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Estudos, Notas e Trabalhos, Instituto Geológico e Mineiro, tomo 40, 1998, pp. 35 - 50

General assessment on the metallogenetic potencial of the Iberian Terrane southern border

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Palavras-chave: Bordo sul do Terreno Ibérico; Zona de Ossa-Morena; Complexo Ofiolítico de Beja-Acebuches; Complexo Ígneo de Beja; zonas de cisalhamento regional; potencialidades metalogenéticas.

Key-words: *Iberian Terrane southern border; Ossa-Morena Zone; Beja-Acebuches Ophiolite Complex; Beja Igneous Complex; regional shear zones; metallogenetic potentialities.*

Resumo:

A Zona de Ossa-Morena corresponde a uma unidade geotectónica meridional do Orógeno Varisco Ibérico, onde numerosas explorações mineiras de pequena escala existiram no passado. As ocorrências minerais conhecidas são muito diversificadas, distribuindo-se por vários distritos mineiros, cujo significado metalogenético nunca foi objecto de uma avaliação precisa. O conhecimento geológico da Zona de Ossa-Morena aumentou significativamente na última década, revelando novos contextos geológicos promissores. O propósito do presente trabalho consiste na revisão, à luz dos conhecimentos actuais, da metade sul da Zona de Ossa-Morena, do ponto de vista da prospecção mineral. Começa-se por apresentar a zonação metalogenética de larga escala e prossegue-se com discussões detalhadas dos contextos geológicos mais importantes (litológicos e tectónicos), sugerindo-se simultaneamente os métodos de prospecção adequados a cada caso. Finalmente, apresenta-se uma listagem dos guias de prospecção e das ferramentas que mais êxito têm tido nos trabalhos realizados nesta região.

Abstract:

The Ossa-Morena Zone is a southern geotectonic unit of the Iberian Variscides where many small scale mines were exploited in the past. The observed mineral occurrences are very diverse and a comprehensive assessment of their metallogenetic significance has never been made. The geological knowledge of the Ossa-Morena Zone has increased significantly in the last decade, and new potential geological targets have come to light. The aim of the present work is to make a review, from the exploration point of view, of the geological situations occurring in the southern half of the Ossa-Morena Zone. The mineral large-scale zonation of the Ossa-Morena Zone is briefly outlined and comprehensive discussions of the metallogenetic potential of the most important geological settings (both lithologic and tectonic), together with suggestions for the exploration tools to be used in each case, is presented. A compendium of the most successful exploration guides and tools so far used in the region is also given.

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1. INTRODUCTION

The Ossa-Morena Zone (OMZ) is a major geotectonic unit located in the southern sector of the Hesperian Massif (LÖTZE, 1945), forming, together with the Central-Iberian Zone (CIZ) the so-called Iberian Terrane (*e.g.* RIBEIRO *et al.*, 1990 - fig. 1). Its northern limit comprises a suite of imbricated, sometimes anastomosed, tectonic structures that, taken as a whole, outline the major NE verging variscan thrusts, such as the Ferreira do Zêzere and Portalegre Thrusts, in Portugal, and the Hornachos-Villaharta Thrust, in Spain; the lateral continuity of these structural corridors is often interrupted by post-collisional igneous intrusions, such as Los Pedroches Batholith (*e.g.* SILVA *et al.*, 1990, APALATEGUI *et al.*, 1990; PEREIRA & SILVA, 1997, and references therein). The southern border of the OMZ comprises highly deformed exotic terranes of oceanic nature; these, including the Pulo do Lobo Accretionary Terrane (PLAT) and the Beja-Acebuches Ophiolite Complex (BAOC) - *e.g.* QUESADA *et al.* (1994) - correspond to a Variscan suture that marks the contact with the South Portuguese Terrane, whose later reactivation led to the development of the SW

