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Portuguese orogenic lode gold deposits: the São Martinho prospect example, N. Ossa Morena Zone

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ABSTRACT
Keywords: orogenic lode gold deposits (OLGD); gold mineralisation; Ossa Morena Zone; Portugal.

The São Martinho (SM) gold prospect, which has a high potential for gold exploitation, has many analogies with other worldwide lode gold deposits. The prospect is characterised by two mineralising events, 1- typical lode gold-style mineralisation and 2- magmatically remobilised gold mineralisation. Each of these stages is characterised by different generations of quartz veins (QI & QII, respectively). Fluid inclusion data indicates that QI was deposited from low salinity, < 500 ºC fluids, while QII fluid inclusions show the fluids to be of high salinity and > 550 ºC. Mineralisation is hosted in amphibolite facies grade Série Negra metapelites and meta-arenites, adjacent to (banded) amphibolites. These rocks show hydrothermal alteration assemblages adjacent to mineralisation. Given the characteristic clustering of OLGD elsewhere in the world, the area around SM has potential for further gold exploration.

RESUMO
Palavras-chave: depósitos tipo "*orogenic lode gold"*; ouro; Zona de Ossa Morena; Portugal.

A ocorrência aurífera de São Martinho (SM) tem o potencial de exploração e mostra muitas similaridades com outros depósitos mundiais do tipo *orogenic lode gold (OLG)*. SM está caracterizado por dois eventos de mineralização, 1- mineralização típica do tipo OLG e 2- mineralização remobilizada por fluidos magmáticos. Cada evento de mineralização tem a sua geração de veios de quartzo, QI e QII, respectivamente. Dados microtermométricos mostram que QI caracteriza-se por fluidos de baixa salinidade de temperaturas < 500 ºC enquanto que em QII os fluidos são de alta salinidade e a temperaturas > 550 ºC. As rochas hospedeiras estão metamorfizadas na fácies anfibolítica e são compostas por metapelitos e meta-arenitos, adjacentes a anfibolitos (bandados) da Série Negra. Estas rochas sofreram alteração hidrotermal junto à mineralização. Devido às características de agrupamento dos depósitos OLG noutras partes do mundo, a área circundante de SM oferece um alto potencial para a prospecção de ouro.

Introduction

Orogenic lode gold deposits (OLGD) are widespread in most Archaean granitoid-greenstone terranes as well as Phanerozoic metasedimentary terrains and account for almost 20% of cumulative world gold production (Roberts, 1988). This type of deposits tends to occur in clusters within mining districts, defined as areas of 100 km^2, and gold production comes mostly from worldclass (> 100 t Au) and a few giant (> 500 t Au) deposits (Hagemann and Cassidy, 2000).
The São Martinho (SM) prospect, situated in the northern Ossa Morena Zone (Fig. 1) is such an example and the characteristics of the host rocks, alteration assemblages, gold mineralisation and fluid inclusion data is set out below.

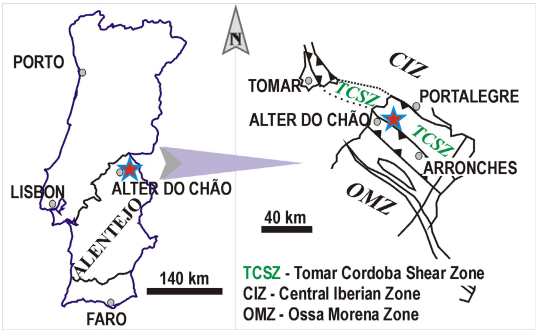

Figure 1 – Location of the São Martinho OLG prospect within the greater TCSZ and approx. 5 km E of Alter do Chão.

