Ore Mineralogy of Bimodal-mafic VMS Deposits Hosted in Early Cretaceous Greater Antilles Island-arc Tholeiite Series

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INTRODUCTION

VMS deposits in the Greater Antilles are described throughout the Dominican Republic and Cuba, genetically linked to two main episodes of the island-arc tectonic and magmatic evolution: 1) bimodal mafic type deposits, formed during the earliest stages of island-arc volcanism and 2) mafic (Cyprus) type, formed in mature back-arc basins (Nelson et al., 2011). Bimodal-mafic VMS deposits are in the main hosted in tholeiitic volcanic rocks of Early Cretaceous age of the Maimón and Amina Formations in Cordillera Central of the Dominican Republic and in Los Pasos Formation and Purial Complex in central and eastern Cuba respectively.

The Dominican Cerro de Maimón Cu-Zn-Au-Ag deposit, hosted in the Maimón Fm., is located 70 km northwest of the Santo Domingo capital city and 7 km east of the Maimón town. Operated by Perilya, it is the only VMS deposit currently under production in the Caribbean realm. The Cuban San Fernando and Antonio VMS deposits are hosted in the Los Pasos Formation, in the Manicaragua municipality in the Villa Clara province, about 20 km south of Santa Clara city and 290 km east of the Havana capital city.

Lithochemistry of the volcanic sequences of the Maimón and Los Pasos Formations turned out to represent an exceptional record of the very first magmatic expressions connected to the onset of an intraoceanic subduction case (Rojas-Agramonte, 2011; Torró et al., 2015). The study of the VMS mineralizations that these two Formations host is, hence, an extraordinary opportunity to describe and understand VMS mineralizing systems linked to the most primitive arc volcanism. Here we present a summary on the ore mineralogy and textures of the Cerro de Maimón, San Fernando and Antonio stratiform primary ores.

GEOLOGICAL SETTING

The geology of the islands of Hispaniola (Haiti and the Dominican Republic) and Cuba resulted largely from the Cretaceous-Tertiary oblique convergence and underthrusting of the North American (Proto-Caribbean) Plate beneath the Caribbean island-arc since ca. 135 Ma (Rojas-Agramonte et al., 2011). The Greater Antilles island arc hosts a wide record of subduction-related volcanism which comprises boninitic and island-arc tholeiitic (IAT) series of dominant Lower Cretaceous age, commonly referred to as Primitive Island Arc (PIA/IAT) that graded to calc-alkaline (CA) and high-K calc-alkaline (K-CA) series during the Upper Cretaceous-Eocene time.

The Lower Cretaceous Maimón and Los Pasos Formations are part of the oldest and chemically most primitive island-arc volcanism in the Caribbean region. On the basis of lithogeochemical data, Torró et al. (2015) classified the basalts of the Maimón Formation as FAB (Fore Arc Basalts), boninites and less abundant low-Ti IAT (LOTI), and those of the Los Pasos Formation as LOTI and normal IAT. Felsic volcanics from the two Formations are geochemically analogous and present M-type, boninitic and tholeiitic signatures, classifying as FIV-type and reflecting typical compositions of post-Archaean VMS-bearing juvenile volcanic suites.

Rocks of the Maimón Formation are metamorphosed to greenschist facies. Draper et al. (1996) suggested that the obduction of the Loma Caribe peridotite, tectonically emplaced over the Maimón Formation, resulted in deformation and metamorphism of the Maimón Formation, particularly in the Ozama shear zone, in which the Cerro de Maimón deposit is located. In contrast, the Los Pasos Formation is only locally deformed by folding. The intrusion of the Manicaragua Batholith granitoids at ca. 83 to 89 Ma (Rojas-Agramonte et al., 2011) resulted in local development of low-grade contact metamorphism.

ORE MINERALOGY AND TEXTURES

Pyrite, chalcopyrite, sphalerite and less abundant tennantite are the major (>99 % in volume) ore components in the three studied deposits; a variety of trace minerals such as galena, sulfosalts, arsenides, tellurides, etc. complete the list and depict three relatively complex although largely analogous paragenetic sequences and formation/recovery/deformation histories. Chalcopyrite, sphalerite and tennantite occur in the main as matrix of pyrite grains and show evidences of plastic deformation and recovery/recrystallization at lower temperature than pyrite. Pyrite, in contrast, displays a conspicuous variety of textures outlining an increasing metamorphic/deformation grade from Antonio to Cerro de Maimón throughout San Fernando deposits (in the knowledge that the nature of metamorphism was different in the Cuban and the Dominican cases). Increase in metamorphic grade resulted in a progressive pyrite average grain-size augmentation and obliteration of original sedimentary-diagenetic growths and syn-sedimentary hydrothermal replacements (i.e. zone refining). Relicts of the first were only preserved in Antonio ores in the form of local framboidal and colloform growths and microcrystallite textures. Spongy texture is the dominant one in this deposit whereas it is sparse in San Fernando

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and nonexistent in Cerro de Maimón; along with spongy textures, free or impingement overgrowths of euhedral and subhedral pyrite crystals with spongy cores and inclusions- and/or porosity-free rims are representative of syn-depositional hydrothermal replacements. Is in Cerro de Maimón where the effects of deformation and metamorphism on sulfides reached greater magnitude; annealment or foam textures with triple junctions at 120º in metablastic pyrite alternate with intense microfracturing and blow-apart and porphyroclastic textures locally developing adjacent pressure shadows.

