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MIOCENE MAGMATISM AND RELATED PORPHYRY AND POLYMETALLIC MINERALIZATION IN THE MOROCOCHA DISTRICT, CENTRAL PERU

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Introduction

The Morococha mining district displays a complex magmatic and hydrothermal history where several intrusive events and spatially associated mineralization and alteration styles are recognized. At least nine main intrusions forming several magmatic clusters and four ore body types occur in the district: porphyry style mineralization, massive pyrite-quartz bodies, polymetallic replacement bodies, and polymetallic veins crossing the entire district. Porphyry mineralization and alteration are restricted to the vicinity to certain intrusions, whereas replacement bodies and polymetallic veins do not seem to show any spatial relationship to a particular intrusion. The different porphyry systems display contrasting mineralization styles and associated alteration patterns and thus represent a good opportunity to study the variety of factors controlling ore formation in such systems.

Geological background

The historical mining district of Morococha is part of the Miocene Belt of the Andes in central Peru. It is located 150 km east of Lima and covers an area of about 70 km^2. The geology of the district consists of continental volcanic rocks and red beds of the Mitu Group (Permian), sedimentary carbonate, volcanic rocks and basalts of the Pucará Group (Triassic-Jurassic), Goyllarisquizga Group, and Chulec, Pariatambo, Jumasha and Celendin Formations (Late Cretaceous), cut by Miocene intrusions with different ages. The oldest intrusion (14.1 Ma; Beuchat, 2003, Kouzmanov et al., 2008) covering large area in the western part of the district is known as Anticona diorite. The Anticona diorite does not show any direct relationship with the Miocene mineralization, which is related to the emplacement of numerous younger intrusions of Late Miocene age (7-9 Ma; Beuchat, 2003, Kouzmanov et al., 2008) – the Potosí, San Francisco, Gertrudis, San Nicolas, Yantac, San Miguel and Ticlio stocks. The whole district is cut by dacitic dykes trending N100°-120° which are probably the last magmatic event that occurred in the studied area, predating the polymetallic mineralization.

Characteristics of mineralization styles

Porphyry style alteration and mineralization are recognized in three areas (Fig. 1): (1) the Toromocho porphyry Cu (-Mo) deposit in the central part of the district (marked by the dotted red line); (2) the Potosí stock in the north-eastern part, and (3) the recently discovered Ticlio porphyritic stock in the westernmost area. Only the latter two are included in this study. Other mineralization styles known in the Morococha district include the following: (a) endo- and exoskarns associated with the intrusions; (b) epithermal pyrite-quartz bodies found in the fringe areas of certain intrusions and/or as replacement of previously formed breccia zones at the contact between the Pucará limestones and the volcanic rocks of the Mitu Group; (c) epithermal polymetallic bodies (“mantos”) with strong lithological control, hosted by the Pucará limestones as replacement of breccia zones and/or specific horizons; (d) epithermal polymetallic veins.

Detailed mapping and field reconnaissance study allowed defining the relative timing of the intrusion emplacement, the mineralization stages in the Codiciada and Ticlio porphyries, and the formation of polymetallic ore bodies, postdating the porphyry mineralization. Figure 2 summarizes the field results for the time relationships including published age data.

