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The metallogenic evolution of the Ossa-Morena Zone

La evolución metalogenética de la Zona de Ossa Morena

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Abstract

The Ossa-Morena Zone contains abundant ore deposits and showings for the most part formed during the Cadomian and the Variscan orogenic cycles, and the intermediate rifting and stable platform stages. Despite major tectonic dismembering during Variscan rejuvenation which masked older geologic features, Cadomian mineralisation is comparable to active arc-related ore deposits, i.e., volcanic-hosted massive sulphides, barite and Zn-Pb SEDEX deposits and some minor porphyry copper-like mineralisation. Post-Cadomian Early Paleozoic ore deposits are scarce. Most are iron oxide stratabound deposits probably related to the Early Cambrian rifting volcanism. Variscan tectonic, metamorphic and magmatic activity led to the formation of very different types of mineralisation, including syn-metamorphic and perigranitic base metal-bearing veins, small volcanic-hosted polymetallic massive sulphide deposits, iron oxide replacements and skarns, magnetite and Cu-Ni magmatic ore bodies and Sn-W veins and replacements. Orogenic Au mineralisation is of imprecise age and could be either Variscan or Cadomian. Relatively low temperature Late Variscan hydrothermal activity is believed to be responsible for the formation of abundant Pb-Zn- and Cu-dominated lodes in different geological settings, Hg replacements and uranium-bearing veins.

As a whole, the diverse Variscan metallogenesis of the OMZ is interpreted as a vertical continuum in a continental crust undergoing transpressional strain. During the Variscan cycle, the OMZ first was an active continental margin –and magmatic arc-, that evolved into a collided zone after amalgamation to the South Portuguese Zone terrane. Furthermore, the recently discovered large mafic-ultramafic body set in the middle crust, probably played a key role in Variscan metallogenesis.

Keywords: Ore deposits, transpression, orogenic rejuvenation, Ossa-Morena Zone, Iberia

Resumen

La Zona de Ossa Morena se caracteriza por la abundancia de depósitos e indicios minerales pertenecientes a los ciclos orogénicos Cadomiense y Varíscico, así como a las etapas intermedias de *rifting* y plataforma estable. A pesar del desmembramiento producido por la orogénesis Varíscica, que enmascara los rasgos geológicos más antiguos, la mineralización Cadomiense reúne muchas de las características de las ligadas a arcos magmáticos en bordes de placa, tales como la formación de sulfuros masivos asociados a rocas volcánicas, depósitos sedimentario-exhalativos de barita y Zn-Pb y pequeños pórfidos cupríferos. Los depósitos minerales de edad Paleozoico Inferior son escasos, destacando sólo las mineralizaciones estratoides de óxidos de hierro relacionadas con el vulcanismo del Cámbrico inferior. La actividad tectónica y magmática ligadas a la orogenia Varíscica dieron lugar a una gran variedad de estilos y tipos de mineralización, incluyendo venas de Zn-Pb-Cu sin-metamórficas y peri-plutónicas, pequeños sulfuros masivos ~~asociados a rocas~~ magmáticas, remplazamientos y skarns de óxidos de hierro, mineralizaciones magmáticas de hierro y Ni-Cu y venas/remplazamientos de Sn-W perigraníticos. Hay algunas mineralizaciones de oro en relación con zonas de cizalla que puede ser

Cadomienses o Varíscicicas. Finalmente, en relación con la actividad hidrotermal tardi- a post-Varíscica tuvo lugar la formación de abundantes filones con Pb-Zn, remplazamientos con Hg y venas de uranio.

En conjunto, la diversidad de la metalogénesis Varíscica de la Zona Ossa Morena se interpreta como un continuo vertical de procesos, en un contexto de deformación regional transpresiva. La Zona Ossa Morena durante el ciclo Varíscico comenzó siendo un margen continental activo (con arco magmático), que evolucionó hacia una zona de colisión, una vez amalgamada al mismo la Zona Surportuguesa. Además, el cuerpo de máfico-ultramáfico recientemente descubierto en la corteza media, en toda la Zona Ossa Morena, debió de jugar un importante papel en la metalogénesis Varíscica.

