

## Geologic Evolution of the Escondida Area, Northern Chile: A Model for Spatial and Temporal Localization of Porphyry Cu Mineralization

JEREMY P. RICHARDS,<sup>†</sup>

Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta, Canada T6G 2E3

ADRIAN J. BOYCE, AND MALCOLM S. PRINGLE

Scottish Universities Research and Reactor Centre, Scottish Enterprise Technology Park, Rankine Avenue, East Kilbride G75 0QF, Scotland, United Kingdom

### Abstract

A program of geologic mapping and lithochemical and geochronological sampling has been carried out over a 745-km<sup>2</sup> area of the Atacama Desert surrounding the porphyry Cu deposits at Escondida, Zaldívar, and Chimborazo (Cordillera de Domeyko, northern Chile). The purpose of this study was to examine the regional tectonic and magmatic setting of this preeminent porphyry Cu district for evidence of features or processes that might explain the giant scale of mineralization at Escondida and provide predictive tools for exploration in other areas.

The geologic history of this area as recorded by exposed rocks begins with voluminous, intermediate to felsic Permo-Carboniferous volcanism (La Tabla Formation), and these rocks appear to constitute the crystalline basement throughout much of the porphyry belt of northern Chile. Geochemically, they are I-type in character, but the parental magmas were relatively dry, and thus did not generate effective magmatic-hydrothermal systems (few significant ore deposits are known to be associated with them).

Andean cycle arc magmatism began in the Triassic, centered on the La Negra magmatic arc (now located near the Chilean coast). Farther inland, near Escondida, back-arc processes led to the eruption of intermediate to felsic lavas and tuffs and the deposition of marine sediments in rift basins. Closure of these basins in the Late Cretaceous resulted in deformation of the volcano-sedimentary sequences and was followed by emplacement of small alkali gabbro stocks and dikes.

The axis of arc magmatism moved eastward in the Paleocene (Central Valley arc) and produced widespread calc-alkaline intermediate to felsic volcanism through to the Eocene. East- to northeast-directed convergence maintained a dextral transpressive regime during this period, and early movements in the West Fissure zone, a corridor of orogen-parallel faults that runs the length of the Cordillera de Domeyko (over 1,000 km), reflect this couple. At the end of the Eocene, however, stresses in the arc appear to have relaxed, and by the late Oligocene, strike-slip movement along the West Fissure zone had reversed to sinistral. This period of stress relaxation at the end of the Eocene period coincided with the voluminous emplacement of dioritic magmas at shallow crustal levels and also with porphyry development.

Six samples of hornblende from these diorites yield <sup>40</sup>Ar/<sup>39</sup>Ar dates between 38.28 ± 0.32 and 36.94 ± 0.46 Ma (2σ). Porphyry emplacement at Escondida, Zaldívar, and Chimborazo was coeval with this dioritic magmatism at ~38 Ma. Where plutonism was intense, the dioritic magma is interpreted to have evolved by processes of assimilation and fractional crystallization to more felsic compositions characteristic of the ore-forming porphyry intrusions. Whole-rock trace element data indicate that hornblende fractionation was an important control on chemical evolution of the diorites and attests to high-magmatic water contents (=4 wt % H<sub>2</sub>O). Volatile saturation would have occurred during further differentiation of these magmas, evidence for which is provided by the porphyry ore deposits.

Porphyry emplacement was localized within a broad zone of intersection between the West Fissure zone and a regionally extensive northwest-trending structural corridor (the Archibarca lineament). It is proposed that the geometry of this junction was conducive to the formation of transtensional pull-apart structures during relaxation or reversal of dextral shear on the West Fissure zone. Such dilational structures would have focused the ascent and pooling of magma in the upper crust and maximized the potential for formation of magmatic-hydrothermal ore deposits.

The formation of giant porphyry systems such as Escondida is, therefore, considered to be the result of a fortuitous coincidence of processes, including generation of suitable volumes and compositions of magma, appropriate lithospheric stress conditions, and structural focusing of emplacement; in addition, the development of thick supergene enrichment blankets has been critical to the economic value of these deposits. None of these contributory processes are in themselves unusual or rare, but because they are largely independent of one another, their constructive cooperation in ore formation is not necessarily repeatable at different places and at different times, thus explaining the relative rarity of giant porphyry deposits.