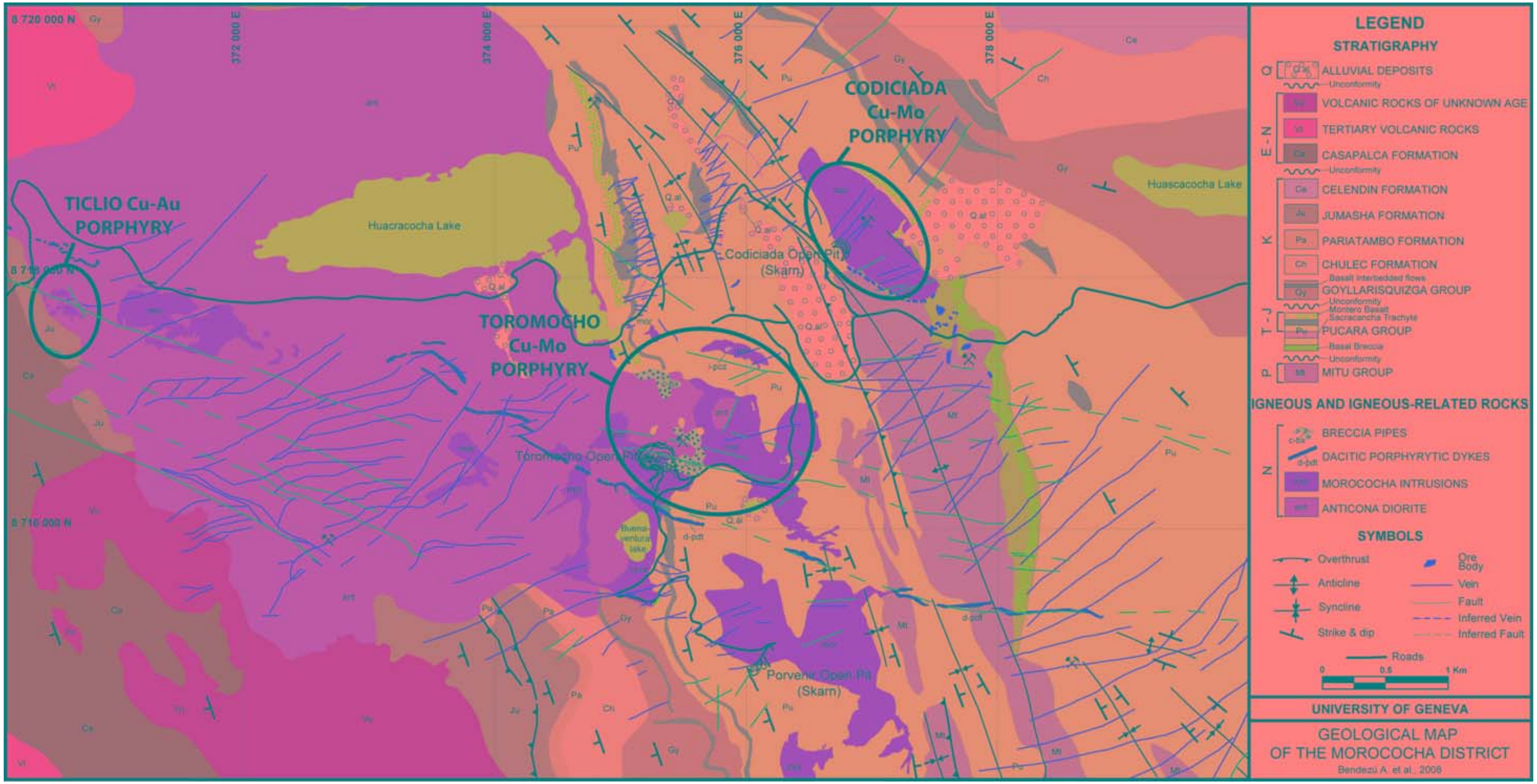

Figure 1: Geological map of the Morococha district (based on Nagell, 1960; Alvarez, 1999; Bendezú, 2007 and maps provided by Pan American Silver Corp.).

