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Primary gold deposits in Portugal – "mesothermal" or epithermal?

CARLOS M. C. INVERNO*

Key-words: Epithermal; "mesothermal"; intrusion-related; gold; deposits; Portugal.

Abstract: The concepts of epithermal, "mesothermal" and intrusion-related gold deposits are briefly reviewed. Their possible application to primary gold deposits and occurrences in the Ossa Morena, Central Iberian and Galiza-Trás-os-Montes zones in Portugal is discussed.

Palavras-chave: Epitermal; "mesotermal"; associado a intrusão; ouro; jazigos; Portugal.

Resumo: Os conceitos de jazigos de ouro epitermais, "mesotermais" e associados a intrusões são brevemente revistos. A sua possível aplicação a jazidas e ocorrências de ouro primárias em Portugal nas zonas de Ossa Morena, Centro-Ibérica e de Galiza-Trás-os-Montes é analisada.

INTRODUCTION

Epithermal Au(-Ag) deposits, as originally defined by LINDGREN (1933), are epigenetic deposits, mainly hosted by volcanic rocks, generated at shallow depths, from the topographic surface to as deep as 1-2 km (rather low pressure), at temperatures of 200-300° C, with distinctive textural and mineralogical features. A category of sedimentary-hosted Au deposits connected to igneous activity was later recognized within these deposits and the development of fluid inclusion techniques enabled to determine a formation temperature range for epithermal Au deposits of < 150-300° C from low-salinity (< 1-5 wt % NaCl equiv.) fluids (BERGER & SIMON, 1983).

LINDGREN (1911, 1933) defined mesothermal deposits as those formed at 1-4.5 km from the topographic surface (moderate pressure) at temperatures of 200-300° C, with extremely variable ore morphology and a distinct carbonatization, among other types of alteration. Later it was recognized that, though more abundant in greenschist facies environments, they can actually occur in prehnite-pumpellyite (subgreenschist) through granulite facies, i. e., were deposited at 150-700° C (most deposits at 200-450° C) under pressures of 0.5 through 6 kb, at a depth up to 12 km (KERRICH *et al.*, 1995; GEBRE-MARIAM *et al.*, 1995), from dominant low-saline (up to 5 wt % NaCl equiv.), high-CO_2, near-neutral-pH fluids (PIRAJNO, 1990). Therefore, this group of deposits is better referred to as "mesothermal" – with quotation marks due to the actual temperature range – gold deposits, either greenstone-hosted or turbidite-hosted gold deposits. For the same reasons, the new term of orogenic lode gold deposits, either Archean or Phanerozoic, was even proposed for "mesothermal" gold deposits (HAGEMANN & CASSIDY, 2000; BIERLEIN & CROWE, 2000), with the Archean ones being subdivided into epizonal, mesozonal and hypozonal deposits (GEBRE--MARIAM *et al.*, 1995).

In terms of Ag/Au ratios, "mesothermal" gold deposits contrast epithermal gold deposits, due to an average Ag/Au ratio of 0.17 (range 0.1-1) in the former and 0.33 - >> 10 ratios in the latter (e. g., HUTCHINSON, 1987).

One of Lindgren's followers, GRATON, introduced in 1933 the term leptothermal deposits to cover those intermediate between meso- and epithermal deposits. The term was modified to transitional deposits (PANTELEYEV, 1991) to designate gold deposits formed between the setting of porphyry-molybdenum systems and that of epithermal environments, and was in part expressed by the subvolcanic intrusion-related Au(-Ag-Cu) pyrrhotite veins (ALLDRICK & HOY, 1997) in British Columbia, Canada.

