(2) ACID DRAINAGE POTENTIAL AT S. DOMINGOS MINE

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Introduction

The S. Domingos mining area located in the Iberian Pyrite Belt is the object of different environmental studies. Its mining history and abandon has been used by different researchers as a source of knowledge of the behaviour at ambient temperature and pressure of the reactions that still generate acid mine drainage (Abreu et al., 2010, Batista, 2000, Quental et al., 2003).
The presence of massive sulphide mineralizations and related hydrothermal alteration system contributed at first for the natural reactions that lead to acid rock generation. The hydrothermal alteration and weathering mapping done in several IPB deposits shows a good correlation between the alunite veins occurrence and pervasive low pH supergene kaolinite/halloysite alteration (Matos et al., 2006, 2003). These studies lead to the conclusion that the occurrence of alunite group minerals, which is restricted to veins, is coherent with very low pH and oxidant fluids circulation, at low temperature (Matos et al, 2003). At surface the outcropping pyrite ore deposits (e.g. Algares, Aljustrel, Caveira, São Domingos in the Portuguese IPB sector) are the main natural source of acid rock drainage.
Nevertheless, this natural phenomenon is not the most important acid generator in the S. Domingos mine, where the history of ore processing, the value of the metals in the market and the gradual change from Cu mining to sulphur producer, generated a variety and volume of waste materials, spread along the main valley and especially in Achada do Gamo that are the main contributor for the acid drainage observed and documented along the years.

Hydrothermal Alteration and Acid Rock Drainage (ARD)

Hydrothermal and supergene alteration observed in S. Domingos Mine corresponds to an intense wall-rock alteration surrounding the ore body, and comprises argilisation (kaolinite and halloysite), sericitisation, chloritisation and silicification.
Vein networks (feeder channels) and disseminations of sulphides that grade into massive sulphide lenses compose the stockwork mineralisation with veins and replacements. Generally, stockworks occur mainly in highly silicified and chloritised footwall volcanic rocks (Barriga and Carvalho, 1983). The stockwork vein structure associated with the massive sulphide single lens exploited at São Domingos is well exposed in the northern sector of the open pit (Fig. 1A) (Matos et al. 2006). Pyrite is dominant in the vein structure with hydrothermal silica. Here the host rock is a felsic coherent volcanic locally with breccias facies, probably rhyolite rock (Matos et al. 2006).
The occurrence of discordant and planar alunite veins are predominant and associated with NE-SW, E-W and WNW-ESE late faults and fractures (Matos et al., 2003). In S. Domingos the presence of alunite group minerals, within veins, corresponds to the interaction with very low pH and oxidant fluids, at low temperature resulting in alteration minerals. A strong chloritization is present in the eastern sector of the pit. Laterally of the Volcano-Sedimentary Complex structure, shales and quartzites of the Phillite-Quartzite Group occurs (Pereira et al. 2008, Matos et al. 2006).

(A)


(B)

Fig. 1- (A) Felsic volcanic rocks and the São Domingos stockwork mineralization in the northern sector of the open pit. The upper levels of the pit are dominated by intense oxidation (B) Oxidized stockwork veins.

The upper part of the open pit is dominated by extreme oxidation. The original *gossan* was totally exploited and destructed. Presently the reddish colour outcrops correspond to the oxidized stockwork zone (Fig. 1B).The hydrothermal alteration associated with the IPB massive sulphide deposits is related with sea water circulation in the host volcanic and sedimentary host rocks (Barriga et al. 1997). Various pH and temperature of fluids produces different alteration minerals depending of the nature of rocks and of the fluid-rocks interaction. After the deformation stages of the Palaeozoic basement, during the Variscan orogeny a global uplift occurs. The exposure of the sulphide mineralizations (massive, stockworks, sparge veins and disseminated) to the superficial oxidant environment promotes the acid rock drainage.
This process though, is the less important pyrite oxidation process that occurs in the mine, when we compare to other mine site such as Rio Tinto. Acid Mine Drainage, which is related to the past mining activity resulting in exposure of the sulphides (mainly pyrite) to air and water, is the most important acid generating process in the S. Domingos Mine.