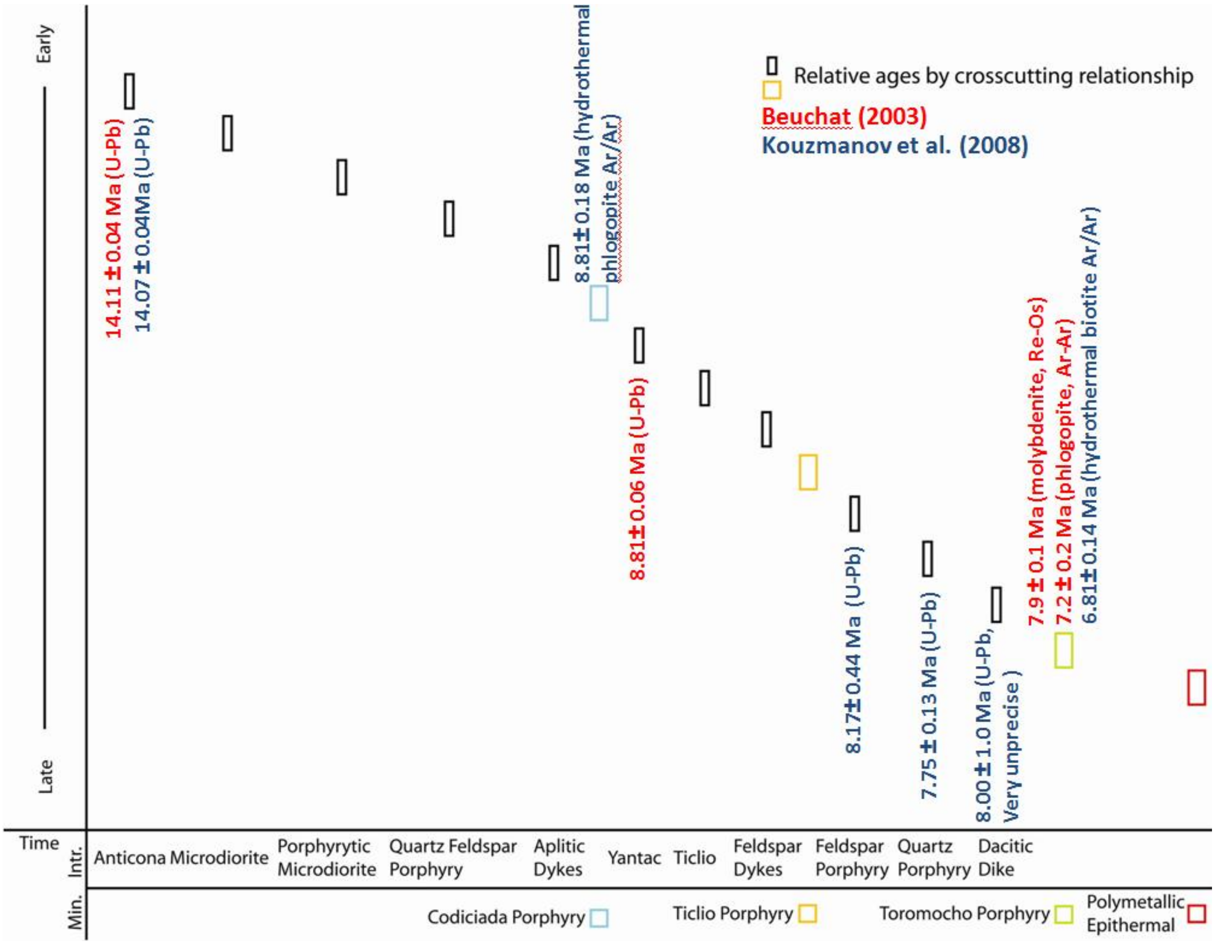

Figure 2: Relative ages of intrusions, porphyry and epithermal polymetallic ore deposits.

The *Codiciada Cu-Mo porphyry system* comprises an igneous suite of microdiorite, porphyritic microdiorite, quartz-feldspar porphyry, and amphibole-biotite porphyry intrusions. Combined XRF and LA-ICP-MS trace element analyses of intrusions in the Codiciada area allow constraining the petrochemical signatures of these rock units. Displayed negative Nb, Ta, and Ti anomalies are indicative for magmatic arc setting (Fig. 3a). Chondrite-normalized REE patterns show weak negative Eu anomalies suggesting minor plagioclase fractionation, probably at shallow crustal levels. Intra-HREE fractionation (e.g. Dy/Yb) suggests a combination of hornblende and garnet fractionation in the magma source (Fig. 3b). The rocks consistently display Sr contents >600-700 ppm and Y contents <18 ppm allowing their classification as adakite-like (Fig. 3c). This is consistent with initial evolution of the magma at the base of a thickened continental crust (e.g. Chiaradia et al. 2004). The alteration styles in this system consist of pervasive Na-Ca, selective pervasive potassic and phyllic alterations, as well as silicification. Porphyry style veinlets are quartz-pyrite-chalcopyrite±pyrrhotite, quartz-molybdenite and quartz-pyrite-sericite in composition. Molybdenite, chalcopyrite and pyrite, occur in much lower quantities, disseminated in the altered rock (Fig. 4).

The newly found *Ticlio Cu-Au porphyry prospect* is a single granodiorite intrusion showing a pronounced zonation pattern with respect to mineralization and alteration. Its central part is characterized by the occurrence of high-density quartz-magnetite±K-feldspar stockwork (Fig. 5a). The zone rimming the core shows strong K-feldspar alteration with low-density magnetite and quartz-magnetite veining (Fig. 5b). This zone hosts small amounts of chalcopyrite and bornite as disseminations and in veinlets. Native Au is observed as small inclusions in chalcopyrite (Fig. 5c). The peripheral parts of the system show weak biotite, K-feldspar and actinolite alteration, as well as weak chalcopyrite and pyrite mineralization. The most distal part of the porphyry system is characterized by weak propylitic alteration (Fig. 5d).

