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Porphyry-related base metal mineralisation styles in the Miocene Morococha district, central Peru

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The Morococha district is part of the Miocene Polymetallic Belt of central Peru. It has been a centre of Ag and Cu mining since pre-colonial times and during the last century became also an important Zn and Pb producer. The district hosts multiple barren and mineralised (Cu-Mo) porphyries of Miocene age intruded into volcanic and sedimentary sequences. Porphyry mineralisation is overprinted by several styles of epithermal mineralisation including polymetallic veins and replacement ore bodies, and massive pyrite-quartz bodies (Fig. 1). Good outcrop conditions and superimposing of different mineralisation styles make Morococha an ideal location for studying the ore-forming processes in a complex porphyry-related magmatic-hydrothermal system. The aim of the present study is to characterise the different mineralisation styles formed from porphyry to shallow epithermal environment.

The geology of the district comprises volcanic sequences of the Permian Mitu Group, overlain by Triassic to Jurassic carbonates of the Pucará Group, including basalt-flow intercalations such as the Montero Basalt, and, mainly in the western part, by Cretaceous carbonate sedimentary sequences.

Miocene magmatic activity in the area started by the emplacement of the Anticona diorite intrusive of mid-Miocene age (14 Ma) dominating the south-western part of the district. There is no indication of mineralisation related to it. In Late Miocene times (7-9 Ma) a series of porphyry intrusions (diorites, granodiorites to quartz-monzonites in composition) intruded the different sedimentary sequences as well as the Anticona diorite. Most of these intrusions are barren, but some of them share features with typical porphyry Cu systems. The world-class Toromocho porphyry Cu-Mo deposit dominates the central part of the district and is associated with extensive potassic and phyllic alteration zones, affecting feldspar-porphyry and quartz-porphyry intrusions. The porphyritic stocks Potosí, San Francisco and Ticlio show K- and/or Na-Ca-alteration with associated porphyry-style mineralisation, including quartz-chalcopyrite, quartz-magnetite, quartz-pyrite-molybdenite and quartz-pyrite veinlets (Bendezú et al., 2007). 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.

Following main mineralisation styles post-date porphyry ore formation in the Morococha district: (a) massive pyrite-quartz bodies (b) polymetallic replacement bodies (c) epithermal polymetallic veins. Pyrite-quartz bodies with phyllic alteration halos are found in the fringe areas of certain intrusives and/or as replacement of previously formed breccia zones such as in the base of the Pucará Group just overlying Triassic volcanics. Polymetallic bodies occur mainly as a replacement of tectonic breccias, in part overthrust planes, within the Pucará Group, and skarnified beds of particular horizons of limestones within the lower units of the Pucará Group (e.g. Manto Italia, Fig. 1). The pyrite-quartz bodies frequently host polymetallic ore bodies fed by polymetallic veins (e.g. Brecha Rosita, Fig. 1). The replacement bodies range in composition from magnetite, chalcopyrite, sphalerite, and galena-bearing, pyrrhotite- and pyrite-dominated bodies to quartz-carbonate-sulphosalts bodies. In the central area mostly sub-vertical 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 are hosted by NNE to ENE trending structures and cut at district scale the intrusive bodies, surrounding sediments, skarn, as well as pyrite-quartz and polymetallic ore bodies (Catchpole et al., 2007). Their vertical extent exceeds 1km, ranging from altitude of about 5100m at the highest points of the district to the lowest mine levels at 4000m. Three zones are well distinguished within the veins. A (i) quartz-pyrite rich zone with arsenopyrite, Fe-rich sphalerite and pyrite with inclusions of pyrrhotite, galena, chalcopyrite, and minor amounts of Bi-Ag-sulphosalts, stannite, scheelite, huebnerite and bismuthinite, is usually followed by a (ii) Cu-sulphosalt - sphalerite - galena zone, including economically important Ag-bearing minerals of the fahlore group, as well as huebnerite, and finally (iii) a Mn-rich zone with abundant quartz and rhodochrosite, and in minor quantities rhodonite, pyrite, fahlore and alabandite with inclusions of native Te and Ag-tellurides. Cu values in the polymetallic veins increase from Zn-Pb rich veins in external parts towards the central parts of the district, as the importance of sphalerite, galena and Mn-bearing minerals decreases, while that of chalcopyrite, tennantite, enargite, and Cu-Sn-bearing sulphides and sulphosalts increases, indicating a higher sulphidation-state of the corresponding mineralising fluids in the central part of the Morococha district. Epithermal polymetallic veins and replacement ore bodies are the economically most important polymetallic ore body types in the district.

A temporal sequence of above described mineralisation styles is documented by crosscutting relationships and mineral assemblages in the Codiciada area (Fig. 2), representative for the different mineralisation styles observed in the Morococha district as a whole. We use this sequence as a basis for further geochronological, mineralogical, stable isotope and fluid inclusion studies which are in progress.