Acid Mine Drainage

Massive sulphides are defined generally as accumulations of sulphides plus gangue minerals in which ore and host rock comprises at least 60 wt % of sulphides (Franklin et al., 1981). However, for geochemical considerations, massive sulphide deposits consist of any rock mass in which the ratio sulphide: silicate is greater than unity on a volume: volume basis.
The reason for this simplified definition involves the ability of sulphides to generate acidic aqueous solutions, and the inability of silicates associated with massive sulphide ores to neutralise low-pH, sulphate-bearing aqueous solutions. Hence, the discussions presented here are also applicable to vein and replacement ores having low neutralising capacity gangue.
The most important acid generating minerals, pyrite and/or pyrrhotite (usually poor in economical commodities), are the main components of all massive sulphide deposits mostly contributing to the waste materials spread in the mine area.

Acid mine drainage occurs after and during mining, related with: a) drainage from underground workings; b) surface run-off from open-pit faces and pit workings; c) waste-rock dumps; d) tailings deposits; e) spent ore piles from leaching (dump, heap, etc.). There are many factors that affect the oxidation rate of pyrite, and hence, control acid generation: a) specific surface area exposed; b) pH and oxygen concentration (in water and gas phase); c) ferric iron concentration; d) temperature and chemical activation energy (required to initiate acid generation); e) bacteriological activity (Elberling et al.,, 1993).

The S. Domingos open pit (Fig. 1A) is permanently filled with water, with seasonal variations, due to high temperatures in summer, consequently high evaporation rate, and low precipitation rate. In the last 10 years the level of the open pit raised considerably, probably due to: local aquifers evolution, the N-S and NW-SE fractures, the abandoned mining galleries network locally affected by subsidence and the probable impermeabilization of the bottom of the pit.

Along the stream between the open pit and the Telheiro area, south of Achada do Gamo, different kind of wastes, produced along the mining history of more than 100 years, such as metalurgical scoria, waste rock, milled pyrite, ore minerals and gossanous dump, etc. were deposited. The majority of these wastes are potential acid mine generators (Matos 2004, Álvarez-Valero et al., 2008; Pérez-López et al., 2008, Mateus et al. 2011).
The most important acid mine generating wastes are located in Achada do Gamo area near two sulphur factories built in the 1930's, where remains of the ore minerals, metallurgical ash, metallurgical scoria and copper cementation remains were left.
The ore processing methods were, ore milling at Moitinha area, ore leaching in several plateaus (with acid water extracted from underground mining works) and copper recovering by cementation process at Achada do Gamo (Mason & Barry unpublished technical reports, LNEG Archives). A large water channel network was built between the upper stream area near the railway facilities and the Chumbeiro dam located 10 km downstream. Several acid water dams are present at São Domingos, promoting water evaporation. These channels extends both sides downstream S. Domingos stream until Chumbeiro Dam and evaporate in a considerably large surface. Acid water was released in this process at about 2 hm^3 / year (Pereira et al., 1995). In certain periods of the year is possible to see the oxidation front in the main stream dams (Fig. 2A).

Fig. 2 – A) Oxidation front S. Domingos dam in the main stream; B) Achada do Gamo lagoon with pH <2 waters.

Near a waste pile of pyrite ore left since closure of the sulphuric acid factories in Achada do Gamo area, a small dam is present, directly associated with the main sulphur plant. In the dry season this extreme acid and highly dense water dries and oxyhydroxides minerals form. The pH reported values are about one or even below related with indigenous acidophilic bacteria activity (Bryan et al., 2006). When the first rains start, the lake fills again with very acid water and soluble secondary minerals that were formed during dry season turn to the solution and bacteria appear again (Abreu et al., 2010).