Somehow following this intermediate terminology route, it should be stressed, on the other hand, the common association of some gold deposits with granitoid intrusions that has been known for a long time, distinct from intrusion-associated porphyry(-Cu)-Au deposits. ROUTHIER (1963), following former authors, considered a peribatholithic zoning, with successive metallic zones, tin, tungsten, gold and other zones, increasingly away from a granitoid cupola (Fig. 1), but recognized that part of them could be in the granitoid endocontact. Recently,

*Instituto Geológico e Mineiro, Estrada da Portela-Zambujal, Apartado 7586, 2720 Alfragide (Lisboa), Portugal; e-mail: carlos.inverno@igm.pt

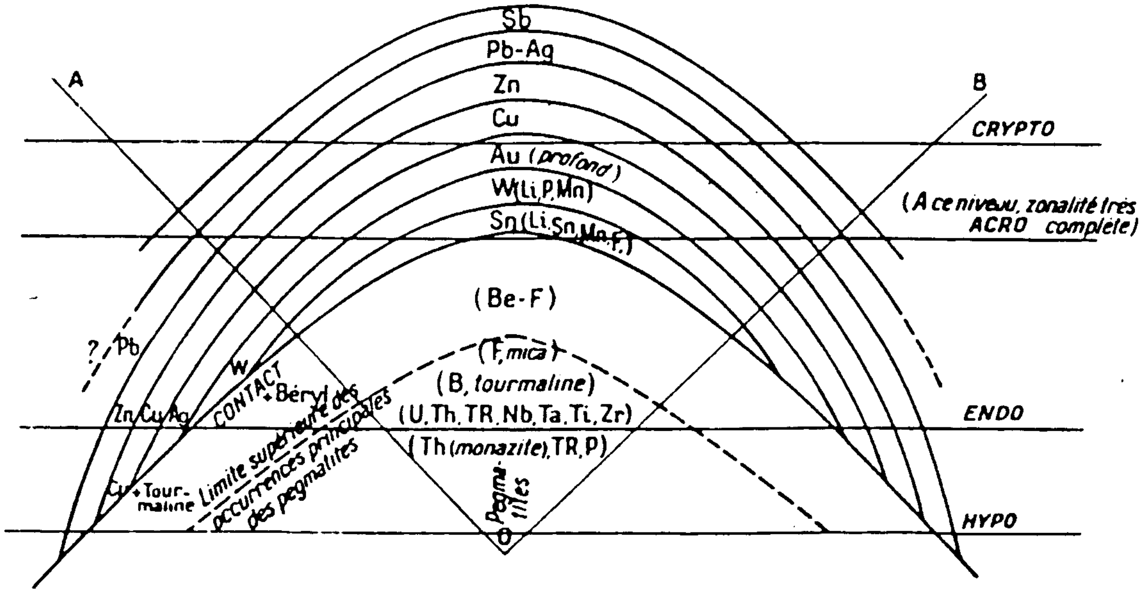

Fig. 1 – Reproduction of historical figure of ROUTHIER (1963), based on FERSMAN (1934), VARLAMOFF (1947) and EMMONS (1940), showing the peribatholithic metallic zoning. Also shown the pegmatites zoning within the intrusion, the granitoid levels of erosion, and the AOB sector that separates apical from lateral geochemical concentrations.

such gold deposits, typically associated with W and/or Sn provinces, have been called intrusion-related, plutonic-related or, simply, intrinsic gold deposits (MCCOY *et al.*, 1997; THOMPSON *et al.*, 1999; SMITH *et al.*, 1999; LANG *et al.*, 2000; LANG & BAKER, 2001; MUSTARD, 2001; BAKER & LANG, 2001).

According to these last authors, in these gold deposits a combination of W, Bi and As is common, though Sn, Mo, Te and Sb are also usually present and Ag may be abundant or scarce (gold fineness of 825-900). Intrusion-hosted deposits contain Au-Bi-Te-W ± (Mo, As, Pb), proximal deposits from the intrusions are enriched in Au-As ± (Sn, W, Sb, Cu, Pb, Zn) and distal deposits contain Au-As-Sb-Hg ± (Ag, Pb, Zn). The sulphide content in ore is variable, but averages about 3 %, with pyrite and arsenopyrite as the dominant sulphides. The most characteristic style of deposit is of intrusion-hosted sheeted veins, but greisen-like, disseminations and breccia deposits are also known within the intrusions, and contact skarns make the transition to the other deposit types, such as peripheral veins and disseminated replacements in the surrounding metasedimentary rocks. Alteration in intrusion-hosted and proximal gold deposits is more commonly fracture-controlled and includes feldspathic (albite and/or K-feldspar rich), sericitic, silicic, greisenous, calc-silicate and/or argillic assemblages, whereas pervasive alteration assemblages of muscovite, chlorite and/or carbonate rarely occur.