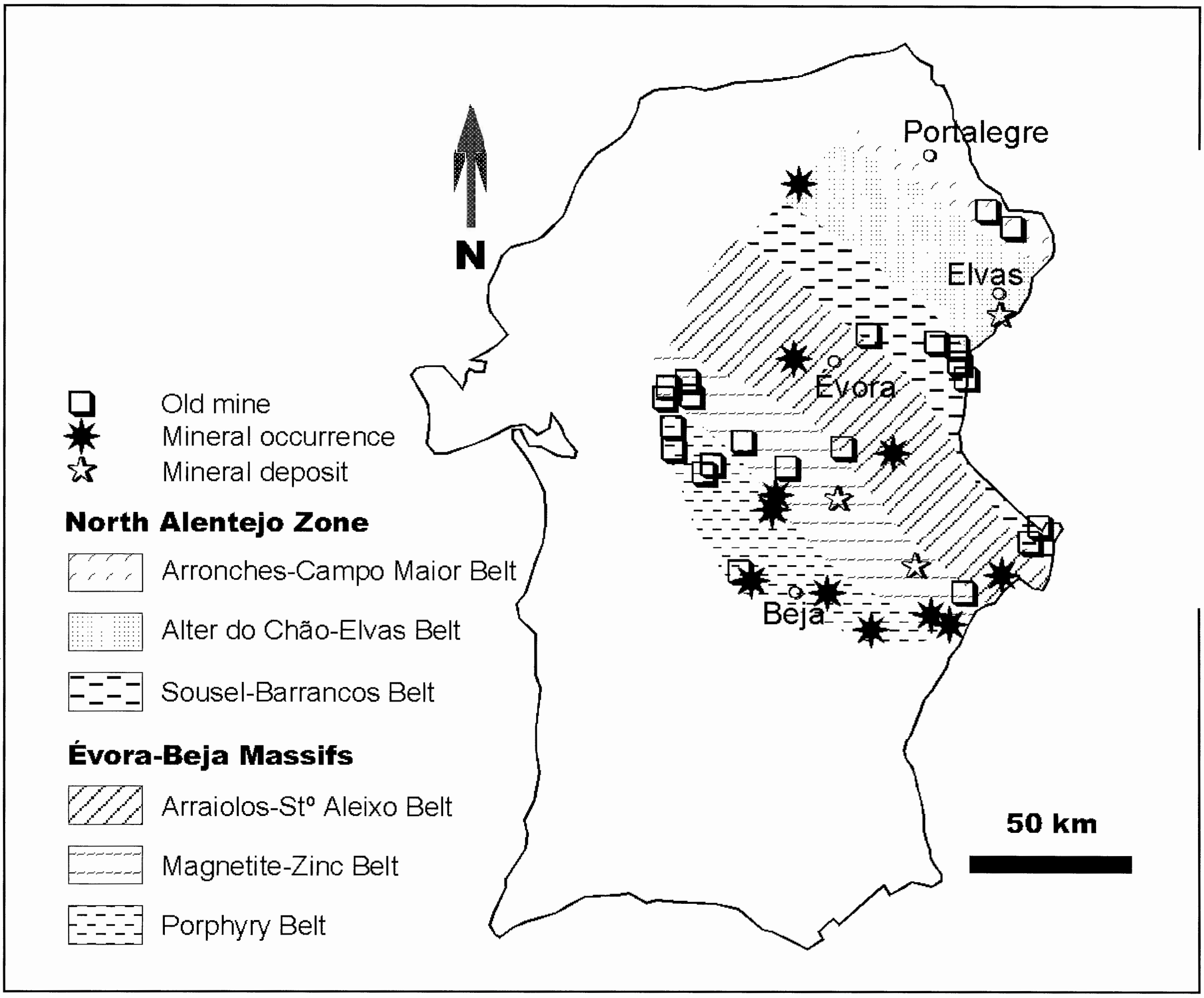

Fig. 1 - Regional setting and simplified geological map of the Évora-Beja Domain (adapted from Quesada *et al.*, 1994 and Dallmeyer *et al.*, 1993)

verging Ferreira-Ficalho-Almonaster Thrust (*e.g.* ARAÚJO, 1989, 1995; FONSECA, 1989, 1995).

Data recently acquired during different research projects are quite significant and represent an important advance in the geological knowledge of OMZ, particularly concerning:

1 – the nature and geodynamic meaning of its northern and southern limits (*e.g.* RIBEIRO, 1981; FLORIDO & QUESADA, 1984; HERRANZ, 1984; MATTE, 1986, 1990; RIBEIRO *et al.*, 1990; ABALOS, 1990, 1991; SILVA *et al.*, 1990; ABALOS & EGUILUZ, 1992; FONSECA & RIBEIRO, 1993; ROSAS *et al.*, 1993; QUESADA *et al.*, 1994; PEREIRA & SILVA, 1995);

2 – the recognition of different paleogeographic environments and their characterization, as well as the dating of major lithostratigraphic divisions (*e.g.* PERDIGÃO *et al.*, 1982; OLIVEIRA & ANDRADE, 1983; OLIVEIRA, 1984; GONÇALVES & PALÁCIOS, 1984; GONÇALVES & OLIVEIRA, 1986; QUESADA, 1990; ROBARDET & GUTIÉRREZ MARCO, 1990; OLIVEIRA *et al.*, 1991; OLIVEIRA & PIÇARRA, 1986; OLIVEIRA *et al.*, 1993; PIÇARRA *et al.*, 1993; PIÇARRA & MENN, 1993; DALLMEYER *et al.*, 1993); and

3 – the general review of the relationships between metamorphism (*e.g.* MATA & MUNHÁ, 1986; QUESADA & MUNHÁ, 1990; FONSECA *et al.*, 1993; PEDRO, 1996; LEAL *et al.*, 1997), igneous activity (*e.g.* OLIVEIRA *et al.*, 1977; CARVALHOSA, 1983; MATA & MUNHÁ, 1985; MUNHÁ *et al.*, 1986; MATA, 1986; CARRILHO LOPES, 1989; SÁNCHEZ CARRETERO *et al.*, 1990, SANTOS, 1990; CARRILHO LOPES *et al.*, 1997; RIBEIRO *et al.*, 1997) and tectonic events (*e.g.* ARAÚJO, 1989, 1995; FONSECA, 1989, 1995; RIBEIRO *et al.*, 1990; APALATEGUI *et al.*, 1990; QUESADA, 1990; SANTOS *et al.*, 1990; AZOR *et al.*, 1993; RIBEIRO, 1993; ARAÚJO *et al.*, 1993a, b, c; QUESADA *et al.*, 1994; LOPES & SILVA, 1995).

According to the available data, the portuguese domain of OMZ may be divided into several sectors with distinct lithostratigraphic and structural features that, most of the times, correspond to lateral extensions of well known tectonostratigraphic units recognised in Spain. The main sectors are known as Alter do Chão-Elvas, Estremoz-Barrancos and Montemor-Ficalho, special domains being the Beja Igneous Complex (including the subsector of Santa Susana-Odivelas) and the Blastomylonitic Belt of Abrantes-Portalegre-Badajoz. In this general perspective, it should be emphasized that the present distribution of the OMZ sectors mainly reflects the tectonic arrangement resulting from the Late-Variscan deformation events; however, many of the geological and structural features observed in each sector are ascribable to former orogenic cycles.

