Zoned Base Metal Mineralization in a Porphyry System: Origin and Evolution of Ore-Forming Fluids in the Morococha District, Peru

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Porphyry-related base metal vein and replacement orebodies (i.e., Cordilleran polymetallic orebodies) are part of a large magmatic-hydrothermal system associated with the emplacement of several late Miocene porphyry intrusions and the formation of important Cu-Mo mineralization in the Morococha district, central Peru. The Cordilleran Zn-Pb-Ag-Cu veins overprint the giant Toromocho porphyry Cu-Mo deposit in the center of the district and display a typical concentric base metal zonation (Cu → Zn, Pb → Ag) covering large parts of the district (Fig. 1). In this contribution we aim to explore the origin and evolution of base metal ore-forming fluids in a porphyry system context and examine their genetic link with higher-temperature fluids that are characteristic for the development of porphyry-style orebodies. A novel district-scale fluid evolution model is proposed, based on results obtained from detailed alteration and ore petrography, fluid inclusion microthermometry and laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) microanalysis, and stable (O-H-C) isotope geochemistry of vein gangue minerals. Intermediate-density fluid inclusions that are found in porphyry quartz veins of the mineralized San Francisco stock are compared to fluid inclusions in Cordilleran polymetallic veins, sampled from representative locations in the district.

Fluids that produced the base metal ores are interpreted as cooled and evolved metal-rich, intermediate-density porphyry-type fluids. In early stages of Cordilleran base metal vein formation, these fluids have low salinities of ~2 to 5 wt % NaCl equiv, CO_2 contents of 3 to 10 mol %, and homogenization temperatures (T_h) of 340° to 380°C. They are similar to intermediate-density fluids documented in a porphyry quartz vein predating Cordilleran polymetallic mineralization. The fluid inclusions in the porphyry quartz vein have similar low salinities (3.0–3.8 wt % NaCl equiv) and low CO_2 contents (6.5–8 mol %), but higher T_h of ~410° to 420°C, compared to the Cordilleran fluids. During cooling of the porphyry-type intermediate-density fluids, the lithostatic pressure regime changed to hot hydrostatic. The fluids experienced pressure drop, boiled, and lost most of their CO_2. Salinity became moderate, and in some cases reached intermediate (~up to 16 wt % NaCl equiv) to typical brine values (34.7 wt % NaCl equiv). The magmatic fluids continued to cool under open-system conditions while precipitating enargite, tennantite-tetrahedrite, chalcopyrite, sphalerite, and galena. Upon cooling below 270°C, the fluids increasingly mixed with meteoric waters and precipitated abundant rhodochrosite and quartz, while following the boiling curve toward lower P-T conditions that correspond to a depth of 300 to 800 m beneath the paleowater table. These data record an evolution from initial relatively deep-seated (minimum depth of 2–1.5 km) precipitation of mesothermal quartz-pyrite and base metal sulfides to final epithermal deposition of carbonates and quartz at temperatures of 220° to 270°C, demonstrating progressive mineralization during exhumation. Oxygen, hydrogen, and carbon stable isotope compositions of Cordilleran polymetallic vein gangue minerals indicate that the hydrothermal fluids have a dominantly magmatic signature, and only get diluted by meteoric waters at cooling during the late carbonate stage.

Cordilleran fluids are either contracted high-density vapors that resulted from boiling of moderately saline magmatic fluids at depth, or directly exsolved low-salinity magmatic fluids. Fluid inclusion data, stable isotope evidence, and additional arguments disfavor diluted brines as origin. Decrease of Cu, S, Zn, Pb, and Mn concentrations of the Cordilleran fluid correlates with decreasing T_h at district scale. It is in good agreement with the overall paragenesis in the Morococha district showing mainly Fe, Cu → Zn, Pb → Ag, Mn sequences of mineral precipitation during the base metal and carbonate stage of ore formation. The new data can be used to explain the commonly observed base and precious metal zonation patterns encountered around porphyry Cu deposits (e.g., Bingham, Butte, USA), and show that both porphyry and polymetallic ores can precipitate from similar magmatic-hydrothermal fluid pulses.