Following the same afore-mentioned authors, these gold deposits form at convergent plate boundaries, being related to reduced plutons of the ilmenite-series or spanning the boundary between ilmenite- and magnetite-series. These deposits generally form at 0.5 - > 1.5 kb and 200-400° C, though homogenization temperatures down to 140° C and over 500° C have also been recorded. Depositional fluids are CO_2-rich and low-saline (0-12 wt % NaCl equiv.) in most deposits, though high-saline fluids (30-65 wt % NaCl equiv.) occur in some of them, with an overall interpretation of magmatic source for the fluids, despite metamorphic or meteoric contributions in the case of exocontact deposits. MCCOY *et al.* (1997) classified these plutonic-related deposits as mesothermal, but their range of temperature deposition led the other afore-mentioned authors to abandon that term and simply call them intrusion-related or plutonic-related gold deposits.

"Mesothermal" gold deposits and occurrences in Portugal

Typical "mesothermal" gold occurrences and deposits, as defined above, are known in Portugal in the tectonostratigraphic Ossa Morena Zone, the most relevant in the regions of Portalegre and Montemor-o-Novo (Fig. 2). The two subareas of S. Martinho, Alter do Chão and Algueireiras--Nave de Grou-Mosteiros, Arronches (Fig. 2) are known in the former and zones from SE to SW of Montemor-o--Novo, between this town and Santiago do Escoural area, are mineralized in the latter.

S. Martinho and Montemor-o-Novo prospects are in amphibolite facies terrains, whereas the metamorphic grade in Algueireiras-Nave de Grou-Mosteiros is not above greenschist facies. Primary gold mineralization occurs in the transition metasedimentary/metavolcanic

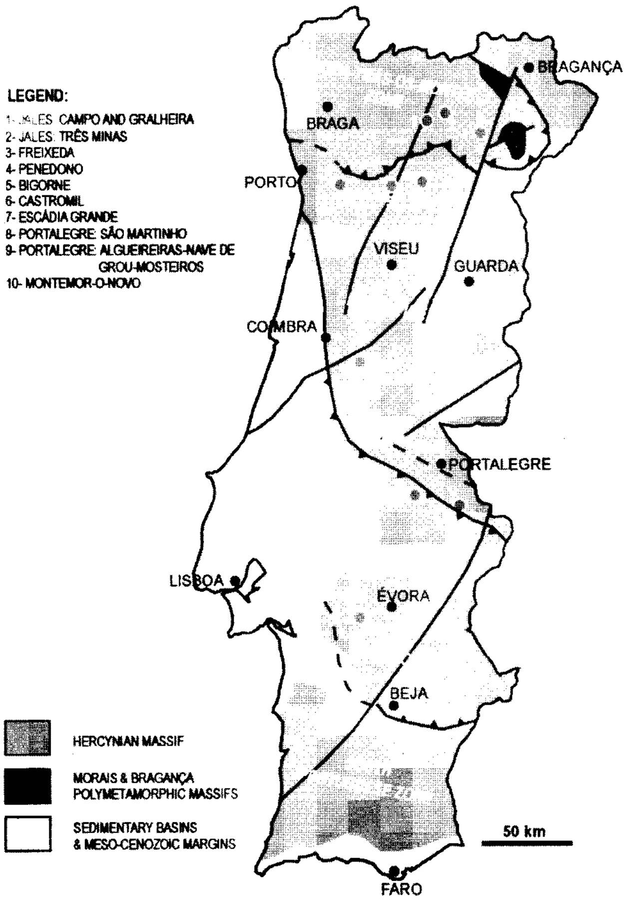

Fig. 2 – Portuguese gold deposits and occurrences mentioned in text.

