The San Miguel deposit, Iberian Pyrite Belt: reconstructing a sub-seafloor replacive VMS.

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1.Introduction

The **San Miguel** volcanogenic massive sulfide (**VMS**) is perhaps one of the most outstanding examples worldwide of massive sulfides being formed by the **replacement** of volcanic rocks when hydrothermal fluids channelized along an syn-volcanic fault crosscut reactive/permeable layers (Fig. 1 and 2).

San Miguel is located in the **northern** Iberian Pyrite Belt (**IPB**), in the southward overturned and thrusted limb of an E-W trending Variscan antiform. The mine was worked during the Roman Empire, with the works oriented to the exploitation of gold and silver that were enriched in the contact of the gossan and the underlying massive sulfides; this enriched layer includes clays with native gold (< 7 g/t) and several hundred ppm of silver in the form of argentojarosite (Fig. 2). In the XIX-XX c. the deposit was mined by pyrite.

2. Geological setting

The IPB is one of the most outstanding mineral belts on Earth, being the largest crustal sulfur anomaly and hosting a significant proportion of the giant VMS. The massive sulfides are hosted in the Volcano-Sedimentary Complex (VS Complex), a thick volcanic sequence including felsic and flows and sills of basalt and andesite will abundant volcaniclastic rocks and shale. It is up to 1,300 m thick sequence deposited in a continental intra- to back-arc marine basin (Tornos et al. 2023); its age is Late Devonian to Early Late Visean (Oliveira, 1990). It is overlain by the Baixo Alentejo Flysch (BAF) Group, a synorogenic turbiditic sequence (2,500 m) and late Visean to Serpukhovian age, result of the growth of a foreland basin during the onset of the Variscan orogeny.

The Variscan deformation is related with continent-continent collision and produced south-ward verging folds and thrusts. Related metamorphism is of very low- to low-grade metamorphism (Schermerhorn 1975; Sánchez España 2000). It was followed by major I-type plutonism (Thiéblemont et al. 1998).

The VMS deposits occur either as (sub-) exhalative stratiform bodies interbedded with shale above the lowermost felsic volcanic rocks (Late Famennian) or replacing felsic volcanic rocks and of early Tournaisian age (Tornos et al. 2023). In both cases, massive sulfides form large lenses with an extensive underlying stockwork. Massive sulfides are dominated by pyrite with lesser amounts of sphalerite, chalcopyrite and galena (Marcoux et al. 1996; Tornos 2006). When exposed subaerially, they are capped by well-preserved gossans and usually small cementation zones (Velasco et al. 2013).

