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Zn-Pb MANTOS & VEINS AT DOMO DE YAULI, CENTRAL PERU: PRODUCTS OF THE SAME HYDROTHERMAL SYSTEM WITH CONTRASTING FLUID INCLUSION CHARACTERISTICS

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Introduction

The San Cristobal-Andaychagua mining center at Domo de Yauli lies 110 km east of Lima in the Western Cordillera of Peru. It is a classical high-temperature, carbonate-hosted, massive sulfide replacement ore deposit district. Such deposits have been traditionally considered in terms of a single evolving hydrothermal fluid traveling differing distances from an intrusive center. By contrast, recent field and geochemical data from a number of North and Central American districts have been interpreted in terms of magmatic fluid and basinal brine mixing (Megaw et al. 1995). The regional geological setting of Domo de Yauli provides an adequate environment for investigating the relationship among different fluid types during ore formation. In this study we contrast the lead and sulfur isotopic composition, and fluid inclusion data of mantos and veins located in the vicinity of Miocene intrusions in order to understand their genetic relationships.

The northwest oriented Domo de Yauli is composed of the Paleozoic Excelsior Group dominated by phyllites, Permo-Triassic volcanic and sedimentary rocks of the Mitu Group, Triassic-Jurassic limestone's of the Pucará Group, and Cretaceous sedimentary rocks. There are two major mining districts, with Morococha in the north, centered on the Toromocho porphyry (U-Pb age of 9 Ma), and San Cristobal-Andaychagua in the south, centered on the Chump intrusion (U-Pb age of 6 Ma) (Beuchat et al. 2000). The Morococha district consists of a Cu-Mo porphyry surrounded by Zn-Pb±Ag±Cu skarns, mantos and veins. By contrast, only mantos and vein-type deposits occur in the San Cristobal-Andaychagua mining district. The mantos are hosted by the Pucará limestone along the contact with the underlying Mitu Group, and occur mainly along the western flank of the Yauli Dome. The veins are steeply-dipping and crosscut rocks of the Mitu and Excelsior Groups, and locally the Pucará limestone. The mantos and the veins have a similar mineralogical composition with sphalerite - galena - pyrite ± chalcopyrite ± sulfosalts ± carbonates ± quartz and pyrrhotite, marcasite, barite, magnetite and hematite in places. One vein in the San Cristobal district contains an early pyrite-wolframite-quartz paragenesis.

Lead and sulfur isotope constraints

Mantos and veins have similar lead isotopic compositions, which overlap those of the residual and leached rock fractions of Miocene intrusions from Domo de Yauli. It indicates a predominant magmatic input of lead, and likely of the other metals, in the ore deposits. It also suggests that mantos and veins were deposited from the same hydrothermal system. These contrasts with previous interpretations advocating a Mesozoic syngenetic origin for the mantos followed by vein formation during the Tertiary (Dalheimer 1990; Kobe 1990).

Sulfides from mantos and veins in the Morococha district have $\delta^{34}S$ values within a narrow range of +0.5 to +4.5 ‰ (CDT) overlapping with the 0 to +3.5 ‰ range of sulfides from nearby porphyry and skarns. It indicates that sulfur in this district is predominantly of magmatic origin and was derived from the Miocene intrusions. By contrast, sulfides from veins of the San Cristobal-Andaychagua district yield higher $\delta^{34}S$ values within a narrow range of +3 to +8 ‰, and sulfides from mantos display a wider range between -3.5 and +8.5 ‰. The higher $\delta^{34}S$ values at San Cristobal-Andaychagua may reflect the input of sulfur of evaporitic origin, or different f_{O_2} conditions of the hydrothermal fluids. Nevertheless, the similarity of the $\delta^{34}S$ values of the veins and mantos in each district are in line with the lead isotopes indicating that both ore types were formed by the same hydrothermal system.

Fluid inclusion microthermometry and Raman spectroscopy

Most of the fluid inclusion data have been obtained from sphalerite, quartz and carbonates of the mantos and veins in the San Cristobal-Andaychagua district. Some preliminary data was from mantos, veins, skarns and the porphyry stockwork in the Morococha district. The inclusions consist of two phases at room temperature, except in the Morococha porphyry where inclusions also contain halite. Inclusions in sphalerite are isolated or occur as groups, in some cases they are nicely distributed along growth zones. Inclusions from the same growth zone or group yield the same homogenization temperatures (Th). The final ice melting temperatures (Tm_{Ice}) of inclusions from veins in the San Cristobal-Andaychagua district fall between -0.5 and -4.2°C. The fluid inclusions homogenize to the liquid phase and yield Ths between 150 and 330°C. Early paragenetic vein assemblages from the deeper part of the hydrothermal system (e.g. wolframite stage, Campbell & Robinson-Cook 1987) typically yield the highest Ths and lowest Tm_{Ice}, while late-stage quartz from shallower environments have trapped lower temperature and more dilute fluids (Tm_{Ice} close to 0°C). Sphalerite from mantos in the San Cristobal-Andaychagua district yield Ths between 220 and 310°C and Tm_{Ice} between -2 and -10°C. At Morococha, $CaCl_2$-bearing fluid inclusions in manto sphalerites have Ths of 240 to 275°C with low Tm_{Ice} between -3 and -29°C.