rocks of Late Proterozoic age, typically quartz-biotite (at times graphitic) slate (or schist) and black quartzite (or metachert) as the metasedimentary component and felsic metavolcanic rocks or amphibolite (or banded amphibole) as the metavolcanic component, and in some Montemor-o-Novo prospects calc-silicate/skarnoid rocks are also present. Small porphyritic intrusions and also a thin (at times thick) felsic-intermediate pyroclastic rock are commonly present close to gold mineralization. Shear planes are in places recognized adjacent or close to gold mineralization. Alteration related to mineralization consists of silicification (quartz veining and masses), chloritization, sericitization and carbonatization, the last sometimes pervasive, as it is the case through ferroan dolomite in Algueireiras-Nave de Grou-Mosteiros and in the Braços prospect, Montemor-o-Novo. Mineralization in gold-enriched zones takes the form of disseminations, quartz veins, veinlets and stockworks and can also be stratabound. It consists mainly of pyrite and pyrrhotite, arsenopyrite being either abundant or absent, and other minor minerals are loellingite, chalcopyrite, realgar, barite and tourmaline. Gold fineness is of 820-920 in S. Martinho, gold grains are up to 20 µm in diameter in all areas and gold grade is in the 1-6(7) g/t Au range (INVERNO *et al.*, 1995; INVERNO, 1997).

These characteristics clearly fit those of eugeosyncline-type ("mesothermal") gold mineralization (INVERNO *et al.*, 1995) as known worldwide (HUTCHINSON, 1987; GROVES, 1993). Fluid inclusion data on the S. Martinho prospect, Portalegre reported by OLIVEIRA (2001) and OLIVEIRA *et al.* (2001a, 2001b) respect to initial low-Au grade mineralization and consist of metamorphogenic, either low-saline (avg. 10 wt % NaCl equiv.) aqueous-carbonic (H_2O-CO_2-CH_4) fluids that homogenize at 245-521° C, or else lower-temperature, H_2O-NaCl-Ca(Mg)Cl_2 fluids with salinities of 1-18 wt % NaCl equiv., overall consistent with "mesothermal" gold mineralization. However, according to the same authors, gold was mainly introduced with a late stage fluid, of hypersaline nature (magmatic), for which homogenization temperatures of 270 - > 550° C and salinities of 32-62 wt % NaCl equiv. are indicated.

Portuguese primary gold deposits and occurrences in Central Iberian and Galiza-Trás-os-Montes zones

Several primary gold deposits and occurrences are known in both the Central Iberian and the Galiza-Trás-os-Montes zones in Portugal. Most of them are hosted in the endo- or exocontact of Hercynian granitoids that intrude either pre-Ordovician Beira slates/schists or similar Silurian rocks.

All these deposits are located in districts or areas with W/Sn deposits. CERVEIRA (1952) was the first to stress a zoning, relative to the granitoids, of W deposits and outer Au deposits in Portugal. ALMEIDA & NORONHA (1988) mentioned the same peri-granitic zoning with inner W deposits and the outer Freixeda Au deposit in the Mirandela area (Fig. 2).

Characteristic features of these deposits can be exemplified in a few of them. The main metallic association As-Au-Bi-W occurs typically in the granite-hosted Penedono gold deposits (SOUSA & RAMOS, 1991), north of Viseu (Fig. 2) and NORONHA & RAMOS (1993) recognized in northern Portugal the association of As-Fe-Bi-Au-Ag (-W-Mo-Sn-Cu-Pb-Zn) in some gold occurrences versus As-Fe-Pb-Zn-Cu-Au-Ag(-Sb-Cd) in other distinct gold occurrences. The most abundant ore sulphides are arsenopyrite and pyrite in all gold deposits and occurrences. Sulphide content in quartz (vein) is of 2.8 % in Escádia Grande, Góis (Fig. 2; CERVEIRA, 1947). Sheeted veins are the style of mineralization in the granite-hosted Bigorne gold prospect, north of Castro Daire (Fig. 2; CAESSA *et al.*, 1998), whereas gold mineralization occurs either in discrete quartz veins or shear zone veinlets in most deposits and occurrences.

