides a minimum age constraint for mineralization at Cove (Emmons and Eng, 1995). Postore development of the Striper splay segmented the highest grade orebody at Cove. Weathering and erosion resulted in oxidation of much of the ore in the upper parts of Cove and McCoy and exposed the Brown stock at McCoy and resistant jasperoids at Cove.

Zonation of the McCoy-Cove system

The spatial associations and proposed genetic links for the late Eocene magmatic center and skarn ore at McCoy and polymetallic vein-type and Carlin-style ore at Cove, the mineralogical and geochemical zonations for the entire McCoy-Cove system, the various locations of ore-grade Au within this system, and the local zonation from higher Ag/Au ratios to higher Au/Ag ratios at Cove all have important implications for the late Eocene porphyry-related (skarn and Carlin-like and/or distal disseminated) and Carlin-type deposits in the Great Basin. The mineralogical and geochemical zonations and positions of Au within the McCoy-Cove system are similar to those observed in other magmatic systems and are discussed first. The mineralogical zonation for McCoy-Cove can be summarized as a proximal Au-Ag

skarn centered on a porphyritic stock with intermediate polymetallic vein-type ore and more distal Carlin-style ore. The polymetallic vein-type ore occupies the center of the apparently telescoped Cove deposit and is surrounded by a wide outer aureole of Carlin-style ore. Within the generalized zonation, economic grades of Au occur in association with three principal assemblages: (1) as native Au particles associated with skarn ore at McCoy, at least some of which are believed to have been originally encapsulated in pyrite (Brooks, 1994); (2) as blebs of native Au and electrum in polymetallic veins at Cove; and (3) as submicroscopic concentrations of Au in arsenian pyrite and arsenopyrite in Carlin-style ore at Cove. The residence and associations of Au in the auriferous, manganiferous jasperoid bodies at Cove were not determined during this study.

The three principal concentrations of ore-grade Au in the McCoy-Cove system are similar to the positions of Au in other Au-enriched, porphyry-related systems. Emmons (1927) recognized two principal Au-bearing zones in Au-enriched porphyry Cu deposits: a zone in the central Cu orebody and a second zone that more or less overlaps an outer Pb-Zn-Ag zone. Jones (1992) presented a similar idealized mineralogical zonation of Au in Au-enriched porphyry Cu deposits, from the center outward: a barren (subeconomic) core, molybdenite, bornite Au, chalcopyrite, a pyrite halo, Pb-Zn-Ag-bearing