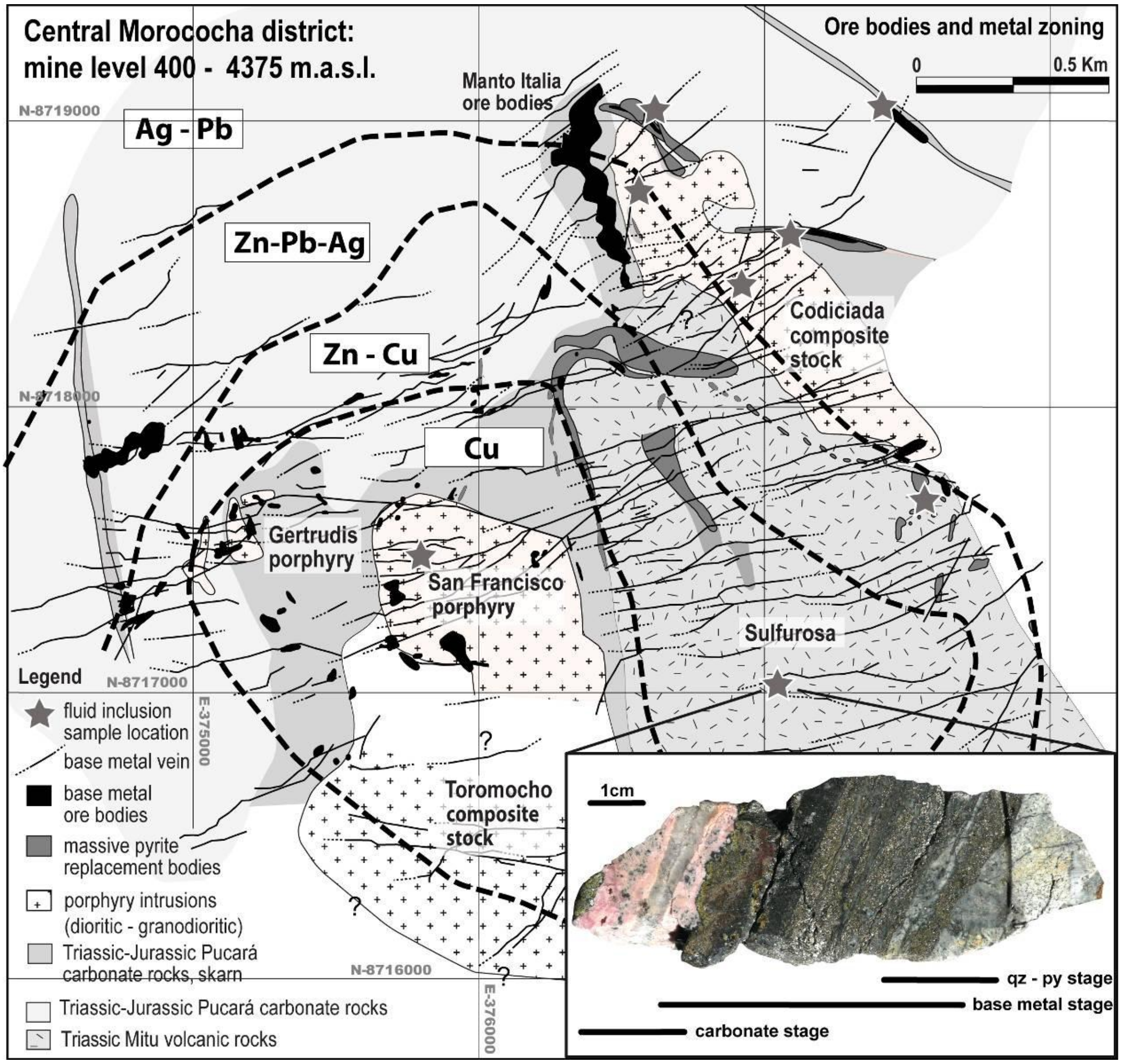

Fig. 1. Geologic map of mining level 400 (4,375 m.a.s.l.) showing the orebody distribution (compiled from multiple mining levels) in the central Morococha district. A metal zonation pattern is indicated by dashed lines. Fluid inclusion sample locations are indicated with star symbols. An example of a zoned Cordilleran base metal vein is presented with paragenetic stages. Compiled from geologic maps of the Cerro de Pasco Copper Corp. (1920–1960), Centromin Peru, and Pan American Silver Corp.