Modeling of the compositional variations of metal tenors in the Aguablanca Ni-Cu-(PGE) sulfide deposit, SW Spain

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The Aguablanca ore deposit (SW Spain) is the first and unique economic example to date of a Ni-Cu magmatic sulfide deposit related to mafic-ultramafic magmatism in southern Europe. It occurs in an uncommon geodynamic context for this ore-type, an orogenic belt developed in a convergent plate margin setting. Sulfides occur in a subvertical magmatic breccia composed of unmineralized igneous rock fragments enclosed within a variably mineralized matrix. Discovered in 1993, Aguablanca (15.7 Mt, at 0.66 wt. % Ni, 0.46 wt. % Cu and 0.47 g/t PGM) was mined as open-pit during 12 years (2004-2015). A small underground mine with a life of 3.5 years is planned to operate soon to recover 3.2 Mt of mineralized rock.

INTRODUCTION

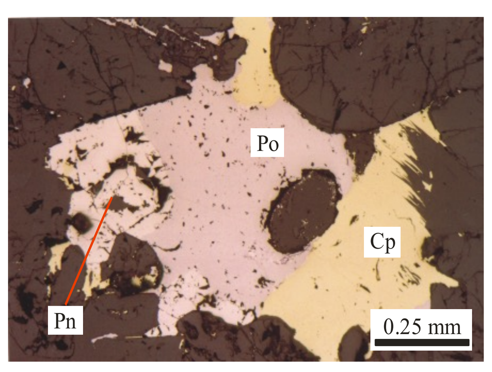
Ni-Cu-(PGE) sulfide deposits are the result of fractionation and crystallization of sulfide melts previously segregated by immiscibility from silicate magmas. The metal composition of the mineralized bodies depends on the initial metal content of the silicate magma, the partitioning behavior of metals during the sulfide segregation and fractionation, and the silicate to sulfide ratio (*i.e.*, R-factor). Modeling of the compositional variations of metal tenor has led to establish the origin and fractionation of the sulfides in the Aguablanca Ni-Cu sulfide deposit. Two main ore-types with distinct metal tenors occur in this deposit: semi-massive and disseminated ore. There are also locally chalcopyrite-rich veinlets but this ore-type is much less abundant.

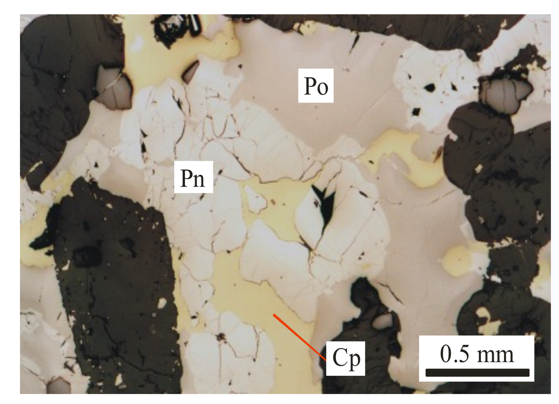
ORE-TYPES

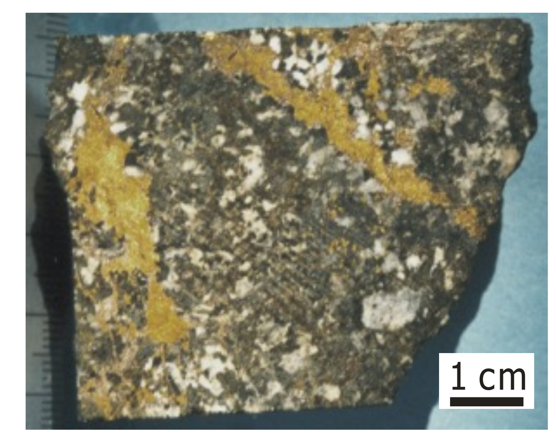
DISSEMINATED ORE: sulfides form variably sized (from few millimetres to 1-2 cm) polymetallic aggregates situated interstitially between silicates of gabbronorite rocks. Pyrrhotite is the most abundant sulfide and chalcopyrite predominates over pentlandite with chalcopyrite/pentlandite ratios ranging 0.06-0.64. Pyrite and magnetite are rare.

