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Unveiling the hydrothermal mineralogy of the Chapi Chiara gold prospect, Peru, through reflectance spectroscopy, geochemical and petrographic data

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ABSTRACT

Southern Peru contains important epithermal Au–Ag (±base metals) deposits, such as Canahuire, Tucari, Santa Rosa, Caylloma, Shila and Paula. The Chapi Chiara gold prospect is located in this region and is part of a paleo-stratovolcano of the Upper Miocene–Pliocene. The hydrothermal alteration of the prospect was characterized based on spectroradiometric data, geochemistry and petrography. The mineralogical data, interpreted based on reflectance spectroscopy, were spatialized using the sequential indicator simulation technique for producing probabilistic maps of alteration. The inner part of the paleo-stratovolcano (SW sector) is marked by three main cores of advanced argillic alteration (AAA) (quartz–alunite supergroup minerals–kaolinite–dickite ± topaz ± pyrophyllite ± diaspore) associated with topographic highs. The AAA1 core is surrounded by argillic alteration (quartz–illite–paragonitic illite–smectite ± pyrite) and propylitic alteration (quartz–plagioclase–chlorite–calcite–epidote–smectite ± kaolinite ± pyrite ± chalcopyrite ± magnetite). The central sector of the prospect, situated in the NE flank of the paleo-stratovolcano, is characterized by hydrothermal breccias structured towards N65E. The main mineral phases comprise quartz and abundant pyrite, sometimes with traces of As. Anomalous geochemical values of Ag, As, Bi, Hg, Se, Sb and Te coincide with high gold contents in this sector of the prospect. Jarosite and goethite are evidence of a subsequent supergene event. Based on the mineralogical characterization, we conclude the existence of a high sulfidation epithermal system in Chapi Chiara. Hypogene minerals of higher temperature in the SW sector of the prospect, such as diaspore, pyrophyllite and topaz in the AAA zone, and epidote in the propylitic alteration zone, can reveal that the system is currently in a relatively deep erosion level, suggesting its proximity in relation to the interface between a deep epithermal system and a mesothermal system.

1. Introduction

Peru is characterized by a series of metallogenetic belts oriented parallel to the Andean Cordillera. These belts were formed in metallogenetic times ranging from Paleozoic to Cenozoic (de la Cruz, 1998). The origin of the mineralization is due to orogenesis associated with the formation of the Andean Cordillera which, in turn, favored the occurrence of metallogenetic processes for the concentration of metals, with the formation of deposits such as the epithermal- and porphyry-type ones (Clark et al., 1990).

The belts responsible for most of the Peruvian gold production are the Epithermal Au–Ag Belt of Miocene, which crosses the entire cenozoic volcanic domain of the Western Cordillera, and the Epithermal Au–Ag Belt of Miocene–Pliocene, restricted to the south-central part of the Peruvian Cordillera (12°30′S–18°00′S) (Fig. 1A) (Acosta et al., 2008; Carlotto et al., 2009; Quispe et al., 2008).

In southern Peru, magmatism and metallogenetic belts were controlled by NW–SE, E–W and N–S fault systems. The epithermal Au and/or Ag (±base metals) deposits are characterized by ages between ~18 and ~4 Ma. Examples of low to intermediate sulfidation deposits include Caylloma (~18 Ma—Echavarria et al., 2006), Selene (~14 Ma—Acosta et al., 2008; Palácios et al., 2004), Shila and Paula (~10 Ma—Cassard et al., 2000; Chauvet et al., 2006), Arcata (~5 Ma—Candiotti

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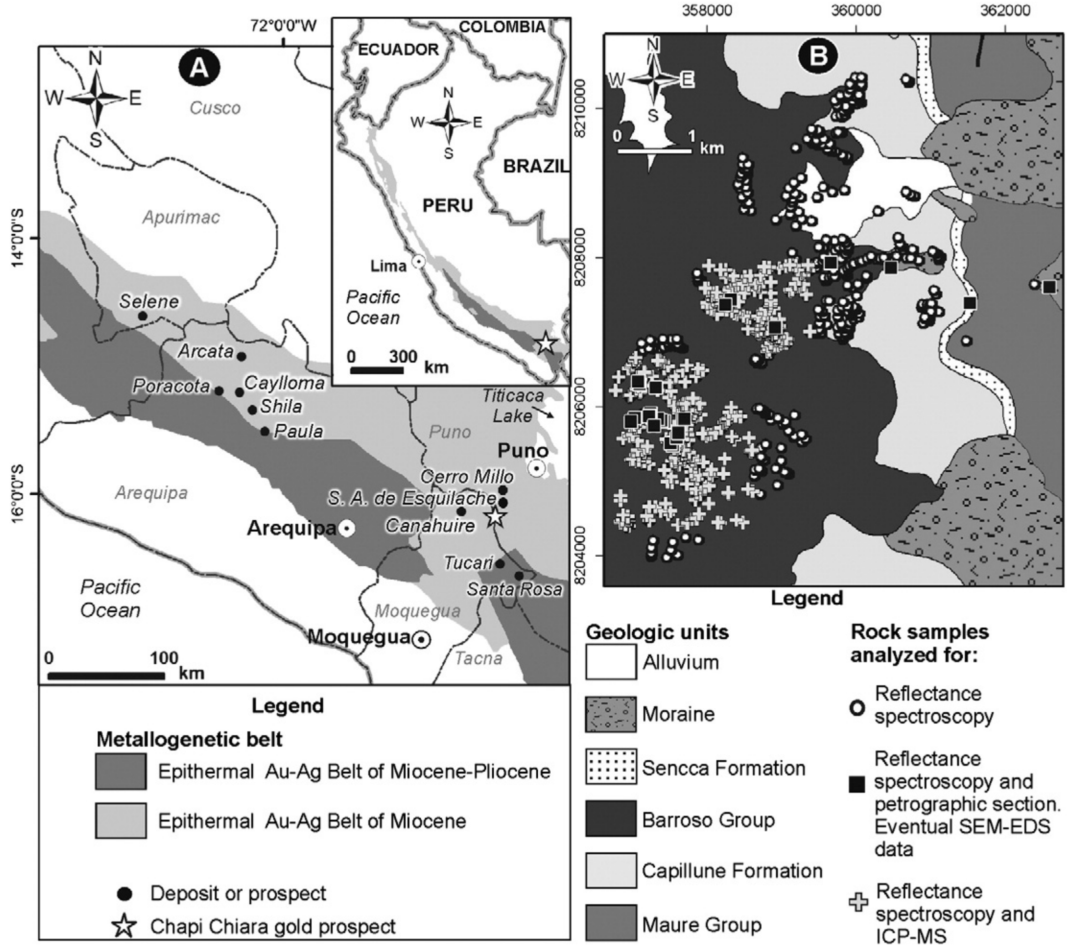

