Freixo de Numão Au-W deposit, Northern Portugal: ore features and mineralization controls

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Abstract. The Freixo de Numão Au-W deposit is located in Vila Nova de Foz Côa region, northern Portugal. Mineralization is hosted in greenschist-facies metasedimentary rocks with lower-Cambrian age.
The mineralized structures are subvertical and trend N10º - 40ºE, crossing-cut bedding and/or regional foliation, and are post-peak of regional metamorphism. Quartz-sulfide veins and visible hydrothermal alteration characterize this mineralization in the field. The quartz veins record two main stages of mineral deposition (I and II), indicating repeat vein re-opening. Stage-I is characterized by milky quartz and arsenopyrite (Apy-1) and scheelite. Stage-II comprises clear quartz, adularia, chlorite, tourmaline, and metallic minerals, mainly arsenopyrite (Apy-2), chalcopyrite and pyrite, with galena and sphalerite in lesser amounts. The gold (native-Au and electrum) is associated with maldonite, native bismuth, and few Au-Ag phases. A detailed ore study has shown two different gold mode of occurrence: i) native-Au and maldonite, along with Bi-native as droplets in arsenopyrite and chalcopyrite; ii) electrum and Au-Ag phases infill interstitial cavities between arsenopyrite crystals and in its microfractures.
These results match with some characteristics of other gold deposits in the European Variscan belt, which revealed a major crustal-scale hydrothermal event responsible by gold mineralization.

1 Introduction

Gold-bearing systems in the European Variscan Belt display a diversity in (a) mineralization style (vein to stockwork, disseminated, or replacement); (b) host rock lithology (volcanic or sedimentary rock, granites); (c) host rocks age (late Proterozoic to Carboniferous), and (d) host rock metamorphic grade (from catazone to epizone or non-metamorphosed rocks) (Bouchout et al. 2005).

Due to this diversity, it is very important to understand the distribution of gold in the paragenetic sequence; the identification of typical mineral assemblages; the associations of Te, Bi, and Sb minerals; and evaluation of the factors controlling the ore-forming processes.

The Portuguese gold deposits have atypical characteristics (e.g. mineralogical signatures, structural controls, relationship with magmatic rocks) which are not easily explained by the models (e.g. Orogenic gold vs Intrusion-related gold deposits). The present work made part of a large research project in which the main proposal is the objectives mentioned above.

The known mineralizations in Freixo de Numão area comprises quartz vein structures with sulfide mineralization; tin in pegmatites; and tungsten in calc-silicate metasedimentary rocks (Ramos and Oliveira 1977). Recently, in the area, occurrences of gold are also found in fractures with main NNE-SSW direction, late Variscan in age, that control the emplacement of the Au mineralized quartz-sulfide vein structures. The northwestern part of Iberian Massif is an important Variscan metallogenic province, particularly for gold and base metals.

In this paper is made a first detailed description of the Freixo de Numão gold mineralization, in order to explain the ore minerals and its relationships, which was essential to mineral processing information to the mining companies, in order to helpful the degree of ore liberation.

This line of study can be helpful to investigate genetic models for gold deposits, especially in Phanerozoic systems.

2 Geological setting

The Freixo de Numão area (FNA) is part of the Iberian Massif, which constitutes the western-most exposure of the European Variscan Belt, resulting from the collision between Laurussia and the Gondwana, and it is described as staking of large-scale thrust crustal nappes, between 360-320 Ma (Ribeiro et al. 1990).

The study area is located in Central Iberian Zone (CIZ) (Julivert et al. 1972), a tectonic-stratigraphic zone characterized by subvertical structures and a large volume of granitic intrusions (Ribeiro et al. 1990).

The tectonic-metamorphic evolution is explained as the result of three main deformation phases (D1, D2, and D3), which are usually considered responsible for the structuration of the NW of the Iberian Massif (Noronha et al. 1979; Ribeiro et al. 1990; Dias and Ribeiro 1995).

During and after D3 phase a large volume of granitic rocks intrudes the country metasedimentary rocks. Considering their time of emplacement related with D3 deformational phase can classified as: early-D3 (380-345 Ma); syn-D3 (313-319 Ma), late-D3 (306-311 Ma), late- to post-D3 (ca. 300 Ma) and post-D3 (290-296 Ma) (Dias et al. 1998).

A later brittle deformation phase, post-D3, performing in Iberian Massif, that is characterized by a set of conjugate strike-slip faults (NNW-SSE dextral, NNE-SSW sinistral and ENE-WSW), whose geometry is often strongly influenced by pre-existent discontinuities (Ribeiro 1974; Pereira et al. 1993).