A complex geodynamic evolution like the one experienced by the OMZ during Pre-Cambrian and Paleozoic times, easily produces a set of geological settings suitable for the development of a great diversity of ore-forming systems, as documented by the widespread distribution of a large number of exploration targets and old mining works all over the area covered by this geotectonic unit (fig. 2). The exploration campaigns performed up to the present favoured, however, the search for base metal mineralisations (Cu, Pb, Zn), iron, and more recently also for Au ± Ag, which mainly occur in the following metallogenetic districts of some economic interest (Table 1, *e.g.* SILVA, 1949; CARVALHO *et al.*, 1971; OLIVEIRA, 1984, 1986, 1992; MARTINS *et al.*, 1998):

– *Sousel-Barrancos Copper Belt*, where mineralisations are hosted by metasedimentary and/or volcanic formations of Ordovician to Devonian age. The Cu (± Zn, Pb) sulphides occur within quartz veins (*e.g.* Miguel Vacas, Bugalho, Mostardeira, Aparis and Minancos Mines) or form disseminations in subvolcanic rock domains subjected to prominent fracturing and brecciation (*e.g.* Defesa das Mercês Mine);

– *Magnetite-Zinc Belt*, represented at Viana, Portel, Moura, Sobral da Adiça and Ficalho regions, comprising domains particularly enriched in: (i) Zn, Pb (Cu), where the stratiform sulphide mineralisations are associated both to dolomitic, locally silicified, marbles of Lower Cambrian age (*e.g.* Algares-Balsa, Preguiça and Vila Ruiva Mines), and to acid volcanic-carbonate series of the base of the Cambrian sequence (*e.g.* Enfermarias ore body); (ii) Fe, either as massive or disseminated magnetite, forming stratiform bodies hosted by basic metavolcanites included in a volcanic-sedimentary sequence whose age has been attributed to Ordovician-Silurian (*e.g.* Orada and Vale de Pães Mines).

Table 1
Former explorations works in Ossa-Morena Zone

POTENTIAL BELTS	GEOLOGICAL GUIDES USED	GEOPHYSICAL & GEOCHEMICAL SURVEYS PERFORMED
Arronches - Campo Maior ***Cu, Pb and (Ag)***	Contacts between different types of gneissic rocks; metamorphic gradients and hydrothermal alteration; metavolcanic acid rocks (pyroclastic facies in particular).	1) Cu, Zn and Pb geochemistry; 2) Magnetometry; 3) Induced polarization; 4) Gravimetry; and 5) Electro-magnetometry of very low frequency.
Alter do Chão – Elvas ***Cu, Pb, Zn, Fe, Sn and W***	Metavolcanic acid-intermediate rocks with strong hydrothermal alteration (sericisation, chloritisation and silicification, in particular); silicified and brecciated metadolomitic limestones; haloes of contact metamorphism; fractures networks underlined by mineral products of metasomatic processes (greisenisation).	1) Cu, Zn and Pb geochemistry; 2) Magnetometry; 3) Induced polarization; 4) Gravimetry; and 5) Analysis of heavy-mineral concentrates.
Sousel – Barrancos ***Cu (and Zn, Pb)***	Lodes developed under reducing conditions; dilatant structures affecting flysh metasediments; distinct sedimentary discontinuities and metadolomitic limestones; evidence for acid volcanic activity and its intrusive and colapse breccias; carbonatisation features.	1) Cu, Zn and Pb geochemistry; 2) Magnetometry; 3) Induced polarization; and 4) Gravimetry;
Arraiolos – Sto Aleixo ***Cu***	Circumscribed plutons and their culminations; evidence for mafic volcanism; brittle fracture networks and associated hydrothermal alteration haloes.	1) Cu, Zn and Pb geochemistry; 2) Magnetometry; 3) Induced polarization; and 4) Gravimetry
Magnetite – Zinc ***Fe, Zn, Pb and Cu***	Silicified and brecciated metadolomitic limestones; evidence for intermediate-acid volcanism and for intense metasomatism (chloritization and silicification in particular), including dedolomitisation (with formation of talc and serpentine); mafic volcanism adjoining late granitic intrusions.	1) Cu, Zn and Pb geochemistry; 2) Magnetometry; 3) Gravimetry; and 4) Induced polarization.
Porphyry Rocks and similar lithologies ***Cu (and Pb, Zn)***	Volcanic and subvolcanic complexes; host rocks of diorites, near the intrusive bodies; pervasive hydrothermal alteration.	1) Cu, Zn and Pb geochemistry; 2) Magnetometry; and 3) Induced polarization.

Other potential belts have already been recognised in OMZ, but their metallogenetic significance has not yet been properly assessed. That is the case of the Arronches--Campo Maior (Cu, Pb, Au ± Ag - where the Tinoca and Azeiteiros Mines are located), the Alter do Chão-Elvas (Cu, Pb, Zn, Sn), and the Arraiolos-St^{o} Aleixo belts (Cu), and of the Porphyry (Cu ± Ag ± Au?) belt. Other geological situations also lack verification of their mineral potential, since they were not yet completely examined from an exploration point of view. In fact: 1) the studies previously undertaken in the Montemor and Portalegre regions do not fully explain the genesis of the observed gold occurrences (*e.g.* RIBEIRO *et al.*, 1993; OLIVEIRA *et al.*, 1995; INVERNO, 1997); 2) more attention should be paid to the

