Elvira: a new shale-hosted VMS deposit in the Iberian Pyrite Belt

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Abstract. The late Paleozoic Iberian Pyrite Belt (IPB), southwestern Iberian Peninsula, hosts one of the largest concentrations of volcanogenic massive sulphide deposits on the Earth's surface. The ore-bearing sequence includes felsic-rock-hosted VMS deposits formed by host rock replacement in the northern area of the IPB, and shale-hosted deposits formed by direct sulphide precipitation on the seafloor in the southern area. The high-grade Elvira Cu-Zn-Pb deposit is the most recent discovery, and is located eastward of one of the largest orebodies in the southern IPB, the Sotiel-Migollas cluster. This deposit consists of a single massive sulphide lens located ca. 250-500 m below the surface and is hosted in an overturned and thrusted sequence dominated by dark shales dated to uppermost Devonian. The stratigraphic footwall includes a well-developed stockwork zone and pervasive chlorite-rich alteration. The massive sulphides show abundant sedimentary structures typical of deposition on the seafloor but also a large zone of sub-seafloor replacement of muds which marks the transition from the feeder zone to the exhalative massive sulphides.

1 Introduction

The Iberian Pyrite Belt (IPB) is an E-W 250 km long by 20-70 km wide VMS district in the southwestern Iberian Peninsula. It represents one of the most important ore provinces in Europe and the largest concentration of sulphides in the Earth's crust (Tornos 2006). It holds over 1600 Mt of massive sulphides originally in place, and about 250 Mt of stockwork ore, distributed in around 90 VMS deposits (Tornos 2006).

Detailed geophysical exploration by MATSA of the areas nearby the Sotiel-Migollas VMS deposits, which have been mined since Roman times, has led to the discovery of a new massive sulphide body called Elvira (37°36'17"N, 6°49'51"W; Fig. 1). Exploration drilling of an electromagnetic (VTEM) anomaly located near the eastern end of the Migollas orebody intersected massive sulphides. This new deposit has been delineated by over 80 drill holes and will start production in late 2019.

2 Geological background

The formation of the IPB is related to the Late Paleozoic (Devonian to Carboniferous) Variscan orogeny. Oblique collision between the South Portuguese Zone, to which the IPB domain belongs, and the Autochthonous Iberian Terrane produced an evolving depositional setting with formation of continental pull-apart basins and intraplate magmatism to which the mineralization is related (Barriga 1990; Leistel et al. 1998; Tornos 2006).

The geological record of the IPB consists of a 1000-5000 m thick stratigraphic sequence. Three main units have been described. The lower Phyllite-Quartzite (PQ) Group (Middle-Late Devonian) consists of interbedded quartz sandstones and shales deposited in a stable and shallow epicontinental platform (Moreno et al. 1996). Subsequent trans-tensional regime related to left-lateral northwards oblique continental collision generated pull-apart basins with lowered, tilted and uplifted blocks that subdivided the depositional environment into several sub-basins separated by shallow marine to subaerial areas (Tornos et al. 2005). Decompression-induced mantle partial melting generated mafic magmas that underplated and intruded the continental crust, promoting its partial melting and the generation of hot dry felsic magmas (Mitjavila et al. 1997). These magmas reached the surface producing a volcanic sequence in which alkaline-tholeiitic basalts and calc-alkaline andesites to rhyolites coexist with mudstone and some chemical sediments (Volcanic Sedimentary Complex; VSC). The massive sulphides formed in response to the accelerated dewatering of the PQ Group and degassing of felsic magmas (Tornos 2006). Finally, compressional tectonism related to the main collisional stage of the Variscan orogeny formed a foreland basin in which syn-orogenic flysch sediments (Baixo Alentejo Flysch Group) were deposited (Oliveira 1990).

The collision-related compressive deformation produced tectonic inversion and deformation forming a S-SW-verging thin-skinned foreland fold and thrust belt (Oliveira 1990; Quesada 1998). Regional metamorphism associated to Variscan orogeny is low grade, from prehnite-pumpellyite to low greenschist facies (Sánchez España 2000). Deformation and metamorphic grade tend to increase from south to north although a general metamorphic gradient is not clear, and are locally enhanced close to high strain zones (Sánchez España et al. 2000).

