Ore-forming fluids associated with the early mineralization at Cerro de Pasco, Peru

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Cerro de Pasco, central Peru, is a large Cordilleran base metal deposit formed along the eastern margin of a diatreme-dome complex, as part of the Miocene metallogenic belt of central and northern Peru (Baumgartner et al, 2008). It was formed during successive stages of mineralization by fluids with contrasting fS_2, fO_2 and pH. During the first stage, were emplaced a number of pyrrhotite pipes that contain minor arsenopyrite and Fe-rich sphalerite as well as traces of chalcopyrite, galena and stannite, they grade outwards into massive Fe-rich sphalerite and galena replacement bodies. They are structurally controlled by major N-S faults. During the second stage, a massive body consisting mainly of pyrite and quartz was emplaced. It is associated with a pervasive sericite-pyrite alteration affecting the diatreme-dome complex. Simultaneously, the root of the diatreme-dome complex (at a depth from 3350 to 3750 m.a.s.l.) is crosscut by structure-controlled pyrite-quartz veins with sericite alteration haloes. These veins are interpreted as feeders of the pyrite-quartz body. Following the emplacement of the pyrite-quartz body, high-sulfidation mineralization was formed, in the western part of the deposit as a set of E-W–trending Cu-Ag-(Au-Zn-Pb) enargite-pyrite veins hosted by the diatreme-dome complex, and, in the eastern part - as large well-zoned Zn-Pb-(Bi-Ag-Cu) carbonate replacement ore bodies (Figure 1).

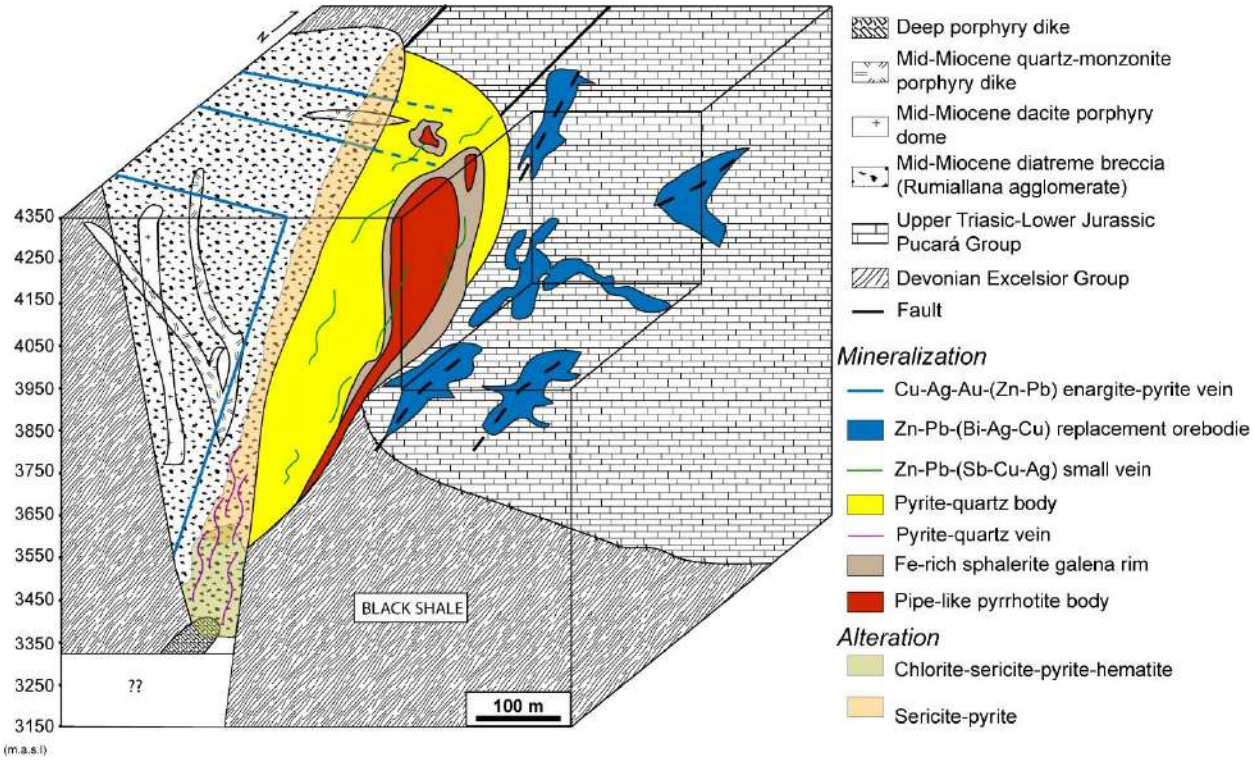

Figure 3: Block diagram showing the different mineralizing events (modified from Baumgartner et al., 2008).