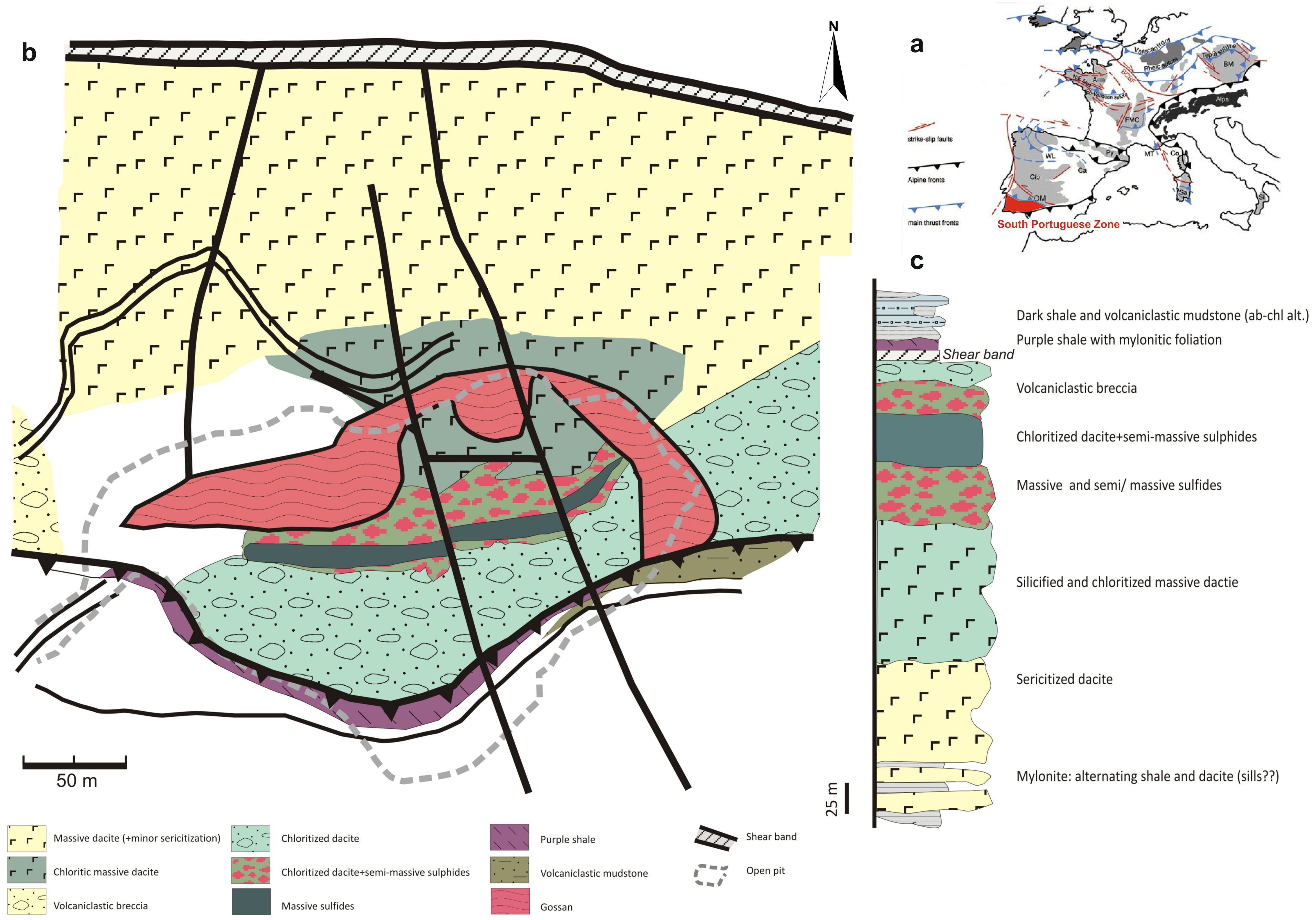
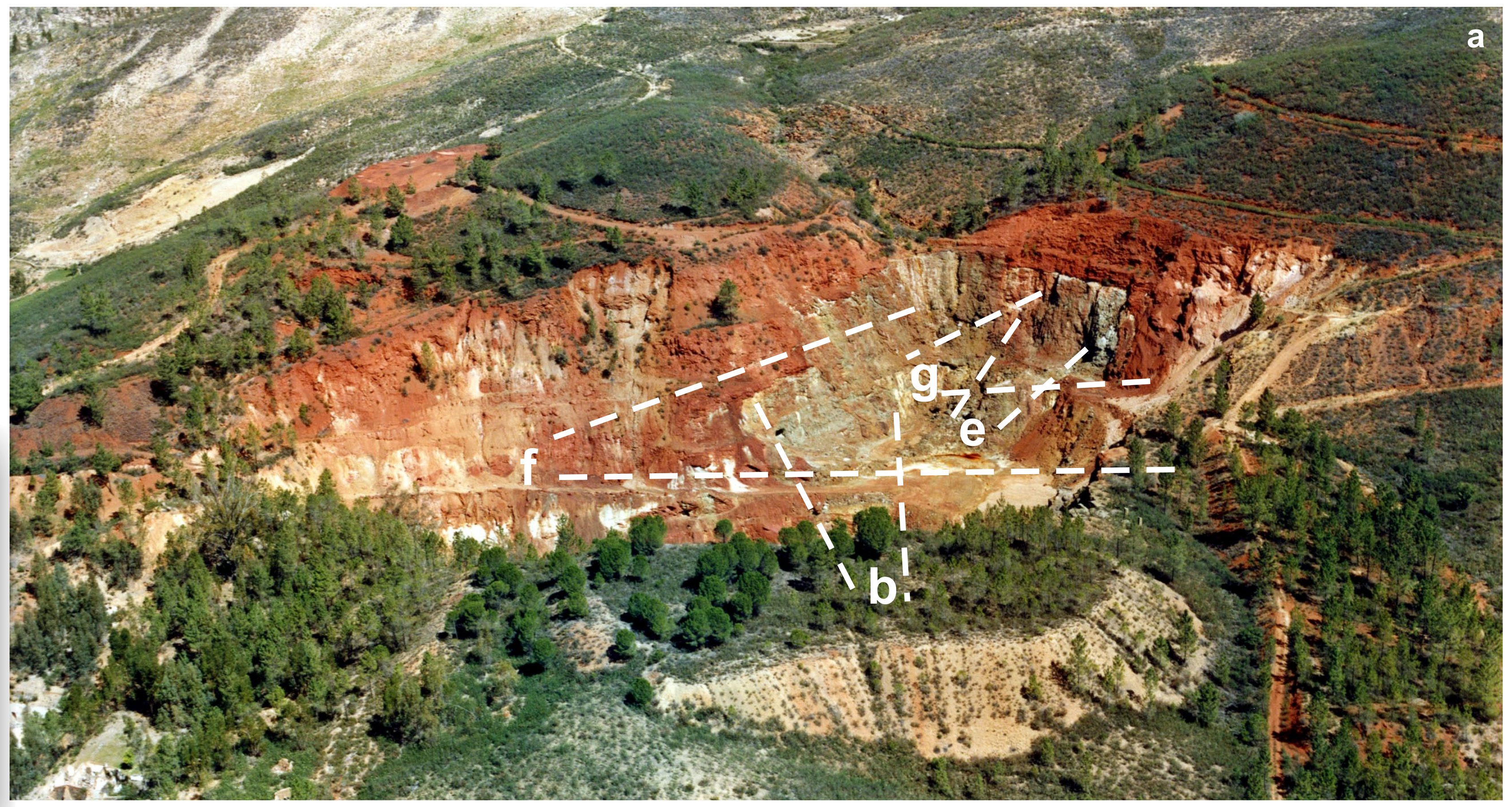
