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The Cristal Zn prospect (Amazonas region, Northern Peru). Part II: An example of supergene enrichments in tropical areas

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ABSTRACT

The Cristal Zn prospect is located in the northernmost part of a wide mining district corresponding to the "Charlotte Bongará Zinc Project", which covers an area of approximately 110 km^2 in the Amazonas region in northern Peru. The mineralized area consists of many Zn occurrences that contain mixed sulfide and nonsulfide mineralizations. The nonsulfide ores are interpreted to be the product of weathering of primary MVT sulfide bodies. The Zn concentrations of the Cristal prospect are hosted by platform carbonates of the Condorsinga Formation (Early Jurassic), which belongs to the Pucará Group. The prospect extends over an area of approximately 2×1 km, with nearly continuous zones of Zn enrichment that has been detected in soil and rock samples. The nonsulfide mineralization consists mainly of semi-amorphous orange to brown zinc "oxides" that include hemimorphite, smithsonite and Fe-(hydr)oxides. The most important mineralized areas are the Esperanza and Yolanda occurrences, which were also most intensively explored. In both occurrences, the supergene Zn-carbonates and silicates infill solution cavities, or replace the carbonate host rocks and/or the primary sulfides, forming smithsonite- and hemimorphite-rich mineralizations. The analyzed drill core samples have on average 20 wt% Zn and maximum Ge concentrations of 200 ppm.

The Bongará area experienced a prolonged phase of weathering from Miocene to Recent under tropical climatic conditions. In these conditions, the weathering processes affected many pre-existing sulfide deposits (e.g. Cristal, Florida Canyon, Mina Grande), where supergene profiles were developed under locally different settings that are defined primarily on the basis of mineralogical and geochemical data. Contrary to the Mina Grande deposit, at Cristal, the development of a karst network was minor due to limited uplift, and supergene alteration did not completely obliterate the roots of the original sulfide orebody. The mineralogy and geochemistry of Bongará nonsulfides is dependent on two main factors at the local scale: (1) uplift rates, and (2) host rock composition. The latter may have favored the development of more (e.g. Mina Grande) or less (e.g. Cristal) alkaline supergene environments. Uplift was controlled by the activity of local faults, which allowed the exposure of sulfide protores at variable elevations in different periods of time and hydrological settings. Such different settings resulted in the precipitation of isotopically different supergene carbonates (e.g. smithsonites and calcites at Mina Grande and Cristal).

1. Introduction

The Cristal Zn prospect is located in the Bongará area (Amazonas region, northern Peru, 740 km north of Lima and 245 km northeast of the coastal city of Chiclayo), at the northern extremity of a carbonate belt that extends for 900 km along the eastern flank of the Andean Cordillera, from the Ecuador border to the south (Fig. 1). This belt is on the western margin of the Subandean Foreland Basin and within the Subandean Fold-and-Thrust Belt domain (Fig. 1) of the Amazonas Region in Peru. The study area is at the junction of the 1:100.000 topographic sheets 12-g (Bagua Grande) and 12-h (Jumbilla) of the Instituto Geográfico Nacional (IGN) of Peru. The geographic UTM coordinates of

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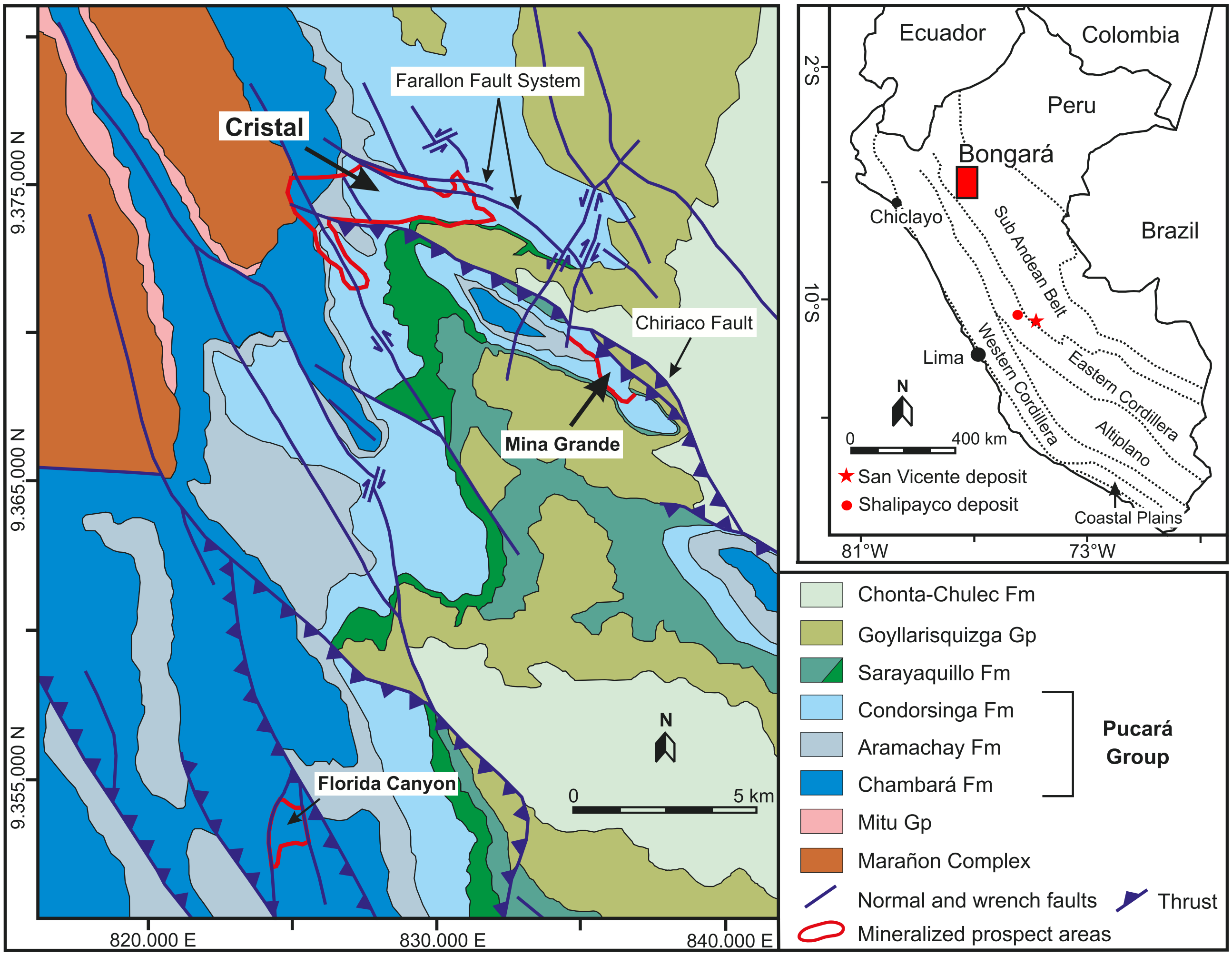