Two styles of VMS deposit formation have been described in the IPB: shale-hosted and felsic volcanic rocks-hosted deposits (Tornos 2006). Shale hosted deposits are mostly interpreted to have been formed in sub-oxic to anoxic third order basins where upwelling deep sulphur-depleted fluids mixed with modified seawater rich in biogenically reduced sulphur, leading to the precipitation of the massive sulphides on the seafloor. Felsic volcanic rocks-hosted deposits are interpreted to

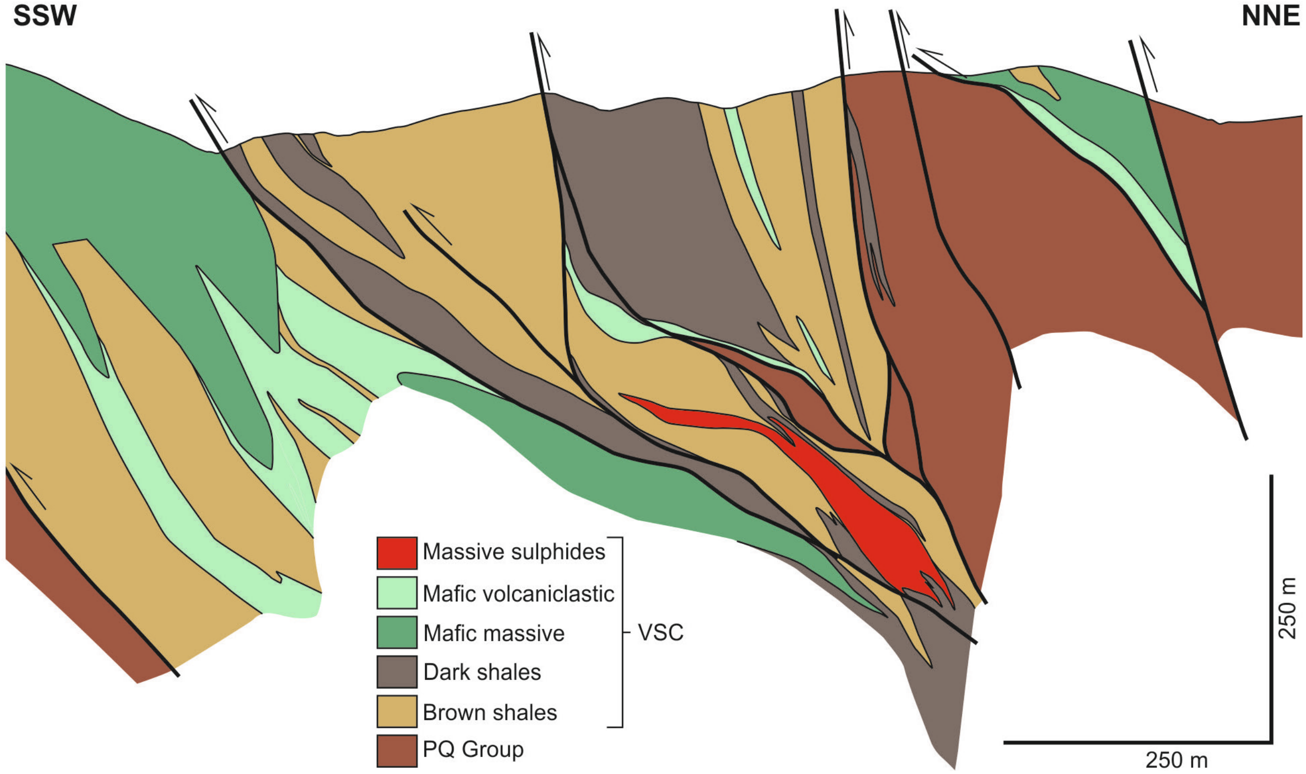

Figure 1. Geological cross section of the Elvira deposit area. Modified from MATSA internal report (2018).

have formed by stratabound replacement of porous or reactive massive and volcaniclastic (vitriclast- or pumice-rich) volcanic rocks. It is suggested that mineralization was triggered by mixing of the deep sulphur-poor fluids with modified seawater bearing variably reduced sulphur acquired from leaching of the host volcanic rocks or by thermochemical reduction of the marine sulphate.

Most of the massive sulphide deposits are underlain by, or imbricated with, large stockwork or stringer zones despite subsequent Variscan thrusting that produced major tectonic inversion (Quesada 1998).

3 The Elvira VMS deposit

The Elvira deposit is located in the eastward continuation of the Sotiel-Migollas massive sulphide cluster (Santos et al. 1996; Velasco-Acebes et al. 2018), located in the south-eastern IPB. It is a polymetallic (Cu-Zn-Pb) pyrite-rich massive sulphide body with evidence of having been dominantly deposited in a sub-oxic to anoxic basin and rooted on a large stockwork zone.