Definition and general characteristics

The distinction between lode gold (LG) and other types of precious metal deposits (e.g. porphyry, Carlin-type, volcanogenic massive sulphide mineralisation or epithermal hot spring) can be made on the basis of a number of key features, namely structural setting, ore fluid chemistry, mineral paragenesis and alteration assemblages. Whilst it is well-recorded (e.g. Bierlein and Crowe, 2000) that LG occurrences are hosted in metamorphic terranes, the timing of the mineralisation has been debated. In many cases, it is quite common that the mineralisation is late in the metamorphic development of a particular terrane. However, due to the diverse nature and age of host rocks and the dominant style of mineralisation and variations in the ratio between gold and other accompanying metals, as well as uncertainties regarding both the origin and relative and absolute timing of structurally hosted LG deposits, a wide

range of terms have been applied to LG deposits in recent times. These include *reef type* (Hodgson and MacGeehan, 1982), *gold-only* (Boyle, 1986), *turbidite-hosted*, *slate belt-hosted* and *greenstone-hosted* (Goldfarb *et al*., 1993), *synorogenic* (Drew *et al*., 1996), *syndeformation-synigneous* (Groves *et al*., 1998) and *epigenetic* (McCuaig and Kerrich, 1998). In view of the unique temporal and spatial association of these deposit types with collisional orogens, Groves *et al*. (1998) have recently proposed to replace the widely adopted, yet misleading term *mesothermal* (Lindgren, 1933) with the more unifying orogenic lode gold classification.

The São Martinho Prospect

Host rocks, tectonic and metamorphic setting – The host rocks to mineralisation are amphibolite facies grade Série Negra metapelites and meta-arenites, adjacent to (banded) amphibolites, outcropping within the Tomar Cordoba Shear Zone (TCSZ). The TCSZ is a geologically complex and diverse zone of intense deformation and metamorphism contemporaneous with a large sinistral displacement, which may be due to a large intracontinental sinistral fault active during the Variscan Orogeny (Berthé *et al*., 1979) with sinistral displacements of 100 km (Burg *et al*., 1981) to 300 km (Abalos and Eguíluz, 1992). Pereira and Silva (2001) considered the TCSZ a major Eohercynian-Hercynian sinistral transcurrent fault overprinting a Cadomian arc localised at a convergent margin of Gondwana.

