



## (1) SÃO DOMINGOS MINING SITE - IBERIAN PYRITE BELT

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### The São Domingos VHMS deposit geology

Located in the northern sector of the Iberian Pyrite Belt (IPB) the São Domingos deposit was mined between 1857 and 1966 for pyrite, copper and sulfur production. During the Roman era the superficial and oxidized part of the unique vertical massive sulphide lens was intensely exploited (Matos et al. 2006; 2011). The São Domingos mine is one of the >90 volcanic-hosted massive sulfide IPB deposits, forming the main European mining region and a world-class base metal belt. The IPB is included in the South Portuguese Zone geological terrain, a major Variscan basement unit. The belt extends 250 km with WNW-ESE direction, from the Marateca area in the Portuguese Atlantic coast, southeast of Lisbon (Alentejo region), to the Seville area in Spain (Andalusia region) (Matos & Martins, 2006; Relvas et al. 2006; Tornos, 2006, Oliveira et al. 2006; Pereira et al. 2008; Matos et al. 2008). The IPB region has a Mediterranean climate characterized by a dry period from May to September and wet period from November to March.

The São Domingos mine is located in the northern branch of the IPB (Oliveira et al. 2006) and is characterized by a complex tectonic dominated by allochthonous structures, where two major units are considered (Oliveira, 1990; Barriga et al. 1997; Silva et al. 1997; Saez et al, 1999; Oliveira et al. 1992; 1997; 2005; 2006; Pereira et al. 2007; 2008): the Phyllite Quartzite Group (PQG) dated as Middle to Upper Devonian age and formed by a succession of phyllites, quartzites, quartzwackes and shales with intercalations of limestone lenses and nodules in the upper part, and the Volcano-Sedimentary Complex (VSC) dated as Upper Devonian to Upper Visean age. The PQG represents the detritic IPB basement forming a marine siliciclastic platform. The base of the unit is unknown [the older sediments were recognized at S. Francisco da Serra and Lousal (Pereira et al. 2010, Matos et al. 2011)]. The VSC incorporates several submarine volcanic episodes with dominant rhyolites, dacites, basalts, minor andesites, and intercalations of black shales, siltstones, minor quartzwackes, siliceous shales, jaspers and cherts, and purple shales. The massive sulphides and the manganese IPB deposits are related with the VSC units. Locally stockwork-type structures occur in the PQG (Barriga et al. 1997, Leistel et al. 1998; Matos et al. 2008; Oliveira et al. 2006; Pereira et al. 2008; Relvas et al. 2006). Above the IPB, VSC and PQG units a thick flysch turbiditic succession occurs (Oliveira, 1990; Pereira, 1999, Oliveira et al. 2006; Pereira et al. 2008) represented by the Baixo Alentejo Flysch Group (BAFG), with > 5 km thickness. The BAFG is represented by the Mértola (Upper Visean), Mira (Upper Visean to Lower Bashkirian) and Brejeira (Bashkirian to Upper Moscovian) formations. In the São Domingos region the first flysch sedimentation is represented by the Feixial Formation (Upper Visean). The IPB contacts in the north area of São Domingos with the Gafo Formation (Lower Frasnian, Pereira et al. 2008), formed by flysch units.

The São Domingos mine was one of the main industrial projects located in southern Portugal in the 19<sup>th</sup> century and until 1950's. Associated with the mining project one of the first railway system was built between the mine open pit and the Pomarão Guadiana River harbor, located 18 km south (Matos et al. 2006). The mine is located ~5kms near the Spanish border. Detailed geological mapping of the old open pit, of the mining area wastes and infrastructures between the São Domingos clear water dams (Tapada Grande and Tapada Pequena) and the downstream Chumbeiro dam permitted a correct interpretation of the mine site characteristics, see Fig. 3 (Matos 2004, Oliveira & Matos 2004, Matos et al. 2006a,b, Alvarez-Valero et al. 2008; Mateus et al. in press; Pérez-Lopéz et al. 2008).