Fig. 1. Geologic map (A) and location of the Bongará district within the Andean morphostructural units of northern Peru (B) (from Arfè et al., 2017, modified).

the center of the area are 826,200 E and 9,375,000 N (Zone 17, Datum WGS 84).

The Cristal prospect is situated in the northernmost part of a wide mining district, corresponding to the so-called “Charlotte Bongará Zinc Project” (Zinc One Resources Inc.), which covers an area of approximately 110 km^2 (Fig. 1). The mineralized area consists of many Zn occurrences that contain mixed sulfide and nonsulfide ores (Anglo Peruana, 2005; Wright, 2010). The nonsulfide ores are interpreted to be the product of weathering of primary sulfide bodies (Anglo Peruana, 2005; Wright, 2010; Brophy, 2012), which have the characteristics of a Mississippi Valley-type mineralization (Reid, 2001; Basuki, 2006; Basuki and Spooner, 2008, 2009; Mondillo et al., in press).

Supergene nonsulfide ores are developed when sulfide bodies are exposed to meteoric alteration (Hitzman et al., 2003). Recent studies (Reichert and Borg, 2008; Reichert, 2009) suggested that arid climate conditions are the most favorable for oxidation and formation of nonsulfide ore bodies. Under an arid climate, enhanced sulfide oxidation has been attributed to scarce biogenic activity within the soil and to the low rates of dilution, dispersion and removal of metals. Such features are mostly related to the low levels of the water table in arid regions. The possibility of developing supergene enrichment in tropical climates has been already discussed by Hitzman et al. (2003) and Boni and Mondillo (2015), who reported that supergene zinc deposits are commonly found in both arid and tropical modern, as well as paleo-environments. Under tropical weathering with high rainfall rates, the oxidation of sulfide bodies results in the formation of acidic and oxidized solutions favoring karst development (Thornber and Taylor, 1992). These solutions become progressively zinc-enriched because zinc is more readily separated from other metals (Rose et al., 1979; Sangameshwar and Barnes, 1983). Significant amounts of smithsonite (and less hemimorphite, hydrozincite and Zn-clays) may precipitate within karst cavities, thus making karst-hosted nonsulfide deposits most common in this climate setting.

Only a few technical reports from mining and consulting companies (Anglo Peruana, 2005; Brophy, 2012; Workman and Breede, 2016) had described the Zn-nonsulfide occurrences in the Charlotte Bongará area. Arfè et al. (2017) presented the first comprehensive study of the Mina Grande nonsulfide deposit, located 6 km SE from the Cristal area (Fig. 1). Hydrozincite, smithsonite and hemimorphite are common in the ore minerals association at Mina Grande, and occur mostly in collapse breccias derived from the weathering of a sphalerite-rich protore in carbonate host rocks (Arfè et al., 2017). However, hydrozincite also occurs as thin blankets on waste dumps throughout the mine site: this is indicative of a recent precipitation under present-day climatic conditions, and of still active weathering. At Cristal, the presence of sulfides (Mondillo et al., in press) and the absence of recent karstic activity suggest that supergene alteration has acted in two different ways at Mina Grande and Cristal.

The main objective of this study is to document the geological, mineralogical and geochemical features of the Zn-nonsulfide mineralization in the Cristal area in order to provide new paleoclimatic, as well as time constraints for the genesis of this supergene deposit. This work aims to extend the knowledge about supergene evolution of sulfides to nonsulfides under tropical climate conditions by comparing the