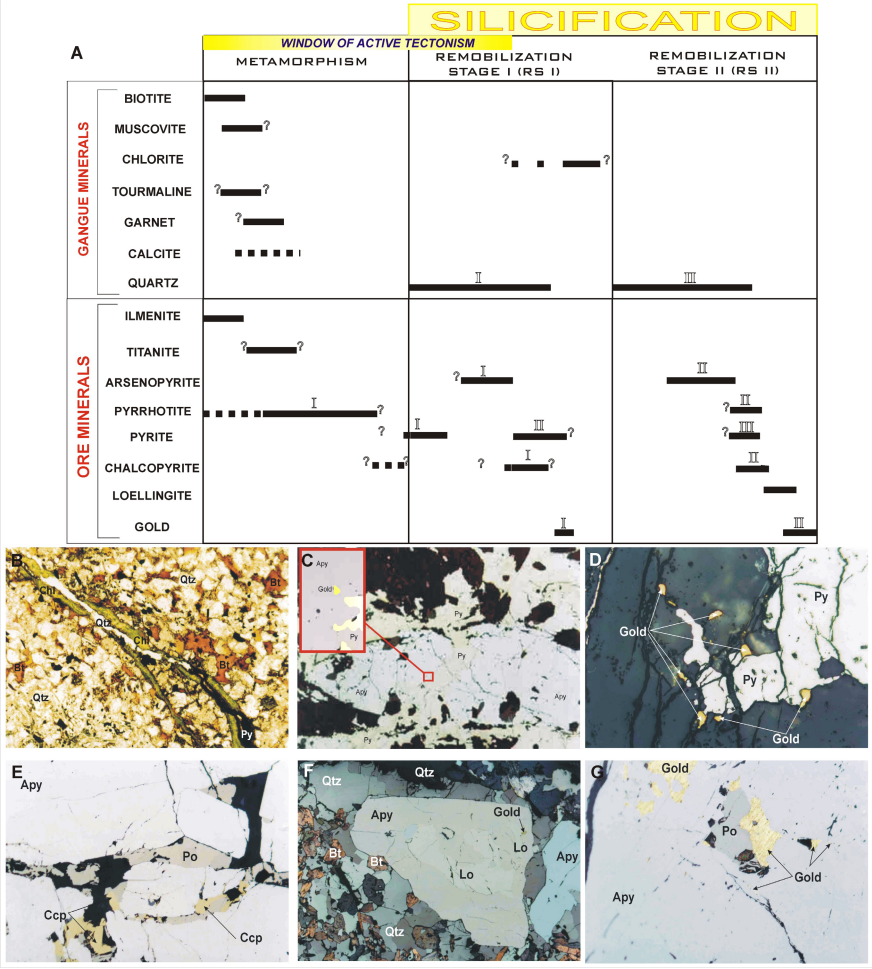

Figure 2 – A- Paragenetic sequence for the SM LG prospect; (B, C, D = event 1 mineralisation) B- Pyrite (Py) II veinlets with chlorite (Chl) alteration haloes [Field of view (FOV)=2mm]; C- deformed Arsenopyrite I (Apy) (FOV=2mm); D- Gold I associated with Py II (FOV=0.25mm); (E, F, G = event 2 mineralisation) E- Late pyrrhotite (Po) II, chalcopyrite (Ccp) II in Arsenopyrite II (FOV=0.5mm); F- Loellingite surrounded by Apy II with Gold II (FOV=2mm); G- Gold II with Po II and Apy II (FOV=0.25mm).

Gold mineralisation shows a strong correlation to first, quartz biotite schist interlayered with banded amphibolite, and secondly, quartz biotite schist that is traversed by late quartz veins. Some gold mineralisation is also observed at the transition between amphibolite and banded amphibolites.

Quartz veins - In the SM area, quartz veins are more abundant than calcite veins since the rocks have undergone hydrothermal silicification (Fig. 2A). This silicification is expressed in terms of two, easily recognisable, generations of quartz. Quartz I (early) (QI) is quartz that is probably emplaced by fluids related to kinematic and metamorphic processes and forms veinlets parallel or subparallel to regional foliation (syntectonic). Where this foliation has since been folded the veinlets are equally folded such that parallelism with regional foliation is maintained. Generally, QI veins are subtle and very narrow in width, as seen in core.

At SM, discrete, large and thicker quartz veins are frequently present. These veins are denominated by quartz II (QII) veins since they cut the regional foliation and QI veins. QII veins, up to 35 cm thick, often contain enclaves of quartz biotite schist and are associated with massive sulphides.

Gold mineralisation – Gold is recognised in two distinct mineralising events, as the ore mineral paragenesis in Fig. 2A shows. Event 1, with QI, is early, typical LG-style mineralisation consisting of pyrite I and II (Fig. 2B) + chalcopyrite I? + (deformed) arsenopyrite I (Fig. 2C) + gold I (Fig. 2D). Event 2, with QII, is late, higher,

temperature, remobilised LG mineralisation characterised by pyrite III + arsenopyrite II (Figs. 2E, F, G) + chalcopyrite II (Fig. 2E) + loellingite (Fig. 2F) + gold II (Figs. 2F, G) (de Oliveira, 2001). Gold grades can reach 12.5 g/t over 4 metres in width where the second mineralising event is present. Whereas with event 1 gold grade is only present, equivalent areas in the same lithological type will only reach 1.56 g/t Au (de Oliveira *et al*., 2001).

Alteration assemblages – Most alteration assemblages, apart from silicification, are subtle. Nonetheless, products of silicification, carbonatisation, sericitisation, chloritisation (± tourmalinisation and albitisation) are recognised in varying degrees of expression in SM. However, the main types of alteration associated with mineralisation are, in event 1, moderate foliation-parallel silicification (QI) and chloritisation (adjacent pyrite II veinlets) and in event 2, intense foliation-normal silicification linked with QII (Fig. 2A).

Fluid inclusions and sources of fluids - Sampling and inspection of QI and QII veinlets and veins showed that few if any primary fluid inclusions are preserved. All fluid inclusions observed are secondary/pseudosecondary. Three main types of fluid inclusions are observed and their microthermometric results are summarised in Table 1. Ore-forming fluids for event 1 mineralisation are derived from metamorphic dehydration reactions in pelites of the Série Negra. However, for event 2 mineralisation, the hotter, magmatic-type fluids are thought to be derived from nearby late, post-tectonic/Hercynian magmas (de Oliveira, 2001; de Oliveira *et al*., 2002).

