ABSTRACT

Porphyry systems and associated deposits constitute an important source for worlds' metal supply. The Polymetallic Belt of Central Peru hosts numerous deposits associated to the emplacement of fertile porphyry stocks during the Oligocene and Miocene. Some of these stocks are emplaced in carbonate sequences associated to back-arc basins developed in the region throughout the Mesozoic, where important carbonate-hosted polymetallic deposits have been form, such as the case of the wold-class Cu-Mo skarn deposit of Antamina and the massive Cu-Zn-Pb carbonate replacement bodies at Huanzala. These deposits appear directly associated to the intrusions and they have been extensively studied, therefore a genetic model for the mineralization has been proposed and has allowed to estimate the overall extension of alteration and mineralization.

Santander deposit, located in the Central Peruvian Polymetallic Belt, has been defined as a distal Zn-Pb(-Ag) skarn and carbonate replacement deposit due to its mineralogy, textures and the absence of causative intrusion associated to mineralization. Mineralization is hosted by the carbonate sequences of the Lower to Upper Cretaceous Pariahuanca, Chulec, Pariatambo and Jumasha formations. Mineralization occurs as clusters that are structurally controlled by regional folds and faults. To date, a genetic model for the alteration and mineralization is still missing and the true extent of the mineralization at Santander is still unknown. In the present study, an extensive set of analytical methods have been used to characterize the gangue and ore mineralization in the area in order to build a framework for more detailed future studies aimed to construct the genetic model of the magmatic-hydrothermal system at Santander. These methods include optical petrography, SEM, EPMA, partial LA-ICP-MS trace element analyses in silicates (garnet, clinopyroxene, epidote, chlorite), sulfides (sphalerite) and oxides (magnetite) together with in-situ U-Pb LA-ICP-MS geochronology on garnets and titanite.

This work has allowed to identify four different alteration/mineralization events at Santander. These events have been defined base on a study of representative samples from four of the mineralized centers in the area:

- A prograde skarn assemblage was identified in all of the studied zones and is characterized by an early massive garnet-clinopyroxene-magnetite-apatite-vesuvianite assemblage and a late formation of garnets and clinopyroxene occurring as veins and disseminations.
- A retrograde skarn assemblage was also identified in the four studied zones and is characterized by epidote-chlorite-actinolite-magnetite-sericite-K-feldspar-plagioclase-quartz and calcite. The retrograde skarn assemblage is superposed onto the prograde skarn and is genetically associated to two stages of polymetallic mineralization, defined in terms of sulfidation state of the ore mineral assemblages. The early stage is characterized by an early pyrite precipitation followed by a low-sulfidation assemblage dominated by Fe-rich sphalerite, pyrrhotite, arsenopyrite, chalcopyrite and minor galena. The late stage is characterized by an

intermediate-sulfidation ore assemblage that includes the replacement of former pyrrhotite by late pyrite and the generation of two different Fe-poor sphalerites together with galena and minor As-Sb-Ag tellurides and sulfides. The two mineralization stages occur superimposed in a single sample and even within a single vein. Textural evidence suggests that the transition between them was a continuous process and reflects the evolution of a single mineralizing fluid. The polymetallic mineralization at Santander can be correlated to an early low- to intermediate-sulfidation mineralization stage reported in various polymetallic deposits associated to the intrusion of Miocene porphyry-stocks in the Central Peruvian Polymetallic Belt. Major and minor element geochemistry of skarn silicates associated to the mineralization show systematic variations resulting from different temperature conditions during the ore deposition in the four studied areas.

- Porphyry-style quartz-molybdenite-pyrite veins were observed in the deep sections of two of the studied areas (Santander Pipe and Blato prospect). They are characterized by multiple vein formation with variable amounts of sulphide and gangue minerals. Alteration associated to this event shares characteristics of potassic alteration in porphyry systems, dominated by K-feldspar, biotite, quartz and titanite with minor amounts of sericite and chlorite. In the Santander Pipe, the veins appear cross-cutting the prograde skarn mineralogy and are in turn cross-cut by the polymetallic mineralization associated with the retrograde skarn formation. In Blato prospect, the veins appear directly cross-cutting the retrograde alteration. These differences suggest a protracted porphyry-style activity during the formation of the skarn alteration and polymetallic mineralization in Santander.
- A late carbonate stage was recognized in all of the studied zones. This fourth event occurs as late vein infill, replacement of skarn minerals and late barren calcite stockwork.

Geochronology carried out on garnet yielded U-Pb ages of 10.72 ± 0.56 Ma, 10.72 ± 0.56 Ma and 9.53 ± 0.56 Ma for the Santander Pipe and 9.60 ± 0.33 Ma in Blato for the prograde skarn formation. Titanite associated to the porphyry-style Qz-Moly veins yielded U-Pb ages of 10.89 ± 0.47 in the Santander Pipe and 11.07 ± 0.45 Ma and 11.69 ± 0.35 Ma in the Blato prospect.

Finally, this work constitutes the foundations and mineralogical framework for future detailed studies intended to build a genetic model for the magmatic-hydrothermal system at Santander and test some potential mineral and geochemical vectors that may effectively guide future exploration efforts in the property and elsewhere.

Keywords: Central Peruvian Polymetallic Belt, Santander, distal skarn, polymetallic mineralization.