Palabras clave: Depósitos minerales, Transpresión, Rejuvenecimiento orogénico, Zona Ossa Morena, Iberia

Resumo

A Zona de Ossa Morena contém abundantes jazigos e ocorrências mineiras, principalmente formados durante os ciclos orogénicos Cadomiano e Varisco e durante os estádios intermédios de “rifting”e de plataforma estável. Apesar do forte desmembramento tectónico, as mineralizações Cadomianas assemelham-se nas suas características às tipicamente geradas por processos mineralizantes em arcos insulares activos, com formação de jazigos de sulfuretos maciços encaixados em rochas vulcânicas, jazigos de barita e jazigos SEDEX e alguma mineralização menor assemelhável à do tipo pórfiro cuprífero. Os jazigos minerais do Paleozóico Inferior são escassos e incluem principalmente alguma mineralizacão estratóide de óxidos de ferro. A actividade tectónica, metamórfica e magmática Varisca levou à formação de tipos de jazigos muito diferentes, incluindo veios de metais básicos sin-metamórficos e perigraníticos, pequenas jazidas de sulfuretos maciços polimetálicos em rochas vulcânicas, corpos de substituição e skarns de óxidos de ferro, jazigos magmáticos de magnetite e de Cu-Ni, e veios e corpos metassomáticos de Sn-W. A mineralização mesotermal de Au é de idade controversa, podendo ser Varisca ou Proterozóica. Finalmente, atribui-se à actividade hidrotermal Varisca tardia, de temperatura relativamente baixa, papel determinante na formação dos abundantes veios predominantemente de Pb-Zn ou Cu em diferentes enquadramentos geológicos, de corpos de substituição de Hg e de veios com urânio. De forma geral, a pouco comum metalogénese Varisca é interpretada como resultado da forte influência exercida pelos efeitos estruturais multi-escala ditados pela tectónica oblíqua, em conjunto com uma actividade magmática relevante.

Palavras-chaves: Jazigos minerais, Transpressão, Rejuvenescimento orogénico, Zona de Ossa Morena, Iberia.

1. Introduction

The Ossa-Morena Zone (OMZ) is the Iberian Massif geotectonic unit that displays the greatest variety of types of mineralisation as well the largest number of ore deposits and showings (>650). It includes a wide range of commodities such as iron, lead-zinc, copper, gold, silver, antimony, nickel, manganese, tungsten, mercury, barite, variscite, uranium and coal. They formed by very different processes in distinct geological settings, ranging from deep mesothermal veins to stratiform exhalative deposits (Table 1).

Despite this diversity, the OMZ was of relatively minor mining importance with only few economically significant deposits discovered to present (Table 2). The Azuaga-Berlanga ore field was an important world leading Pb producer in the second half of the 19th century (c.) and the first half of the 20th c. and significant iron mining took place in the central OMZ during the middle 20th c. Additionally, minor production of copper, gold, zinc, tungsten, tin, uranium and barite took also place. First evidence of mining comes from the Argaric and Iberian cultures that worked some small Cu-Ag veins *circa* 2000 BC. The Roman Empire systematically exploited many of the outcropping mineralisation, including Pb-Ag veins, iron in Jerez de los Caballeros, the Cu-(Au) veins of Sultana, Abundancia, Encinasola and Llerena areas (Domergue, 1987), the Cu massive ore in Tinoca and Azeiteiros (Campo Maior), Cu veins in Salvação do Índio (Azaruja) and probably also Fe in Monges. After the Roman period, little evidence exists of extensive mining except in the 16th c., when some Pb and Cu veins were worked. In 1848 the systematic exploitation of the Azuaga-Berlanga ore field started, initiating a renewed mining interest in the area. Many mines were opened in the following years that persisted until 1940-45. In the same period, several Cu lodes and iron ores were also exploited in Portugal, namely in the Sousel-Barrancos region; mining activity was extended to very rich supergene Zn ores at Vila Ruiva. Tungsten-tin deposits were worked in Spain during the first half of the 20th century, and iron oxide deposits were mined extensively till the sixties in Portugal and the 1980´ in Spain. In the last 20 years there has been a renewed interest in the metallogenic potential of the OMZ and new deposits have been discovered. It is worth noting that most of the recently discovered deposits are ‘unusual’, because they are only represented by a few examples and belong to uncommon deposit types. Also, the reappraisal of some long known deposits has shown that they can be classed among types which have only been recently defined in the literature.