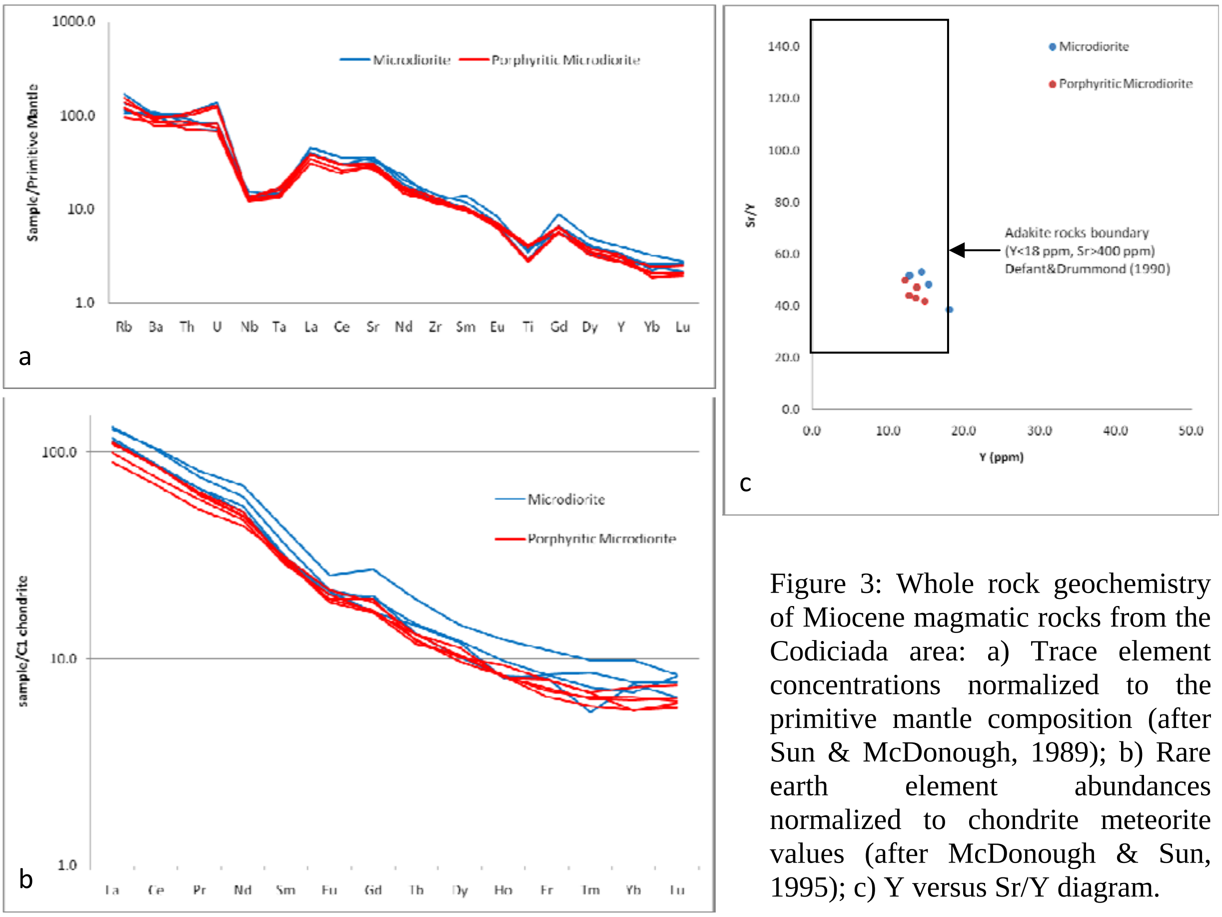

Figure 3: Whole rock geochemistry of Miocene magmatic rocks from the Codiciada area: a) Trace element concentrations normalized to the primitive mantle composition (after Sun & McDonough, 1989); b) Rare earth element abundances normalized to chondrite meteorite values (after McDonough & Sun, 1995); c) Y versus Sr/Y diagram.