In the present work, primary and pseudo-secondary fluid inclusion assemblages (FIAs) hosted in Fe-rich sphalerite and quartz from the pyrrhotite pipes and their rims and in quartz from the pyrite-quartz

body have been studied. In the deep pyrite-quartz veins, pseudo-secondary and secondary FIAs, clearly coeval with pyrite precipitation, have been used. All fluid inclusions are aqueous, liquid-rich, with 20-30 vol% vapor phase. No evidence of phase separation has been observed. FIAs show progressive salinity decrease with time from 18.5 to 2.7 wt% NaCl equiv. at relatively constant homogenization temperatures (Th) between 280 and 220°C; higher Th (up to 350°C) are also recorded in the deep pyrite-quartz veins.

Typical intermediate-density fluids exsolving directly from magma have salinities between 3 and 8 wt% NaCl equiv (Audétat et al., 2008). Fluid salinities above these values generally result from boiling and/or mixing with basinal brines. However, at Cerro de Pasco, neither boiling nor mixing with external brines could be evidenced. A way to explain such high salinity is to mix deep magmatic brines previously formed and stored at depth with less saline fluids.

Preliminary fluid inclusion analyses by LA-ICP-MS have been conducted on FIAs hosted by Fe-rich sphalerite from the pyrrhotite pipes and quartz from the deep pyrite- quartz veins. The results show that FIAs with higher salinity are highly enriched in metals, up to 1.3 wt% Mn, 0.9 wt% Pb, 0.5 wt% Sb in the pyrrhotite pipes, and up to 5.3 wt% Fe, 2.3 wt% Mn, 0.9 wt% Zn, 0.2 wt% Sb, 0.1 Wt% Pb in the deep pyrite-quartz veins. Decrease of metal content correlates with decrease in salinity, less saline FIAs show metal contents which are at least two orders of magnitude lower. Our results are compatible with progressive dilution of stored metal-rich magmatic brines at depth. Significant differences in Pb, Sb and Mn contents between high-salinity fluids from the pyrrhotite pipes and the deep pyrite- quartz veins suggest that the two mineralization styles were formed by two separate mineralizing stages, related to chemically different fluids.

Origin of less saline fluid diluting the stored brines is quite puzzling. At Fresnillo, Simmons (1991), and Wilkinson et al. (2013) invoke implication of meteoric water. No low-salinity fluids (< 2 wt% NaCl equiv.), generally attributed to meteoric water, have been identified for the studied stages in the present work. Strong magmatic signature of the fluid is also supported by oxygen isotopes of hydrothermal quartz from the pyrite-quartz body $\delta^{18}O_{quartz}$ = 16.0 - 17.2‰ VSMOW (Baumgartner et al., 2008) corresponding to $\delta^{18}O_{water}$ = 6.5 - 7.2 ‰ VSMOW (at 250°C). These heavy $\delta^{18}O_{water}$ values are unlikely equilibrated meteoric waters. Modeled $\delta^{18}O$ values of exchanged with surrounding host rocks meteoric water, calculated using the equation of Ohmoto and Rye (1974), show that very low water/rock ratio (<0.1) and relatively important temperature (>250°C) are necessary to obtain such signatures. In addition, Cs content in the different FIAs is constant, which is incompatible with a mixing with meteoric water scenario. The new data are best explained by mixing between two different magmatic fluids, a brine previously formed by deep boiling and stored at depth, and a low-salinity one (≤3 wt% NaCl equiv.) probably exsolved directly from a new magma batch.

This mechanism, could explain the rise of base metal-rich high-salinity fluids derived from magmatic brines in the shallow epithermal environment of porphyry systems, and therefore the high Zn-Pb-(Ag) grades of such deposits, without invoking mixing with meteoric fluids at considerable depth.

REFERENCES

Audétat A, Pettke T, Heinrich C, Bodnar R (2008) The composition of magmatic–hydrothermal fluids in barren versus mineralized intrusions. Economic Geology. V.103. p.877–908.

Baumgartner R, Fontboté L, Vennemann T (2008) Mineral zoning and geochemistry of epithermal polymetallic Zn-Pb-Ag-Cu-Bi mineralization at Cerro de Pasco, Peru. Economic Geology. V.103. p.493-537.

Simmons S (1991) Hydrologic Implications of Alteration and Fluid Inclusion Studies in the Fresnillo District, Mexico: Evidence for a Brine Reservoir and a Descending Water Table during the Formation of Hydrothermal Ag-Pb-Zn Orebodies. Economic Geology. V.86. p.1579-1601.

Wilkinson J, Simmons S, Stoffell B (2013) How metalliferous brines line Mexican epithermal veins with silver. Scientific reports. V.3. 7p.

Ohmoto H, Rye R (1974) Hydrogen and oxygen isotopic composition of fluid inclusions in the Kuroko deposits, Japan. Economic Geology. V.69. p.947-953.