Mineralization, structural, and geochemical characteristics of the Toldojirca prospect and the San Andrés vein, Morococha district, central Peru

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Abstract. The Morococha district of central Peru hosts a large variety of porphyry-related ore bodies mined mainly for Cu (Mo), Ag, Zn and Pb, as well as minor amounts of Au. Recently, a gold and silver anomaly was found in the eastern part of the district, known as the Toldojirca prospect. The present work suggest that the Au anomalies in the Toldojirca area, restricted to the first few meters from surface, formed by oxidation and subsequent supergene enrichment of Cordilleran replacement bodies and polymetallic veins.

Keywords. polymetallic vein, mineralogy, fluid inclusions, Toldojirca, Morococha, Peru

1 Introduction

The world class mining district of Morococha (Petersen 1965; Catchpole at al. 2011) is located in the central part of the Miocene polymetallic belt within the Western Cordillera of Peru (Noble and McKee 1999). Various porphyry-centered ore types occur in the district: porphyry mineralization, skarns and polymetallic vein and replacement bodies (mantos), hosted by intrusive, volcanic and carbonate rocks of various ages. The central, northern and eastern parts of the district are the most intensively mineralized areas and have been mined mainly for Ag, Cu (Mo), Zn and Pb. Small amounts of gold were produced historically in the western part of the district from quartz-pyrite veins essentially as a by-product of Cu and Ag production. This study is devoted to the Toldojirca prospect in the eastern part of the district, where, in the Toldojirca hill and surrounding areas, Au and Ag anomalies grading up to 8 and 300 g/t respectively, of unknown origin, have been identified recently (Pérez 2009). The present study focuses on the structural, geochemical and mineralogical characteristics of this anomaly and the adjacent polymetallic veins, with the aim of recognizing the origin of the mineralization at Toldojirca in the context of the Morococha district.

2 Geology, mineralized structures and paragenesis

The mineralized structures include veins with different orientations as well as replacement bodies (mantos). All the structures are hosted by carbonate rocks of the Triassic to Early Jurassic Pucará Group (Rosas et al. 2007). In the host carbonate sequence occur five roughly bed-parallel carbonate clast-supported breccias which are interpreted as overthrust tectonic breccias that partly have subsequently been subjected to strong dissolution related to weathering (Fig. 1 and 2). Similar breccias are mineralized in other parts of the district.

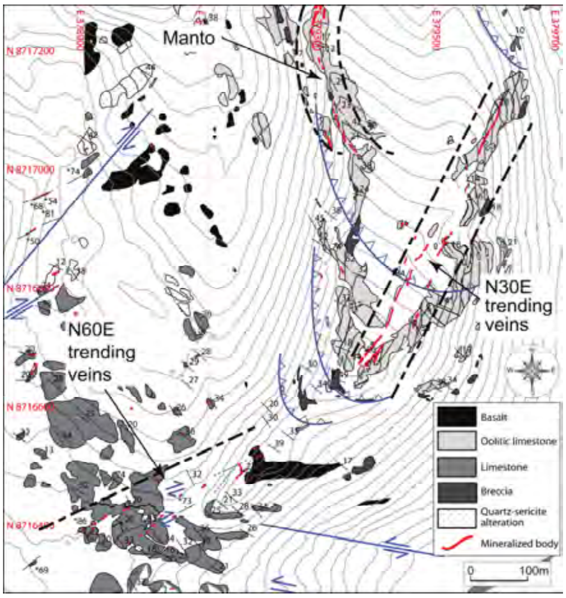

Figure 1. Geology and mineralized structures of the Toldojirca prospect.

Three groups of mineralized structures are found in the Toldojirca prospect (Fig. 1). A group of roughly trending N30°E discontinuous veins crops out on top of the Toldojirca hill. These structures are intensively oxidized and only Fe and Mn oxides/hydroxides can be recognized macroscopically in an intensely silicified matrix. Microscopy revealed a mineral association consisting of galena, sphalerite (inferred), pyrite, and marcasite with subordinate fahlore group minerals and associated hydrothermal rutile. Preserved sulfides are surrounded by Pb- and Zn-bearing carbonates with a dominant presence of Mn oxides/hydroxides.

A set of N60°E trending veins crops out in the south-western part of the Toldojirca area and corresponds to a group of strongly silicified structures with brecciated texture (Fig. 3). Clasts within the veins consist of carbonate rock replaced by pyrite and silica and are cemented by quartz associated with sphalerite, fahlore group minerals, pyrite, chalcopyrite, and galena (Fig. 4). Finally, the whole structure is crosscut by barren quartz and chalcedony veinlets.

Figure 2. Bed-parallel carbonate breccia. Note the carbonate clast bearing a calcite vein that formed before brecciation.