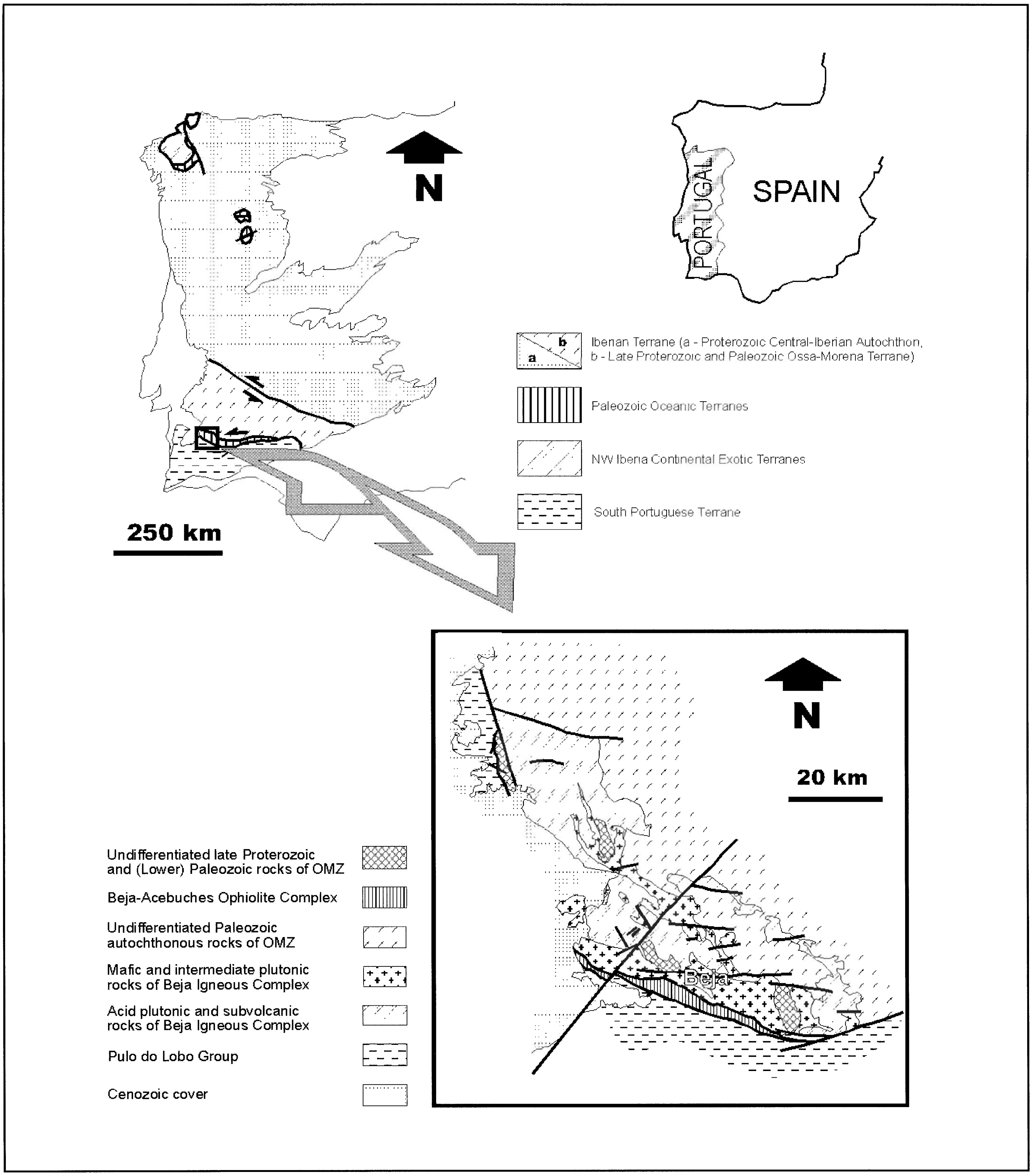

Fig. 2 - Major metallogenetic districts in OMZ (adapted from Oliveira, 1986

Variscan shear or fault zones of polyphasic evolution where strong hydrothermal circulation is completely recorded; and 3) comprehensive examination of the Beja-Acebuches ultramafic-mafic belt and of the Beja Igneous Complex is needed for an accurate definition of their real metallogenetic potential. The following comments will essentially focus on the last subject, with some additional general remarks about the geochemical meaning of the main features associated to the strong and polyphasic hydrothermal activity in the vicinity of regional shear zones.

2. METALLOGENETIC POTENTIAL OF THE BEJA-ACEBUCHES OPHIOLITE COMPLEX

The Beja-Acebuches Ophiolite Complex (BAOC) is a structurally involved, ophiolitic assemblage of peridotites, gabbroic rocks (gabbro-gabbronorites and minor troctolites), and basaltic lavas of tholeiitic nature; deep marine sediments and examples of sheeted dike complexes are almost absent (*e.g.* MUNHÁ *et al.*, 1986, 1989; QUESADA *et al.*, 1994). During BAOC emplacement, the lower ophiolite section experienced syntectonic recrystallization under high temperature conditions (800-900°C); Variscan metamorphism took place during collision of the Iberian and South-Portuguese Terranes, reaching typical amphibolite facies P-T conditions (QUESADA *et al.*, 1994; FIGUEIRAS *et al.*, 1998).

Examination of the main ultramafic units outcropping at the Guadiana and Ferreira do Alentejo-Mombeja areas (MATEUS *et al.*, 1998c) has shown that, despite extensive serpentinisation, original differences in composition are preserved; harzburgite is the dominant protolith throughout. These rocks have usually disseminated micrometric Fe-Ni-Co (±Cu) sulphides, and their whole-rock content has positive covariations with the chondrite-normalised abundances of the Pd subgroup of PGEs (MATEUS *et al.*, 1997, 1998c), suggesting that the transitional domains between the ultramafic cumulates and gabbroic rocks represent favourable sites for the development of pods and small bodies of sulphides, particularly if magma mixing took place. This is also consistent with the chemical nature, textural relationships and relative abundances of primary sulphides within wehrlite-troctolite rocks at the Palmeira site (Guadiana Valley area), as comprehensively discussed in MATEUS *et al.* (1998b).

The general petrogenetic setting suggested by the whole-rock geochemical signature and the mineral chemistry obtained for representative ultramafic samples of BAOC (MATEUS *et al.*, 1998c), indicates that banded chromitites may have formed, especially in the ultramafic domain outcropping between Ferreira do Alentejo and Mombeja. In this area, a detailed petrographic examination of drill-cores, resulting from boreholes drilled some years ago near Ferreira do Alentejo, should be done in order to precise the relationships between the different peridotite bodies and to investigate the eventual presence of relics of the upper mantle section. A complete assessment of the real metallogenetic potential of the Ferreira do Alentejo-Mombeja area requires however a specific approach, since the location, orientation and shape of chromite ore bodies in deformed ultramafic sequences are determined by a variable number of factors (see, *e.g.*, KRAVCHENCKO, 1986 and CHRISTIANSEN, 1986, for a general review). Aeromagnetic and detailed gravimetric surveys should be performed in order to better characterize the anomalous alignments already defined by the Instituto Geológico e Mineiro (IGM); high resolution data is needed to outline the anomaly patterns at a scale suitable for correlation with detailed geological mapping, and its reliability should be further confirmed by ground magnetometer traverses and gravimetry profiles. Short wavelength, high amplitude variations are predicted over the serpentinites indicating strongly magnetised rocks; the magnetic response would be in this case mainly controlled by the proportion of secondary magnetite in the rock, which can be used to delimit of less-magnetised, but potentially mineralised areas.