The São Domingos deposit is a sub-vertical massive sulfide orebody located at the top of a VSC geological sequence, represented by black shales, felsic, basic and intermediate-basic volcanic rocks

(Matos et al. 2006a). These rocks are bounded, through thrust faults vergent to SW, by shales and quartzites of the Phyllite-Quartzite Formation and black shales and banded shales ascribed to the PQG Formation, both of late Devonian age (Pereira et al. 2008). The CVS and the deposit are preserved in a tectonic sheet with sigmoidal geometry and sinistral tectonic tension displacement.

The São Domingos VHMS deposit present the following main characteristics (Alvarez-Valero et al. 2008 in Mateus et al. 2011, Matos et al. 2006a,b, Matos & Oliveira 2004, Carvalho 1971, Webb 1958, Cabral 1889, inc. ref.):

Mineral assemblage: pyrite, sphalerite, chalcopyrite, galena, arsenopyrite and sulfosalts. Orebody footwall rich in copper (actual orebody northern sector), western and southern sectors rich in zinc.

Ore grades: 1,25% Cu, 2-3% Zn and 45-48% S.

Dimension: ~25Mt of massive sulfides, one pyrite lens being 537m long and 45m to 70m thick.

Mining methods: open pit and underground, pillars and chambers, cut and fill. Ore transported from open pit by railway to **Moitinha ore mills**, to the **Achada do Gamo sulphur factories** and to the **Pomarão harbour** (Guadiana River). Cu obtained by cementation evolving intensive ore leaching at Moitinha plateaus. Sulphur obtained by Orkla process.

Mine products: py, roasted py, sulphur, copper.

Reserves: gossan and roman slag wastes in excess of 1Mt have 1g/t Au.

Mining waste types: gossan (oxidized pyrite ore), host rocks (volcanics+shales), brittle massive pyrite and stockworks, roasted pyrite, sulphur plants ashes, modern slag and roman slag.

### **The São Domingos mine life cycle, from Romans to closure**

The São Domingos gossan (iron cap) and associated roman slags were discovered in 1854 (Matos et al. 2006a,b inc. ref.). The Mason & Barry Company mine owner exploited the São Domingos deposit by open pit until 120m depth and by underground works until 420m depth. Between 1867 and 1880 3 Mm<sup>3</sup> of rock were extracted from the open pit (Cabral et al. 1889). The drift network extends 1080m at the 150m level, from the main water pump shaft (headgear n° 6) to the ventilation shaft (n° 7) located in the eastern sector of the mine.

The mine closure in 1966 led to a social and economic decline of the region. Presently, a large negative environmental impact is detected in the mining area along the São Domingos stream valley, 11km affected by direct Acid Mine Drainage (AMD) from mine infrastructures (Matos & Martins 2006, Alvarez-Valero et al. 2008; Mateus et al. in press; Pérez-Lopéz et al. 2008). The Achada do Gamo sulfur factories area is marked by significant Pb, As, Sb, Cu, Zn and Fe anomalies in stream sediments, soils and waters. From 2004 onwards LNEG, the municipality of Mértola and the CCDR Alentejo have promoted a new approach to the São Domingos mining site with geo-eco-mining tourism as a possible solution. The excellent geological and mining heritage site conditions have been largely promoted, considering a network of geossites and mining areas along the Portuguese and Spanish Iberian Pyrite Belt (Matos et al. 2011).

The São Domingos massive sulphides ore mined in the mine's open pit and galleries were transported by railway to the Moitinha ore mills located downstream (see Fig. 1). Underground acid water pumped from 150 m depth at Shaft nr. 6 was transported by a network of channels to the Moitinha plateaus (Matos et al. 2006a,b). Here the pyrite ore was leached by acid water (Cabral 1889). The resulting copper enriched liquid was transported to the Achada do Gamo tanks to obtain native copper by cementation process (ionic change between iron from added scrap and copper dissolved in the mine acid water). At Achada do Gamo, Orkla process sulfur factories were constructed in the 1930's. This ore process method permitted the production of sulphur after pyrite roasting and gas control with a catalytic system. All mine products were transported by railway to the Pomarão harbor on the Guadiana River and exported mainly to Great Britain.