Fig. 1. Location of the Chapi Chiara prospect in relation to the main epithermal Au–Ag belts of southern Peru (A) (modified from Carlotto et al., 2009). A simplified geological map of Chapi Chiara is shown in (B) (Rodríguez et al., 2000), including the location of the rock samples analyzed for reflectance spectroscopy, petrography, semiquantitative mineral chemistry (SEM-EDS) and whole rock geochemistry (determination of Ag, As, Au, Bi, Hg, Mo, Sb, Se, and Te contents using ICP-MS).

et al., 1990), Canahuire (Santos et al., 2011); examples of high sulfidation deposits include Poracota (~14 Ma—Sarmiento et al., 2010), Santa Rosa (~7 Ma) and Tucari (~4 Ma) (Barreda et al., 2004 in Carlotto et al., 2009; Loayza et al., 2004), as well as the Cerro Millo prospect (~11 Ma—Hennig et al., 2008) (Fig. 1A).

The high sulfidation systems are preferentially located in the extreme southern Peru, near the boundary of Puno and Moquegua provinces (Fig. 1A), and are related to the volcanism of the Upper Miocene–Pliocene. The volcanic events are temporally associated with the Quechua compressive phases of the Andean Orogeny (Benavides-Cáceres, 1999).

In the Quechua Phase I (~17 Ma), deformational events occurred in southern Peru, registered by open folds and reactivation of faults formed during the Peruvian (84–79 Ma: NW–SE faults) and Incaic (59–22 Ma: NE–SW, E–W and NW–SE faults) compressive phases in pre-existing sedimentary and volcanic rocks (Benavides-Cáceres, 1999). After this phase, erosion events and a shallow lacustrine environment predominated. In this episode, between ~11 and 8 Ma, sedimentary rocks (e.g., limestone, sandstone, mudstone, siltstone), interlayered with lava and tuffs of trachyandesitic, dacitic and rhyolitic composition, were formed (Benavides-Cáceres, 1999; Palácios, 1995; Sánchez and León, 1995). These rocks comprise the Maure Group and the Capillune Formation, both occurring in the study area (Fig. 1B).

Between the compressive phases Quechua II (~8–7 Ma) and III (~5–4 Ma), the volcanic sequence of the Barroso Group was formed. It is characterized by andesite and trachyandesite, in addition to tuffs with similar composition and, less commonly, with rhyolitic composition (Benavides-Cáceres, 1999; Marocco and Del Pino, 1966; Palácios, 1995; Sánchez and León, 1995). Rhyolitic tuffs are predominant in the Sencca Formation, which is interpreted as a contemporary unit to the Barroso Group (Sánchez and León, 1995). Current records of well-preserved paleo-stratovolcanoes, as in Cerro Millo, are evidence of volcanic activity from this period. The migration of the Barroso magmatic arc towards the Peru–Chile trench resulted in the current active volcanism to the west of the high sulfidation epithermal systems above mentioned (Benavides-Cáceres, 1999; Mamani et al., 2010).

The Chapi Chiara gold prospect, recently investigated by Gold Fields Inc. and Vena Resources Inc., is located next to Canahuire, Tucari and Santa Rosa deposits, as well as San Antonio de Esquilache (an old mine exploited for Cu, Pb, Ag, Zn and Au since colonial times) (Canchaya and Aranda, 1995) and Cerro Millo (a gold-bearing high sulfidation epithermal system) (Hennig et al., 2008) (Fig. 1A and Table 1).

Chapi Chiara is the focus of this study, which is based on the integrated analysis of reflectance spectroscopy, geochemical and petrographic data. The goal is to determine the mineralogy and chemistry of the