Fluid inclusion evidence from these deposits shows that metamorphogenic aqueous carbonic (H_2O-$CO_2 \pm CH_4 \pm N_2$) fluids, with salinities of 1-10 wt % NaCl equiv. and either high or low % mol. CO_2, and coeval with arsenopyrite, pyrite and a trace of gold, were the first to deposit at a temperature of 300-400° C and a pressure of 1-2 (to 4) kb. They were followed by aqueous (H_2O-NaCl) fluids with salinities of 0-15 (occasionally higher) wt % NaCl equiv. and trapping temperatures of 200-300° C, due to mixing of, on one hand, basinal brine and/or possible magmatic fluids and, on the other hand, meteoric fluids causing cooling and dilution; gold (± bismuth) deposition at a pressure of 0.5-1.5 kb was contemporaneous with this stage. This is in general terms and at least partially the case for instance in Penedono (NOGUEIRA & NORONHA, 1993; BOIRON *et al.*, 1996), Jales-Campo and Gralheira (MARTINS, 1987; SHEPERD & OLIVEIRA, 1990), Jales-Três Minas (NORONHA *et al.*, 2000), Freixeda (ALMEIDA & NORONHA, 1988), Castromil-Paredes (SHEPERD, 2001) and Escádia Grande (MURPHY & ROBERTS, 1997), all shown in Fig. 2.

Some authors, such as BOIRON *et al.* (1996), suggested that there was no genetic link between these gold mineralizations and the Hercynian granites hosting or close to them, which would act passively, with gold leached from metasediments during metamorphism. They based mostly on halogen ratios of fluid inclusions and favoured the interference of basinal brines conducting to gold deposition. However, some of the Penedono Au-related fluids in a graph log(Br/Cl)-log(I/Cl) plot (Fig. 8 in BOIRON *et al.*, 1996) midway between typical basinal brine and typical magmatic fluids, in spite of Três Minas equivalent plot (Fig. 5 *in* NORONHA *et al.*, 2000) being more characteristic of the former. Also, NORONHA & RAMOS (1993), MURPHY & ROBERTS (1997) and NORONHA *et al.* (2000) went further, on admitting that the intrusion of granites was at least the heat source for these gold mineralizations.

Either as heat engine and/or as one of the contributors to fluids in the late main gold stage, the role of the granitoids appears to be significant in this type of gold deposits genesis, even when located rather distant from granitoid contacts. Anomalous high Au contents in granite and aplite and pegmatite veins in Jales, together with low Au values in the Beira Slates, led NEIVA & NEIVA (1990) to conclude that gold in the region was intrinsically related to the granite, also indicated by sulphur isotope and transparent and opaque mineral chemistry evidence (ROSA, 2001). Even in a case such as the slate-hosted Escádia Grande deposit, a hidden granitoid may be inferred, since the deposit is located midway between a small granite intrusion (south of trigonometric beacon Lousã), some 5 km to the SW, and the Senhora da Guia zone, to the NE, where the pushing aside of the slaty cleavage around a rigid body at depth is probably due to a hidden granitic cupola.

With respect to classification of these gold deposits and occurrences, the prior difficulty in classifying them led several authors (e. g., MURPHY & ROBERTS, 1997; BOIRON *et al.*, 1996) to consider each individual deposit as having a "mesothermal" stage followed by an epithermal stage, the latter more enriched in gold. However, the current intrusion-related gold deposits classification term enables to surpass that difficulty, since the specific conditions of formation of these deposits, including those farther away from the intrusion, occur over a wide range of temperature and other parameters. In fact, recently ROSA (2001) clearly proposed that the Jales deposits (Campo, Gralheira and Três Minas) in Trás-os-Montes were intrusion-related gold deposits as defined modernly (see above). CAESSA *et al.* (1998) had also tentatively suggested the same for the granite-hosted, sheeted-vein Bigorne gold prospect.

Concluding statement

Despite occurring in Spain (e. g., Rodalquilar [Almeria]; ARRIBAS *et al.*, 1995), no evidence was found so-far for the presence of epithermal, either low-sulphidation or high-sulphidation, gold deposits in Portugal. Typical "mesothermal" gold deposits and occurrences in Portugal are restrited to the Ossa Morena Zone. The majority of gold deposits and occurrences in Portugal are located in the Central Iberian and Galiza-Trás-os-Montes zones, in districts and areas with W/Sn deposits, and are of intrusion-related (plutonic-related) gold deposit type as currently defined, even when farther away from a granitoid. Unfortunately, no rich gold province such as the Rio Narcea gold belt (Asturias) - El Valle and other deposits – of this last type was found to date in Portugal.

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