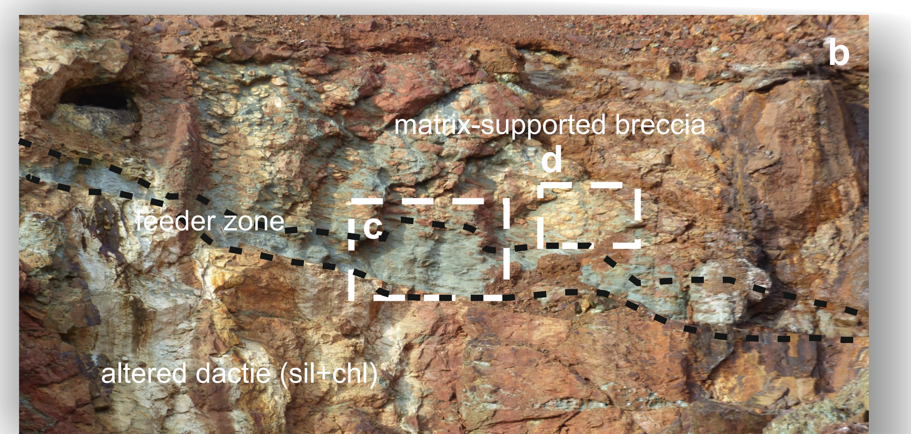
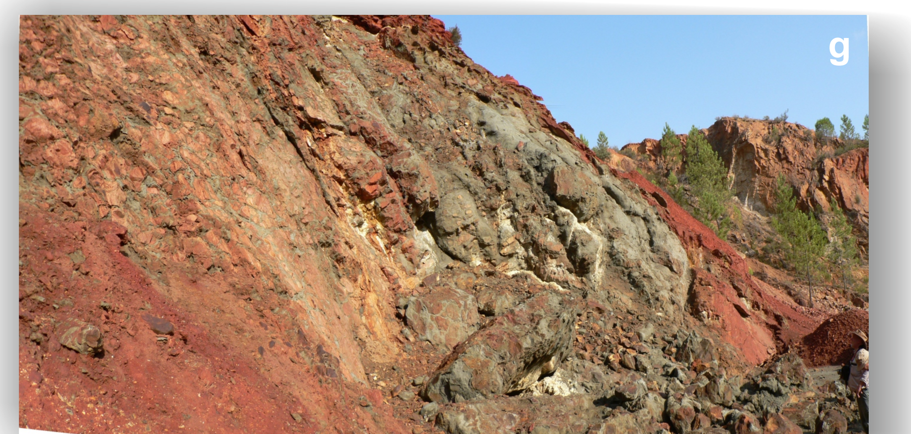


