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EPITHERMAL GOLD/SILVER DEPOSITS: THE GEOTHERMAL CONNECTION

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ABSTRACT

Epithermal precious metal deposits in the western United States can be related to two main plate tectonic regimes: (1) active subduction zones of Mesozoic to Quaternary age with associated subduction-related magmatism and geothermal phenomena and (2) extensional tectonics of Tertiary-Quaternary age with associated rifting, magmatism and geothermal activity.

Three main deposit types and numerous subtypes of epithermal gold-silver deposits can be recognized in the western U.S.: (1) volcanic- or volcaniclastic-hosted vein, disseminated and stockwork deposits in or adjacent to volcanic centers; (2) sediment-hosted, stratigraphically-controlled replacement and stockwork deposits, typically in thin-bedded carbonaceous limestones or calcareous, carbonaceous shales (Carlin type), or in solution breccias, paleokarst horizons and channels (Sherman type), (3) hot spring-related stockwork and fissure systems, in which permeable rock horizons including volcanicalastics and hydrothermal explosion breccias are common host rocks for massive silicification and mineralization. Volcanic and subvolcanic rocks are common in the vicinity due to the association of volcanism with geothermal systems.

Mineralized fossil goethermal systems are directly analogous to a number of modern geothermal systems and the processes involved are essentially identical. Modern geothermal systems that contain significant amounts of base and precious metals (e.g. Taupo zone, New Zealand; Salton Sea, California; Steamboat Springs, Nevada; O-Yunuma and Sakurajima, Japan) are related to volcanic centers active within the Quaternary. Geothermal systems unrelated to volcanic centers, the deep circulation type related to high regional heat flow, typically contain very minor amounts of metals (e.g. Beowawe, Buffalo Valley and Darrough in central Nevada; Rio Grande rift in New Mexico).

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INTRODUCTION

Epithermal precious metal deposits in the western United States can be related to two main plate tectonic regimes: (1) subduction zones of Mesozoic to Quaternary age with associated subduction-related magmatism and geothermal phenomena, and (2) extentsional tectonics of Tertiary-Quaternary age with associated rifting, magmatism and geothermal activity. Deposits related to subduction-generated magmatism are associated with volcano-plutonic belts that range in magma chemistry from calcic through calc-alkaline, high potassium calc-alkalic, alkali-calcic and alkalic (Westra and Keith, 1981; Keith, this volume). The subduction-related deposits occur in subparallel, time-dependent belts and their metallogeny reflects the magma chemistry of associated igneous rocks (c.f. Keith, this volume). Deposits related to extensional tectonism are associated with rhyolites of the bimodal, basalt-rhyolite assemblage (McKee, 1971; Christiansen and Lipman, 1972). The rhyolites of this suite are high-silica, subalkaline or peralkaline types. No significant precious metal deposits are associated with volcanic centers in which only basalt or peralkaline rhyolite is present.

Three main types and numerous subtypes of epithermal gold/silver deposits can be recognized in the western U.S.: (1) volcanic and/or volcaniclastic-hosted vein, disseminated and stockwork deposits in or adjacent to volcanic centers; (2) sediment-hosted, stratigraphically-controlled replacement and stockwork deposits, typically in thin-bedded carbonaceous limestones or calcareous, carbonaceous shales (Carlin-type), but also in solution breccias, paleokarst horizons and channels (Sherman-type); (3) hot spring-related stockwork and fissure systems, in which permeable rock horizons including volcaniclastics and hydrothermal explosion breccias are common host rock for massive silicification and mineralization. Volcanic and subvolcanic rocks are usually associated with hot spring precious metal deposits, reflecting the common relationship between volcanism and metal-bearing geothermal systems (White, 1981).

EPITHERMAL Au-Ag DEPOSIT TYPES

The term epithermal (Lindgren, 1933) denotes Au-Ag deposits with the following generalized characteristics: deposition from relatively low salinity fluids (12% equivalent NaCl or less) at temperatures in the 150°-300°C range; limited vertical range of

Au-Ag deposition, typically 400 m or less and within 1000 m of the premineral surface; and, presence of As, Sb, Hg, Tl, Se, Te minerals associated with electrum, silver sulfides and sulfosalts with variable base metals. Au-Ag tellurides or Ag selenides are important ore minerals in some districts.

