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Evolution of the Late Miocene – Early Pliocene Cu-Mo porphyry belt of the Andes between 31°-35°S.

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The belt of Miocene-Pliocene porphyry copper deposits of the Principal Cordillera of central Chile (31°-35°S) is economically the most important segment of the Miocene to Early Pliocene metallogenic belt of the Andes that extends for about 6,000 km [1]. The porphyry deposits were related to the development of the Farellones arc in the Principal Cordillera during crustal thickening due to compressive tectonics. The largest deposits were formed during the waning stage of this magmatic arc, representing its latest igneous activity. The earliest porphyry copper mineralization in the Principal Cordillera of central Chile was at ~15-14 Ma, when low-grade deposits were formed (<0.2% Cu), such as Novicio [2]; [3], Los Piches-Los Machos [4], and Paramillos Norte in Argentina [5]; [6]. The onset of porphyry mineralization coincides with an arc-normal compressive environment that lead to the initial development of a retro-arc, fold and thrust belt; the Aconcagua fold and thrust belt in easternmost Chile, but typically in westernmost Argentina [7]. This stage represents a marked eastward migration of deformation towards the eastern Principal Cordillera at that time, which has been attributed to a basal detachment of the orogen (thick-skinned) associated with a shallow detachment that affected the Mesozoic deposits on the easternmost western flank and the eastern flank of the Andes [7]. Volcanism along the Farellones arc was uninterrupted during this compressive tectonics, but the chemical signature of the volcanic rocks changed from a pyroxene-dominated to amphibole-dominated residual mineralogy of the magma source, compatible with thickening of the continental crust [8]; [9]. Farther north in the Maricunga area (27°S) at ~14-12 Ma the Marte, Lobo, Valy, El Volcán, and Escondido porphyry Au and Cerro Casale porphyry Cu-Au were formed as the crust thickened over shallowing portions of the Wadati-Benioff zone [8].

During the period from ~12-10 Ma porphyry Cu-Mo mineralization developed at Los Pelambres (31°43'S) [10] [11] and at Vizcachitas (32°25'S) [12], and El Altar and Cerro Mercedario prospects in Argentina [13] within the Farellones arc; these were formed at the time of continuation and eastward expansion of the thin-skinned tectonics of the Aconcagua fold and thrust belt in the back-arc area at 31°-32°S latitudes. This generated a low angle eastward-tapering wedge that was subjected to periods of frontal deformation and internal deformation in order to restore its critical angle [14].

During the period comprised between ~12 and 8 Ma plutonism associated with the Farellones arc expanded at least ~30 km to the east and the time-span from ~10 to 8 Ma corresponds to a profusion of porphyry Cu-Mo mineralization along the Farellones arc in the Principal Cordillera of central Chile and Argentina (tectonic expansion event in [15]). The porphyry prospects Amos, Pimentón, West Wall, El Plomo-San Manuel, Agua Amarga, Olla Blanca, Rosario de Rengo and Infiernillo, were formed during this time-span in Chile, and the porphyry prospects El Pachón, Andrés, Los Bagres, Piuquenes, Río de las Vacas, Cerro Bayo del Cobre, and y Diente Verde in Argentina [15]. In general, these deposits are characterized by relatively low copper grades (<0.7% Cu). This period coincides with the beginning of the uplift of the Cordillera Frontal in front of the Aconcagua fold and thrust belt in Argentina [14], and with the out- of- sequence thrusting and west-vergent back thrusts in the westernmost part of the Aconcagua fold and thrust belt, but also with the reactivation of steeply dipping faults along the axis of the Principal Cordillera with reverse and strike-slip motions (in Chile some of these faults have a westward vergency). Intrusive bodies were emplaced as sills within the Miocene volcanic sequence along NNW-trending reverse faults and intersections with dextral NE-trending faults. Volcanic activity of the Farellones arc continued at this time accompanied by crustal thickening [16] [9], but volcanic rocks of this age have been described only at the Aconcagua mountain [17] (32°40'S) and at the Teniente Volcanic complex [9] (34°S), suggesting restriction of volcanism at regional scale. At this time, the mountain range did not form an elevated topographic ridge. A peneplain surface, which is presently preserved at high altitudes, began to form extending over most of the western Principal Cordillera and cutting plutonic bodies emplaced at 8 Ma (i.e. La Gloria Pluton). This surface is covered by 4.9 to 4.0 Ma old of volcanic complexes that constrain its age between ~8 and 5 Ma [18] [19].

The period from ~7 to 4 Ma represents the end of the arc magmatism and the culmination of porphyry Cu-Mo mineralization in the Principal Cordillera of central Chile, with the development of the world-class deposits of Río Blanco-Los Bronces and El Teniente with high hypogene copper grades, as significant volumes of ore contain >1% copper. Reported resources plus production at El Teniente attain to 94 Mt Cu [20], and recent, deep drilling exploration at Río Blanco-Los Bronces expanded its copper resources to 150 Mt Cu; making it the largest porphyry copper deposits in the world. This metallogenic maximum is associated with arc-normal compression and waning of volcanism, except for the local Early Pliocene La Copa rhyolite complex at Río Blanco

[21]. The giant Río Blanco – Los Bronces and El Teniente porphyry Cu-Mo deposits are associated with Late Miocene to Early Pliocene felsic intrusives that were localized at intersections of NW- and NE-trending faults. These rocks have a chemical signature consistent with a garnet-dominated residual mineralogy at their magma source as a result of increased crustal thickness [9] [22]. Rapid surface uplift and mass wasting took place along the former Farellones arc [23] [14], leading to the rapid exhumation of Río Blanco-Los Bronces and El Teniente porphyry systems [24] [25]. In fact, the Río Blanco porphyry Cu-Mo orebody, was formed at a probable depth of ~2-3 km in association with an epizonal, multistage intrusive complex from 6.3±0.1 to 4.3±0.1 Ma according to U-Pb, $^{40}Ar/^{39}Ar$, K-Ar and Re-Os ages [21] [26], but it was rapidly unroofed before being covered by rhyolitic tuff deposits of the La Copa complex dated by K-Ar from 4.9±0.2 to 4.0±0.2 Ma [21] [26]. The waning stage of Pliocene igneous activity along the Farellones arc and the formation of giant Cu-Mo deposits preceded a 50 km eastward arc migration, to the currently active Southern Volcanic Zone of the Andes [9].

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