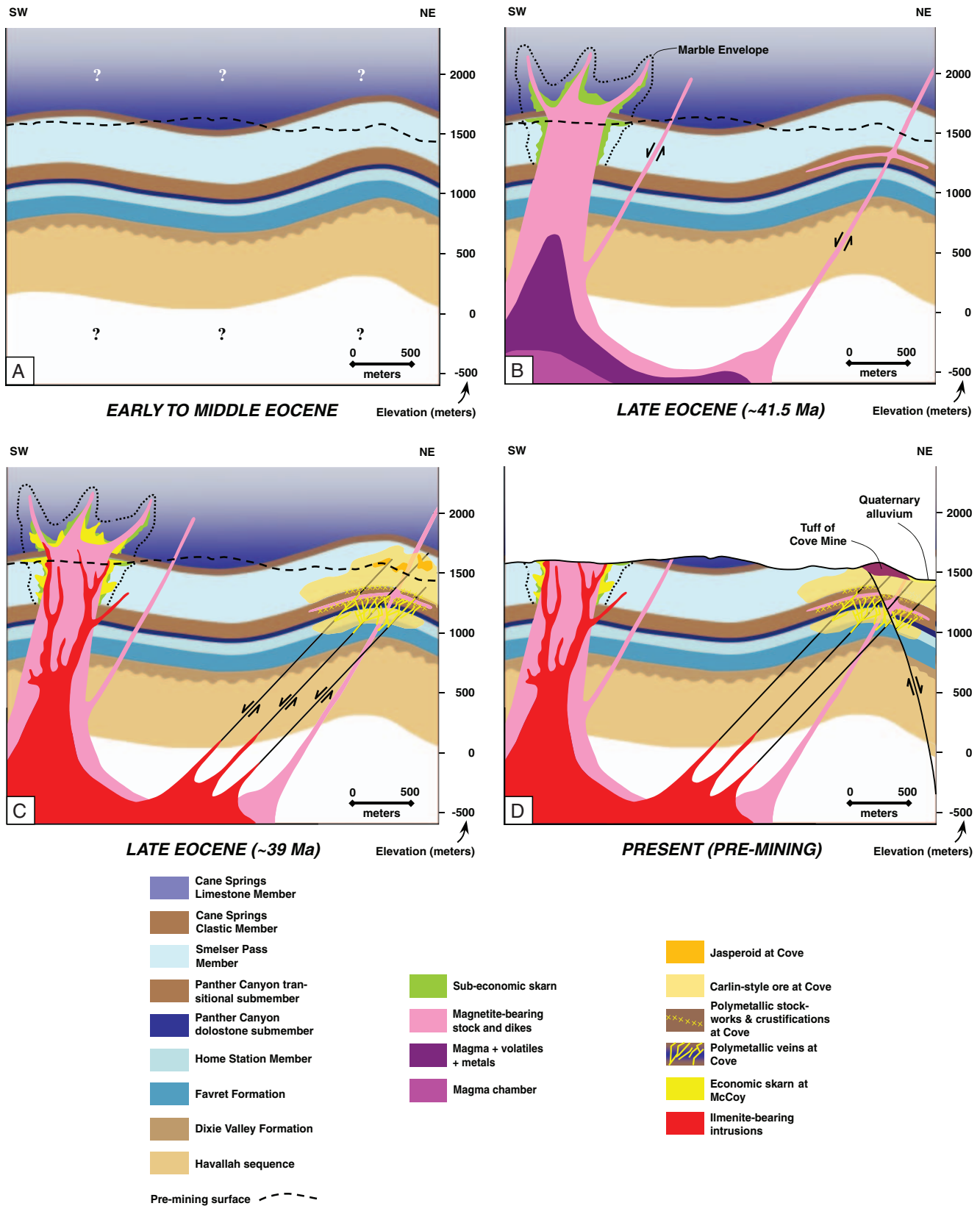


FIG. 18. Genetic model of the McCoy-Cove system. A. Pre-late Eocene cross section of the McCoy-Cove (early to middle Eocene), looking northwest. B. Stage 1 magmatism and subeconomic mineralization at McCoy-Cove (~41.5 Ma). C. Stage 2 magmatism and economic mineralization at McCoy-Cove (~39 Ma). D. Premining cross section for McCoy-Cove, showing postore effects.

minerals, and distal epithermal Au. In many Au-enriched porphyry copper deposits (e.g., Dos Pobres, Granisle, Bell, Dizon, Panguna, Sapu Alegre, Ok Tedi), Au is positively correlated with Cu in the proximal potassic alteration zone (the "central" Au zone of Jones, 1992). In other deposits (e.g., Fortitude, Star Pointer, San Manuel-Kalamazoo, Tanama, Helecho, Mt. Milligan), the Au-rich zone falls outside the more proximal Cu zone and inside of the more distal Pb-Zn-Ag zone (the "intermediate" Au zone of Jones, 1992). This intermediate Au zone is coincident with the pyrite halo in many porphyry Cu systems. Some sedimentary rock-hosted disseminated Au deposits (e.g., Barneys Canyon, Melco, Mercur, La Plata, Bau, Purisma-Concepcion) may be examples of the "distal" Au zone described by Jones (1992) (see also Alvarez and Noble, 1988; Sillitoe and Bonham, 1990; Cunningham et al., 2004). In the McCoy-Cove system the central Au zone is the Au-Ag skarn at McCoy, where Au is positively correlated with subeconomic Cu (Emmons and Eng, 1995). The intermediate and distal Au zones occur at Cove, where the intermediate zone is represented by the Pb-Zn-Ag-Au part of the system at Cove and the distal Au occurs as Carlin-style ore in carbonate host rocks.