The third mineralization type in the Toldojirca prospect comprises a highly-oxidized replacement body that crops out in the NW and NE part of the Toldojirca hill, consisting mainly of silica and Fe-Mn oxides/hydroxides. This replacement body is hosted by oolitic limestone beds in the upper stratigraphic unit of the Pucará Group (Condorsinga Formation, in pale-gray on Fig. 1). The only preserved hypogene minerals in this body are Ag-sulfosalt miargyrite ($AgSbS_2$) and disseminated pyrite.

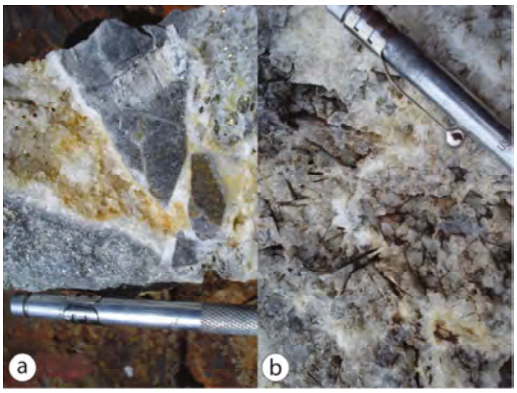

Figure 3. Breccia in N60°E trending vein. a) Different replacement intensities and quartz generations. b) Platy mould s possibly from platy-calcite related to late barren quartz, pretty typical (relict) boiling textures.

To constrain the origin of the mineralization in the Toldojirca prospect in the context of the wider polymetallic mineralization known in the Morococha district, the nearby and less oxidized N40°E trending San Andrés vein, located 1.25 km to the east of Toldojirca, was studied. Two stages of mineralization were recognized: an early pyrite-quartz stage forming low-sulfidation mineral assemblage with arsenopyrite, adularia and pyrrhotite; and a later base-metal stage dominated by an early Bi-rich mineralization, followed by galena - sphalerite - fahlore group minerals and a final carbonate - quartz - adularia association (Figs. 5 and 6). Textures of the vein vary from massive to brecciated. Early mineralization is crosscut by veins of the later stage.

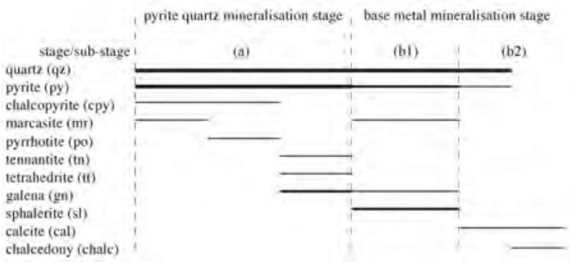

Figure 4. Paragenetic sequence of the N60°E structures in the Toldojirca prospect.

Both mineralization stages are not necessarily present together in the same structure and can develop as independent pyrite-quartz massive structures (veins or replacement bodies) or as base-metal veins. In addition to the rare miargyrite, main carriers for silver in the studied veins are galena (up to 2.2 wt.% Ag) and fahlore group minerals, mainly tetrahedrite, with Ag content reaching 4.5 wt.%.

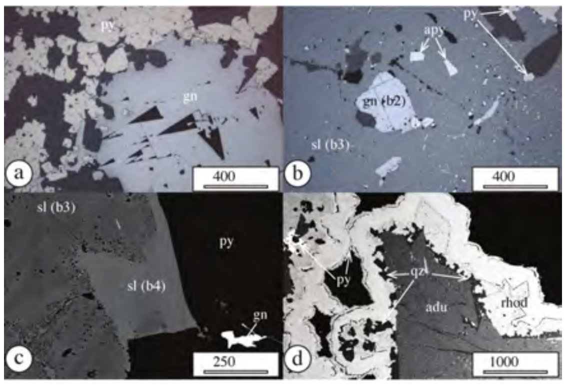

Figure 5. Reflected light photomicrographs and BSE images of polished sections from the San Andrés vein: a) Pyrite from the early stage (a2) corroded by later galena (b2); b) Galena, pyrite and arsenopyrite inclusions in sphalerite, later affected by chalcopyrite disease; c) Two generations of sphalerite: sl (b3) affected by chalcopyrite disease overgrown by later sl (b4) unaffected; d) Carbonate stage (b5) - adularia overgrown by quartz, rhodochrosite and later quartz, associated with rare pyrite and marcasite. *Abbreviations:* adu - adularia, apy - arsenopyrite; gn - galena; py - pyrite; sl – sphalerite.

3 Fluid inclusion microthermometry and sulfur isotopes

Microthermometry measurements on quartz-hosted fluid inclusions have been performed on underground and surface samples from the different mineralization stages recognized in the San Andrés vein. Results are reported in Table 1.