The source of the metals in epithermal Au-Ag deposits is an unresolved problem. Stable isotope data from many deposits indicate that the ore fluid was dominantly composed of highly exchanged meteoric water and sulfur derived from a sedimentary source. This has led many workers to propose that the metals were derived by hydrothermal leaching of source rocks, principally sedimentary rocks. Conversely, the close spatial association with intrusive and extrusive igneous rocks at nearly all deposits suggests to some that igneous rocks may have been the source of at least part of the metals present.

Continuing detailed geologic studies at a large number of deposits, involving stable isotopes, geologic mapping, geochemistry of the mineralized zones and related unmineralized sedimentary rocks and associated igneous rocks, and detailed fluid inclusion studies will be required in order to more closely define sources of metals.

Volcanic-Hosted Epithermal Au-Ag Deposits

Volcanic-hosted Au-Ag deposits include many of the famous bonanza deposits of the Circum-Pacific rim. In the western U.S. and Mexico they include such major districts as the Comstock Lode, Tonopah and Goldfield in Nevada, Cripple Creek in Colorado, and Guanajuato, Pachuca-Real del Monte and Tayoltita in Mexico. Deposits are typically in the 1-10 million ton range but often occur in districts with as many as thirty discrete orebodies. Grades vary widely up to a hundred ounces per ton silver and ten ounces per ton gold, but are generally less.

The observed ages of mineralization vary from late Mesozoic through the Cenozoic, coinciding with the ages of the volcanotectonic complexes with which they are genetically associated. Conceptually, older volcanic-hosted Au-Ag deposits will occur insofar as their supracrustal host rocks are preserved. Conversely, these deposits - as well the other epithermal types - are in the process of formation today at various locales around the Circum-Pacific region.

Three main subtypes of volcanic-hosted Au-Ag deposits can be distinguished by differences in alteration mineralogy, major and trace metal content, gold/silver ratios, and associated igneous rock types.

I. Enargite-gold subtype

One major type is characterized by advanced argillic alteration, gold associated with enargite-group minerals, high total sulfur content in both sulfides and sulfates, and by associated volcanic and subvolcanic igneous rocks ranging in composition from andesite to rhyodacite. Goldfield, Nevada, El Indio, Chile, and Summitville, Colorado are major examples of this deposit type. Silver-bearing tetrahedrite, galena and sphalerite underlie gold-enargite mineralization in some districts but, are virtually absent in others. Bismuth and tellurium are important trace metals. The gold mineralization commonly occurs in silicified hydrothermal breccias. Grades are often erratic and can be spectacularly high. Alteration, both hypogene and supergene, is widespread and typically extends far beyond economic mineralization.

Sillitoe (1983) has recently described enargite-bearing massive sulfide bodies with associated gold mineralization which occur in volcanic host rocks within zones of advanced argillic alteration. His enargite-bearing massive sulfide deposits, several of which he shows as genetically related to porphyry copper systems, are a variant of our enargite-gold deposit type.

II. Silver-base metal subtype

A second major subtype is associated with quartz-adularia-K-mica alteration, a generally high silver to gold ratio, a low total sulfur environment, geochemically anomalous amounts of Mo, W, Mn, F, and Se, variable amounts of Pb and Zn, and minor Cu. Genetically related igneous rocks are high and low-silica rhyolites. Deposits related to high-silica rhyolite systems typically contain more Mo, W, Sn, F and Mn than those associated with low-silica rhyolite systems. Many of the major bonanza, epithermal silver districts of western North America such as Creede, Colorado; Comstock and Tonopah in Nevada; Delamar, Idaho; and Tayoltita and Pachuca-Real del Monte in Mexico are examples of this deposit type.

Propylitic alteration is pervasive in these deposits, with potassic and phyllic alteration typically restricted to veins and immediately adjacent wall rocks. Quartz, adularia, fluorite, manganese carbonates and silicates, calcite and barite are the common gangue minerals. Argillic and phyllic alteration can form an alteration halo adjacent to and above the silver-gold ore bodies (Buchanan, 1981; Randall, 1979; Giles and Nelson, in press). The major precious metal ore minerals are electrum with silver sulfides, sulfosalts and/or selenides. The chief base metal sulfides are galena, sphalerite, and chalcopyrite with variable pyrite. Molybdenite is present in trace to minor amounts in many deposits, and huebnerite or wolframite occurs in several districts and may be present, but unidentified, in many more.