According to the available results (MATEUS *et al.*, 1997; 1998c), the metagabbroic rocks belonging to BAOC may host Ti-V anomalies of potential economic interest. This reflects mostly the relative abundance of disseminated ilmenite ± Ti-rich magnetite whose subsequent alteration may lead to extremely Ti-rich mineral aggregates, particularly significant in strongly hydrothermally altered (mostly carbonatised) rock-samples. Although significant concentrations of primary oxides were not yet found, the analysis of soil geochemistry appears to be a powerful tool in the discrimination of non-outcropping metagabbros and metaperidotites (GONÇALVES *et al.*, 1998c); this could also be used as a first approach for the definition of major geochemical anomalies whose metallogenetic potential should be evaluated further in detail by conventional exploration tools.

Given the scarcity of outcrops throughout BAOC and the pronounced weathering exhibited by most of them, the characterisation of stream sediments (already underway) and the subsequent examination of heavy mineral concentrates seems to be a more reliable indicator of potential mineralised targets associated to the ultramafic and mafic rocks. This will provide also the opportunity to determine the nickel, gold, silver and PGEs abundances, and to analyse the geographical distribution patterns of Ti, V, Cr and Cr/Fe, by means of detailed geochemical/mineralogical characterisation of the obtained heavy mineral concentrates.

3. METALLOGENETIC POTENTIAL OF THE BEJA IGNEOUS COMPLEX

The Beja Igneous Complex (BIC) has been tentatively interpreted as the root domain of a magmatic arc established at the OMZ southern margin. Its emplacement, being initially coeval with the variscan orogenic metamorphic peak (therefore post-dating BAOC obduction), took place under geodynamic conditions favourable to calc-alkaline igneous activity which lasted until Late Visean times (*e.g.* ANDRADE, 1974, 1983; SANTOS *et al.*, 1990; DALLMEYER *et al.*, 1993; QUESADA *et al.*, 1994). This persisting igneous activity led to the development of several rock types that can be grouped in three main lithological complexes: 1) the Beja Gabbroic Complex, mainly consisting of olivine-bearing gabbros, bordered by heterogeneous diorites resulting from variable extents of magma mixing at the margin of the intrusion; 2) the Cuba-Alvito Complex, comprising mostly granodiorites, diorites and gabbros; and 3) the Baleizão Acid Porphyry Complex lately emplaced at relatively shallow crustal levels.

Although detailed geochemical characterisation of these complexes is far from complete, their genesis can be envisaged as a gradual rise of calc-alkaline magmas progressively enriched in volatiles and metals (because of increasing crustal contamination), taking place in thermal regimes adequate for mineralising systems to develop. In this scenario, the formation of ore bodies within the most primitive intrusive rock-suites (such as gabbros) may depend essentially on the original magma composition and on its differentiation path, which can lead to the accumulation of some ore minerals (oxides, in particular - *e.g.* ilmenite/hematite and magnetite) by means of filter pressing or magmatic injection processes; this could be, for instance, the case of the Fe-Ti(-V?) ores found in old prospects near Odivelas. But it will be the interplay between the rising asthenospheric melts generated by slab break-down and the host lithologies (metasediments, in particular) that may promote the genesis of some of the polimetallic anomalies intimately associated with dioritic and late porphyritic rocks, since it provides the means for the incorporation of large amounts of sulphur (and of some metals) into the system, therefore favouring the development of sulphide ores.

Porphyry and epithermal styles of mineralisation related to the igneous activity of the late stages of continental collision and orogenic collapse are better documented and included within the so-called Porphyry Belt, where the most notable mineral occurrences are Corte Pereiro, Caeirinha and Alcáçovas (*e.g.* OLIVEIRA, 1986; RELVAS, 1987; MASSANO, 1988). Data reported in Andrade (1983) and Relvas (1987) clearly show, however, that a typical geological framework for Cu-rich porphyry deposits is not found in this belt. Instead, it seems more appropriate to look for epithermal systems characterised by several superimposed and cross-cutting stages of pervasive fracturing and hydrothermal circulation (locally controlled by major shear zones or thrusts) that may generate Ag and Au (and in a few exceptional cases also Bi, Cu, Pb and Zn) geochemical anomalies. This is also in agreement with the fact that sulphide mineralisations spacially associated with dioritic rocks occur frequently along or nearby the contacts with later intrusives, especially acid porphyritic rocks, suggesting that the early hydrothermal activity (related to dioritic bodies emplacement) does not favour the genesis of ore-grade mineralisations in BIC.

From the above considerations, one may therefore conclude that economic mineralisations of porphyry-epithermal styles in BIC should be restricted to highly localised and fractured domains of the intrusive complex where, invariably, strong and polyphasic hydrothermal alteration of igneous rocks can be easily recognised. A significant variety of mineralising styles (mainly replacements, breccias and veins), that usually occupy a vertical span of no more than 500 m, should then be expected, since these features usually reflect the common variations in temperature, pressure, and composition of the ascending (mineralising) solutions in relatively shallow crustal environments. Detailed examination of old prospects should therefore be done in order to characterise: 1) typical mineral assemblages, paragenetic sequences, and zoning relationships among major alteration assemblages; 2) the constraints on fluid composition; and (3) the nature of controls exerted by the composition and/or differentiation history of the associated igneous intrusions. All these aspects will provide important information on the establishment of predictive metallogenetic model(s), defining, therefore, coherent geological frameworks in which it will be possible to apply the defined exploration tools. In other words, the examination of both the rock association and the hydrothermal alteration (type, pattern and sequence), combined with multi-element geochemical analysis, are the main exploration guides for mineralised areas in the Porphyry Belt. Geophysical data may also be useful at the early exploration stage if magnetic studies successfully help defining of the structural framework, and the electrical methods allow the delimitation of either the extent of the hydrothermal system or one or more of its mineralised components.