Recently discovered and evaluated deposits include Puebla de la Reina and Nava Paredón (Cu-Zn-Pb, VHMS), Oropesa (Sn, replacement), Aguablanca (Ni-Cu, magmatic hosted) or Algueireiras-Nave de Grou-Mosteiros

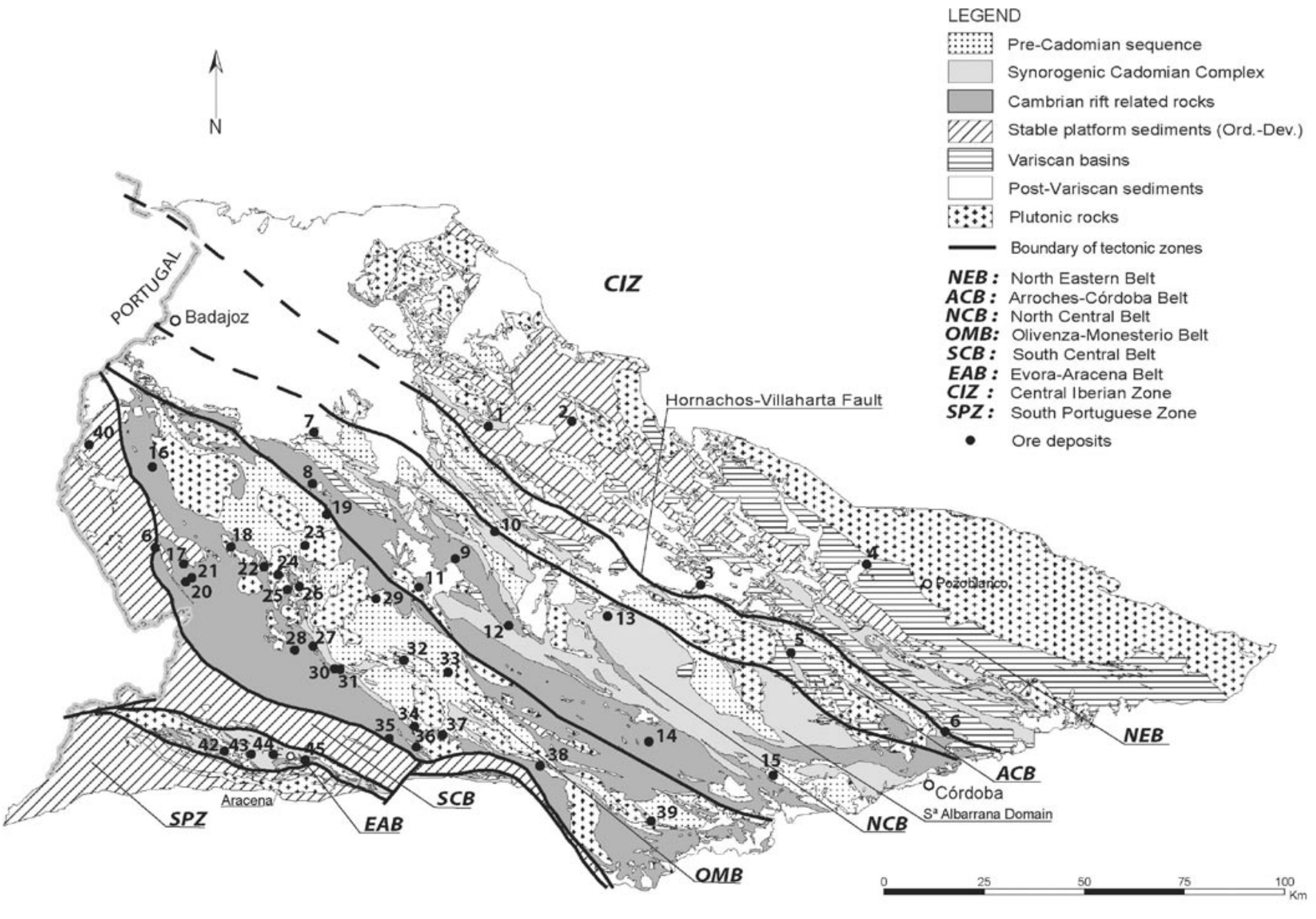

Fig. 1.- Figure 1. Synthetic geologic map of the Ossa-Morena Zone in Spain showing the metallogenic belts and the location of the major deposits and districts described in the text. Deposits and occurrences: 1. Puebla de la Reina (Cu-Zn-Pb); 2.- San Nicolás (W-(Sn-Bi)); 3.- Oropesa (Sn); 4.- El Soldado (Pb-(Zn-Ag)); 5.- Nava Paredón (Zn-Cu-Pb); 6.- Los Arenales-Cerro Muriano (ba-fl-F-(Zn-Pb-Ag)); 7.- Santa Marta (Pb-Zn-(Ag); 8.- Alfredo (Fe); 9.- Mariquita-Sultana (Hg-(Cu-Pb-Ba)); 10.- Retín (Zn-Pb); 11.- Calzadilla de los Barros (Cr); 12.- Llerena (barite); 13.- Azuaga-Berlanga ore field (Pb-(Ag-Zn)); 14.- Cerro del Hierro (Fe); 15.- Sierra Albarrana (U-(REE)); 16.- Las Herrerías (Fe-(Cu)); 17.- Oliva-Zahínos (Mn); 18.- La Bóveda (Fe); 19.- Abundancia (Cu); 20.- Mari Juli (W-(Bi-Au)); 21.- Virgen de Gracia (W); 22.- La Bilbaína (Fe-(Cu-Au)); 23.- Monchi (Fe-(Co-REE-U)); 24.- Colmenar-San Guillermo-Santa Justa (Fe-(Cu)); 25.- Bismark (Fe); 26.- La Berrona (Fe); 27.- La Valera (Fe); 28.- Los Eloys (Fe); 29.- La Hinchona (Cu); 30.- Chocolatero (Au); 31.- Guijarro (Au); 32.- Monesterio (Cabra Alta) (U-(Ni-Co)); 33.