Economic Geology
Vol. 97, 2002, pp. 1701–1740

Anatomy, Evolution, and Metallogenic Significance of the Supergene Orebody of the Cerro Colorado Porphyry Copper Deposit, I Región, Northern Chile

Farhad Bouzari† and Alan H. Clark

Department of Geological Sciences and Geological Engineering, Queen's University, Kingston, Ontario K7L 3N6, Canada

Abstract

The 51.8 Ma Cerro Colorado porphyry Cu(-Mo) deposit is situated at 20º 2' 41" S; 69º 15' 35" W at an altitude of 2,600 m a.s.l. on the Pacific slope of the central Andean Cordillera Occidental. Supergene processes at Cerro Colorado generated a complex weathering profile that attains a present depth of 450 m and incorporates the Cu orebody of ca. 228 Mt at 1.0 percent. The extant supergene profile comprises four facies: (1) Leached cap, underlying the Choja pediplain, a regionally extensive mid-Tertiary erosion surface; (2) Upper Supergene ore; (3) Lower Leached zone; and (4) Lower Supergene ore. Both the Leached cap and Lower Leached zone are mainly hematitic, implying chalcocite-rich precursors. The Upper Supergene ore is dominated by brochantite and atacamite with relics of chalcocite, but it includes a superimposed zone of abundant chrysocolla veins. Chalcocite, usually accompanied by supergene kaolinite and smectite, is the main ore mineral of the Lower Supergene ore, which overlies the 0.4- to 0.5-percent-Cu hypogene protore.

Dating of supergene alunite-group mineral separates from various ore facies and elevations by laser $^{40}Ar/^{39}Ar$ incremental heating reveals a supergene history extending over at least 20 m.y. Fifteen multistep age spectra for alunite, natroalunite, and jarosite yielded acceptable plateau dates, ranging from the earliest Oligocene, 35.26 ± 0.68 Ma, to the middle Miocene, 14.59 ± 2.46 Ma; five samples of alunite-natroalunite mixtures, however, produced staircase spectra with no direct age significance. Following hypogene mineralization in the middle Eocene, the deposit was probably unroofed at ca. 42 Ma, at the initiation of the Incaic orogeny in northern Chile. An age of 35.26 ± 0.68 (2σ) Ma for alunite associated with hematite in a clast in gravel overlying the Leached cap demonstrates that both formation and oxidation of a stage I chalcocite blanket had occurred by earliest Oligocene. During stage II (>35.26 ± 0.68 Ma to <22.42 ± 1.6 Ma), continued uplift and pedimentation caused leaching and thickening of the blanket, forming the surviving hematitic Leached cap and chalcocite-dominated Upper Supergene ore. Stage III (>21.49 ± 0.49 Ma to 19.25 ± 0.43 Ma) was initiated by the major Pehuenchean (Aymará) tectonic event, when rapid regional uplift and a drastic fall in the water table renewed intense leaching to form the Lower Leached zone. At this time the chalcocite blanket was thickened below the Lower Leached zone, generating the Lower Supergene ore, and oxidized above it to form the Cu oxide-dominated Upper Supergene ore. At 19.25 ± 0.43 Ma, an ignimbrite flow, up to 95 m thick, covered much of the deposit, temporarily interrupting supergene activity but imposing lateral ground-water flow through the lower 20 m of the ignimbrite and underlying supergene profile during stage IV. Oxidation was then reactivated, generating chrysocolla veins along northwest-trending fractures, which are inferred to be genetically linked to exotic mineralization in gravels below the ignimbrite 1.5 km north of the deposit. Further uplift and climatic desiccation in the middle Miocene, during stage V (<14.59 ± 2.46 Ma), terminated significant supergene processes and preserved the existing supergene orebody from lateral dispersion of metal.

Evidence from Cerro Colorado and elsewhere in northern Chile (e.g., Spence and Angelina) confirms that Paleocene to middle Eocene porphyry and allied Cu deposits experienced intense enrichment both in the late Eocene to early Oligocene and the late Oligocene to early Miocene. We argue that the establishment of a "proto-Humboldt Current" and the onset of the Incaic orogeny in the late Eocene provided a climatic and physiographic environment favorable for supergene enrichment of Cu deposits undergoing exhumation in the rain shadow of an uplifting terrain. Some of the earliest, upper Eocene, deposits emplaced along the Domeyko fault system (e.g., El Salvador) may similarly have been upgraded during the Incaic orogeny, but the main enrichment in the upper Eocene to lower Oligocene Cu deposits occurred during the late Oligocene to early Miocene, coinciding with formation of the Lower Leached zone at Cerro Colorado. The pyrite-rich hypogene assemblages of the giant deposits of the younger belt, e.g., Chuquicamata and Escondida, resulted in stronger and more rapid enrichment than in the relatively pyrite-poor older deposits, such as Cerro Colorado, despite the more protracted supergene histories experienced by the latter. The low enrichment rate of the Paleocene to middle Eocene deposits may also be attributed to the lateral copper loss during Oligocene pedimentation. Because the Upper Supergene ore at Cerro Colorado formed during the Oligocene tectonic quiescence following the Incaic orogeny, we propose a single Cenozoic supergene metallogenic epoch in northern Chile, ca. 20 or even 30 m.y. in duration, which attained its greatest efficacy in the early Miocene.

†Corresponding author: e-mail, farhad@geoladm.geol.queensu.ca