In a geological scenario dominated by a huge and polyphasic igneous intrusion, such as BIC, affecting metasedimentary sequences (often bearing thick series of carbonate rocks), skarn type mineralisations are also expectable. However, as far as can be judged from the published data, no record of these kind of ores other than Fe-skarns (such as those of Alvito and Corujeiras) is available for the OMZ southern domain.

Skarn deposits may have significant economic interest (especially if gold-bearing), and therefore further adequate exploration campaigns should be performed in OMZ southern border in order to search for suitable geological settings for such type of mineralisations. Particular attention should be paid to places where metasomatic transformations of metasedimentary rocks intruded by BIC took place, especially if polyphasic. The most favourable sites are those where carbonates represent the main plutonic-wall rock type, since interaction between the ore-forming fluids and the carbonates usually enhance metal concentration (exceptionally effective in the presence of Au-bearing fluids). Detailed geochemical characterisation of the igneous rocks is also recommended since it may provide important clues to exploration; according to Meinert (1995), for instance, plutons commonly related to Au-skarns are similar to those associated with Fe-skarns in their metaluminous nature and their Si, Mg, Cr and Sc contents, but similar to Cu-skarn plutons in their Ni, V and Y contents, having however a mineral assemblage formed in distinctively more reduced conditions.

4. METALLOGENETIC POTENTIAL OF REGIONAL SHEAR ZONES

During BIC emplacement, high geothermal gradients were generated, sustaining the development of a prevalent hydrothermal activity in a deforming brittle crust, most intense in Late-Variscan times but could probably be further renewed in Early-Alpine times. If conveniently focussed, these fluid flows might have generated mineralising systems of moderate to low temperature with particular importance in the formation of different lode ores, namely those of a general metal assemblage Au-Ag (-Sb-As), Sb-Pb(-Cu-Zn), and Pb-Zn(-Cu). Therefore, a general characterisation of the major shear zones that outcrop in the OMZ southern border is needed for any assessment of their significance as preferred conduits for repeated fluid discharge and thus as structural barriers of ore development, as documented by the Peroguarda and Asseiceiras mineral occurrences.

A simple inspection of the available geological maps at different scales shows that the OMZ southern border displays a relatively complex fracture network that affects all the geologic and lithostratigraphic units belonging to BAOC, BIC and to the autochthonous sequence of the Iberian Terrane. The fracture network comprises mainly four different systems: 1) NNE-SSW to NE-SW left-handed strike-slip faults, represented by several major accidents (*e.g.* the Messejana Fault), whose development is usually ascribed to the late-variscan stress field; 2) N-S to NW-SE right-handed faults, often of minor extension and commonly interpreted as the conjugate system of the prevailing structures referred to in the previous item; 3) ENE-WSW left-handed, brittle shear zones (*e.g.* the Ficalho Fault) that in some places may form complex structural arrays with the structures mentioned below; and 4) major E-W to WNW-ESE shear corridors of predominant sinistral kinematics, generated during the variscan collisional events (under a left-lateral transpressional regime) between the Iberian and the South Portuguese Terranes (*e.g.* QUESADA *et al.*, 1994) and that were repeatedly reactivated (*e.g.* MATEUS *et al.*, 1997, 1998a,c).

Although the most conspicuous shear and fault zones belong, respectively, to the WNW-ESE and to the late N-S and NE-SW systems, clear evidence for multi-phase tectonic movement and strong hydrothermal activity exists at all scales, irrespective of the type and cartographic extension of the tectonic structures. Fluid discharges, expressed by abundant quartz and/or carbonate deposition, sometimes accompanied by sulphides, are commonly observed and may occur in three main settings: 1) dilatant jogs along the main shear structures; 2) tensional domains in subsidiary structures, such as tension gashes; and 3) multistage networks of veinlets in strongly hydrothermally altered host rocks. Hydraulic breccias, comprising fragments of the host rocks cemented by a siliceous matrix which may be enriched in sulphides or their weathering products, can also be recognised in many places, as well as faint sulphide mineralisations (both of vein and disseminated type). Unfortunately, lack of representative outcrops in many areas prevents detailed geological mapping and gathering a complete set of structural and geochemical information required for the evaluation of the metallogenetic potential of several major tectonic accidents. Nevertheless, either the lateral continuity of these main shears and faults or their relative importance in the regional structural arrangement of the OMZ southern border, can easily be confirmed by the available magnetic and gravimetric surveys performed by IGM, which also put in evidence the distinct structural control of many important anomalous geophysical alignments, some of them awaiting an appropriate investigation.

4.1. WNW-ESE shear zones

The hydrothermal alteration halos shown by the peridotites of BAOC adjoining the WNW-ESE shear zones and the silicified carbonate infillings of these tectonic accidents, were recently investigated in several areas between Serpa and Ferreira do Alentejo in order to evaluate their metallogenetic potential for precious metals (especially for gold - MATEUS *et al.*, 1998c).

