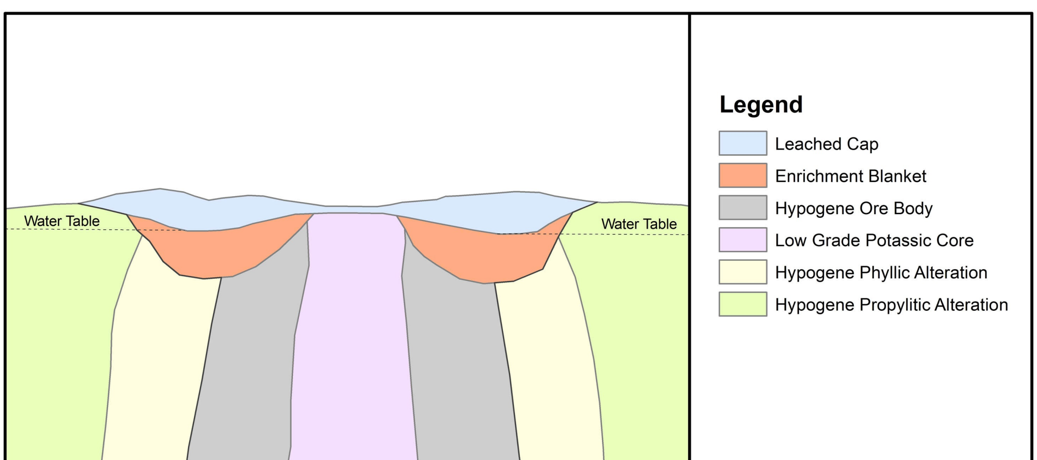
Supergene Enrichment - How Natural Processes have Transformed Low-Grade Copper Mineralization into Economic Ores

by David F. Briggs

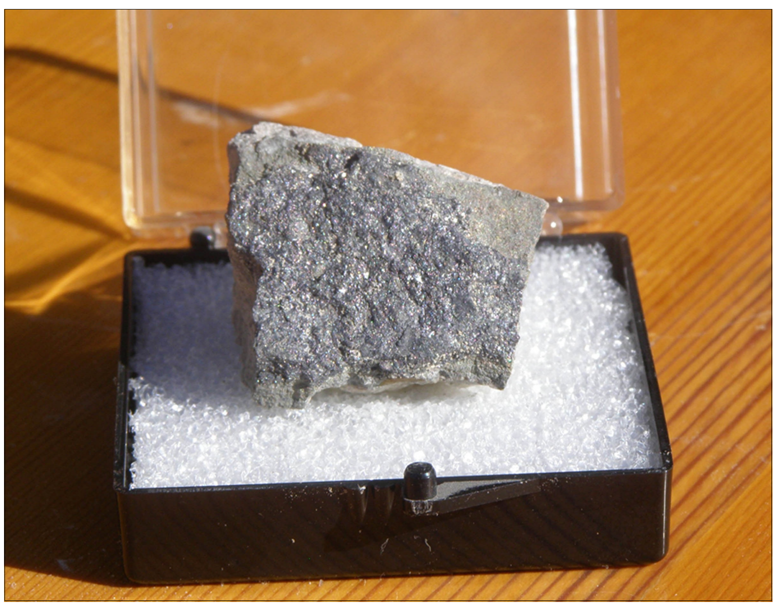
In “What is a Porphyry Copper Deposit?”, I discussed the general relationships of the primary alteration and mineralization that are found within porphyry copper systems. Also known as “hypogene” alteration and mineralization, these assemblages are produced by the circulation hydrothermal solutions (hot water) as a porphyry copper is formed at depth. Today’s article will discuss “supergene” alteration and mineralization assemblages, which are formed when these sulfide-bearing deposits are exposed to near-surface, oxidizing solutions (groundwater) as they are exhumed by erosion and exposed to weathering. The simplified cross-section shown below, represents a vertical slice (like cutting a slice of cake) through the shallow levels of an idealized porphyry copper system that has been exposed by erosion.



Simplifed Cross-Section through a Porphyry Copper System Showing Supergene/Hypogene Alteration and Mineralization (Modified from Guilbert and Park (1986)

Summarizing the primary (hypogene) alteration and mineralization observed in porphyry copper systems, the low grade potassic core is located at the center of the system. It is characterized by quartz, potassium feldspar, biotite and anhydrite with minor amounts of sulfide-bearing minerals. Phyllic alteration assemblages contain quartz and sericite with abundant pyrite and lesser amounts of copper-bearing sulfides. Chlorite, epidote and calcite with minor amounts of pyrite are typically found in the outer propylitic zone. Straddling the boundary between the low grade potassic core and the phyllic zone, the primary (hypogene) ore body contains chalcopyrite, bornite, and molybdenite (minor) with minor to moderate amounts of pyrite.