SEMI-MASSIVE ORE: characterized by euhedral to subhedral (up to 0.5 cm across) silicates enclosed by an assemblage of sulfides (> 40 vol. %) composed mostly of pyrrhotite and pentlandite, with minor amounts of chalcopyrite, pyrite, magnetite and an PGM assemblage formed mainly by Pt-Pd bismuthotellurides and sperrylite.

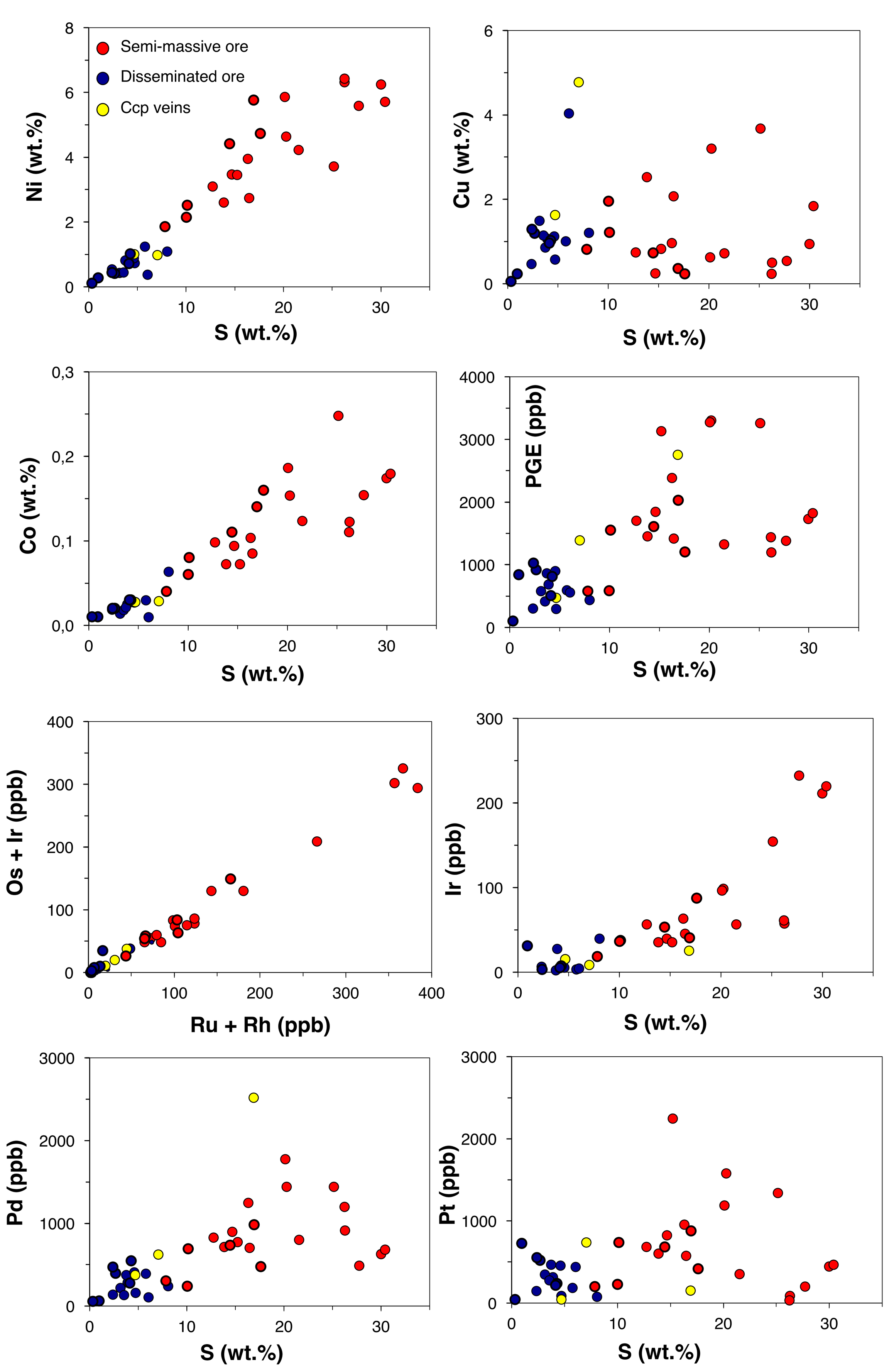
CHALCOPYRITE VEINLETS: they represent a very minor ore-type in Aguablanca (< 5 %). They occur crosscutting both semi-massive and disseminated ores. They are made up of massive chalcopyrite, minor amounts of pyrrhotite and pentlandite, and traces of argentopentlandite located within chalcopyrite.