In the Iberian Massif, this Late Variscan deformation gave rise to some of the most important observed basement faults, like the NNE–SSW Vilariça and Penacova-Régua-Verín faults in Northern Portugal.

2.1 Regional-deposit scale

The FNA is located in the CIZ, within the western part of a narrow E-W trending metamorphic axis, Marão-Vila Nova de Foz Côa axis (Ribeiro et al. 1990; Dias et al. 2006; Moreira et al. 2010). This belt is bordered by the Variscan Penedono-Mêda-Escalhão massif to the south, and by the Vila Real-Carviçais massif to the north (Ferreira da Silva et al. 1989). In addition to the granites mentioned above, more two small granite plutons intruded in this area: i) Numão granite: biotite>muscovite granite with an emplacement syn to late-D3; ii) Freixo de Numão granite: biotite-rich and it is considered post-tectonic-D3 (Figure 1).

This metamorphic axis belongs to the Pre-Ordovician Schist Greywacke Complex (SGC) (Carrington da Costa 1950; Teixeira 1955) integrated into the so-called Douro Group (Sousa 1982). From stratigraphic and palaeogeographical information, the SGC has been defined as the Super Group Dúrico–Beirão, consisting of the Douro Group, lower-Cambrian in age and Beiras Group Precambrian in age (Oliveira et al. 1992). The Douro Group is composed of several formations Bateiras, Ervedosa do Douro, Rio Pinhão, Pinhão, Desejosa, and S. Domingos from the older to the younger in age (Sousa 1982).

In FNA only outcrops three formations Rio Pinhão, Pinhão and Desejosa. The Rio Pinhão Formation is composed of metagreywackes and metaquartzogreywackes inserted with thin layers of dark phyllites. The Pinhão Formation, consisting in a green colored, thin bedding sequence, characterized by a psammitic (quartz-rich) and pelitic (mica-rich) layering with the particularity of the presence of magnetite crystals and more irregularly pyrite crystals in the psammitic and pelitic layers. The Desejosa Formation is defined by the presence of stripped phyllites that are the result of a thin interchanging of dark with clear layers and metagreywackes (Figure 1). The occurrence of calc-silicate levels in the Desejosa formation is common.

The D1 phase in Foz Côa area induced the formation of wide zones gently folded bounded by coeval narrow bands emphasizing stronger deformation (Moreira et al. 2010). This sequence corresponds to a succession of a large amplitude synclines and narrow anticlines, with an axial trace N100º-N150º (Marques et al. 2002).

In this area, regional metamorphic grade corresponds to greenschist facies conditions, but increases near the granitic plutons, resulting in spotted schists and hornfels.

The most significant brittle structures of the region extend in the NNE-SSW direction and correspond to the important sinistral wrench-faults (namely Vilariça Fault) related with the late Variscan phase (D3) of brittle faulting (Figure 1).

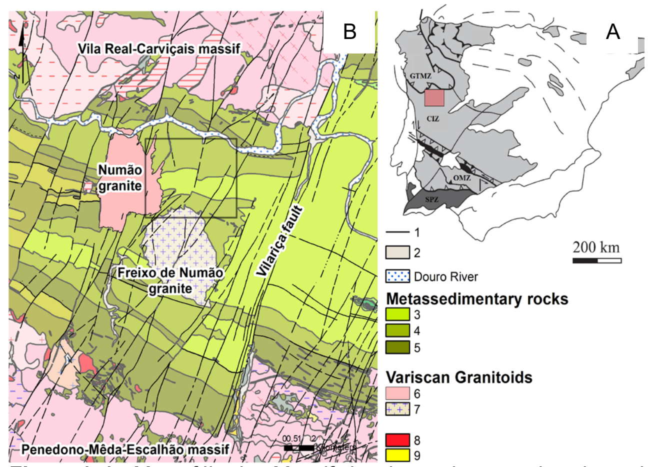

Figure 1. A - Map of Iberian Massif showing major tectonic units and main structures. B – Geological map of regional geology (modified from Ferreira da Silva et al. 1989). The black square corresponds to the deposit scale geology - FNA. 1 – faults; 2 – study area; 3 – Pinhão Formation; 4 – Desejosa Formation; 5 – Rio Pinhão Formation; 6 – Numão granite; 7 – Freixo de Numão granite; 8 – aplite-pegmatite veins; 9 - quartz veins.

3 Sampling and analytical methods

In the fieldwork and sampling, a set of 40 samples were collected from underground workings and 12 samples from drillcores.

The observations of mineral assemblages and chronological successions were carried out by microscopy in transmitted and reflected light, at Institute of Earth Sciences and in Department of Geosciences, Environment and Spatial Planning in the University of Porto.

