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The Miocene Morococha District, Central Peru – Large-Scale Epithermal Polymetallic Overprint on Multiple Intrusion-Centred Porphyry Systems

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ABSTRACT

In the world-class mining district of Morococha, epithermal polymetallic replacement bodies and veins overprint porphyry mineralisation and skarns related to subvolcanic intrusions of Miocene age, thus indicating ore formation in two different environments, separated in time or forming a continuum.

The district covers an area of about 70 km^2 in the north-western part of the Domo de Yauli complex in the Western Cordillera of central Peru and is part of the Miocene polymetallic belt, also hosting the deposits of Colquijirca (Bendezú *et al*, 2008b) and Cerro de Pasco (Baumgartner, Fontboté and Vennemann, 2008). Multiple late-Miocene porphyry stocks intruded Permian, Triassic-Jurassic and late-Cretaceous sedimentary carbonate and volcano-sedimentary formations, as well as large mid-Miocene barren intrusions (Figure 1). Extensive field work and detailed mapping of different styles of orebodies suggest that ore formation in the area was related to the late-Miocene magmatism. Good outcrop conditions and superimposing of different mineralisation styles make Morococha an ideal location for studying ore-forming processes in a complex porphyry-related magmatic-hydrothermal system in which porphyry-to-epithermal transition occurred.

Miocene magmatic activity in the area was started by the emplacement of the Anticona diorite intrusive of mid-Miocene age (14 Ma), dominating the north-western part of the district. There is no indication of mineralisation genetically related to it. In late-Miocene times (7 to 9 Ma) a series of porphyry intrusions (diorites, granodiorites to quartz-monzonites, normal calc-alkaline, medium to high-K in composition) intruded into the different sedimentary sequences as well as the Anticona diorite. The recently re-evaluated Toromocho porphyry Cu-Mo deposit (Figure 1) dominates the central part of the district and is associated with extensive potassic and phyllic alteration zones, affecting feldspar-porphyry, quartz-porphyry and granodiorite-porphyry intrusions. Additional (so far) subeconomic quartz-magnetite Au-bearing or Cu-Mo porphyry mineralisation and associated K- and Na-Ca- alteration zones have been identified in most of the other younger intrusions (eg Ticlio porphyry

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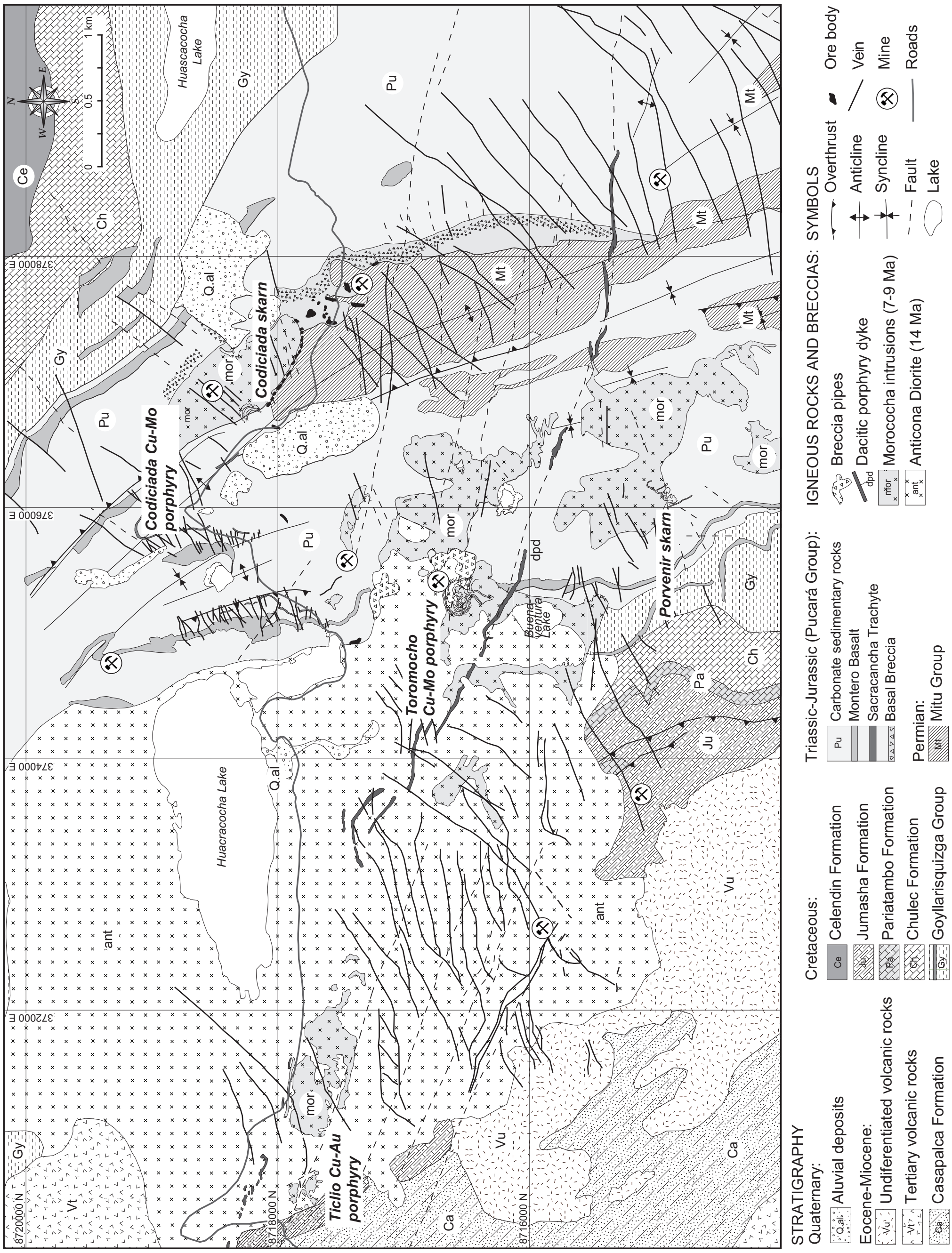