Fig 1. Geological setting maps. (a) Schematic map of Variscan Fold Belt in Europe (Regorda et al. 2020). (b) Geologic map of the open pit and © simplified lithostratigraphic sequence of the San Miguel Mine showing the main volcanic rocks and hydrothermal alteration (modified of Tornos and Velasco 2007)







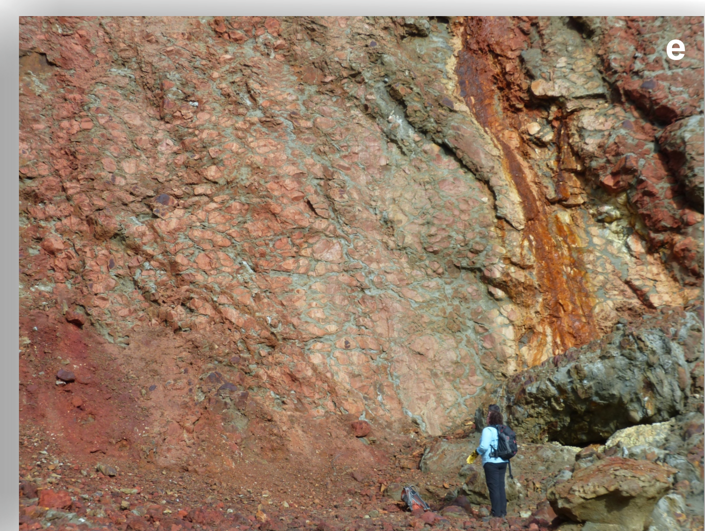


Fig 2. Representative photographs of the San Miguel ore deposit. (a) Photoarea of the San Miguel open Pit. (b) Feeder structure infilled with pyrite and located along in a normal fault that puts in contact massive and brecciated dacite. (c) Volcanic breccia partially replaced by pyrite and chlorite but showing oriented remnants of the fragments. (d) Detailed photograph of the ghosts of an ancient fragmental rocks (autoclastic breccia or a hyaloclastite) replacive by pyrite-chlorite massive sulfides with inherited quartz phenocrysts. (e) Photograph of the so called "stockwork" but interpreted as semi-massive sulfides cementing a volcanic breccia. (f) Landscape of the NE wall of the open pit showing the mineralized sequence and the overthrusted siliciclastic unit and capped gossan. (g) Photograph showing the aspect of the massive sulfides replacing the volcanic breccia in the footwall and hangingwall. The volcanic hangingwall volcanics

3. Geology and mineralization

The San Miguel Mine host **several subvertical massive sulfide bodies**, being the largest one exposed in a small ellipsoidal open pit some 200 m in length (Fig 2a). The unaltered **host rock** is a thick felsic unit including coherent quartz-feldspar-phyric dacite interbedded with lenses of breccia with a similar composition (in-situ and transported hyaloclastite); they are interbedded with more polymictic mass flows including coherent dacite, pumice-rich fragments and hyaloclastite supported by glass- and pumice-rich sandstone. The total thickness of this unit is ca. 300 m. **U-Pb dating** of the dacite has yielded an age of **352 ± 3Ma**. Near the orebody, these rocks have an external halo of phyllic alteration and an internal zone of pervsive chloritization (Fig. 2b).

The VS Complex is overthrusted by a siliciclastic unit. The contact mylonite the it grade to shale and feldspar-bearing volcaniclastic mudstone and sandstone.

The **massive sulfides** are exposed in the northern part of the pit (Fig 2a). They consist of a E-W trending subvertical lens, dipping ca. 70°S. The massive sulfides are dominated by coarse-grained pyrite intergrown with chlorite (brunsvingite-diabanite) and hydrothermal quartz (Polo 2022). The rock also includes magmatic zircon inherited from the protolith. The ratio between sulfides and silicates is outlined by a differential erosion that highlights the presence of ghosts of an ancient fragmental rock (Fig. 2c) that could well be an autoclastic breccia or a hyaloclastite. The fragments show a E-W subhorizontal foliation perpendicular to the orientation of the lens. In detail, there is a **gradation** from pyrite-poor footwall to pyrite-chlorite supporting ghosts of altered dacite and massive chlorite-bearing massive sulfides with inherited quartz phenocrysts (Fig. 2c).

The **footwall** of the massive sulfides includes a sub-horizontal fracture infilled with pyrite that has a sharp to replacive contacts with the dacite (Fig. 2d). If restored to the assumed original, horizontal, position, this structure should be vertical and, thus, probably corresponds to a tensional feeder zone to the San Miguel VMS system. The alignment of the fragments situated near the structure, also originally vertical, is also consistent with **vertical fluid flow**.

4. Discussion

The San Miguel Mine has been traditionally interpreted as a stockwork zone grading into overlying exhalative massive sulfides. Here, we suggest that the mineralization is **replacive on felsic volcanic rocks** and the **formation** of the **massive sulfides** is **controlled** by variations in the permeability and reactivity of the **host sequence**: the stockwork is the footwall of the mineralization and the breccia-like structure are primary structures enhanced by alteration. The San Miguel mine does not have a stockwork underlying the mineralization but a fault-controlled feeder zone.

It is unlikely that massive sulfides form and are preserved in high energy systems such as during the dynamic growth of felsic domes – any exhalative body will not have time to grow and would have been destroyed by mass flows or magmatic/hydrothermal explosions. It is much more likely that the VMS formed after the growth of the volcanic complex, something that also facilitates its preservation.

The envisaged **model** includes the **upflow** of **hydrothermal fluids** along a **tensional fault** till arrive to **permeable/reactive rocks** that were probably **capped** by **impermeable rocks** such as shale or coherent volcanic rocks. Reaction of the **hot** and **metal-carrying fluids** with cooler modified **seawater** probably rich in **reduced sulfate** should have promoted the precipitation of sulfides and chloritization of the host rocks. What remains intriguing is the geochemical mechanism that ultimately drives the dissolution of the Al-rich phases, leaving a rock composed by pyrite, few remnants of quartz phenocrysts and magmatic zircon.

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EIS Exploration Information System

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