Table 1. Summary of fluid inclusion microthermometry data from the Toldojirca N60E oriented structures compared with the San Andrés vein.

	Toldojirca (surface)	San Andrés (surface)	San Andrés (underground)	
Th (°C)	~ 252° *from 228° to 272°*	~ 278° *from 223° to 350°*	~ 334° *from 293° to 339°*	py - qz stage
Salinity (wt% NaCl eq.)	~ 8.0 *from 7 to 9*	~ 1.1 *from 0.5 to 2*	~ 4,2 *from 2 to 5*	
Th (°C)	~ 226° *from 220° to 237°*	~ 200° *from 193° to 212°*	~ 250° *from 243° to 258°*	base metal stage
Salinity (wt% NaCl eq.)	~ 2.8 *from 2 to 3,5*	~ 1.8 *from 0.5 to 2*	~ 10.0 *from 8 to 11*	

Primary/pseudosecondary fluid inclusions are two-phase (liquid-vapor) and homogenize to a liquid phase. Temperatures of homogenization measured in quartz from the early stage of mineralization on underground samples (682 m depth from the present-day surface) range from 293° to 339° with a mean of 334°C. From surface samples, quartz from the same stage shows homogenization temperatures in a range 223°-350°C with a mean of 278°C.

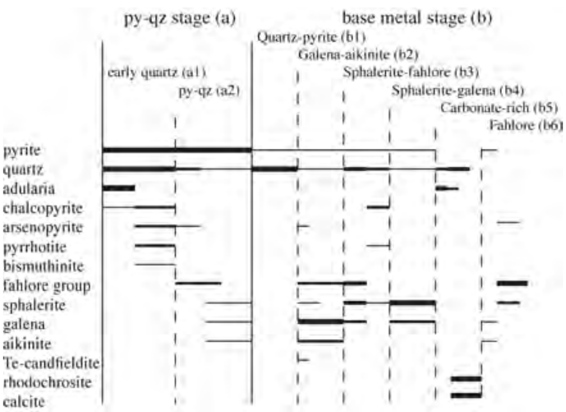

Figure 6. Paragenetic sequence of the San Andrés vein. Stages and sub-stages have been defined by crosscutting relationships.

Salinity of the fluids for the respective localities correspond to average values of 8.8 ± 1.6 wt.% NaCl equiv. and 2.4 ± 0.2 wt.% NaCl equiv., following a mixing trend between intermediate-salinity hot magmatic fluids and cold and diluted meteoric waters. Homogenization temperatures from the later mineralization stage are well constrained, with a mean of 250°C for underground and 226°C for surface samples. Overall, measured fluid salinities increase from early to late quartz generation. These variations go from 4.2 up to 10.0 wt.% NaCl equiv. for underground samples and from 1.1 to 1.8 wt.% NaCl equiv. for surface samples. This salinity increase at constant temperatures can only be explained by boiling.

Fluid inclusion microthermometry on the early stage mineralization in the N60°E structures at Toldojirca yields homogenization temperatures in the range 228° - 272°C with a mean at 252ºC. Later base-metal mineralization shows temperatures of homogenization between 220° and 237°C. Salinities of 8.0 ± 1.3 wt.% NaCl equiv. for the early stage and 2.8 ± 0.7 wt.% NaCl equiv. for the late stage of mineralization were calculated.

Figure 7 summarizes sulfur isotope data for sphalerite ($\delta^{34}S$ = 3.1-3.7‰), galena ($\delta^{34}S$ = 2.5-3.5‰) and pyrite ($\delta^{34}S$ = 1.5-6.2‰) from the San Andres vein. Results are consistent with a magmatic source for the sulfur in the studied system.

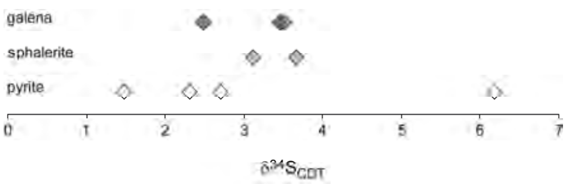

Figure 7. Sulfur isotope data for sulfides from the San Andres vein.

3 Conclusions

The present study allows suggesting that the mineralized structures in the Toldojirca prospect are the oxidized expression of replacement bodies and of polymetallic veins similar to those of San Andrés and other Cordilleran veins in the Morococha district (Catchpole et al. 2011). The Au anomaly in the Toldojirca area, restricted to the first few meters from surface, formed probably by oxidation and subsequent supergene enrichment of hypogene sulfide minerals containing traces of gold, such as pyrite and/or arsenopyrite.

Acknowledgements

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