The Au-enriched porphyry Cu system at Bingham Canyon may be particularly relevant to the discussion of the McCoy-Cove system in that both systems are located in the Great Basin and both are genetically related to late Eocene magmatic-hydrothermal activity. From the center outward, the metal zoning at Bingham comprises (1) a barren (subeconomic) core, (2) a molybdenite zone, (3) a bornite zone, (4) a chalcopyrite zone, (5) a pyrite halo, (6) a Pb-Zn-Ag zone, and (7) Au-Ag veins (James et al., 1961; John, 1975, 1978; Atkinson and Einaudi, 1978; Jones, 1992; Babcock et al., 1997). Gold occurs in all of these zones except the barren core and molybdenite zone. The Carlin-type deposits at Barneys Canyon and Melco are possibly distal expressions of the Bingham system (Sillitoe and Bonham, 1990; Cunningham et al., 2004).

Implications for Carlin-type and distal disseminated deposits

Most workers acknowledge that controversy still exists regarding the ultimate relationships between Carlin-type and distal disseminated and/or Carlin-like deposits (e.g., Muntean, 2004). In this discussion the "distal disseminated" classification will be used for deposits that have an established genetic link with late Eocene magmatism, whereas the "Carlin-type" classification refers to deposits that have been described as lacking such genetic links with igneous activity.

In the Battle Mountain district, north of McCoy-Cove, the distal disseminated deposits at Lone Tree and Marigold (Fig. 1) have been interpreted to be coeval with porphyry Cu and Au skarns (e.g., those at Copper Canyon; Theodore, 1998b). Polymetallic vein and replacement bodies with lower concentrations of Au and/or Ag are also present in the district (Doebrich and Theodore, 1996; Theodore, 1998a). These relationships support a proposed continuum between porphyry, skarn, polymetallic, and distal disseminated deposits (Carten et al., 1993; Titley, 1993; Pierce and Bolm, 1995), all of which are widespread in the Battle Mountain district (Theodore, 1998a).

In the Railroad (Bullion) district, distal disseminated deposits occur as mineralized jasperoid bodies as far as 3 km from the late Eocene and/or early Oligocene Bullion stock

(~36 Ma; Armstrong, 1970; Rayias, 1999). The Bullion stock is associated with proximal Cu and W skarn deposits, and Pb-Zn mantos occur between the proximal and distal disseminated deposits (Gillerman, 1982). In the Bingham area, Barneys Canyon and Melco lie beyond the pyritic halo of the late Eocene Bingham stock, and late Eocene, hypabyssal intrusions are also spatially associated with the Mercur deposit (Wilson and Parry, 1995; Presnell and Parry, 1996; Ballantyne et al., 1997; Mako, 1997).

Despite strong temporal links between various types of late Eocene deposits in the northern Great Basin, and the fact that many of the porphyry-related systems display classic zonation patterns in which Carlin-type deposits are proposed to occupy the most distal positions (e.g., Sillitoe and Bonham, 1990), the Carlin-type deposits have traditionally been considered as a separate and unrelated class of deposits. The main reasons for this are (1) $\delta^{34}\text{S}$ values from several deposits implicate a sedimentary source for the bulk of S, (2) δD and $\delta^{18}\text{O}$ values for many deposits implicate meteoric water as the mineralizing fluid(s), (3) clear zonations of hypogene alteration assemblages, metal ratios, and fluid inclusion temperatures have not been demonstrated, (4) there is a lack of appreciable base metal concentrations within the deposits, and (5) there is a lack of obvious associations with magmatism. These observations have been interpreted to indicate a lack of genetic association with contemporaneous igneous activity for Carlin-type deposits (e.g., Weiss et al., 2000). However, recent δD , $\delta^{18}\text{O}$, and $\delta^{34}\text{S}$ data implicate magmatic and/or metamorphic fluids in some classic Carlin-type deposits, including those at Getchell (Folger et al., 2000), Deep Star (Heitt et al., 2003), and Goldstrike (Kesler et al., 2005). In particular, the isotopic data from the Getchell, Deep Star, and Goldstrike deposits indicate a possible association with igneous activity, and late Eocene magmatism has been implicated in the formation of other deposits in the Goldstrike area and Genesis complex along the Carlin Au belt. At least several deposits that are widely regarded as classic Carlin-type deposits, including two of the largest deposits on the Carlin Au belt (Betze-Post and Genesis), appear to be related to a magmatic center in the northern Carlin trend-Emigrant Pass complex (Henry and Ressel, 2000; Ressel and Henry, 2006). This igneous complex lies directly adjacent to the Carlin Au belt and has been suggested to be the largest late Eocene intrusive center in Nevada, possibly explaining the unusually large concentration of Au along the Carlin Au belt (Henry and Ressel, 2000; Ressel and Henry, 2006). Other magmatic centers have been proposed for Carlin-type deposits elsewhere (Henry and Ressel, 2000). The influx of local meteoric, exchanged meteoric, or other waters in the most distal parts of some systems may help to explain the nonmagmatic isotopic signatures for many Carlin-type deposits (Johnston and Ressel, 2004).

