

OCCURRENCE MODEL FOR ENARGITE-GOLD DEPOSITS

By

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Enargite-gold deposits are found associated with major volcanic piles, especially those dominated by intermediate calc-alkalic volcanic rocks, throughout the world. Calc-alkalic volcanic rocks occur in several tectonic settings; the deposits occur in all these settings, but are most common in island arcs and back-arc spreading areas. There are two particularly intriguing aspects of these deposits. First, they are always associated with areas of acid-sulfate hydrothermal alteration. Large acid-sulfate areas comprised of argillic and locally advanced argillic rocks occur in all the major accumulations of calc-alkalic volcanic rocks in the western United States, so that much prospective ground may be encountered on Federal lands to be assessed. Second, they occur, again accompanied by acid-sulfate alteration, above and peripheral to some porphyry copper deposits in several of the major porphyry copper provinces of the world. Thus enargite-gold deposits may be shallow-level indicators of deeper porphyry systems, as well as potentially significant gold and copper sources.

The following occurrence model is based mainly on features of four districts: Goldfield, Nevada; Summitville, Colorado; Pyramid, Nevada; and Chinkuashih, Taiwan. Other examples include Bor, Yugoslavia; Kasuga and Akeshi, Kyushu, Japan; Lepanto, Phillipines; El Indio, Chile; Red Mountain district, south of Ouray, Colorado; and Peavine-Wedekind districts, Nevada. Relatively large deposits of this type may contain 1×10^6 to 5×10^6 oz gold and/or 3×10^5 to 1×10^6 tons of copper metal. Most deposits have a high gold-silver ratio (>1:3), but a few are relatively silver-rich. Good examples of enargite-gold deposits or enargite occurrences demonstrated to be associated with porphyry copper systems include Cananea, Mexico (Colorado Pipe); El Salvadore, Chile (upper levels); and Red Mountain, Arizona.

Host rocks for enargite-gold deposits are usually intermediate volcanic rocks, most commonly rhyodacites, less commonly trachyandesites or quartz latites, and least commonly rhyolites. Sedimentary sequences, usually volcanic-bearing clastics, may also be hosts. Interestingly, intermediate volcanic rocks are always found in the vicinity of these deposits even in districts where most of the ore bodies are in sedimentary rocks. These intermediate volcanics are always porphyritic, and often strikingly so, with a varied assemblage of large and abundant phenocrysts. In the few districts where extensive geochronologic studies have been carried out, the intermediate rocks closely associated spatially with the deposits include units closely associated temporally with hydrothermal alteration and ore deposition. One or more volcanic units usually show intrusive relations, or both intrusive and extrusive relations, to surrounding rocks, indicating that porphyritic domes and flow-dome complexes are typical sites for the acid hydrothermal systems that produce enargite-gold deposits. Most if not all known deposits are of Cenozoic age.

Associated hydrothermal alteration is predominantly argillic. Quartz-montmorillonite is the most common assemblage; it has been documented in many districts, and may be present in every district. Quartz-kaolinite, quartz-kaolinite-K mica, and quartz-mixed layer illite-montmorillonite are other common assemblages. The argillic zone contains advanced argillic zones with

various assemblages that surround the former feeder conduits for the hydrothermal solutions. Assemblage include quartz-alunite + kaolinite, quartz-alunite-native sulfur, quartz-diaspore, quartz-pyrophyllite-diaspore, quartz-alunite-pyrophyllite-diaspore, and quartz-alunite-sericite. Advanced argillic zones within individual districts may display only a few or all of the above assemblages; usually two or three are typical. Which ones develop depends upon intensity of leaching (H^+ supply), total sulfur concentration, and concentration of alkalis (K^+ , Na^+) in the hydrothermal solutions. A titanium oxide phase, either anatase or rutile, is present in any rock that had an appreciable titanium content before alteration. The most intense leaching results in vuggy masses of quartz with minor rutile. Pyrite is ubiquitous in the argillic and advanced argillic zones, usually relatively abundant in rocks that were originally relatively mafic, and scarce in rocks that were originally silicic. Oxidation of this pyrite at the surface produces outcrops with gaudy yellow, brown, orange, or red limonite stains (note the association of deposits with geographic features named "Red Mountain"). Relict textures may be subtle but are common, attesting to the fact that this alteration is largely a replacement process. Propylitized rocks are found peripheral to the argillized rocks in every district, but mineral assemblages vary a great deal both within and between districts. The argillic-advanced argillic alteration of some districts is surrounded by large tracts of strongly propylitized volcanic rocks, whereas in other districts propylitization is restricted to patchy occurrences around the outer edges of the argillic zone.