Thus fluid inclusions from veins and mantos yield two different Th vs Tm_{Ice} trends, with a large variation in Th's and a relatively narrow distribution of Tm_{Ice} for the veins, while the mantos display a trend with a smaller variation in Th's and a large range of Tm_{Ice}. Moreover, fluid inclusions in veins yield lower Th's than fluid inclusions trapped in spatially associated mantos. A similar discrepancy of Th's between both ore types has been noted previously by Bartlett (1984) at San Cristobal, and by Beaty et al. (1990) in associated vein and high temperature, carbonate-hosted Pb-Zn replacement deposits in the Gilman district, U.S.A. The high Th's recorded in the mantos, particular in clearly recognizable primary fluid inclusions in sphalerite, are further arguments against a possible syngenetic origin of the mantos.

No separate liquid-vapor CO_2-phases or clathrate have been detected by microthermometry in any of the fluid inclusions. However, Raman spectroscopy has revealed the presence of dissolved CO_2 with an approximate density of 0.1 g/cm^3 in inclusions from the mantos and from the paragenetically earlier and deeper parts of the vein system within the San Cristobal-Andaychagua district (e.g. in quartz associated with the wolframite stage). Therefore, salinity's reported in earlier studies (Bartlett 1984; Lavado 1996) are partly overestimated. This is the first direct evidence of CO_2 in the hydrothermal systems that formed the mantos and veins at Domo de Yauli. Its presence in the fluids forming the mantos was suspected by Bartlett (1984), and is predictable because of the absence of calc-silicates in the mantos.

The bulk of the fluid inclusion data from the veins of the San-Cristobal-Andaychagua district is interpreted as reflecting progressive CO_2-degassing concomitant with dilution by meteoric water of a hot, moderately saline (less than 6-7 wt% NaCl) hydrothermal fluid, possibly of magmatic origin. Such a dilution-degassing scenario is typical for epithermal systems.

The fluid inclusion data from the mantos can be interpreted as mixing between the hot, moderately saline related to the vein system, and a hot, more saline fluid (brine) along the contact between the Pucará limestone and the Mitu volcanic and sedimentary rocks. This brine channelled along the Pucará-Mitu contact could either be a heated basinal fluid or correspond to sporadic injections of a magmatic fluid. Bartlett (1984) has described highly saline magmatic fluids (32-45 wt% NaCl equiv.) in the Chump intrusion. Therefore assuming that the Chump intrusion is genetically related to mantos, it could be the source of such very saline fluids. However, it remains enigmatic why such a magmatic fluid would only be present in the mantos and absent in the hydrothermal vein system more proximal to this intrusion. An alternate explanation is that the higher salinities reflect local boiling of the moderately saline fluid as it was channelled by the vein system into the Pucará carbonate rocks. Such an interpretation might be more suitable for mantos containing high salinity fluid inclusions and which are remote from Miocene intrusions. Moreover, Tm_{Ice} can vary very abruptly in some manto sphalerites while Th's remain more constant. Intermittent boiling might be a more likely process to explain such fluid inclusion data. However, no separate vapor-rich inclusions coexisting with the saline fluid inclusions have been recognized at this stage of the study.

Higher Th's in sphalerites from mantos than in the veins, despite their close spatial association, appear to be a paradox. Formation of the veins and the mantos under different pressure conditions (lithostatic vs hydrostatic, respectively) are unlikely based on field relationships that indicate contemporaneity of both ore types. It also appears difficult to envisage early formation of mantos along the Pucará-Mitu contact, with subsequent migration of the cooling fluids from the Pucará carbonate rocks into the veins hosted by the basement rocks and centered on the Miocene Chump intrusion. Moreover, based on our observations, differences in dissolved CO_2–concentrations of the fluids forming mantos and veins are negligible. Therefore, the discrepancy of the Th data cannot be explained by different pressure corrections that must be applied to fluids with contrasting compositions (e.g. H_2O-NaCl vs H_2O-CO_2-NaCl). A possible explanation for the Th discrepancy might be different controls on metal precipitation. Indeed, the solubility of chlorozinc complexes is a function of pH, temperature and chloride concentration (Ruaya & Seward 1986). Sphalerite deposition in the mantos hosted by the Pucará carbonate rocks might be related to the sudden and drastic pH increase as the high temperature hydrothermal fluids were migrating away from the Chump intrusion, out of the Mitu and Excelsior silicate basement rocks. By contrast, and in line with the fluid inclusion data (variable Th for relatively constant Tm_{Ice} in vein minerals), cooling and decreasing chloride concentrations due to mixing with a meteoric fluid may have been the main triggers favoring sphalerite precipitation (and the other sulfides) at lower temperature in the veins hosted by the silicate rocks of the Mitu and Excelsior Groups.

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