Conclusion

The ^{40}Ar - ^{39}Ar age data indicate that ore at McCoy and Cove formed contemporaneously and that magmatism and mineralization at Cove were essentially coeval. The δD and $\delta^{18}\text{O}$ values for ore-related, polymetallic vein-type quartz and Carlin-style jasperoid indicate a magmatic source for the mineralizing fluids at Cove. The $\delta^{34}\text{S}$ values for hypogene sulfides

from skarn ore at McCoy and from polymetallic vein-type and Carlin-style ore at Cove indicate a common source of S, which is consistent with a magmatic origin. The McCoy-Cove system exhibits mineralogical and geochemical zonations that are nearly identical to the zonation proposed for typical Auriferous porphyry-related systems (e.g., Sillitoe and Bonham, 1990; Jones, 1992). Thus, Cove appears to be a telescoped deposit consisting of a central zone of polymetallic vein-type ore and distal disseminated ore.

The deposits at McCoy and Cove are genetically related to a large magmatic system that evolved during the late Eocene. The initial pulse of magmatic activity produced relatively oxidized, magnetite-bearing intrusive rocks. The second pulse produced relatively reduced, ilmenite-bearing intrusive rocks. During both pulses, fluids were presumably released from a pluton at depth, and heat and fluid flow were focused at shallower levels by the apical Brown stock and associated dikes. Economic gold mineralization occurred with the second, relatively reduced pulse.

The late Eocene magmatism was the heat source responsible for driving convective hydrothermal circulation at McCoy-Cove, similar to that proposed for other deposits in Nevada and at Bingham (Sillitoe and Bonham, 1990; Theodore, 1998b; Henry and Ressel, 2000; Cunningham et al., 2004; Johnston and Ressel, 2004; Ressel and Henry, 2006). In some cases (e.g., Getchell and Goldstrike), magmatic links have already been proposed; in other cases (e.g., Twin Creeks, Cortez and/or Pipeline, and Alligator Ridge), no clear spatial-temporal links to magmatism have yet been recognized. The McCoy-Cove model presented in this study is a possible example of the link between Carlin-type deposits and magmatic activity and may serve as a basis of comparison for occurrences of Carlin-type and porphyry-related deposits in the Great Basin and elsewhere.

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APPENDIX

⁴⁰Ar-³⁹Ar Analytical Methods

Samples were wrapped in Al foil and stacked inside a Pyrex™ tube. Individual packets averaged 3 millimeters in thickness. Neutron fluence monitors (ANU 92-176 and Fish Canyon Tuff sanidine) were placed every 5 to 10 millimeters along the tube. Synthetic K-glass and optical grade CaF₂ were included in the irradiation packages to monitor neutron-induced Ar interferences from K and Ca.

