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Fluid evolution in zoned Cordilleran polymetallic veins — Insights from microthermometry and LA-ICP-MS of fluid inclusions

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ABSTRACT

Fluid inclusion analysis through the paragenetic sequence of one symmetrically zoned vein sample is used to reconstruct the P–T–X fluid evolution of a porphyry intrusion-related Cordilleran polymetallic vein from Morococha, central Peru. Results record an evolution from initial deep-seated precipitation of quartz–pyrite and base metal sulphides to final near-surface deposition of carbonates, demonstrating progressive mineralisation during uplift and erosion. This is the first detailed study addressing meso- to epithermal Zn–Pb–Ag–Cu-rich ore in a magmatic–hydrothermal system by combination of fluid inclusion microthermometry with laser ablation inductively coupled plasma mass-spectrometry (LA-ICP-MS) quantifying metal, as well as sulphur concentrations in the evolving hydrothermal fluid.

Scanning electron microscopy cathodoluminescence (SEM-CL) imaging of quartz and detailed transmitted- and reflected-light petrography provide textural evidence that early, moderately saline (4–5 wt.% NaCl eq.) and CO_2-bearing fluids with homogenisation temperatures of 340°–380 °C precipitate Cu-bearing minerals. In this open hydrothermal system the fluids record decreasing salinities, CO_2-contents and temperatures, while Zn-, Pb-, and Ag-sulphides precipitate. Fluids related to early precipitation in the vein have metal contents of several 1000 μg/g S and Fe, over 1000 μg/g Cu, 100 μg/g Pb, 10 μg/g Ag, and several 100 μg/g Zn. Sulphur concentrations in the fluid are sufficiently high to precipitate all metals in solution as sulphides. The latest generation of fluid inclusions associated with abundant carbonate precipitation in the centre of the vein has homogenisation temperatures ranging from 260° to 220 °C, low metal concentrations, and no measurable CO_2.

During vein formation, cooling and several kilometres of erosion resulted in "telescoping" of consecutively precipitated mineral assemblages. The deep input fluid dominating in the early vein stage is interpreted to be of magmatic origin, most likely a single phase magmatic fluid of intermediate salinity and density. It cooled to an aqueous liquid, separated minor CO_2-rich vapour, and was eventually diluted by meteoric water in the late stages of vein formation when the progressively eroded land surface was only several hundred meters above the vein location.

1. Introduction

Porphyry-related base metal mineralisation is an important Zn–Pb–Ag–Cu ore type, usually occurring as meso-epithermal veins and massive manto- and chimney-type carbonate replacement bodies. These ores are variably described as Cordilleran, Butte-type, or high- and/or intermediate-sulphidation epithermal deposits, and are characteristic of the late stages of porphyry copper systems (Meyer et al., 1968; Guilbert and Park, 1986; Bartos, 1989; Einaudi et al., 2003; Sillitoe, 2010). Mineral zonation is a common feature observed during field mapping and mine exploration essaying, and occurs from the small scale of individual base metal veins though large replacement ore bodies to entire ore deposits or mine districts. Classic examples include Casapalca (Rye and Sawkins, 1974), Butte (Meyer et al., 1968), Colquijirca (Bendezú and Fontboté, 2009), Morococha (McLaughlin and Graton, 1935; Cerro de Pasco Copper Corporation, 1948; Petersen, 1965; Catchpole et al., 2008). These deposits and districts typically show a Cu-rich core area, Zn–Pb–Mn–Ag dominated ores in an intermediate to external position and in places As–Sb–Ag–Hg–Au ores towards the outermost areas. The processes controlling metal zonation have been studied in experiments (Hemley and Hunt, 1992; Hemley et al., 1992; Seward and Barnes, 1997). However, the zonation as a function of the chemical evolution of the hydrothermal fluid by in situ fluid inclusion analysis has not been clearly demonstrated to date.

The combination of microthermometry and LA-ICP-MS applied to fluid inclusions has proven to be a powerful tool in understanding ore forming processes in porphyry systems. Several studies document

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