The São Domingos mining wastes were mapped at 1/2500 scale by ex-INETI (current LNEG). Several waste classes were identified at São Domingos during the LNEG mapping surveys performed in the terrain (Matos 2004, Matos et al. 2006a,b) and validated by hyperspectral image classification (Quental et al. 2002, 2003). Several mining wastes are considered (see Fig. 1): gossan material, brittle pyrite ore, host

rocks (volcanics and sediments), slag (Roman and modern), pyrite roasting products (Pb-rich ash and hematite-rich material), clay-silt leached materials.

Slag piles at São Domingos represent 8% of the mine residues accumulated in that place, recording discarded outputs of the ore smelting carried out in different periods of the massive sulfide and related gossan exploitation. The major slag constituents are crystalline silicates (mostly olivine and pyroxene), magnetite and glass; accessory amounts of sulfides and metal alloys are also present, sometimes coupled by sulfosalts (Pinto et al. 2007, Mateus et al. 2011). The slag is typically Fe-rich (30-40%) and contains up to 1.7% Zn, 0.9% Pb and 0.5% Cu, besides minor to trace contents in many other metals (e.g. Mn, Sb, Co, As, In, Ag, Bi, Ge). The maximum tailing thicknesses are found near the open pit with up to 14m of gossan+volcanic wastes (Matos et al. 2006a,b). Mining activities at São Domingos affected a total area of 2,963,900 m<sup>2</sup>, from the village to the Chumbeiro downstream dam, located 11km southeast. Along the valley of the São Domingos stream, 767,659 m<sup>2</sup> is the area occupied by industrial landfill+leaching/cementation tanks and 722,737 m<sup>2</sup> of ore + host rocks tailings. In the mine area a total of 14,7Mm<sup>3</sup> of mining wastes are estimated, present in mining landfills and tailings with a heterogeneous size, changing from 14m near the open pit to less than 1m in the downstream areas (Matos 2004, Matos & Martins 2006, Alvarez-Valero et al. 2008; Mateus et al. in press; Pérez-Lopéz et al. 2008). Between Moitinha and the downstream Chumbeiro dam, and especially in the vicinity of the Achada do Gamo sulphur factories, large and significant AMD effects can be seen (Abreu et al. 2010). Large no-vegetation areas reflect the negative impact of decades of old mining techniques including acid water volume control using down slope water percolation to increase evaporation. Geochemical research shows anomalies in the following materials (Oliveira 1997, Batista et al. 2003, Quental et al. 2003, Matos & Martins 2006, Pinto et al. 2007):

Soils – Pb, As, S, Cu, Cd, Hg; Stream sediments - Pb, As, Sb, Cu, Zn, Fe, Ag, (V, Cr); Tailings – Zn, Pb, Sb, Cu, Ag, Hg, Cd; Superficial waters – Fe, Al, Mn, Co, Cu, As, Sb, Ni.