FIG 1 - Geological map of the Morococha district (from Bendezú *et al*, 2008a).

in the westernmost part of the district and Codiciada porphyry in the NE part; see Figure 1). The mineralisation in the latter consists of quartz-chalcopyrite, quartz-magnetite, quartz-pyrite-molybdenite or quartz-pyrite stockworks (Figure 2, Bendezú *et al*, 2008a). Massive magnetite-serpentine exoskarns and diopside-garnet endoskarns, partly hydrated to epidote, amphibole and chlorite, often bearing polymetallic mineralisation, are found where mainly Jurassic dolomitic carbonates of the Pucará Group are in contact with porphyry intrusions (eg Codiciada and Porvenir skarns in Figure 1).

Recent U-Pb and Ar/Ar dating (Beuchat, 2003; Kouzmanov *et al*, 2008) indicates that the magmatic and associated hydrothermal activity in the different parts of the Morococha district took place over a protracted period of at least two million years. Thus, the particularly high abundance of various economic orebodies in the district most probably results from the spatial superposition of multiple late-Miocene magmatic and associated hydrothermal events, which seems to be one of the main factors controlling the formation in the giant porphyry-related ore deposits (Gustafson *et al*, 2001).

A particular feature of the Morococha district is the overprinting of porphyry systems by a later district-scale polymetallic epithermal mineralising event (Figure 2). The following main mineralisation styles post-date the porphyry ore formation at Morococha (Catchpole *et al*, 2008):

- massive pyrite-quartz bodies,
- polymetallic replacement bodies, and
- epithermal polymetallic veins.

Pyrite-quartz bodies with phyllic alteration halos are found in the fringe areas of certain intrusives and/or as replacements of previously formed breccia zones such as in the base of the Pucará Group