Ore bodies are always located in or adjacent to advanced argillic zones. Low-grade ores with pyrite as the only obvious sulfide mineral appear merely to be mineralized advanced argillic rock. High-grade ores (>1 ox/ton Au and/or $>1\%$ Cu), however, always fill open-space breccias or fractures formed by breakage of advanced argillic rocks (usually relatively quartz-rich, hard, "silicified" varieties) after alteration was mostly or entirely complete. At Summitville, ore minerals fill voids formed by complete acid leaching of feldspar phenocrysts. In some cases the high-grade ore bodies are formed in post-alteration fault breccias, but in most cases they have very irregular crudely pipe-like or tabular forms not obviously related to any post alteration faulting or jointing. The advanced argillic zones enclosing the ore bodies, however, are often obviously developed along highly permeable structural features such as faults, or stratigraphic features such as coarse clastic or volcanoclastic beds, flow breccias, or lithologic contacts. The mechanism responsible for this late-stage brecciation that is apparently often important in providing the open space necessary for the sulfosalts-rich enargite-bearing high grade ores is still something of a mystery. The latest thought is that the alteration process, through choking of conduits by silica deposition and later boiling, may locally lead to a hydrofracturing stage that produces these breccias. District-wide structural and stratigraphic control varies in detail from district to district, although at least a few large through-going faults are present in every case. Original rock type appears to influence alteration patterns only through permeability, not compositional control, and has no significant influence on localization of ore.

Ore mineralogy is dominated by sulfosalts, including enargite-luzonite series minerals, tetrahedrite-tennantite series minerals, and in some cases silver sulfosalts, and characterized by enargite and luzonite. Pyrite is ubiquitous. Other important minerals vary from deposit to deposit, and

include bismuthinite, native gold, and tellurides. Chalcopyrite is common but minor. Late stage marcasite occurs in some deposits. Galena, sphalerite, and wurtzite are minor and sporadic, but in some districts become more consistently present and locally abundant at the outer edges of productive areas, suggesting a tendency toward district-wide zoning of base metals. The most abundant gangue mineral in ore-mineral breccia fillings is quartz, which forms combs as opposed to the fine-grained mosaics that typify the advanced argillic wall rocks. In addition, barite, alunite, or kaolinite may be important gangue minerals in breccia fillings. However, the ore-filled breccias or fractures are often so intricately interspersed with wall rock on a fine scale that whatever minerals comprise the advanced argillic host rocks must also be considered gangue minerals.

Quantitative fluid inclusion data on hydrothermal alteration phases and quartz comtemporary with ore minerals are sparse, and material usable for quantitative measurements is typically scarce. The limited information available indicates that the fluids responsible for the acid alteration had generally low, perhaps moderate salinity, and boiling occurred commonly. No data are available on fluids present during the ore-forming stage. Temperatures range from less than 200°C to over 300°C. The common appearance of pyrophyllite accompanied by diaspore indicates that temperatures during hydrothermal alteration exceeded 270-300°C in many systems. Since ore deposition always occurs late in the evolution of these hydrothermal systems, prevailing temperatures may well be less than 270°C during ore formation.

Stable isotope data are also limited. Sulfur is often apparently from a magmatic source, but if a source of sedimentary sulfur was encountered at depth by the hydrothermal fluids, sulfide sulfur may be dominantly from this sedimentary source. Hypogene alunite is moderately to strongly enriched in S^{34} relative to pyrite in advanced argillic rocks. Oxygen and deuterium data indicate that these systems are meteoric-water dominated, as is the case for other epithermal deposits.

Exploration geochemistry utilizing rock samples often does not produce results satisfactory for locating specific drilling targets, especially in the relatively high-gold, low-copper occurrences, because copper and other base metals are leached at the surface and redistributed during oxidation of the abundant pyrite, and precious metals do not form extensive hypogene halos surrounding the ore bodies. However, altered areas that are locally mineralized may have sporadic anomalous amounts of Au, Ag, As, Sb, Pb, Bi, Hg, and possibly Te, Se, or Mo in advanced argillic rocks. Stream sediments analyzed by the semiquantitative spectrographic technique are most likely to show anomalous Ag, Pb, Bi, Ba, and possibly Mo above lower detection limits. Soils may show Ag, Pb, and Bi, but are less likely to show Ba or Mo. The most favorable fractions will vary with prevailing climatic and terrain conditions.

Geophysics has not contributed much to finding ore bodies of this type as far as I know, but much work done by private companies is not published. Detailed magnetic surveys are locally useful in determining the extent of argillic plus advanced argillic rocks under cover and down dip. Electrical methods of various types (resistivity and IP) are capable of detecting variations in character of sulfide mineralization in these areas, but unpredictable variations in abundance of clay and the ubiquitous pyrite make interpretation of results very difficult. Other methods (AFMAG, VLF) have been employed, at least in Nevada areas, but I do not know the results.

Selected References

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