Economic silver-gold mineralization is underlain in some deposits by a zone of high base metals, chiefly Pb and Zn with some Ag. The silver-gold ore zone is typically exposed at the present erosion surface, but blind orebodies are present in some districts, e.g. Pachuca-Real del Monte and Tonopah. Structures above buried orebodies are typically narrow zones of quartz-calcite stringers which are essentially devoid of precious metals and sulfides. Anomalous amounts of Hg, As and Sb are usually present with sulfidic silicification above the precious metal ore shoots. If the water table at the time of alteration and mineralization did not intersect the paleosurface, there will be no hot spring sinters deposited, and hypogene solfataric alteration will take place. A productive precious metal system can be overlain by rock which contains no anomalous silver-gold mineralization, but may contain alunite, cinnabar, native sulfur and various sulfate minerals.

III. Gold telluride subtype

The third major deposit subtype is characterized by quartz-fluorite-adularia-carbonate alteration, a low silver to gold ratio with gold and silver occurring chiefly as tellurides, and a genetic relationship to alkalic igneous rocks. Fluorine and tellurium are diagnostic geochemical indicators for this type of deposit. Small amounts of base metal sulfides, stibnite and cinnabar may also occur with the precious metal ores. Cripple Creek, Colorado and Zortman-Landusky, Montana, are examples.

Gold telluride mineralization at Cripple Creek is hosted by quartz-fluorite-carbonate-adularia stockworks, veins, breccia shoots (Cresson Pipe) and sheeted zones which are surrounded by an envelope of propylitized volcanic rock. It seems probable that the Cripple Creek type of deposit is the volcanic and sub-volcanic expression of alkalic porphyry Cu-Au-Ag-Pt mineralization, such as that recently described by Werle and others (1982) in the Allard stock, Colorado.

Carbonate-hosted Epithermal Au-Ag Deposits

Deposits in this group are frequently referred to as "Carlin-type" deposits after the Carlin gold mine in Eureka County, Nevada. Host rocks for this group of deposits are typically thin-bedded, calcareous, carbonaceous, clastic sediments.

The carbonate-hosted deposits are hydrothermal, disseminated-replacement gold deposits. They are characterized by a high gold/ silver ratio and a geochemical association of Au, As, Sb, Hg, Ba and Tl. Anomalous amounts of W, Mo, Sn and F are usually present. Gold grades are typically in the 0.1 to 0.4 ounce/ton range with initial reserves ranging from a few hundred thousand tons to over one hundred million tons. Typical ore bodies range from five to fifteen million tons in size.

Host rocks are decarbonated in the ore horizon and variably silicified and argillized. Hydrocarbons are dissolved in hydrothermal fluids and reprecipitated adjacent to zones of acid alteration and in haloes around the ore zone. Jasperoid replacements occur in and adjacent to high-angle fault conduits. Jasperoid usually shows evidence of multiple periods of brecciation and may occur above, within or below the main ore horizon. Jasperoid is ore grade in some deposits, and almost always contain geochemically anomalous amounts of gold. In addition to the ubiquitous silicification, alteration minerals typically present include illite, montmorillonite, kaolinite, chlorite and sericite.

Spatially associated with nearly all Carlin-type deposits are stocks, dikes, sills and plugs ranging from granodiorite to rhyodacite in composition. Intrusive rocks are usually altered and mineralized and, in some deposits, contain economic gold mineralization. Primary controls of ore deposition in Carlin-type deposits are high-angle faults which transect a favorable host rock type, typically a thin-bedded, silty to sandy carbonaceous siltstone or carbonate. The gold in Carlin-type deposits is typically submicroscopic and has particle sizes in the micron to submicron range (Radtke, 1981). Gold occurs as free gold, coatings on pyrite, as gold-organic complexes dispersed on amorphous carbon grains, as discrete grains in realgar, and in solid solution in realgar and native arsenic (Radtke, op. cit.).