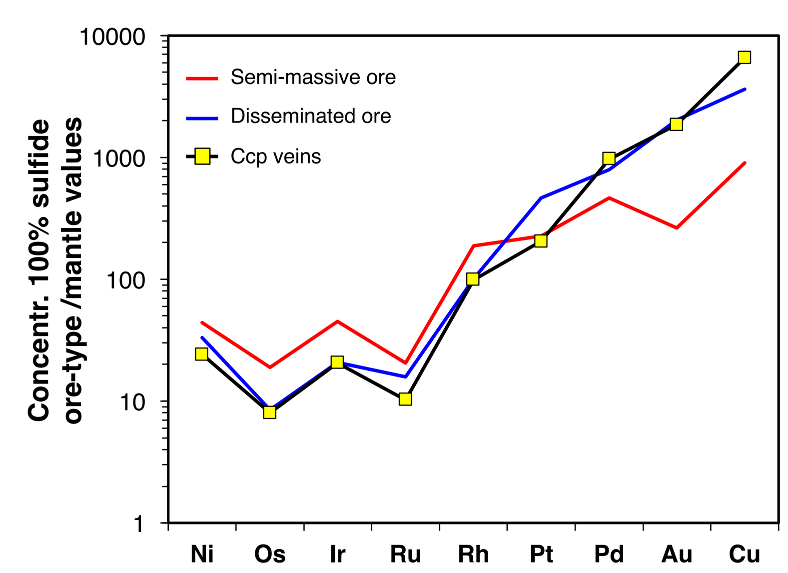




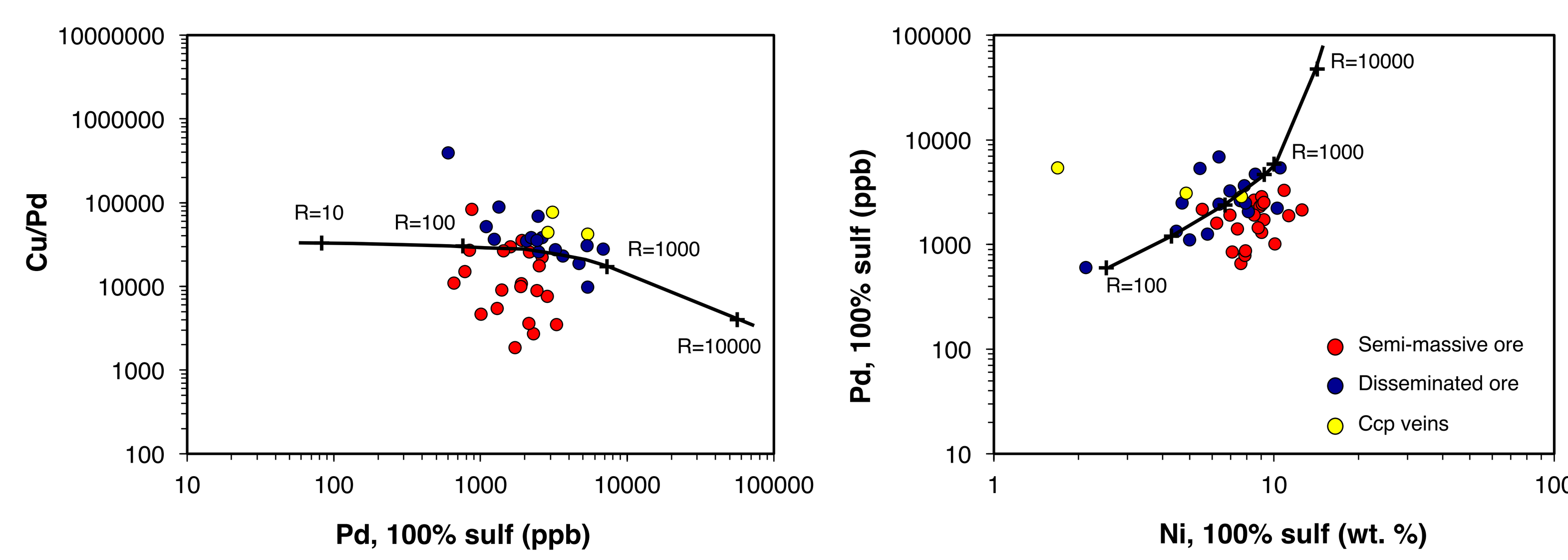
ORE GEOCHEMISTRY



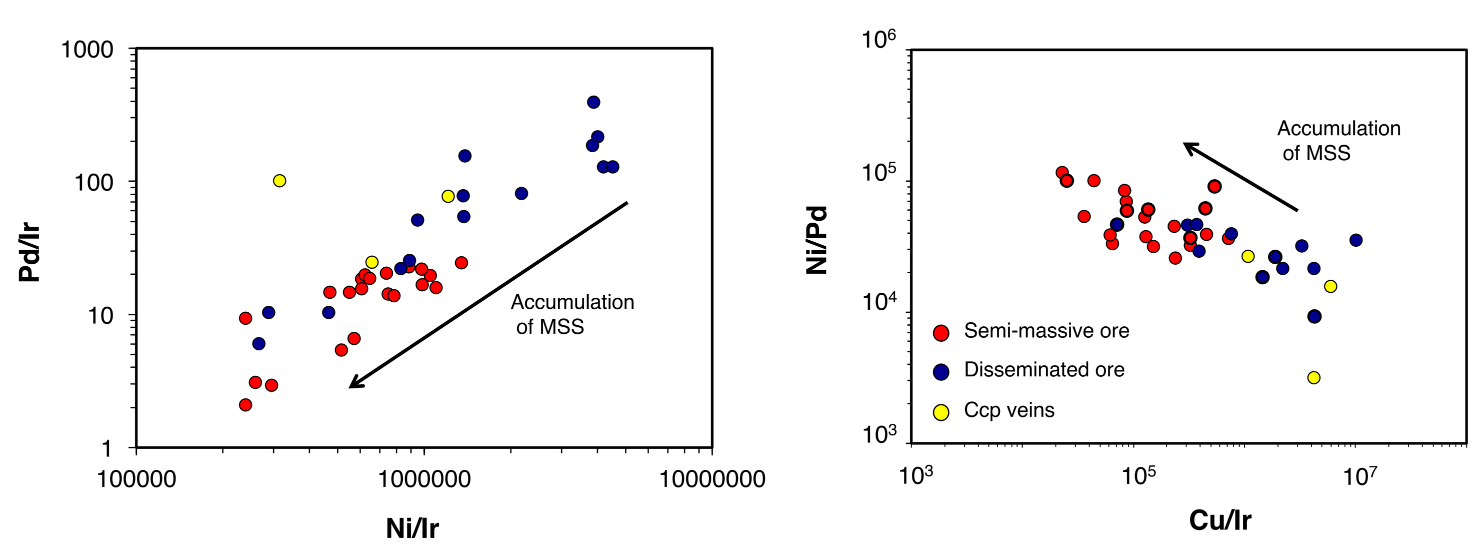
Variation diagrams showing the correlations between different elements from samples from semi-massive, disseminated and chalcopyrite-veined ores: Ni vs S, Cu vs S, Co vs S, PGE vs S, Os+Ir vs Ru+Rh, Ir vs S, Pd vs S, and Pt vs S. Data are from Piña et al. (2008) and Peralta (2010)