The examined hydrothermal precipitates display variable amounts of disseminated sulphides (mainly pyrite ± chalcopyrite ± sphalerite), or their weathering products, and several generations of carbonates. The first carbonate generations (of prevailing ankerite-dolomite nature) result from the substitution of primary silicate phases of the host rocks, such as amphiboles, and later, plagioclases, as is seen in the less altered specimens from some of the studied areas (MATEUS *et al*, 1998a, c; GONÇALVES *et al.*, 1998a, b). However, the latest carbonates (typically calcite in nature) are direct precipitation phases, and this might have been possible due to boiling of rising solutions favoured by repeated pressure drops in the system after successive seismic rupture episodes (related to the reactivation of the shear zones). If so, any amount of H_2O present in these fluids may have separated from CO_2 which would be fixed by carbonate precipitation. Accepting this hypothesis, a favourable system for gold concentration at higher crustal levels should be expected (see, *e.g.*, BOWERS, 1991), ruled predominantly by the mechanisms pointed out by Seward (1984, 1989) for gold solubility and precipitation. Taking all these features together, a straight comparison with particular geological frameworks that commonly lead to listwaenite genesis or to mesothermal lode-gold occurrences hosted by hydrothermally altered mafic/ultramafic rocks is extremely appealing (*e.g.* EARHART *et al.*, 1997; MATEUS *et al.*, 1998c).

Mineralised listwaenites are known in several ophiolitic sequences (*e.g.* Voltri-Liguria, Italy; Bou Azzer-Morocco) and always show quartz and sulphides (disseminated pyrite, in particular), suggesting that: 1) bissulphide is the most favourable complexing ligand of gold in this chemical system; and that 2) gold precipitation is mostly favoured by pH lowering (RENDERS & SEWARD, 1989). Nevertheless, as comprehensively discussed by GONÇALVES *et al.* (1998a, b) and by MATEUS *et al.* (1998a, c), no evidence exists for significant K-metasomatism and that seems to be essential in all known listwaenite rocks and their genetically associated mineralisations (Au and less commonly Au-Sb, Sb, Cu, Ni, Co) - for a detail review of the subject see, *e.g.*, Halls & Zhao (1995) and references therein. The green carbonate assemblages observed in BAOC are in fact relatively enriched in chlorite and in relics of serpentine instead of the fuchsite/mariposite typically found in listwaenites associated to lodegold deposits.

The hydrothermal flows focussed along the WNW-ESE shears mapped in the OMZ southern border, being clearly

CO_2 rich, are quite similar to those typically related to the genesis of many mesothermal lode-gold mineralisations. But in these geochemical systems, ore grades may be found in a wide range of situations and, apparently, there is no particular mineralogical assemblage that can be used as an exploration guide. That is why the majority of the exploration programmes carried out in the world most significant gold provinces (such as greenstone belts of all Archaean shield areas) are chiefly structurally based, despite the fact that the development of gold-bearing pathways are commonly (but not necessarily) related to chemical processes that led to strong CO_2 metasomatism of the host rocks (*e.g.* KERRICH & FYFE, 1981). Therefore, along the same shear zone, non-mineralised segments coexist with mineralised ones and, in general, the distribution of Au-contents is strongly erratic, being the ore shoots usually localised in specific structural sites (preferentially those related to duplexing and releasing bends formation).

Accordingly, the lack of any anomalous metal content in the examined segments of the WNW-ESE shear zones between Serpa and Ferreira do Alentejo, is not a definitive proof that these regional structures are completely barren. In this perspective it should be emphasised that the only real evidence for historical attempts of mineral exploitation in BAOC is the abandoned trial workings in western Mombeja area which are located along the southern border of the serpentinite belt and are structurally controlled by WNW-ESE shear zones (MATEUS *et al.*, 1998c). The origin and chemical nature of these mineralisations are presently unclear and should be investigated in the future (see also the data reported in EARHART *et al.*, 1997).

4.2. Late N-S and NE-SW strike-slip fault zones

Fluid circulation associated with crustal fracturing that took place in Late-Variscan and/or Early-Alpine times in the Iberian Terrane may be intimately related to the genesis of several ore-forming systems (of low-sulphidation type, in particular), specially at localities where repeated hydrothermal discharge is clearly recorded. This geochemical/structural framework, well known in the northern domain of the Iberian Terrane, is indeed commonly responsible for a great diversity of mineral lode deposits, namely a significant number of Au-Ag-As(-Pb) mineralisations (*e.g.* MATEUS & BARRIGA, 1991; CATHELINEAU *et al.*, 1993; NORONHA *et al.*, 1995; SHEPHERD *et al.*, 1995; OLIVEIRA *et al.*, 1995; BOIRON *et al.*, 1996; MATEUS, 1997), as well as many Pb-Zn(-Cu) occurrences, and the majority (if not all) of the known Sb-Pb(-Zn-As-Au) deposits (*e.g.* PORTUGAL FERREIRA, 1971; GUMIEL & ARRIBAS, 1987; COUTO *et al.*, 1990; ORTEGA & VINDEL, 1995; NORONHA *et al.*, 1998). In OMZ southern border, a systematic and appropriate geochemical and geophysical exploration for these mineralisation types is still lacking, although several mineral occurrences can be listed, Palmas (GOINHAS & MARTINS, 1986) and Ventosa (MATEUS *et al.*, 1998c) being the better known of them.

According to the available data, the association Sb-Cu (-As-Ag-Au) precises quite well the general metallic assemblage of the Ventosa ores, which are structurally controlled by a subvertical, near N-S, right-handed fault. Repeated fluid pumping (triggered off by recurrent seismic events responsible for the successive reactivation of the fault) led to the development of a polyphasic mineral paragenesis dominated by quartz + siderite ± calcite + stibnite + tetrahedrite + pyrite + arsenopyrite + berthierite, accompanied by some additional accessory sulphide and sulphosalt phases. The identification of micrometric crystals of aurostibite along the sharp boundaries between tetrahedrite and famatinite-stibioluzonite, as well as the recognition of erratic distributions of Au(-Ag) in arsenopyrite and pyrite crystals (namely those belonging to the late generations), is, however, worth noting. But the evaluation of its precious metal potential requires additional investigations, since the intermittent depressurisation of the system induced by the repeated seismic tectonic events might have interrupted some relevant chemical reaction paths, leading to abrupt variations of several critical parameters that rule Au(Ag) behaviour in solution, hindering their precipitation (BOWERS, 1991; MATEUS, 1997).