Sulfide minerals present in Carlin-type deposits include pyrite (2%) and, typically, highly variable amounts of cinnabar, realgar, orpiment, and stibnite. Small amounts of base metal sulfides including sphalerite, galena, chalcopyrite and molybdenite are usually present. Several rare thallium-bearing minerals have been identified in a few deposits. The amount of arsenic present in Carlin-type deposits is highly variable; some deposits such as Getchell, Nevada and Mercur, Utah contain abundant arsenic sulfides; others such as Northumberland and Alligator Ridge, Nevada contain only small amounts of arsenic.

Unoxidized primary ore at a number of Carlin-type deposits is overlain by a zone of hypogene oxidation produced by a late stage of boiling of the hydrothermal solutions. Supergene oxidation may be superimposed on the zone of hypogene oxidation, making separation of hypogene and supergene alteration stages difficult (Radtke, 1981; Wells and others, 1969).

The age of Carlin-type deposits is a subject of some controversy. Many workers prefer a late Tertiary age for all deposits of this type. Their argument is based on apparent control by Basin and Range faults of late Tertiary age, and an inferred relationship to late Tertiary intrusion and volcanism as a heat source for the hydrothermal fluids (Radtke and Dickinson, 1974; Radtke, 1981). Indeed, a remnant volcanic surface of the same age as the younger felsic dikes and sills associated with mineralization is frequently located within several kilometers of the deposits (Stevens and Hawkins, in press). On the other hand, K-Ar ages of hydrothermal sericite from several of the Carlin-type deposits give ages that range from at least Cretaceous to late Tertiary (e.g. Silberman and others, 1974; Norton and others, 1977; Berger 1980; Bonham and Silberman, unpub. data).

In some deposits, as at Getchell and Gold Acres, the geologic relationships further suggest a genetic connection between mineralization and older granodioritic or granitic plutons near the ore zone (Silberman and McKee, 1971; Wrucke and Armbrustmacher, 1975; Berger, 1980). Clearly, more work is needed to establish whether the ages of formation of Carlin-type deposits range from late Mesozoic through the Teritiary, or are confined to a distinct time span within the Tertiary.

Several published models for the formation of Carlin-type deposits have placed a strong emphasis on hot-springs model. This is somewhat misleading, because there does exist a class of disseminated gold-silver deposits (discussed later in this paper) which clearly formed in a hot springs environment, within 100 meters or less of the paleosurface. The Carlin-type deposits are certainly related to fossil geothermal systems, and some or all of these systems must have vented to the surface as hot springs. However, none of the Carlin-type deposits have as yet been conclusively shown to have formed in an actual hot spring environment.

Current estimates on the depth vary from as shallow as 200 meters to as deep as 2000 meters. Such estimates usually reflect the inferred connection - or lack thereof- of mineralization with a deeper plutonic body, shallow volcanic surface, and the like as discussed above. Proponents to the shallower environment cite as further evidence the apparent open and short lived nature of the mineral systems, probable boiling of the hydrothermal fluids, and abrubt changes in fluid Eh and pH as reflected in the mineral and alteration assemblages.

Dissiminated, stratiform replacements in solution breccia (paleokarst) horizons developed on thick limestone units are another type of carbonate-hosted deposit. These gold-silver deposits have been informally termed "Sherman-type" after the Sherman mine in the Leadville district, Colorado. Paleokarst zones in upper lower Mississippian strata (e.g. Madison, Leadville) provide favorable ore locales throughout the Rocky Mountain region. Examples include the Warm Springs (Gilt Edge) and Kendall districts in Montana, the Aspen and Gilpin districts in Colorado, and possibly the Lake Valley district in New Mexico. In all cases there is evidence of associated igneous activity.

The host in these deposits is dominantly paleokarst fill material, usually a heterogeneous mixture of limestone solution-breccia fragments and blocks in a carbonaceous, calcite-cemented siltstone and clay matrix. The old solution channels, combined with the porous and reactive infill, focus hydrothermal fluids and localize ore. Gold/-silver ratios vary widely within and between deposits, as does the accompanying base and trace metal assemblage. As examples, Gilman and Aspen are Pb-Zn-Ag districts with little gold; Sherman and Lake Valley are oxidized silver deposits; Gilt Edge and Kendall contain micron-size gold with pyrite, fluorite, minor base metals, and an As-Sb-Hg trace metal signature (Giles, 1983). The ore shoots are very irregular in plan, reflecting the primary ore control. The various central Montana deposits contained 1-2 million tons averaging around 0.4 ounces Au per ton.