Located near the surface, the leached cap and enrichment blanket are features that form as a result of the oxidation and weathering of the sulfide-bearing minerals contained within a porphyry copper system. As these mineralized rocks are exposed to the elements, the sulfide minerals (i.e. pyrite, chalcopyrite, bornite) contained with the rocks are oxidized. During the oxidation process, any iron contained in these minerals is transformed into red, reddish brown, orange and yellow colored iron oxides, while the sulfur is combined with groundwater to produce a weak sulfuric acid solution. Any copper contained within the rock is dissolved by these acidic solutions, which percolate downward to the water table, where they encounter reducing conditions that allow the copper to precipitate out as chalcocite (a copper-bearing sulfide). Over time this action forms a thick, copper-rich, blanket-shaped zone, known as an enrichment blanket.



The Grayish Metallic Mineral is Chalcocite from Red Mountain in Santa Cruz County, Arizona (Photo taken by David Briggs)

Leached cap and the underlying enrichment blanket primarily occur above the primary ore body and phyllic zone due to the presence of copper sulfides and the relatively abundant amounts of pyrite within these zones. Ideally, enrichment requires a sulfide assemblage that contains more pyrite than copper sulfides, because the pyrite is the primary source for the acid required for their development.

The moderately to strongly fractured nature of these zones also permit the movement of supergene solutions downward through these zones. Leached cap and the enrichment blanket are generally thin or absent above the low grade potassic core and propylitic zone due to their low pyrite content and low fracture density.

The presence of abundant calcite (limestone or skarn) is not conducive for the development of enrichment blankets, because the calcite neutralizes any acid that may be formed by the oxidation of pyrite contained within these rocks. Similarly, the presence of calcite in the outer propylitic zone of alteration also inhibits its development in this area.

The absence of a well-defined enrichment blanket at the Rosemont deposit in Pima county, Arizona is due to the low total sulfide content of the ore and the presence of abundant calcite in the host rocks.

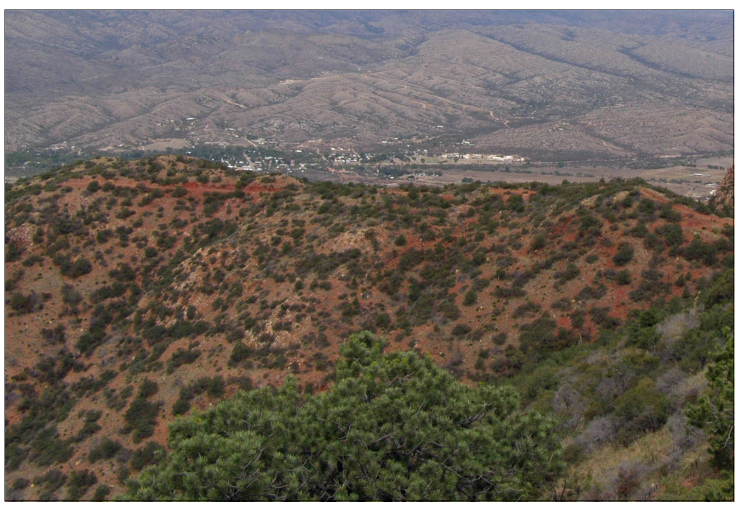
In rocks where the formation of acidic solutions does not occur due to the absence of pyrite or presence of neutralizing agents (i.e. calcite), the copper-bearing sulfides are oxidized in place to form ores containing green and blue copper oxides, like chrysocolla, malachite, azurite, atacamite and brochantite.

Azurite from Morenci mine, Greenlee County, Arizona (Photo taken by David Briggs)

The leached cap is typically characterized by a strongly oxidized, clay-altered rock, which ranges from 0 to 1,600 feet in thickness. Iron oxides are common, including hematite (red), goethite (brownish red), limonite (orange) and jarosite (yellow). Little copper remains within the leached cap.

Leached caps overlying many porphyry copper deposits form large, conspicuous color anomalies like the one, which is observed at Red Mountain near Patagonia, Arizona. This association makes them attractive exploration targets for drilling programs.

Strongly Oxidized Leached Cap at Bisbee, Arizona
(Photo taken by Jan Rasmussen, April 2005)



Strongly Oxidized Leach Cap Developed in Volcanics that Overlie the Porphyry Copper Deposit at Red Mountain, Santa Cruz County, Arizona
(Photo taken by David Briggs, October 2009)

Enrichment blankets at many porphyry copper deposits form large laterally extensive zones (up to 30-40 square miles) that typically range from 200 to 1,000 feet in thickness, but thin laterally to 10 to 100 feet. The enrichment blanket at the Chuquicamata deposit in Chile is reported to attain a thicknesses of up to 2,500 feet. The copper content of enrichment blankets generally ranges from two to eight times greater than the non-enriched primary sulfide mineralization (0.1 to 0.4% copper). Small very high-grade enriched zones, averaging 20% Cu, were mined at Morenci during the 1880s. Enriched sulfide ores are mainly composed of sooty to fine-grained chalcocite that coats and/or replaces pyrite and copper-bearing sulfides.

If it were not for the presence of large enrichment blankets at many of the world's porphyry copper systems, it would not be economical to mine the copper contained within these deposits. Much of the copper production from the world's major copper provinces in southwestern North America (i.e. Morenci, Ray, Cananea and La Caridad) and northern Chile (i.e. Chuquicamata, Escondida, El Teniente and Los Pelambres) has been and continues to be derived from the products of oxidation and enrichment.

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