Structural control in the Codiciada area

A large number of veins, veinlets, and fractures were analyzed in the field. The porphyry quartz-molybdenite and quartz veinlets dip steeply, trending from N 110° E to N 150° E. Their orientation suggests that these veins are possibly structurally related to the emplacement of quartz-feldspar porphyry dykes found in the Codiciada area and showing the same trend.

The late porphyry-stage pyrite-quartz-sericite veinlets, ranging from 1 mm to 1 cm in thickness, cut the quartz-molybdenite veins. These veinlets show, a not well defined N 70° E orientation and dip from 80° to 90° NW-SE. This style of veining is well developed inside the intrusions.

The epithermal polymetallic veins are the economically most important ore type in the Morococha district. They are fault-controlled and belong to two main systems: (a) normal dextral or sinistral faults striking N60-80, and (b) normal dextral faults striking N20-30. Field evidences suggest 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 veins cutting all previously described ore body types are the latest mineralizing event in the district. Individual veins can reach up to 2 km in length. Polymetallic mineral association (e.g., galena, sphalerite, chalcopyrite ± quartz and carbonates) can be found as well in some re-open N 70° E trending pyrite-quartz-sericite porphyry veinlets.

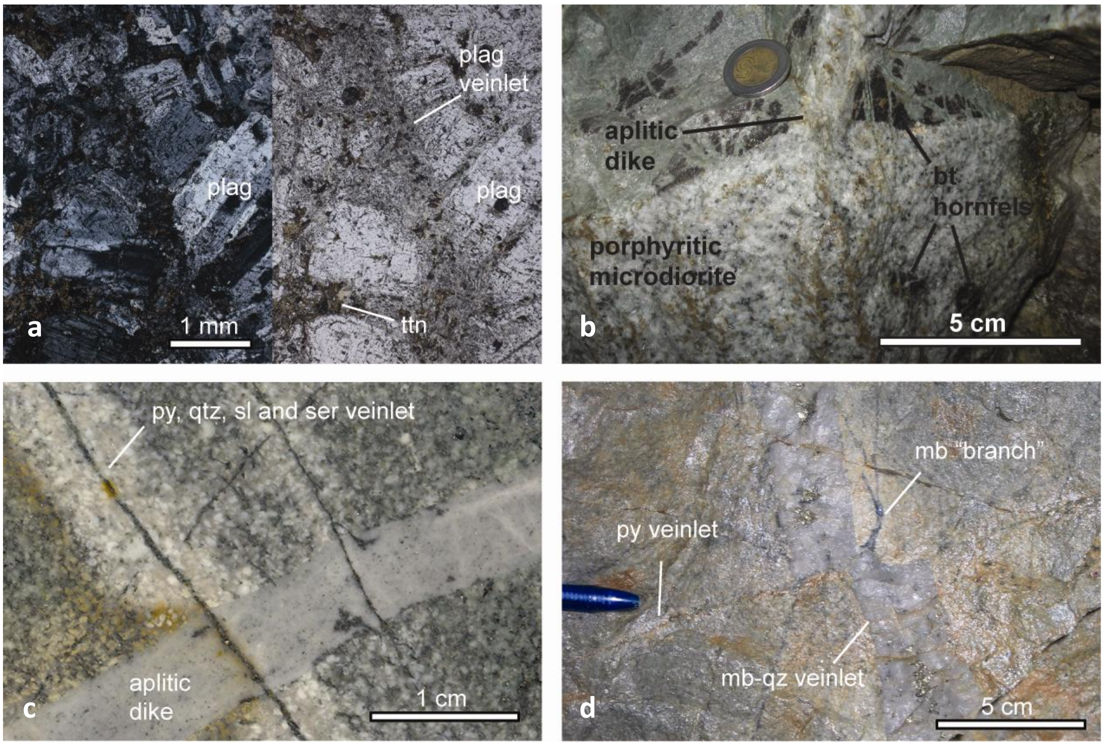

Figure 4: Codiciada porphyry: a) Na-Ca alteration-related vein-like structure in the microdiorite (xN and //N); b) Hydrothermal biotite patches in porphyritic microdiorite; c) Pyrite, quartz and sphalerite veinlets with sericite halo cutting microdiorite and aplitic dike; d) Quartz-molybdenite vein cut by pyrite veinlet (*Abbreviations:* plag: plagioclase, ttn: titanite, bt: biotite, py: pyrite, qtz: quartz, sl: sphalerite, ser: sericite, mb: molybdenite).