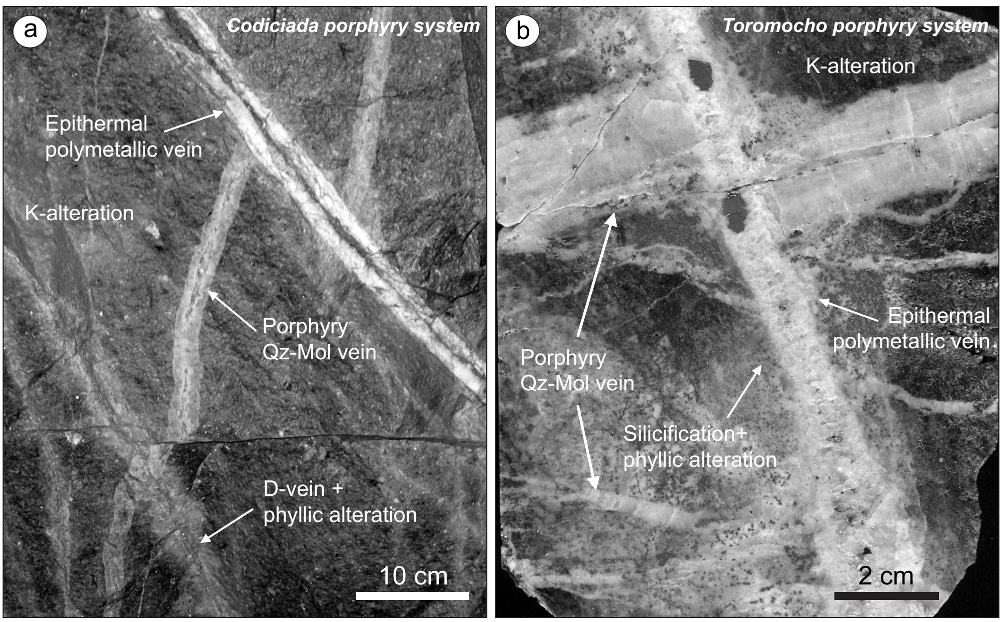

FIG 2 - Porphyry-epithermal transition in the Morococha district: (A) Codiciada porphyry system: porphyry quartz-molybdenite vein cutting K-altered microdiorite and cut by porphyry 'D' vein with phyllic alteration halo. Later carbonate-bearing epithermal polymetallic vein cross-cut and offsets the porphyry veins; (B) Toromocho porphyry system: early-stage quartz-molybdenite porphyry vein cross-cut and offset by quartz-bearing epithermal polymetallic vein with strong silicification and phyllic alteration halo.

just overlying the Permian Mitu Group (Figure 1). Polymetallic bodies occur mainly as skarnified beds of particular horizons of limestones within the lower units of the Pucará Group and replacement of tectonic breccias, in part along overthrust planes, within the Pucará Group. The pyrite-quartz bodies frequently host polymetallic orebodies fed by polymetallic veins. The replacement bodies range in composition from magnetite, chalcopyrite, sphalerite, and galena-bearing, pyrrhotite and pyrite-dominated to quartz-carbonate-sulfosalts bodies. In the central area mostly subvertical Cu-rich tube-like bodies located at the rim area of the San Francisco intrusive were exploited in the early 20th Century, providing rich chalcopyrite, fahlore and enargite ores. Steeply dipping epithermal Zn-Pb-Ag-Cu-bearing veins with phyllic alteration halos have historically constituted, economically, the most important ore type in the Morococha district. They are fault-controlled and belong to two main systems:

1. normal dextral or sinistral faults striking N60-80, and
2. normal dextral faults striking N20-30.

Field evidence suggests that the N60-80 system predates the N20-30 one. Both systems are enriched in base-metals, whereas the N60-80 has higher contents in quartz and pyrite. The polymetallic vein system cutting all previously described orebody types is the latest mineralising event in the district. Individual veins can reach up to 2 km in length. Their vertical extension exceeds one kilometre, ranging from altitude of about 5100 m at the highest points of the district to the lowest mine levels at 4000 m.

District-scale zonation consists of Cu-rich central part, dominated by chalcopyrite, tennantite, enargite and Cu-Sn-bearing sulfide and sulfosalt mineralisation, with transition towards Zn-Pb rich veins in the external parts of the district, as the importance of sphalerite, galena and Mn-bearing minerals increases. The highest sulfidation-state of the corresponding mineralising fluids is reached in the central part of the Morococha district.

The elaborated detailed temporal and paragenetic sequence of the above described mineralisation styles served as a basis for further geochemical analyses. A combined fluid inclusion and stable isotope (C, O, S) study on carbonate-hosted epithermal veins in the distal south-western part of the Morococha district reveals temperatures of ore-formation in the range 240 - 270°C from low to moderate-salinity fluids of mixed magmatic-meteoric origin. In contrast, preliminary fluid inclusion data on epithermal polymetallic veins hosted by a porphyritic stock in the Codiciada area in the NE part of the district (Figures 1 and 2a) indicate ore-formation at temperatures as high as 370°C, from intermediate-salinity fluids and progressive mixing with cooler and low-salinity fluids, most probably of meteoric origin. Sulfur isotopes indicate magmatic origin of the sulfur (-3 to +5‰) in the different types of orebodies, in agreement with previously reported data for the Morococha district (Petersen, 1972; Moritz *et al*, 2001).

Ongoing parallel studies of geochemical parameters of ore-formation in different parts of the Morococha district, including porphyry and epithermal (to mesothermal) environments, in combination with high-precision U-Pb and Ar/Ar dating of the different mineralising events, aim to construct a geological and geochemical model for the temporal, geochemical and space evolution of this large and complex magmatic-hydrothermal system that was active for more than two million years.

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