3.1 Local stratigraphic sequence

The stratigraphic sequence in the Sotiel-Migollas-Elvira area is highly tectonized, with individual units limited by major thrusts (Fig. 1). It consists of: (1) a structural footwall dominated by felsic dome complexes intruding and interbedded with dark shales; (2) an overlying shale unit which hosts the massive sulphides; and (3) the structural hanging wall including the PQ Group, which hosts a well-developed stockwork in the Migollas deposit (Santos et al. 1996; Velasco-Acebes et al. 2018). The contact between the VS Complex and the PQ Group is interpreted to be a major thrust located in the inverse limb of a major south-verging fold (Velasco-Acebes et al. 2018). This contact is delineated by abundant bands of mylonite developing zones of tectonic mélange with lenses of mixed lithologies from both groups and that show widespread chlorite and carbonate alteration (Velasco-Acebes et al. 2018). This surface was interpreted to have favoured the widespread remobilization of the sulphides in the Sotiel-Migollas-Elvira area, showing abundant thin sulphide-rich veins parallel to the foliation and zones of high grade copper with massive chalcopyrite concentrations along shear bands (Velasco-Acebes et al. 2018).

If overturned to its original position, the stratigraphic sequence would include:

1) A footwall dominated by the PQ Group, consisting of a monotonous sequence of shale and quartz-rich sandstone with only some minor lenses of limestone, which is crosscut by abundant microdiorite sills and dykes (Velasco-Acebes et al. 2018).

2) A 400 m-thick dark shale sequence which is host to the massive sulphides. This sequence is locally carbon-rich and presents a cm-thick sedimentary layering. It includes sparse levels of volcaniclastic sandstone of dacitic composition, some layers of quartz-rich sandstone, and abundant disseminated to stratiform pyrite, with local bodies of likely sedimentary breccias with chloritized fragments supported by unaltered shale

(Velasco-Acebes et al. 2018). In addition, in the direct structural footwall to the Sotiel-Migollas massive sulphides the shale hosts a discontinuous layer of black limestone with organic matter and disseminated pyrite. At the Elvira deposit, the massive suphides are hosted in a shale-dominated sequence that includes black shales both in the footwall and hanging-wall to the ore body, with only minor fragmental volcanic rocks (Fig. 1). This suggests that its position is more distal to the domes than Sotiel-Migollas. The age of the ore-hosting sequence is uppermost Devonian (Gonzalez et al. 2006).

3) A felsic volcanic sequence which is several hundred meters thick and is dominated by felsic volcanic rocks with abundant lateral changes; these are mostly dacites forming dome complexes (Velasco-Acebes et al. 2018). It also presents abundant intercalations of mafic rocks; these are likely submarine lava flows, related volcanoclastic rocks, and subvolcanic sills that become gradually more abundant towards the structural footwall. In the structural footwall of Elvira, a coherent (lava/dike) volcanic to subvolcanic mafic rock has been intersected (Fig. 1).

3.2 Location and shape of the deposit

The Sotiel-Migollas-Elvira is one of the largest clusters of massive sulphide deposits in the IPB, with a tonnage well above 100 Mt. The Sotiel-Migollas part consist of three large stratabound massive sulphide bodies (Sotiel, Sotiel Este and Migollas) and several smaller lenses, which are aligned along a E-W 2 km-long narrow area (Velasco-Acebes et al. 2018). Elvira deposit represents the eastward continuation of the Sotiel-Migollas cluster.

The Sotiel orebody is up to 60 m thick and consists of three stacked lenses separated by up to 20 m thick barren shale; Sotiel Este is up to 40-50 m thick and is distributed in six stacked lenses; Migollas is up to 120 m thick and includes two large stacked dome-shaped lenses separated by shale (Santos et al. 1996). These massive sulphides occur at depths between near surface to ca. 700 m.

Elvira consists of a single sulphide lens located 250 to 500 m below the surface (Fig. 1). As in the Migollas deposit, the stockwork related to Elvira deposit is located in its hanging-wall.

3.3 Ore mineralogy

Most of the shale-hosted VMS deposits in the IPB do not display either clear metal zonation or zones of major base metal enrichment (Tornos 2006). In Sotiel-Migollas, Cu and Zn–Pb rich zones are common, but they do not show a well-defined distribution (Santos et al. 1996), and neither does Elvira. The style of mineralization in the Sotiel-Migollas cluster has been observed to vary between the individual orebodies (Velasco-Acebes et al. 2018). The mineralization at Sotiel and Sotiel Este is banded and dominated by alternating layers of massive sulphides and hydrothermally altered shale. On the other hand, the mineralization at Migollas, the deposit closest to Elvira, is mostly massive and with no interbedded shale, and is dominated by a siderite-rich massive sulphide. The style of mineralization in Elvira is yet to be studied in detail, but exhalative massive sulphides and dark shale interbedding is locally observed (Fig. 2).