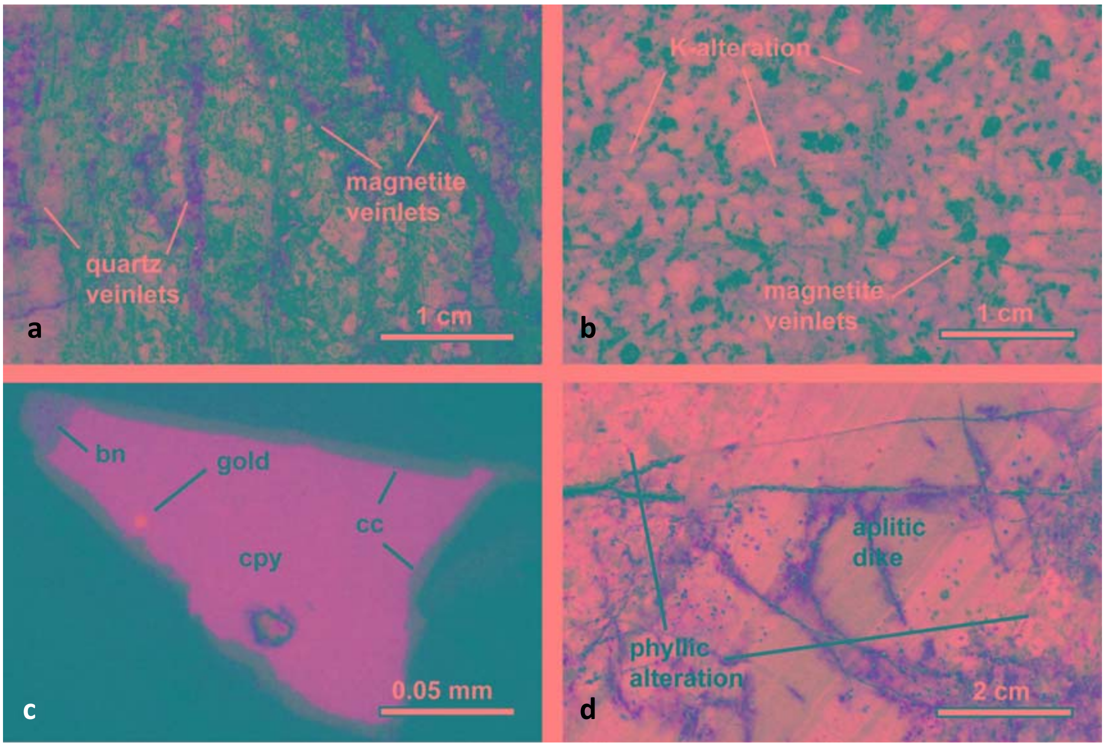

Figure 5: Ticlio porphyry: a) Quartz and quartz-magnetite stockwork; b) Strong potassic alteration in groundmass; c) Gold grain in chalcopyrite rimmed by bornite and chalcocite (reflected light microscopy); d) Strong phyllic alteration assemblage replacing magmatic feldspar and groundmass (*Abbreviations:* bn: bornite, cpy: chalcopyrite, cc: chalcocite).

Conclusions

- The Ticlio (Cu-Au) and Codiciada (Cu-Mo) porphyries show differences in their alteration and mineralization styles. In the central part of the Ticlio porphyry the alteration is represented by strong silicification with moderate to strong magnetite veining. This core zone is rimed by strong K-feldspar alteration grading towards an outer zone of secondary biotite and K-feldspar. In contrast, the Codiciada porphyry has a core of strong Na-Ca alteration and scarce clusters of silicification related to quartz veinlets while in the peripheral zones a weak secondary biotite alteration is developed. In both cases phyllic and argillic alteration is weak and is restricted to small areas or along the polymetallic veins.

- The earliest porphyry veinlets strike N120° on average. This orientation is similar to that of dacitic dykes crosscutting the entire district, suggesting a temporal association. Pyrite-quartz-sericite veinlets show a less defined N70°E orientation. The late epithermal polymetallic veins strike N20°-30° and N60°-80°. The latter are hosted by dextral-sense strike-slip and normal faults; they cut all alteration and veining styles related to the porphyries.

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