The Aguablanca Ni-Cu-PGE Ore Deposit, Spain: A Case of Magmatic Sulfide Mineralization in Southern Europe

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Introduction

In the Iberian Peninsula there are a number of PGE occurrences but the Aguablanca Ni-Cu-PGE sulfide deposit, discovered in 1993 (Ortega *et al*., 2000), is the only one having sufficient tonnage to be economically viable. In addition, the geological relevance of Aguablanca is highlighted by the fact that Ni-Cu mineralization associated with mafic intrusions are not common in Europe: the known examples occur in Finland (Vammala, Hitura and Kotalahti deposits, Frietsch et al., 1979; Hakli et al., 1979; Gervilla et al., 1998), Norway (Rana deposit, Boyd and Mathiesen, 1979) and Italy (Ivrea-Verbano deposits, Garuti et al., 2001).

This mineralization was discovered by Presur - Atlantic Copper S.A. (a joint-venture between the Spanish State, represented by Presur, and Atlantic Copper S.A., formerly Rio Tinto Minera S.A.) in 1993 during a gold exploration program. A regional exploration survey carried out by Presur found a geochemical nickel anomaly related to a gossan developed on altered gabbros. Short (less than 5 m) vertical percussion drilling and long (up to 550 m) 45° dip diamond coring were carried out by Atlantic Copper S.A. to trace the downward extension of the observed oxidation cap and to identify the extension of the sulfide mineralization. Drilling to date has revealed the existence of two subvertical mineralized bodies containing geological ore reserves of 31 Mt grading 0.6-0.7%Ni, 0.5-0.6%Cu, 0.02%Co and 0.75 g/t Pt+Pd+Au. Since June 2001, the company Rio Narcea Gold Mines is the owner of Aguablanca and plans to start the exploitation in the next few years.
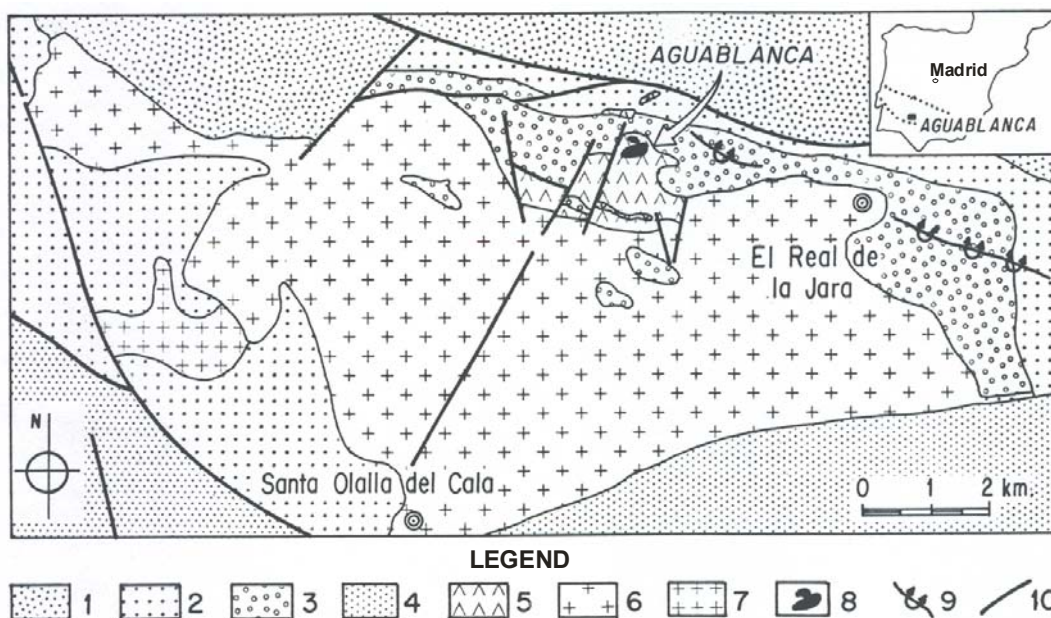