Nevertheless, as noticed by Williams-Jones & Normand (1997), the presence of significant amounts of gold(-silver) in antimony (stibnite-rich) deposits could be ascribed to the establishment of pH conditions along the H_2S-HS^- predominance boundary, and fO_2 values slightly below the stability field of sulphate species. Therefore, considering the speciation behaviour of stable Au and Sb species in low-salinity hydrothermal fluids, bisulphide complexes, such as $Au(HS)_2^-$ (*e.g.* SEWARD, 1989), and species such as HSb_2S_4 at intermediate pH values (KRUPP, 1988; SPYCHER & REED, 1989) or of hydroxy-bisulphide complexes, like $Sb_2S_2(OH)_2$, under low pH conditions (KRUPP, 1988), will play an important role on the transportation of appreciable amounts of Au(-Ag) and Sb. Deposition of native gold (or electrum) and stibnite during system cooling is thus favoured by pH decreasing, with or without reduction. It is worth noting that within a highly oxidising environment (clearly within the SO_4^{2-} stability field), antimony could be carried away in solution but not gold(-silver); sulphur-poor fluids may also severely restrict the Sb and Au(Ag) co-transportation.

A metamorphic and/or a strongly modified meteoric origin for mineralising fluid flows in similar tectonic settings is often pointed out (according to the chemical signatures displayed by fluid inclusions and/or the stable isotope data), but given the timescale and the driving mechanisms involved in fluid pumping into dilatant fault segments, a suitable thermal gradient for stibnite formation may easily never be established. However, in the absence of a favourable thermal gradient, reduction and sulphidation processes can be extremely effective in the formation of stibnite deposits (*e.g.* WILLIAMS-JONES & NORMAND, 1997). Therefore, similar Sb-Cu mineralisations may occur in the OMZ southern border, and the most interesting targets for new exploration endeavours will be located within metamorphosed black shales or alternating sequences of metamorphosed black shales and marbles affected by strike--slip fault zones and subject to more or less obvious hydrothermal alteration.

5. CONCLUDING STATEMENT

From the published data it is often inferred that the metallogenetic potential of the OMZ in general, and of its southern border in particular, is actually of minor importance. Conclusions such as these are, however, quite premature, since accurate scientific documentation is lacking and a great variety of metallogenetic scenarios can easily be envisaged, most of them confirmed by the widespread presence of faint mineralisations (both of vein and disseminated type).

The development of banded chromitites in the ultramafic domain of BAOC outcropping between Ferreira do Alentejo and Mombeja is suggested by the available data, although detailed magnetic and gravimetric surveys are needed for their recognition and further caracterisation. Also, (sub-economic ?) Ni-(Co-PPGE) sulphide mineralisations are to be expected in particular domains of the lower and intermediate sections of BAOC, especially if evidence for magma mixing is discovered. Titanium-vanadium anomalies of potential economic interest closely associated either with metagabbroic rocks of BAOC, or with gabbros belonging to BIC, are also predictable on the basis of the available geological information.

A specific exploration program is required to properly evaluate the complete spectrum of mineralisations that might be related to BIC evolution, which embraces different magmatic-hydrothermal systems whose metal assemblages are mainly dependent on subtle variations of a global ore forming process. Improved understanding of the critical features related to the known mineral occurrences (including those intimately related to the source(s) of mineralising fluids and the controls exerted by the composition and/or differentiation history of igneous intrusions), will enable the development of metallogenetic models that will provide a better scientific basis and, therefore, an increased certainty to mineral exploration. Epithermal (high-sulphidation, in particular) ore forming systems are to be expected, especially in typical structural and geochemical frameworks generated during multiple and late intrusion of more differentiated magmas; in these circumstances, the main exploration guides to be used consist of detailed characterisation of rock association and of hydrothermal alteration (type, pattern and sequence) combined with the multi-element geochemical analysis.
Along the BIC margins, skarn type mineralisations are also expected to develop, and an appropriate exploration programme should be undertaken in order to define the most favourable settings for Cu(-Co-Bi)- and Au(-Bi)-skarns genesis.

Low-sulphidation ore-forming systems of potential economic interest for Au-Ag-As-Sb-Cu-Pb-Zn can also be found in the OMZ southern border. These different mineralisations are structurally controlled by major shear and fault zones of predominant WNW-ESE, N-S and NE-SW strike, whose relative importance in controlling particular geophysical anomalies (some of them awaiting an appropriate investigation) can easily be checked by the available magnetic and gravimetric surveys performed by IGM. In these geological framework, ore genesis are related to the intense hydrothermal activity that took place in Late-Variscan times, and, probably, also in Early-Alpine times in some N-S and/or NE-SW faults.

The relative intensity of the hydrotermal alteration experienced by BAOC rocks adjoining the WNW-ESE shear zones lead usually to the development of silicified aggregates of ankerite-dolomite somewhat enriched in chlorite and relics of serpentine. The lack of evidence for strong K-metasomatism prevents the classification of these hydrothermally altered rocks as listwaenites, although the extent and the mineralogical nature of the observed metasomatism may be used to infer the development of CO_2 rich hydrothermal systems similar to those described for many mesothermal lode-gold deposits. Therefore, specific exploration programmes should be carried out in the future in order to completely evaluate the real metallogenetic potential of the WNW-ESE shear zones.

The N-S to NE-SW strike-slip fault zones, particularly at segments where repeated hydrothermal fluid discharge took place, represent another type of structures that did act as privileged traps for distinct mineralisations developed in Late-Variscan and/or Early-Alpine times. That is the case of several mineral occurrences characterised by the metal assemblage Sb-Cu(-As-Ag-Au), preferentially hosted by metamorphosed black shales or alternating sequences of metamorphosed black shales and marbles.

ACKNOWLEDGEMENTS

The authors grateful acknowledge the financial support of Fundação para a Ciência e Tecnologia (FCT - Ministério da Ciência e Tecnologia, Portugal) through the Research Grant PBICT/CTA/2112/95 - MIZOMOR.

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