Hot Spring-related Au-Ag Deposits

Hot spring lode gold deposits are silicified breccias and vein stockworks of quartz-sulfide mineralization found at or very near the pre-mineral surface. They represent an important and relatively new source of gold production. Examples currently include Kasuga, Iwato and Akeshi in Japan; Waihi and other deposits of the Hauraki goldfield in New Zealand; Cinola in British Columbia; Hasbrouck, Borealis and McLaughlin in the United States. Hydrofracted vein stockworks and mineralized explosion breccias are the main ore hosts.

Ascending fluids produce a typical mushroom-shaped cap of near surface silica replacement and flooding. The cap is often overlain by hot spring sinter. Ore grades are typically 0.05 to 0.5 oz per ton with local grades in confined volcanic throat areas and vein clusters up to 1 ounce per ton. Supergene processes may lead to local silver enrichment. The Au-Ag ratio is overall about 1:1, but is widely variable within and between deposits. Individual orebodies known to date range from 1.5 million tons (e.g. Kasuga) to more than 20 million tons (e.g. McLaughlin).

Ore is typically composed of micron-sized native gold and electrum. Associated minerals include fine-grained pyrite-marcasite and a large suite of silver sulfosalts. The gangue mineralogy is microcrystalline quartz and chalcedony with lesser calcite and adularia. Cinnabar and stibnite are zoned toward the surface; minor base metals are enriched at depth. Host rocks are typically hardened by a pre-ore episode of K-Na metasomatism and near-surface silicification. Sulfide ore is often enveloped by alunite, kaolinite and montmorillonite, and late acid supergene leaching often overprints the mineralization.

Hot spring environments contain the strongest enrichment in the epithermal geochemical suite, a response to shallow boiling and steep near-surface gradients in temperature. Mercury, antimony, thallium and arsenic are typically anomalous. The geochemical suite is identical to that identified in the bonanza and disseminated replacement environment, but concentrations are up to several orders of magnitude higher. Individual elements may be absent, e.g. mercury in some Japanese deposits, or additional elements may be present, e.g. tungsten at Cinola, British Columbia, depending on local source rock characteristics.

Hot spring lode gold deposits are associated with the sealed portions of fossil geothermal systems and may be considerably offset from currently active centers of geothermal activity. All deposits discovered to date are associated with explosive fracturing (hydrofracting) and hydrothermal brecciation. Explosive release of pressure and resultant high permeability contribute to shallow boiling of rapidly rising hydrothermal fluids and to repeated episodes of mineralization. Temperatures of precious metal deposition are under 200°C, and the fluids are meteoric and dilute.

SUMMARY AND CONCLUSIONS

Epithermal gold/silver deposits can be subdivided into a series of subtypes based upon mineralogy, alteration characteristics, host rock lithology, magma chemistry of associated igneous rocks, depth of formation and deposit form (vein, stockwork, breccia-hosted, etc.). They are essentially confined to arc and back-arc settings and are predominantly of Mesozoic or Cenozoic age. Depth of formation ranges from surface hot spring environments to at least 2000 meters. The fluids associated with ore deposition range from dilute alkali chloride waters to acid sulfate waters with temperatures ranging from 150°C to 300°C.

This diversity in host rock lithology, ore fluid chemistry, tectonic setting and depth of formation, leads to an equal diversity in deposit form, ore mineralogy and wallrock alteration. Recognition of this diversity of epithermal gold/silver deposit types is a key factor in exploration. For example, gold/silver deposits in carbonate host rocks typically have inconspicuous wallrock alteration haloes, but engargite-gold deposits have very extensive wallrock alteration haloes.

The unifying factor in epithermal gold/silver deposits is their clear relationship to geothermal systems. The study of modern geothermal systems in the Circum-Pacific belt, in particular, has led to a better understanding of this diverse group of deposits. Future research in active geothermal systems will clearly lead to a better understanding of epithermal gold/silver deposits.

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