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Hyperspectral remote sensing applied to mineral exploration in southern Peru: A multiple data integration approach in the Chapi Chiara gold prospect

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ABSTRACT

Remote sensing is a strategic key tool for mineral exploration, due to its capacity of detecting hydrothermal alteration minerals or alteration mineral zones associated with different types of mineralization systems. A case study of an epithermal system located in southern Peru is presented, aimed at the characterization of mineral assemblies for discriminating potential high sulfidation epithermal targets, using hyperspectral imagery integrated with petrography, XRD and magnetic data. HyMap images were processed using the Mixture Tuned Matched Filtering (MTMF) technique for producing alteration map in the Chapi Chiara epithermal gold prospect. Extensive areas marked by advanced argillic alteration (alunite-kaolinite-dickite ± topaz) were mapped in detail, as well as limited argillic (illite-smectite) and propylitic (chlorite spectral domain) alteration. The magmatic-hydrothermal processes responsible for the formation of hypogene minerals were also related to the destruction of ferrimagnetic minerals (e.g., magnetite) of host rocks such as andesite, and the remobilization/formation of paramagnetic Fe-Ti oxides (e.g., rutile, anatase). The large alteration zones of advanced argillic alteration are controlled by structures related to a regional NW-SE trend, and also by local NE-SW and ENE-WSW ones.

1. Introduction

The evaluation of physical-chemical conditions and geochemical evolution of hydrothermal fluids, such as temperature, pH, fluid/rock ratio, among others, can be performed from the study of altered rocks, by specifying hydrothermal minerals types and texture relations, including the understanding of the spatial distribution of minerals and the identification of paleoconduits (Beane and Bodnar, 1995; Corbett and Leach, 1998; Hedenquist et al., 2000). For this purpose, indirect data, such as hyperspectral remote sensing and geophysics, can be employed in conjunction with petrographic and geochemical studies.

Airborne and orbital hyperspectral imaging have been employed for mapping geological units and hydrothermal alteration in different mining districts around the world, in order to retrieve information on mineralogical composition of ground targets in the visible to shortwave infrared spectral range (e.g., Crósta et al., 1998; Rowan et al., 2004; Cunningham et al., 2005; Kruse et al., 2006; Rockwell et al., 2006; Swayze et al., 2014). This type of remote sensing data, in conjunction with reflectance spectroscopy, comprises a powerful tool for mineral exploration, focusing on the fast identification of mineral phases and hydrothermal zoning for selecting priority areas.

In addition, changes in the physical and chemical properties of rocks caused by hydrothermal alteration can be assessed by collecting, processing and interpreting geochemical and geophysical data. The integration of multiple data sources provides additional mineralogical information in relation to those derived only from optical remote sensing (Allis, 1990; Irvine and Smith, 1990; Chang et al., 2011; Morrell et al., 2011).

Southern Peru has a marked potential for metal exploration related to recent volcanic activities (Acosta et al., 2008; Fig. 1A, B). A multiple data integration approach comprises a strategic step for discovery and characterizing new targets in detail. In this context, an integrated analysis using hyperspectral remote sensing, mineralogy and magnetic data is presented on the Chapi Chiara epithermal gold prospect in southern Peru (Fig. 1A), to study the alteration mineralogy and structural controls.