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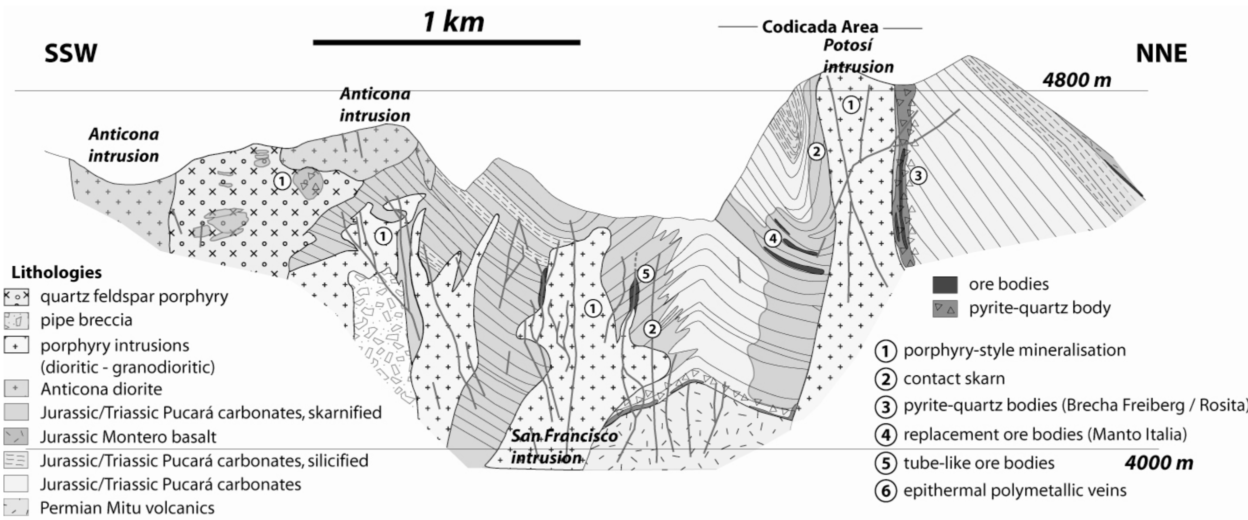

Figure 1: Schematic cross-section through the Morococha district including lithologies and mineralisation styles (vertically exaggerated, southern section modified after Leon, 2006, based on geological maps from the Cerro de Pasco Copper Corporation; northern section modified after geological maps from the Pan American Silver Corporation).

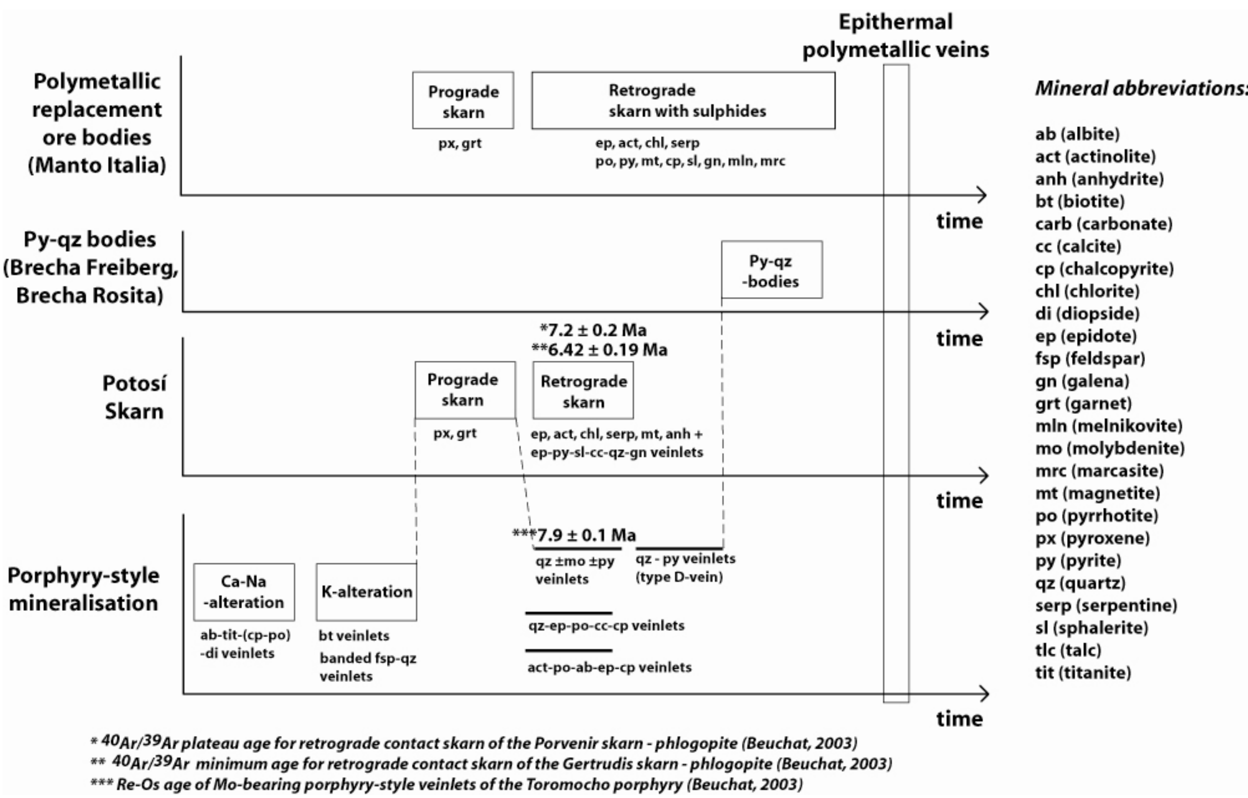

Figure 2: Relative temporal relationship of mineralisation styles in the Codiciada area in the north of the Morococha district; published age data (Beuchat, 2003) from the Morococha district are included**.**