Figure 1. Geological map of the Aguablanca area. *1. Greywake and slate (Riphean). 2. Slate and metavolcanic rocks (Upper Riphean - Lower Cambrian). 3. Marble, limestone, skarn and garnetites (Upper Riphean - Lower Cambrian). 4. Limestone, slate and greywacke (Lower Cambrian Lower Carboniferous). 5. Aguablanca gabbro and diorite. 6. Santa Olalla tonalite. 7. Alkaline granite. 8. Gossan over the Ni-Cu deposit. 9. Anticline. 10. Fault.*
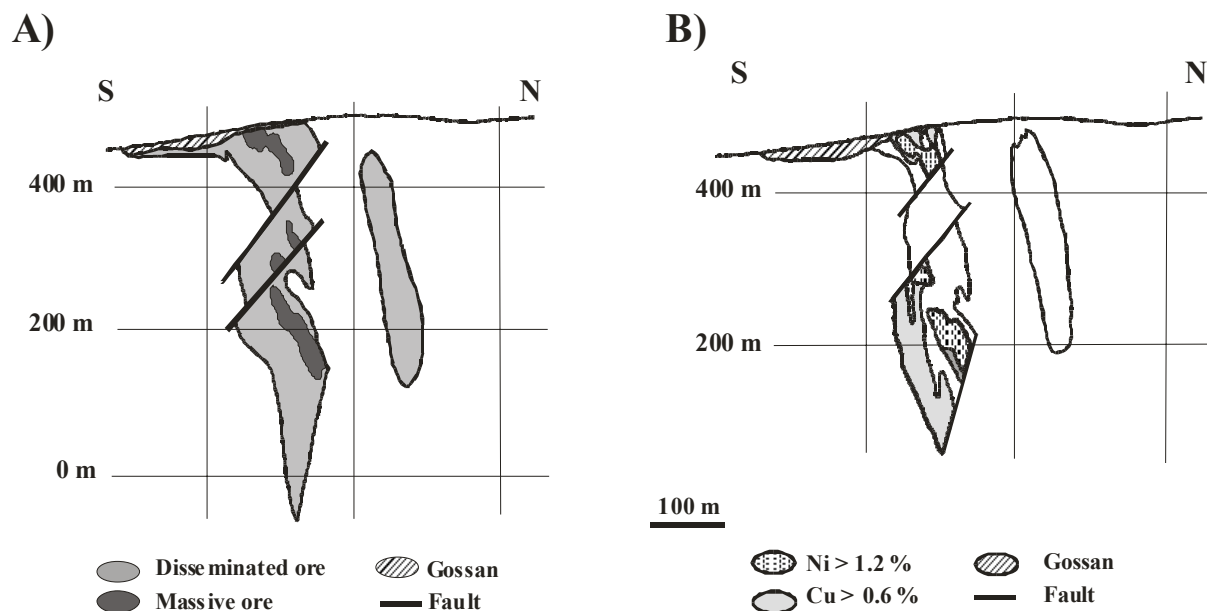
A)

S   N

400 m

200 m

0 m

- ◯ Disseminated ore
- ◯ Massive ore
- ▨ Gossan
- ▬ Fault

B)

S   N

400 m

200 m

100 m

- ⬮ Ni > 1.2 %
- ◯ Cu > 0.6 %
- ▨ Gossan
- ▬ Fault

Figure 2. Outline of the mineralised bodies at Aguablanca. A. Distribution of the massive and disseminated ores. B. Distribution of Ni and Cu.

Geology and Mineralogy of the Deposit

The Aguablanca deposit is located in the Ossa Morena Zone of the Iberian Massif, the westernmost belt of the European Variscan chain. The ore-bearing igneous body (Fig. 1) is hosted by a Lower Cambrian volcanosedimentary unit with terrigenous and carbonate sequences towards the top. The major structures recognized in the area developed during the first phase of Hercynian deformation and correspond to WNW-ESE asymmetric folds with subhorizontal axes and vergence to the SW and longitudinal transcurrent faults and thrusts. Late Hercynian oblique faults transect the previous structures. The Hercynian regional metamorphism in this area is of low grade, greenschist facies.