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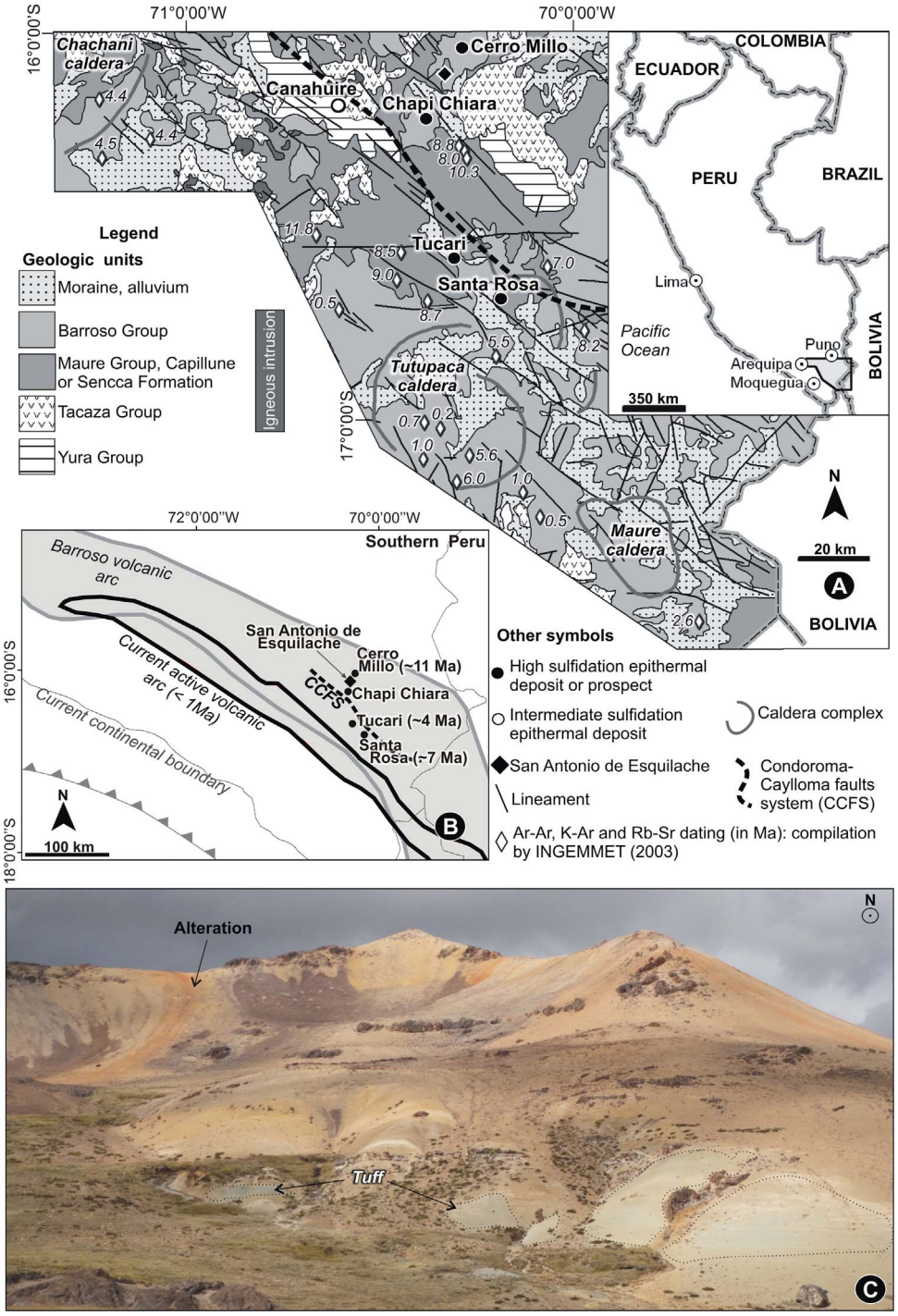

Fig. 1. (A) Regional geological map of southern Peru showing the location of epithermal gold deposits and the Chapi Chiara prospect (INGEMMET, 2003; Acosta et al., 2008). The paleogeography of southern Peru during the Miocene-Pliocene (Mamani et al., 2010), and the location of contemporary hydrothermal targets are shown in (B). Example of outcrops in the SW sector of the Chapi Chiara prospect (C), with hydrothermal alteration marked by ochre color, and tuff-rich areas exhibiting white to green colors. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Specifically, the Chapi Chiara prospect is a well exposed target (Fig. 1C), and was assessed by a joint venture between Gold Fields Inc. and Vena Resources Inc. This prospect is located near other Miocene-Pliocene epithermal deposits, including Canahuire (Santos et al., 2011), and Tucari and Santa Rosa (Loayza et al., 2004), in a region bounded by the cities of Puno, Arequipa and Moquegua (Fig. 1A).

1.1. Geology of the study area

The oldest lithostratigraphic unit of the Chapi Chiara prospect region (Fig. 1A) is the Yura Group, characterized by sedimentary sequences formed during episodes of marine transgression in the Jurassic-Cretaceous. Subsequent deformation of this unit during the