Characterization of the Diagenesis, Alteration, and Cu Mineralization in the Cretaceous Sedimentary Rocks of the Tordillos Deposit, Neuquén Basin, Argentina

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The Neuquén Basin hosts 21 red-bed type stratiform copper deposits in which mineralization is related to basin-scale fluid migration. The Tordillos deposit is one example, located in the northern sector of the Dorsal Huincul and hosted in the red-bed succession of the Cretaceous Neuquén Group. The Tordillos deposit has an estimated resource of 9.5 Mt at 0.42% Cu, with U (135-251 ppm) and V (250-980 ppm) anomalies. The mineralization occurs in fluvial channel facies of the Huincul Formation, where the originally red sandstones and conglomerates have been bleached. Bitumen impregnations are common in these bleached rocks. The red layers are preserved only in the less permeable rocks of the floodplain facies.

Pink, fine-grained sandstones owe their color to hematite coatings on quartz grains and micro inclusions of hematite inside calcite-1 cement. These rocks also contain kaolinite and thin barite (barite-1) rims on some sandstone grains. In contrast, in the bleached rocks hematite coatings are absent, bitumen coats detrital grains, authigenic minerals like kaolinite and calcite-I are partially to completely dissolved, and porosity is considerably enhanced (20 vol. %). New mineral precipitation includes: quartz overgrowths, smectite ± chlorite coatings that also replace detrital clasts, and early kaolinite, pore-filling pyrite and late poikilitic, white and gray calcite (2 and 3). In the western area of the deposit, Ba anomalies up to 2% correlate with the presence of coarse and tabular barite-2 crystals that fill the primary and secondary porosity and are cut by veinlets of barite-3. Calcite-2 and 3 show $\delta^{13}C_{PDB}$ (-11 to -7) and $\delta^{18}O_{PDB}$ (-13 to -10) values typical of an organic source. Quartz overgrowths, barite-2, and calcite-3 host abundant organic fluid inclusions with bluish and yellowish fluorescence. Aqueous fluid inclusions associated with organic fluid inclusions in quartz homogenized to temperatures between 91 and 120°C (n=19), their initial melting temperatures (between -35 and -9 °C) indicate the presence of $FeCl_2$ or NaCl–MgCl (n=4) and KCl (n=10), respectively, and their final melting temperatures ranged between -7 to -0.3°C.

The mineralization is epigenetic and fills the secondary porosity of the permeable and bleached rocks of the Huincul Formation. It consists of minerals of the chalcocite group with relict chalcopyrite and bornite, and supergene Cu-V-U minerals (covellite, brochantite > malachite, copper wad-tenorite and cuprite, chrysocolla, Cu-K Ba vanadates and urovanadates) always in contact with impregnations of bitumen. Chalcocite-spionkopite minerals have $\delta^{34}S$ values that range from -7.3 to -17.8. Peripheral to the mineralized layers, sandstones and conglomerates are cemented by Cu-smectite ± V-hematite.

The following features document a complex history for the formation of this deposit: 1) redox reactions occurred when the Huincul Formation acted as a petroleum conduit, causing dissolution of

grains and early authigenic minerals (hematite-barite1-calcite-1), and precipitation of new cements (calcite-2, clays, pyrite, and calcite-3), 2) the mixing of Ba-rich basinal water that migrated along with hydrocarbons, with interstitial sulfate-rich water caused the precipitation of barite-2, and 3) the late input of Cu chloride brines precipitated Fe-Cu and Cu sulfides at the expense of pyrite and BSR of sulfates. Andean tectonics during the Miocene triggered the breakdown of seals and upward flow of these multiple fluid pulses from underlying oil reservoirs through existing structures of the Dorsal de Huincul into the host Huincul Formation.