The mineral assemblage of the massive sulphides in the Sotiel-Migollas-Elvira area is dominated by massive pyrite with variable amounts of chalcopyrite, sphalerite and galena, lesser amounts of arsenopyrite, pyrrhotite, magnetite and tetrahedrite-tennantite, as well as trace amounts of sulfosalts (boulangerite, bournonite, jaskolkiite and meneghinite), cassiterite, native bismuth and electrum (Velasco-Acebes et al. 2018 and references therein).

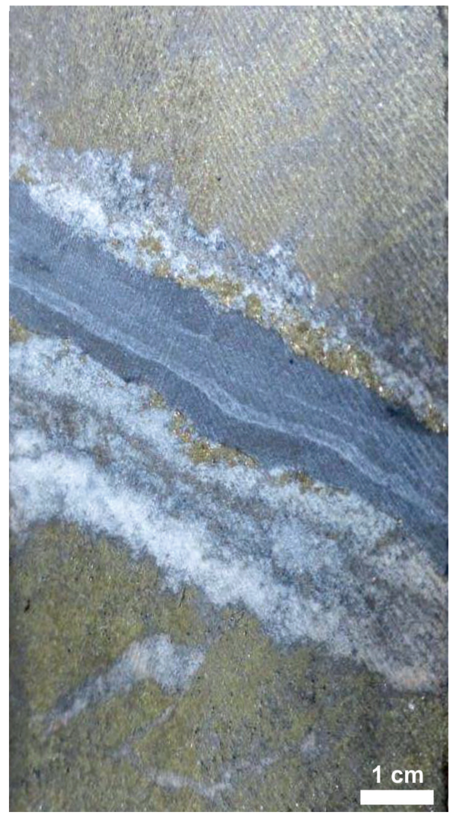

Figure 2. Exhalative pyrite-dominated massive sulphide with interbedded dark shale and quartz. Drill core from Elvira deposit.

3.4 Alteration characteristics

Characteristics of the hydrothermal alteration related to the shale-hosted massive sulphide deposits in the southern IPB differ from those of deposits located in felsic volcanic rocks in the northern IPB. The alteration is conspicuous in the footwall, less pervasive and irregular adjacent to the mineralization and almost non-existent above it, and mostly produces a unique zone of massive chlorite ± quartz.

Alteration characteristics in the Sotiel-Migollas area have been described by Velasco-Acebes et al. (2018). The less hydrothermally altered shale mainly consists of a foliated groundmass of fine-grained illite ± muscovite, sparse pyrite, disperse grains of anhedral quartz, carbonates, ilmenite (altered to rutile) and zircon. In areas affected by hydrothermal alteration chloritic alteration is closely associated to zones of brecciation or veinlets of carbonates and sulfides ± quartz. Primary shale layering was lost during chloritization, and the illite was replaced by massive chlorite. The resulting mineral assemblage contains clinochlore ± chamosite, variable amounts of carbonates, abundant anhedral pyrite (10-30%), and small amounts of disseminated sphalerite, chalcopyrite, galena, monazite and a significant amount of hydrothermal zircon. In the Migollas area, the shale between the individual lenses and lateral to the mineralization shows irregular chloritization and a subtle carbonate-rich alteration.

Like Elvira, Migollas deposit has an associated stockwork, which in this case is hosted by the PQ Group rocks in the structural hanging wall. The stockwork includes a zone of pervasive chloritization with a network of abundant 1-20 cm thick veins of medium- to coarse-grained sulphides, dominantly disseminated pyrite, and abundant stratabound layers of massive pyrite. The altered shale in the stockwork area shows zones of widespread carbonatization with abundant sparsely disseminated carbonate. The Migollas stockwork also has a carbonate-rich zone with veins of coarse-grained siderite and scarce sulphides that postdate the pyrite-rich veins. Despite major deformation, the intensity of alteration seems to increase downwards towards the contact with the massive sulphides (Velasco-Acebes et al. 2018).

Remarkably, the volcanic rocks in the footwall of the massive sulfides in the Sotiel-Migollas-Elvira area lack hydrothermal alteration and only the peperites host some alteration with replacement of the volcanic fragments by quartz, sericite and pyrite; in contrast, the few layers interbedded with the sulphide-hosting shales show a conspicuous replacement by illite and pyrite (Velasco-Acebes et al. 2018).

Acknowledgements

The authors thank MATSA for providing information and access to drill cores from Sotiel-Migollas and Elvira deposits. This research has been conducted within the NEXT (New Exploration Technologies) project and has received funding by the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 776804.

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