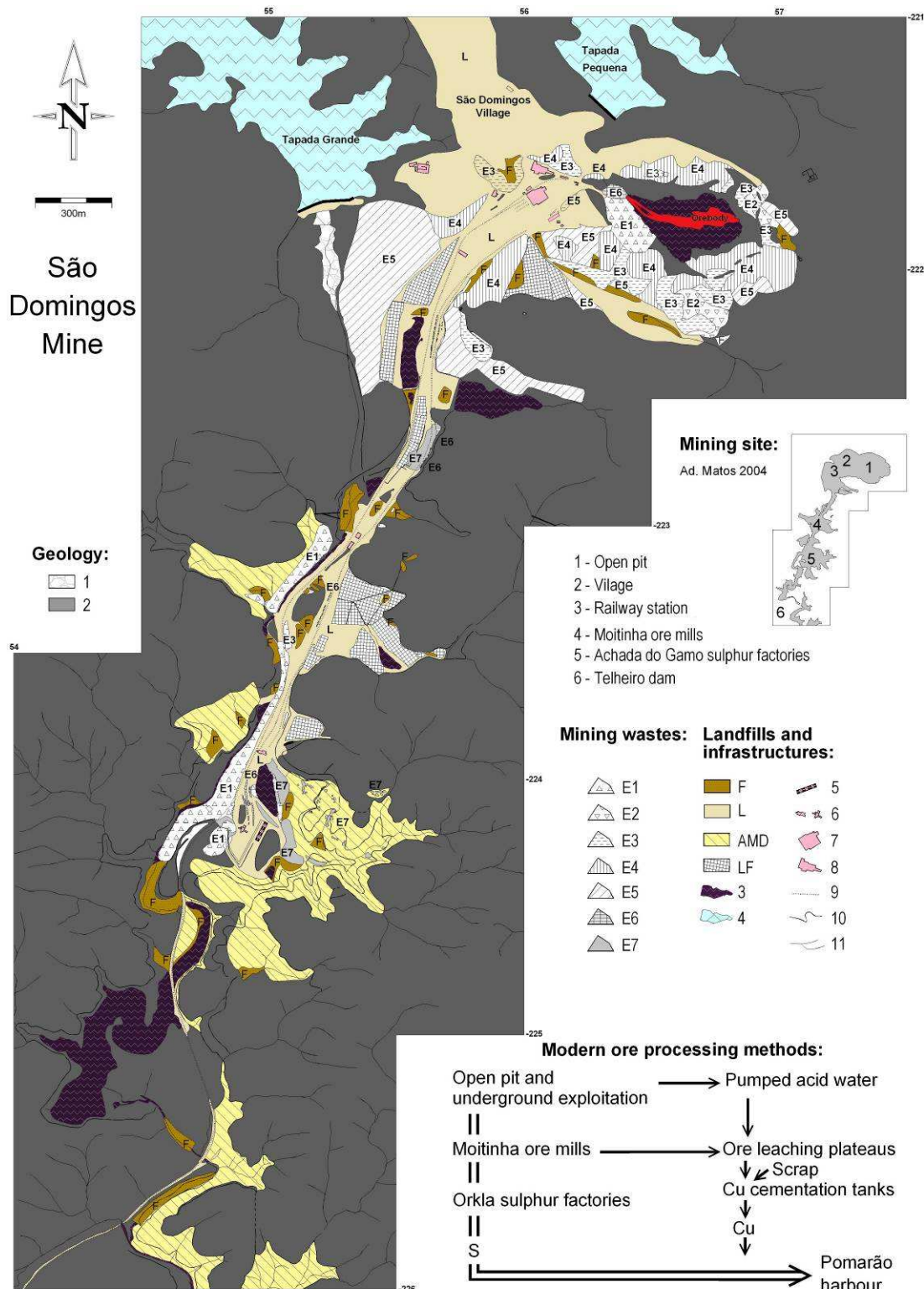


Fig. 1 - Simplified mining map of the São Domingos mine (ad. Matos 2004, in Mateus et al. 2011), Hayford-Gauss coordinates in km. Geology: 1. Alluvium; 2. Paleozoic basement. Mining waste: E1. Modern slag; E2. Roman slag; E3. Iron-hat material; E4. Meta-volcanic rocks and shales; E5. Shales; E6. Finely crushed sulphide ore; E7. Roasted sulphide ore. Landfills and infrastructures: F. Water-laid contaminated materials in seasonally flooded areas; L. Mine/urban contaminated landfills; AMD. Soilless areas due to ancient protracted acid mine water flow; LF. Sulphide ore leaching plateau; 3. Acid water dam/lagoon; 4. Clean

water dam; 5. Cu cementation tank; 6. Orkla sulphur factories; 7. Railway station; 8. Power plant; 9. Abandoned mine railway; 10. Mine canal; 11. Stream

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