Complementary studies for characterization of gold minerals were carried out by SEM/EDS performed with a resource to a High-resolution Scanning Electron Microscope with X-Ray Microanalysis: JEOL JSM 6301F/ Oxford INCA Energy 350, in Materials Centre of the University of Porto.

4 The Freixo de Numão deposit

4.1 Vein system

The exposed rocks in underground works are a succession of interlayers of quartzogreywackes, phyllites, quartzites, and calc-silicate rocks, exhibiting a foliation, defined by preferential orientation (S1) of small muscovite and chlorite. The mineralized veins crosscut S1 that is usually parallel to the stratification S0 (N120º).

In the field, it was visible quartzite ridges with a direction N100º-120º; subvertical.

The mineralization occurs in two types: i) disseminated in host rocks (less in the phyllites), and ii) quartz-sulfide veins.

The metasedimentary host rocks are strongly crosscut by a main and systematic vein system (N-S to N40º; 50ºW to sub-vertical) (Figure 2). The vein system consisting of subparallel veins with variable spacing and length function of nature of host lithology. Within fine-grained pelitic rocks, the mineralized veins have a small spacing (10-20 cm) and are scarce.

However, in more competent host rocks (quartzite and/or calc-silicate rocks), the veins are locally anastomosed (like a stockwork) and have a larger spacing (> 50 cm). The veins also lack ductile shear markers or lineations. In addition, the veins crosscut all foliations (S0, S1) but lack any displacement.

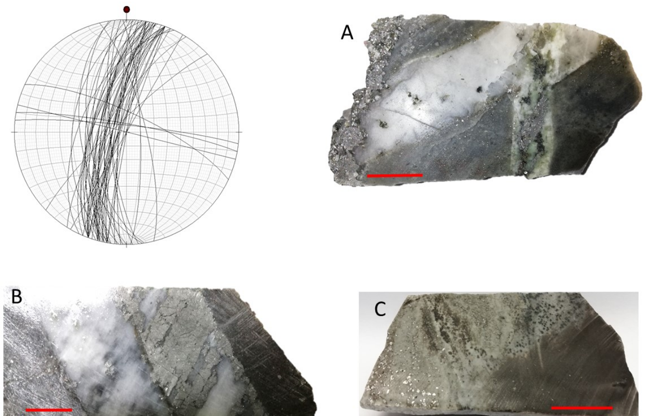

Figure 2. Different types of mineralized structures. A – quartz-sulfide veins with chlorite and adularia alteration; B – Vein of early quartz + quartz-sulfide vein crossing-cut quarzitic rocks; C – Disseminated arsenopyrite in calc-silicate rock. Red bar = 2 centimeters.

There is another mineralized vein system, sub-parallel to the calc-silicate and the quartzite rocks, N100º-115º; 70ºW – subvertical. Finally, there is a barren vein system N80º; 20ºN sometimes is folded.

Petrography of all the different types of mineralized veins indicated that they are extension veins, as reflected by the growth directions of the quartz crystals in some cases it usually found *hybrid* extension-shear veins with similar textures with quartz grains elongated at an oblique angle near the vein walls (Fig. 2-B).

4.2 Relation of gold to other minerals

The quartz veins record two main stages of mineral deposition (I and II), indicating successive periods of vein re-opening.

Stage-I is characterized by milky quartz (mQ), arsenopyrite (Apy-1) and scheelite. Scheelite is the only W-bearing phase at the deposit. It forms coarse-grained euhedral to subhedral grains in the quartz veins cutting calc-silicate rocks, while that hosted in quartzite and calc-silicate rocks is fine-grained and xenomorphic.

Stage-II corresponds to the quartz-sulfide veins formation and comprises clear quartz (cQ), K-feldspar (adularia), chlorite, tourmaline, and metallic minerals, mainly arsenopyrite (Apy-2), chalcopyrite and pyrite, with galena, bismuthinite and sphalerite in lesser amounts.

The gold minerals show two different mode of occurrence: i) native-Au and maldonite (Au_2Bi), along with native-Bi as droplets in Apy-2 and chalcopyrite; ii) electrum, and Au-Ag phases infill interstitial cavities between arsenopyrite crystals and in its microfractures (Figure 3). The size of gold particles ranges to 3 microns to 50 microns.

