Detailed characterization of vectors to ore in replacive volcanogenic massive sulphide (VMS) deposits of the northern Iberian Pyrite Belt (Spain): the Aguas Teñidas case study

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INTRODUCTION

Volcanogenic massive sulphide (VMS) deposits represent a major source of base (Cu, Pb, Zn), precious (Ag, Au), and other metals of economic importance. Due to progressive exhaustion of the shallowest and most easily accessible deposits, the search for new resources faces challenges such as exploration at increasing depths or in non-conventional settings. In this context vectors to ore play a vital role.

The Iberian Pyrite Belt (IPB) is an outstanding VMS district located in the SW of the Iberian Peninsula. It is arguably the largest known accumulation of sulphides on the Earth's crust (>1.6 Bt) and represents one of the main zones of base metal production in Europe. However, the characterization of vectors to ore in the IPB is far from systematic or complete. In addition, previous works have mostly focused on the study of the larger shale-hosted exhalative deposits of the southern IPB or the giant Rio Tinto deposit; but less attention has been paid to the predominantly volcanic-rock-hosted replacive deposits of the northern IPB, which, although generally smaller in size compared to southern deposits, typically present higher base metal concentrations.

In this work we have performed a detailed study of the main vectors to ore to a representative volcanic-rock-hosted replacive VMS deposit located in the northern IPB, the Aguas Teñidas deposit. Investigated vectors include: (1) host sequence characterization and mineralized unit identification based on whole rock geochemistry discrimination diagrams; (2) study of the characteristics and behaviour of whole rock geochemical anomalies around the ore (e.g. alteration-related, geochemical halos of indicative elements such as Cu, Zn, Pb, Sb, Tl, and Ba around the deposit); (3) application of portable X-ray fluorescence analysis to the detection of the previous vectors; (4) mineralogical zoning; (5) mineral chemistry vectors in muscovite and chlorite using major (EMPA) and trace (LA-ICP-MS) elements. In addition, a conceptual model has been proposed which accounts for the observed mineralogical and mineral chemistry trends across the hydrothermal footprint of the deposit.

The data presented in this work are not only applicable to VMS exploration in the Iberian Pyrite Belt, but they will also contribute to improving our general understanding of vectors to ore in replacive-type VMS deposits.

MAIN RESULTS

Results summarized here have been published in Gisbert et al. (2021) and Gisbert et al. (2022), where they are presented and discussed in detail.

Mineral zoning

In the footwall, a concentric cone-shaped hydrothermal alteration zone bearing the stockwork passes laterally, from core to edge, from quartz (only local) to chlorite–quartz, sericite–chlorite–quartz, and sericite–quartz alteration zones. The hydrothermal alteration is also found in the hanging wall despite being tectonically allochthonous to the orebody: a proximal sericite alteration zone is followed by a more distal albite-rich one.

Mineral chemistry

White micas are dominated by muscovite in both regionally altered lithologies and within the hydrothermal system, with coexisting paragonite occurring in a halo beyond the first disseminated pyrite surrounding the stockwork and in the proximal hanging wall. Systematic variations have been observed in FeO/(FeO + MgO) and $Na_2O/(Na_2O + K_2O)$ across the alteration zone. Systematic variations in Ba, Cs, Li, Pb, Rb, Sn, Sr, Tl and Zn have been observed in white micas consistent with a proximal-distal transition (vector).

Chlorite is predominantly clinochlore in composition, with chamosite restricted to the centre of the hydrothermal system. In regionally altered lithologies it is characterized by a constantly low Al and Al^{IV} at variable Fe/ (Fe + Mg); in rocks influenced by the hydrothermal system it presents higher Al^{IV} and total Al, and a progressive increase in Al, Al^{IV} and Fe/(Fe + Mg) towards its core. Trace element trends in chlorite have been less well characterized due to analytical limitations, although variations have been observed in As, Co, Li and Zn contents.

Whole rock geochemistry

Whole rock major elements show an increase in alteration indexes (e.g. AI, CCPI) towards the mineralization, a general SiO_2 enrichment, and FeO enrichment as well as K_2O and Na_2O depletion towards the centre of the hydrothermal system, with MgO showing a less systematic behaviour. K_2O and Na_2O leached from the centre of the system are transported and deposited in more external areas. Some element ratios present clear trends around the deposit, becoming useful pathfinders; these are: 1) $Na_2O/(Na_2O + K_2O)$, which is mainly controlled by white micas in proximal rocks; 2) FeO/(FeO + MgO), controlled by both white micas and chlorite, as well as by the presence of other Fe-bearing phases such as Fe oxides and pyrite; and 3) Rb/K_2O. These vectors allow detection of the influence of the hydrothermal system, although they can be strongly influenced by lithological changes.

Copper, Pb, and Zn produce proximal anomalies around mineralized areas, while the more mobile Sb, Tl, and Ba generate wider halos. Whereas Sb and Tl halos form around all mineralized areas, Ba anomalies are restricted to areas around the massive sulfide body.

Our results show that proposed vectors, or adaptations designed to overcome p-XRF limitations, can be confidently used by analysing unprepared hand specimens with a p-XRF device, including the external rough curved surface of drill cores.

Conceptual model

A conceptual model has been proposed which accounts for the observed mineralogical and mineral chemistry trends across the hydrothermal footprint of the Aguas Teñidas VMS deposit. Major element signatures in white micas and chlorite are interpreted as having been controlled by the upwards and outwards flow of hot reducing Fe-rich hydrothermal fluids; these produced a coupled increase in temperature and fluid Fe/(Fe + Mg), and a decrease in fO_2, with increasing fluid/rock ratios towards the centre of the stockwork.

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