Table 1 - Summary of the microthermometric results for fluid inclusions in the SM prospect. [*: Th_{tot}, total homogenization temperatures, including homogenization to aqueous phase (bubble point), carbonic phase (dew point) and critical behaviour; **: 22 measurements over 550 ºC not included; Temperatures expressed as range (upfront) and average (in brackets). n=number of inclusions]. (Adapted after de Oliveira *et al*., 2002).

Minera-lisation stage	Fluid inclusion type	Microthermometric results (ºC)									Salinity
		Tm_{CO2}	$Th_{CO2(L)}$	$Th_{CO2(V)}$	Te	Tm_{ice}	Th_{tot}*	$Th_{(L)}$	$Th_{(V)}$	Tm_{dau}	wt% NaCl equiv.
?	Type B (CO_2)	-60	-0.9 to +7	-	-	-	?	-	-	-	-
Event 1 (S1)	Type C (H_2O-NaCl -CO_2-CH_4)	-71 to -60 (-64.1, n=20)	-	-21 to +7 (+2.3, n=18)	-	-	245 to 521 (371, n=28	-	-	-	~9.0
	Type D (H_2O-NaCl)	-	-	-	-52.6 to –38.7 (-41.7, n=72)	-13 to +1.3 (-3.6, n=74)	-	112 to 212 (129, n=76)	-	-	0.5 to 17.2
Event 2 (S2)	Type E (H_2O-NaCl) Hypersaline	-	-	-	-	-	-	120 to 470 (290, n=161)	-	290 to >550 (400**, n=131**)	32 to 62

Discussion and conclusions

In light of the following arguments, the SM prospect represents a Portuguese example of a Phanerozoic OLGD because:

1. The TCSZ is located within an extensive area *(s.l.)* that formed part of landmasses involved in major continent-continent collisions throughout the evolution of the Iberian Massif. This feature is broadly analogous of other areas where lode gold deposits are located.
2. The mineralisation in SM is hosted in amphibolite facies grade Série Negra metamorphic rocks. A determining factor in lode gold deposits is that they are often found within rocks that range in metamorphic grade from subgreenschist to amphibolite facies. Metamorphic paths have been determined to be clockwise, i.e., P-T-t paths that deep crustal rocks might experience during continent-continent collisional events are those in which pressures increase substantially (as a result of thrust-sheet and nappe formation) before rocks begin to equilibrate thermally by relaxation of isotherms (England and Thompson, 1984). In this scenario rocks experience maximum pressures long before thermal maximum. Maximum temperatures are attained during a period of unloading (Bohlen, 1987). The metamorphic history of the SM rocks reflects a clockwise P-T-t path and hence this characteristic is analogous with those of OLGD.
3. The ore minerals and the simple ore paragenesis found at SM are consistent with those found in other lode gold deposits. In the SM case, an original OLGD (event 1) has been overprinted by a hotter, remobilising mineral paragenesis (event 2).
4. The source of the mineralising fluids within the study area is thought to be firstly, a mixture of dilute brines containing CO_2 and CH_4 derived from metamorphic devolatilisation or dehydration reactions and secondly, a

later, hotter, hypersaline fluid derived from the emplacement of late-post Hercynian felsic magmas. These features are consistent with those occurring in other well-known lode gold deposits. Fluid homogenising temperatures for several lode gold deposits are indicated to occur anywhere between 140 and 450 ºC. Local variation within deposits is great and the homogenisation temperatures of the fluids measured at SM are well within this range.

5. In terms of wallrock alteration, typical, subtle lode gold deposit type alteration assemblages are observed at SM, e.g. silicification, carbonatisation, sericitisation, chloritisation ± tourmalinisation and albitisation.

The recognition of such a class of deposit, which normally occurs as several mining camps elsewhere in the world, implies the possibility of several other LG occurrences in the vicinity and the TCSZ presents a prime exploration target for gold.

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