Superficial, seepage and groudwaters pH-Eh water results

Superficial waters from artificial lakes in the S. Domingos stream and open pit, stream water, seepage waters and groundwater from wells and drillholes were analysed for pH and Eh. Redox potential (*Eh)* was related to pH in order to determine the stability field of natural environmental waters and is represented in Figure 3B. Groundwater, superficial water and seepage water distribution is shown in Figure 3A.

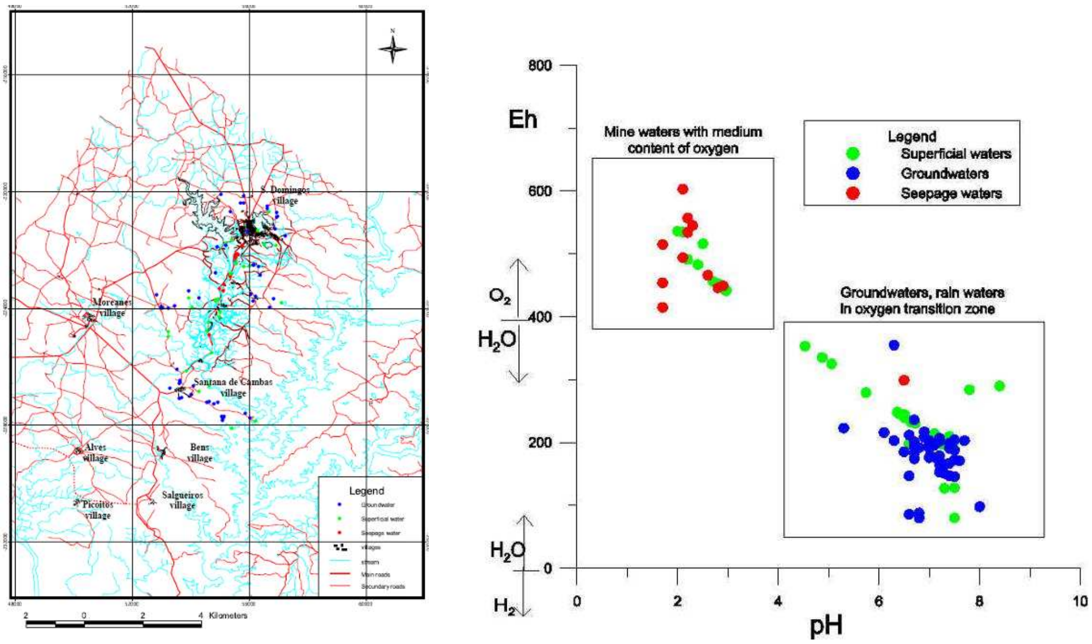

Fig. 3 A) Water measurements location; B) pH-Eh Stability diagram of the waters in the S. Domingos mining area (modified from Garrels & Christ, 1965 *in* Appello & Postma, 1996)

Conclusions

The S.Domingos mining area is characterised by a long-term mining activity, since pre-Roman times until 1966. Several facilities (open pit, Achada do Gamo sulphur factories, railway and Pomarão Harbour at Guadiana River) were built for mining works and ore transportation, covering an area of 50 km^2, facilitating dispersion of related pollutants. The main environmental problem is acid mine drainage identified in seepage water from under the dump piles into the main stream, open pit water, main stream dams and Achada do Gamo lagoon. This AMD occurs due to oxidation of the sulphides exposed to atmospheric conditions (temperature, oxygen and rain water) High concentrations of hazardous chemical elements such as As, Cd, Cu, Hg, Pb, Sb and Zn, are more effectively mobilised in the presence of acid waters with pH values between less than one until three in a wide area such as the S. Domingos river valley. Hydrothermal alteration and consequent acid rock drainage is observable in the wall rock of the open pit, where the orebody is located and is visible due to the stockwork and the alteration minerals. Although the importance of the process this is not the most significant and certainly not the reason for the environmental impact observed in the mine area. Acid waters are mainly generated when water circulates through pyrite (and pyrrhotite) rich grey colour waste piles disposed in the open pit, in Achada do Gamo area, and in some slopes sections of the main stream valley.

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