In Cerro de Maimón ores, the coexistence of cataclastic and annealment textures in pyrites even over short distances is observed to correlate with the abundance and composition of matrix phases within pyrite grains. Porphyroblastesis of pyrite in soft sulfide matrix (i.e. chalcopyrite and sphalerite) enhanced pyrite grain growths whereas where pyrite grains impinged upon one another (i.e. little or inexistent matrix), significant fracturing occurs. By means of orientation contrast (OC) imaging and electron backscatter diffraction (EBSD), Barrie et al. (2010) concluded that the preservation of annealment textures in greenschist metamorphosed Norwegian Caledonides massive sulfides potentially represented surface-driven processes (re-arrangement by a dissolution/ syntaxial overgrowth) during the metamorphism; this conclusion contrasts with the classical assumption that foam textures results from recrystallization. The very limited gold mobilization during metamorphic upgrading observed may be a likely consequence.

Syn-metamorphic (including pre-, syn- and post-metamorphic peak) sulfide recovery/recrystallization led to the metamorphic remobilization and local redistribution of trace elements, including base and precious metals. Subsequently, discrete minerals such as galena, Bi-, Ag- and Pb-tellurides, tetrahedrite, arsenopyrite/löllingite, Ag-sulfosalts (the last two only in San Fernando), electrum and (Ag,Hg) amalgams formed. These phases commonly concentrate along sulfide contacts and voids and show textural evidences of both equilibrium and non-equilibrium along the three deposits indicating that their crystallization also extended to the whole metamorphic history.

ORE MINERAL GEOCHEMISTRY

Sphalerite from the three deposits returned remarkably low Fe/Zn ratios (<0.12) and low to intermediate S contents (30.81 to 34.27 wt. %). Copper contents in analyzed sphalerites are as much as 1.16 wt. % and hence are below the 2 wt. % threshold suggested by many authors as indicator of preservation of primary compositions and minor impact of remobilization or chalcopyrite disease. The low Fe/Zn ratios and low to moderate S is typical of sphalerite precipitated in a sediment-starved setting (Keith et al., 2014). Keith et al. (2014) proposed a formula for the calculation of venting fluid temperatures from $Fe/Zn_{sphalerite}$ (sphalerites precipitated in sediment starved environments, and not affected by metamorphism of higher grade than greenschist facies); estimated minimum venting fluid temperatures were of 250 ºC for Cerro de Maimón and Antonio, and would have increased from about 250 ºC during the deposition of the lower section to 300 ºC in the upper section in San Fernando.

Fahlores analyzed in the three deposits resulted to be largely tennantite (As>Sb), and only traces of tetrahedrite, crystallized during pre- and post-metamorphic peak low temperature replacements, were detected in San Fernando. Concentration of Ag-tellurides in the borders of recovered/ recrystallized tennantite suggests that this mineral would have been an important contributor of this metal for the subsequent crystallization of late (metamorphic) Ag phases. Antimony concentration in tennantite from the three deposits is remarkably low, as typically occurs in VMS mineralizations formed in juvenile intraoceanic island-arc settings (e.g. Seal & Piatak, 2012). Nonetheless, a fair trend towards Sb enrichment in the stratiform mineralizations from Cerro de Maimón (av.: 0.27 at. %, Sb/(Sb+As)=0.02) throughout Antonio (av.: 0.61 at. %, Sb/(Sb+As)=0.04) to San Fernando (av.: 1.39 at. %, Sb/(Sb+As)=0.10) deposits is evident. Galena returned higher Se contents in Cerro de Maimón (to 3.83 wt. %) than in San Fernando (of 0.22 wt. %). Tellurium and Ag concentrations are higher in San Fernando (to 0.43 and 0.40 wt. %) than in Cerro de Maimón (to 0.25 wt. % and <d.l., respectively). Antimony and Bi (to 0.11 and 0.71 wt. %) were only detected in galena from San Fernando.

FINAL REMARKS

Mild though decided trend toward Sb enrichment in tennantite from stratiform ores in the San Fernando and Antonio deposits with respect to Cerro de Maimón parallel lower values of Se and As and higher contents in the more incompatibles Sb, Te and Bi in galena. These nuances in ore geochemistry support a slightly more primitive setting of formation of VMS mineralization in the Maimón Formation denoted by the lithogeochemistry of the hosting volcanic units (Torró et al., 2015).

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