The Aguablanca intrusion (Fig. 1) is a small mafic-ultramafic igneous body of tholeitic affinity and is made up by sulfide-bearing gabbros, norites and subvertical layers of pyroxenites and peridotites in the northern part of the intrusion which grade into diorites to the south. These rocks show pervasive retrograde alteration with two assemblages, an early one consisting of actinolite ± epidote ± chlorite ± albite ± serpentine, postdated by talc ± carbonates ± chlorite. The age of Aguablanca is still a matter of debate, however, a number of geological features of the intrusion and the associated mineralization suggest that it is pre-Hercynian and was folded and metamorphosed during the Hercynian orogeny. To the south,

Aguablanca is cut by the Santa Olalla pluton (Fig. 1), a Hercynian calcalkaline intrusion with flat lying foliation that shows a zoned structure with granodiorites and monzogranites in the core rimmed by quartzdiorites and tonalites. In the contact aureole of these intrusions, the carbonate rocks are metamorphosed into skarns (i.e. garnetites, calcic silicate rocks and marbles) notably at the northern border of Aguablanca and to the west of the Santa Olalla pluton.

The ore is made up by pyrrhotite, pentlandite, chalcopyrite and pyrite and is concentrated in two subvertical bodies (Fig. 2A & B). The following types of mineralization are recognized: 1) Disseminated ore (Ni/Cu = 1-1.5), which is the dominant ore type and is made up by sulfides occurring interstitially to the igneous silicates; 2) Massive ore (Ni/Cu = 2-5), that account for the 10-15% of the total mineralisation and consist of sulfides making up to the 85% of the rock and developing net to poikilitic textures; 3) Breccia ore, with a total volume less than 1%, consisting of rounded fragments of unmineralized igneous enclaves in a massive sulfide matrix; 4) Nodules of sulfides, centrimetric in size, occurring outside of the ore bodies to the south; 5) pyrrhotite veinlets, and 6) chalcopyrite veinlets. The two latter cross-cut the earlier magmatic sulfides (pyrrhotite, pentlandite and chalcopyrite) and have been interpreted as metamorphic remobilizations. The magmatic assemblage is also overprinted by meta-

morphic and hydrothermal pyrite.

The massive and breccia ores are characterized by coarse equant anhedral crystals of annealed hexagonal pyrrhotite with sparse flame exsolutions of pentlandite and surrounded by polycrystalline, chain-like pentlandite aggregates and anhedral crystals of chalcopyrite. The disseminated ore presents sulfide mineralogy and textures similar to those of the massive and breccia ores, although it concentrates higher proportions of chalcopyrite than the massive sulfides, notably along the southern border of the main mineralised body. This observation is further supported by the distribution of both Cu and Ni in the deposit (Fig. 2B).

The pyrite (usually less than 5% of total sulfides) is either replacing pyrrhotite and/or cross-cutting the sulfide assemblage described above, and therefore postdates the magmatic crystallization of the sulfides. Textural features and Co/Ni ratios alow identification of three main generations of pyrite: 1) large euhedral crystals of early metamorphic pyrite, present throughout the deposit overprinting the magmatic recrystallized pyrrhotite, in veinlets with remobilized pyrrhotite, and in the barren gabbros and country rocks; 2) pyrite in aggregates nucleated on flame pentlandite within hexagonal pyrrhotite (massive ore) and as ribbon-like crystals within monoclinic pyrrhotite (disseminated ore); and 3) pyrite replacing pyrrhotite and plagioclase along grain boundaries and infilling late fractures. This late replacement thought to be hypogenic as it can be observed even in deep parts of the deposit.

Platinum Group Mineralogy

The platinum group minerals are usually associated with the sulfides and include michenerite, merenskyite, moncheite, palladian melonite and sperrylite. These mostly occur within pentlandite and pyrrhotite, or close to the contacts between two sulfide grains and are notably absent within pyrite. Most of the PGM occur as single grains, although composite grains with non-PGE tellurides are common. These include bismuth, bismuth-silver and silver tellurides such as tellurobismuthite, volinskyite and hessite. Native gold is also found spatially related to the PGM.