Loaded tubes were packed in an Al container for irradiation. Samples were irradiated for 14 hours in the D3 position on the core edge (fuel rods on three sides, moderator on the fourth side) of the 1MW TRIGA-type reactor at the Nuclear Science Center at Texas A&M University. Irradiations were performed in a dry tube device, shielded against thermal neutrons by a 5-millimeter-thick jacket of B₄C powder, which rotated about its axis at 0.7 revolutions per minute to mitigate horizontal flux gradients.

Correction factors for interfering neutron reactions on K and Ca were determined by repeated analyses of K-class and CaF₂ fragments. Measured (⁴⁰Ar-³⁹Ar)_K values were $1.38 (\pm 0.30) \times 10^{-2}$. Ca correction factors were (⁴⁰Ar-³⁹Ar)/Ca = $2.78 (\pm 0.02) \times 10^{-4}$ and (⁴⁰Ar-³⁹Ar)/Ca = $6.82 (\pm 0.11) \times 10^{-4}$. J factors were determined by fusion of 4 to 5 individual crystals of neutron fluence monitors which gave reproducibilities of 0.05 percent to 0.27 percent at each standard position. An error in J of 0.5 percent was used in age calculations. Variation in neutron flux along the 100-millimeter length of the irradiation tubes was <4 percent. No significant neutron flux gradients were present within individual packets of crystals as indicated by the excellent reproducibility of the single crystal flux monitor fusions.

Irradiated crystals and CaF₂ and K-glass fragments were placed in a Cu sample tray in a high vacuum extraction line and were fused using a 20 watt CO₂ laser. Samples were viewed during laser fusion using a video camera system, and positioning was accomplished via a motorized sample stage. Samples analyzed by the furnace step heating method utilized a double vacuum resistance furnace similar to the Staudacher et al. (1978) design. Reactive gases were removed by a single MAP and two GP-50 SAES getters prior to being admitted to a MAP 215-50 mass spectrometer by expansion. The relative

volumes of the extraction line and mass spectrometer allow 80 percent of the gas to be admitted to the mass spectrometer for laser fusion analyses and 76 percent for furnace heating analyses. Peak intensities were measured using the Balzers electron multiplier by peak hopping through 7 cycles; initial peak heights were determined by linear regression to the time of gas admission. Mass spectrometer discrimination and sensitivity was monitored by repeated analyses of atmospheric Ar aliquots from an on-line pipette system.

Measured ⁴⁰Ar/³⁹Ar ratios were 289.79 ± 0.35 percent during this work, thus a discrimination correction of 1.02972 (4AMU) was applied to measured isotope ratios. The sensitivity of the mass spectrometer was $\sim 2 \times 10^{-17}$ mol mV⁻¹ with the multiplier operated at a gain of 100 over the Faraday. Line blanks averaged 1.8×10^{-16} mol for mass 40 and 8.0×10^{-19} mol for mass 36 for laser fusion analyses and 7.0×10^{-16} mol for mass 40 and 8.0×10^{-18} mol for mass 36 for furnace heating analyses. Discrimination, sensitivity, and blanks were relatively constant over the period of data collection.

Computer-automated operation of the sample stage, laser, extraction line, and mass spectrometer, as well as final data reduction and age calculations, were performed using labVIEW software written by B. Idleman (Lehigh University). An age of 27.9 Ma (Steven et al., 1967; Cebula et al., 1986) was used for the Fish Canyon Tuff sanidine flux monitor in calculating ages for unknown samples.

For ⁴⁰Ar-³⁹Ar analyses, a plateau segment is defined as consisting of contiguous gas fractions having analytically indistinguishable ages (i.e. all plateau steps overlap at $\pm 2\sigma$ analytical error) and comprising a significant portion of the total gas released (typically >50 percent). Total gas (integrated) ages were calculated by weighting the amount of ³⁹Ar released, whereas plateau ages were weighted by the inverse of the variance. For each sample, inverse isochron diagrams were examined to check for the effects of excess Ar. Reliable isochrons are based on the criteria of Wendt and Carl (1991) and, as for plateaus, must comprise contiguous steps and a significant fraction of the total gas released. All analytical data are reported at the confidence level of 1σ standard deviation.