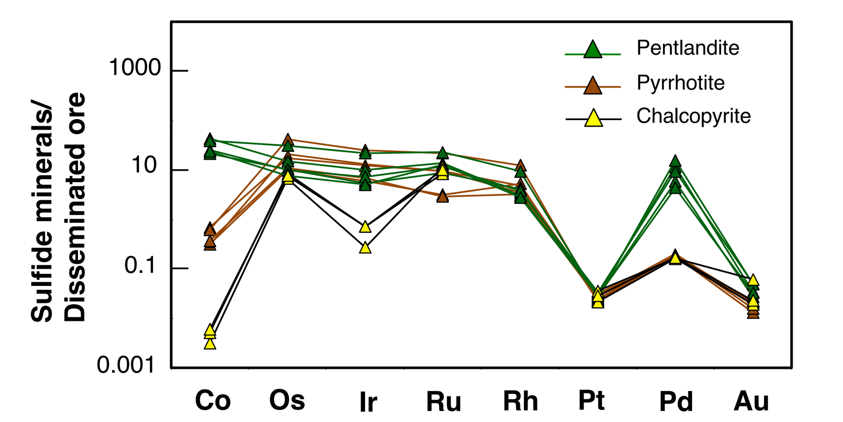
Mantle-normalized metal patterns for the average values of semi-massive, disseminated and chalcopyrite-veined ores. Data from Piña et al. (2008) and Peralta (2010)



Cu/Pd versus Pd (100% sulf), and Pd (100% sulf) versus Ni (100% sulf) diagrams for Aguablanca sulfides. Model curves display the compositional variation of sulfide melts segregated from silicate magma containing 250 ppm Cu, 300 ppm Ni and 6 ppb Pd at varios R factor values. Data from Piña et al. (2008) and Peralta (2010)



Ratio diagrams of Pd/Ir versus Ni/Ir, and Ni/Pd versus Cu/Ir of Aguablanca sulfides showing that semi-massive sulfides represent MSS cumulates. Data are from Piña et al. (2008) and Peralta (2010)



Metal content in pyrrhotite, pentlandite and chalcopyrite from semi-massive ore normalized against the average whole rock content of the disseminated ore. Figure and data are from Piña et al. (2012)

ORIGIN of ORE-TYPES

- The high modal abundance of pyrrhotite, the predominance of pentlandite over chalcopyrite and the enrichment in Ni, Os, Ir, Ru and Rh and depletion in Cu, Au, Pt and Pd relative to disseminated ore indicate that the **semi-massive ore represents MSS-enriched cumulates**. Os, Ir, Ru and Rh are enriched in pyrrhotite and pentlandite from the semi-massive ore by a factor of 3 to 15 relative to the disseminated ore, and Pt and Au are depleted by factors of 0.1 and 0.01, respectively. These values are within the range of partition coefficients of these metals between MSS and sulfide melt, suggesting that the **disseminated ore** may represent **an original sulfide liquid from which MSS crystallized**. Modeling of the composition of disseminated sulfides indicates that they may segregate from a relatively Cu-rich silicate magma containing ~ 250 ppm Cu, ~ 250 ppm Ni and ~ 6 ppb Pd, under R-factors ranging from 200 to 1000. The high Cu content could well be due to the assimilation of crustal components from the country rocks characterized in the surrounding area by hosting small stratabound concentrations of chalcopyrite and bornite.

- The high Cu, Pd, Pt and Au tenors suggest that **chalcopyrite veins** likely represent the **crystallization of a Cu-rich fractionated sulfide liquid** after MSS fractionation. However, the abundance of chalcopyrite-rich veinlets is very low considering the high amount of semi-massive ore (i.e., MSS cumulates), so the emplacement of the sulfide melts in shallow crustal levels and the subsequent rapid cooling of the melt may prevent extensive fractionation of the sulfide melts and only small amounts of Cu-rich residual sulfide melt generated. This melt was then likely retained with the MSS cumulates or percolated away the mineralized breccia, and uniquely in some places, this liquid precipitated as Cu-Pd-Pt-Au-rich chalcopyrite veinlets.

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