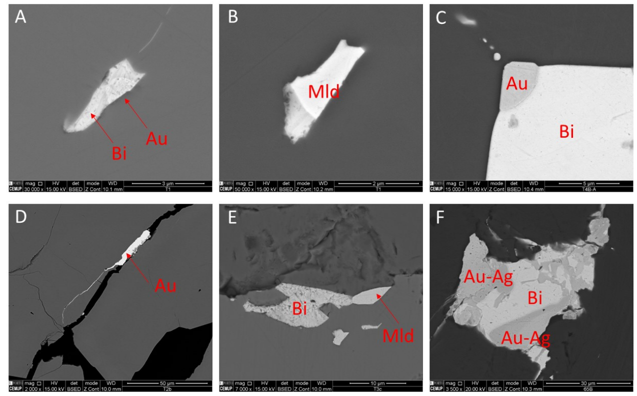

Figure 3. Different modes of gold occurrence. A – Native-Au + native-Bi in arsenopyrite; B – Maldonite (Mdl) in arsenopyrite; C- Electrum and native-Bi in chalcopyrite; D – Electrum filling fractures in arsenopyrite; E – Maldonite and native-Bi in arsenopyrite; F – Native-Bi in association with Au-Ag phases.

4.3 Hydrothermal alteration

At FNA, the hydrothermal alteration is volumetrically restricted to the quartz-sulfide veins system and the mineralized disseminated zones, consisting of i) early silicification characterized by the filling of tensional quartz veinlets (Fig. 2-B); ii) tourmalinization, feldspatization, chloritization associated to the sulfides precipitation.

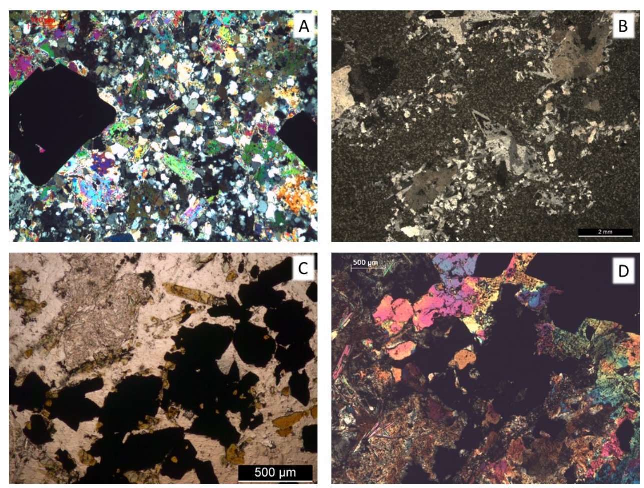

Figure 4. Different types of hydrothermal alterations. A – muscovitization; B – Chlorite + adularia associated with quartz-sulfide veins; C – Tourmalinization; D – Muscovite with anomalous birefringence and epidote.

In mineralized disseminated zones related to quartzite rocks, the muscovitization is the main present alteration. It corresponds to subhedral muscovite with symplectic borders, with quartz intergrowth and quartz droplet inclusions (Figure 4 - A). In quartz-sulfide veins, the main hydrothermal alteration is silicification, tourmalinization, K-feldspatization, chloritization, and carbonatization. However, not always present. In most cases, tourmaline is associated with this silicification (Figure 4 - C). Later, the early quartz undergoes deformation and polygonization. A polygonal quartz results from the second silicification stage, associated with the sulfides (mostly arsenopyrite). In calc-silicate rocks, the silicification, tourmalinization, and sericitization are the most pervasive alterations. In this stage, a muscovite with anomalous birefringence, epidote, clinozoisite and fluorite are frequent (Figure 4 - D). Carbonatization occurs mainly in microcracks crosscutting all lithologies, which along with feldspatization and chloritization represents the last hydrothermal event.

5 Final remarks

The quartz–sulfides bearing veins, which record two main stages of mineral deposition indicating successive periods of vein re-opening.

Gold deposition occurred in two discrete periods: 1) first as minute inclusions (Au-native and maldonite + Bi-native) that are coeval with the formation of Apy-2 and chalcopyrite during the quartz–sulfide stage; 2) later electrum and Au-Ag phases occur filling fractures and interstices between arsenopyrite crystals.

The Freixo de Numão gold mineralization periods imply hydrothermal alteration processes. The association scheelite ± fluorite ± native gold is related to the chlorite ± adularia hydrothermal alteration. The hydrothermal suite suggests a typically low-temperature hydrothermal environment and indicate near-neutral pH conditions, due to the presence of adularia and calcite.

Indirect evidence suggests that the ore-forming fluids can be related to the second and third order structures parallel to the major regional Vilariça fault (late-Variscan strike-slip fault) and/or related to the fracture systems, which controlled the emplacement of the late-to post-tectonic granitoids in the area that provided conduits for subsequent low-temperature mineralizing events (Noronha et al. 2000 and references therein).

Acknowledgments

The first author is financially supported by SFRH/BD/114693/2016 (FCT Portugal). The authors acknowledge the funding by COMPETE 2020 through the Institute of Earth Sciences project (UID / GEO /04683/2013) with POCI-01-0145 reference - FEDER007690. Minaport - Minas de Portugal, Lda are acknowledged for their technical support and assignment of samples.

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