The PGE-tellurides show an extensive substitution of Bi for Te, that in the case of merenskyite indicates temperatures of formation up to 500ºC, according to Hoffman and MacLean (1976). The presence of michenerite in the PGM assemblage is in agreement with this estimation as this bismuthotelluride is stable only below 500ºC. These relatively low temperatures of crystallization

suggest that the current PGM assemblage was generated during the retrograde evolution of the ore. This is further supported by the occurrence of numerous bismuthotellurides at the sulfide-silicate grain boundaries in the disseminated ore and in areas of semi-massive sulfides with high pyrite content. However, in the massive ore most of the PGM occur enclosed within the magmatic sulfides and only a few are located at the contact between them. This distribution strongly suggests that prior to remobilization as bismuthotellurides, a magmatic-related PGM assemblage initially formed and probably exsolved during the low temperature reequilibration of the mss. Nevertheless, this mobilization took place at grain scale as most PGM remained within the sulfides where they initially formed, notably in the massive ore. The occurrence of paladian melonite restricted only to the massive ore, in which the exsolved pentlandite is more abundant, further supports this hypothesis.

Chondrite normalized PGE contents in samples recalculated to 100% sulfides show a general positive trend, with peaks in Pt and Pd reflecting the observed PG mineralogy. The highest PGE contents are found in the sulfide fraction of the Cu-rich disseminated ore occurring in the southern part of the deposit (Fig. 2), which is notably enriched in Pt and Pd with respect to the other ores. By contrast, the chalcopyrite veinlets have different PGE patterns that broadly mimic the pattern in the ores that they cut, with higher PGE contents when crossing the PGE-rich disseminated sulfides. This behaviour supports the interpretation of chalcopyrite veinlets as remobilizations of the magmatic ore, although only over short distances. Regarding the massive ore, enrichment in Pd and Pt is observed when this ore is overprinted by abundant early pyrite.

Values of the (Pt+Pd):(Ru+Ir+Os) ratio vary between the ore types. The Cu-rich disseminated ore shows a ratio of ~ 30.7, up to fifteen times the value for the massive ore with low pyrite content. These features strongly suggests that the preferential concentration of Pd and Pt in the disseminated sulfides is a primary magmatic feature that results from fractionation of these PGE towards the southern border of the mineralization, following the trend observed for Cu (Li *et al* 1996; Barnes *et al*. 1997). One chalcopyrite veinlet sampled cross-cutting disseminated ore also displays a high (Pt+Pd):(Ru+Ir+Os) ratio of 48.42, almost fifteen times the ratio for the chalcopyrite veinlets cross-cutting the massive ore. These figures further support the idea indicated above that veinlets can be filled by locally remobilized components of the magmatic sulfides.

Proposed Model

The geological, mineralogical and textural features of the Aguablanca deposit suggests that the ore developed along three main events: 1) magmatic crystallyzation and subsequent sub-solidus reequilibration of a sulphur-rich liquid immiscible with the silicate parental magma, that resulted in magmatic pyrrhotite, pentlandite and chalcopyrite; 2) metamorphism and deformation of these sulfide assemblage, with recrystallyzation and remobilization of pyrrhotite, growing of metamorphic pyrite and remobilization of chalcopyrite; and 3) late circulation of hydrothermal fluids, that produced replacement of pyrrhotite and locally plagioclase by pyrite. In this context, the distribution of the PGM, closely related to the magmatic sulfides, suggests that they had been initially exolved during the subsolidus recrystallyzation of the magmatic ore. However, the current PGM composition indicating crystallyzation temperatures below 500ºC and their location close to sulfide edges, notably in areas with abundant metamorphic pyrite, clearly point towards a later remobilization of the tellurides in relation to the metamorphism of the deposit and maybe during the late hydrothermal events. However, this remobilization took place at short distances as most of the PGM remain within the sulfides in which they initially formed and have not been observed within pyrite or within the veinlets of pyrrhotite. The remobilization could have been more important towards the chalcopyrite veinlets that contain higher amounts of PGM.

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