1 Introduction

The general features of ore deposits in the epithermal environment are influenced by their tectonic, magmatic and geologic affiliations (Sillitoe and Hedenquist, 2003). Alteration and ore minerals plus textures, and zonation patterns, are highly variable and are defining characteristics. These variations have implications for the assessment of prospects during mineral exploration.

Waldemar Lindgren recognized over a century ago that the group of ore deposits he called epithermal formed within the upper km of the Earth’s surface. He and his colleagues appreciated that geothermal hot springs and volcanic fumaroles are the active surficial expression of hydrothermal systems that formed epithermal deposits. Lindgren realized that the epithermal group has characteristic styles of deposits, including 1) Au-Ag (±Se or Te rich), 2) Ag-Au (±Zn, Pb and/or Cu; base metal sulfides—bms), and 3) Au-Ag-Cu-As; the first two groups have gangue and alteration minerals indicating near-neutral pH fluids, whereas alunite alteration halos of the latter deposit style are consistent with an acidic pH of the alteration fluid.

2 Depth of Formation

The Ag-Au and Au-Ag-Cu-As deposits form as deep as ~1 km (Table 1), with vertical ore intervals up to 500-600 m; the top of ore may be 100-300 m below paleosurface, but can be more shallow. By contrast, Au-Ag deposits form at a shallower depth, and the top of ore veins may lie just below the paleosurface, capped by silica sinter, with a surficial blanket above the groundwater table of steam-heated acid sulfate water (pH~2.5) and kaolinite-alunite alteration.

Temperatures at the paleosurface would have been a maximum of ~100ºC, whereas temperature increases along the boiling point-for-depth curve to ~300ºC at 1000 m depth. This temperature-depth relation controls the distribution of temperature-sensitive alteration minerals.

3 Alteration Minerals and Zonation

Alteration mineralogy is controlled largely by pH and temperature. In Au-Ag deposits, their shallow depth of formation (Table 1) means that the paleotemperature was low, typically <230ºC at paleodepths <300 m. At this temperature the alteration is dominated by illite next to the vein, plus local adularia and silicification. At distal positions or depths <150 m (<200ºC), interstratified illite-smectite and then smectite are the stable clays. Ag-Au deposits typically form at greater depths and hence higher temperature, to nearly 1 km and ~300ºC. Above ~250ºC the white mica in the alteration halo is muscovite, with illite and lower temperature clays in distal positions or shallow depths over the ore vein.

By contrast, Ag-Ag-Cu-As deposits are proximal to intrusive centers, hosted by earlier-formed hypogene advanced argillic alteration. Core zones of residual quartz, closest to feeder zones, form by acidic condensates of magmatic vapor with pH~1; halos consist of an inner zone

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of quartz-alunite that grade outward to quartz-kaolinite (with quartz-dickite at depth), then to clays. High-temperature pyrophyllite± diaspore is common in feeder zones. Similar advanced argillic alteration may occur along structures that are subsequently reopened by quartz Ag-Au-(bms) veins of a later system with deep white mica halos.

4 Gangue Minerals and Textures

Ag-Au-(bms) and Ag-Au-Cu-As deposits commonly have sulfate minerals such as barite and anhydrite as gangue, which indicate relatively oxidized fluid. By contrast, Au-Ag deposits do not have sulfate minerals, and the pyrrhotite, arsenopyrite plus Fe-rich sphalerite indicate a reduced composition.

Both Au-Ag and Ag-Au veins are dominated by quartz, with subsidiary adularia, carbonates (bladed calcite and - in Ag-Au veins only - Mn carbonates ± rhodochrosite). Crystalline quartz occurs in the deeper, higher temperature Ag-Au veins, commonly with banded or crustiform textures, whereas finer quartz and chalcedony occur at the shallower depths of Au-Ag veins; colloform textures are present where extensive boiling and sharp cooling saturates the fluid with amorphous colloidal silica.

5 Ore Sulfides and Sulfidation State

The low sulfide-content Au-Ag deposits typically contain arsenopyrite or pyrrhotite plus Fe-rich sphalerite, indicating a low-sulfidation state, in addition to pyrite; chalcopyrite and other intermediate sulfidation-state sulfides can be present in minor quantities, caused by events of sharp cooling. By contrast, the more sulfide-rich Ag-Au-(bms) veins contain chalcopyrite, tennantite/tetrahedrite, galena and low-Fe sphalerite, as well as local hematite and pyrite, defining an intermediate sulfidation-state.

The Ag-Au-Cu-As deposits are defined as high sulfidation state by the presence of enargite plus fine pyrite, locally with covellite (in contrast to the coarse pyrite of the early - essentially barren - residual quartz host and advanced argillic alteration); cooling of an intermediate sulfidation-state fluid within residual quartz, in the absence of any rock buffer, drives the fluid to high sulfidation-state stability. The Au stage is mainly later than the Cu stage, and is associated with chalcopyrite, tennantite/tetrahedrite and low-Fe sphalerite. Dominantly intermediate sulfidation-state veins (Ag-Au-bms) can have a high sulfidation-state assemblage proximal to the feeder zone, consistent with the close association of the two deposit styles.

6 Exploration Implications

Exploration for and assessment of epithermal prospects requires an understanding of the paleodepth of erosion and zonation that can indicate direction to the feeder conduit of upflow; alteration mineralogy is the principal tool that allows such interpretations. Paleosurface features (silica sinters or colloidal silica laminites, the latter in crater lakes), as well as steam-heated alteration indicate little erosion. Patterns of temperature-dependent alteration mineralogy and mineral composition can be mapped, assisted by SWIR; Au-Ag-Cu-As deposits are hosted by mineralogy that indicates the most acidic pH occurred prior to metal deposition. Knowledge of the style of deposit as well as the mineralogy helps the geologist to interpret both geochemical anomalies and geophysical signatures.

References