- Pallarés (Cu-Ba); 34.- Sultana (Cu-(Au-Bi)); 35.- Cala (Fe-(Cu)); 36.- Teuler (Fe); 37.- Aguablanca (Ni-(Cu-PGE)); 38.- Cazalla de la Sierra (Fe); 39.- Constantina-Huéznar (Au); 40.- Novillero (Fe-(Cu); 41.- Villanueva del Fresno (Cabra Baja) (U-REE); 42.- Aroche (wollastonite) 43.- Maria Luisa (Cu-Zn-(Pb)); 44.- Fuenteheridos (Zn-Pb-Ag); 45.- Aracena (Zn-Pb-Ag-Ba).

Fig. 1.- Mapa geológico sintético de la Zona Ossa Morena en su parte española, mostrando la división en zonas metalogenéticas y la localización de los principales depósitos y distritos citados en el texto. Depósitos e indicios: 1. Puebla de la Reina (Cu-Zn-Pb); 2.- San Nicolás (W-(Sn-Bi)); 3.- Oropesa (Sn); 4.- El Soldado (Pb-(Zn-Ag)); 5.- Nava Paredón (Zn-Cu-Pb); 6.- Los Arenales-Cerro Muriano (ba-fl-F-(Zn-Pb-Ag)); 7.- Santa Marta (Pb-Zn-(Ag); 8.- Alfredo (Fe); 9.- Mariquita-Sultana (Hg-(Cu-Pb-Ba)); 10.- Retín (Zn-Pb); 11.- Calzadilla de los Barros (Cr); 12.- Llerena (barite); 13.- Azuaga-Berlanga ore field (Pb-(Ag-Zn)); 14.- Cerro del Hierro (Fe); 15.- Sierra Albarrana (U-(REE)); 16.- Las Herrerías (Fe-(Cu)); 17.- Oliva-Zahínos (Mn); 18.- La Bóveda (Fe); 19.- Abundancia (Cu); 20.- Mari Juli (W-(Bi-Au)); 21.- Virgen de Gracia (W); 22.- La Bilbaína (Fe-(Cu-Au)); 23.- Monchi (Fe-(Co-REE-U)); 24.- Colmenar-San Guillermo-Santa Justa (Fe-(Cu)); 25.- Bismark (Fe); 26.- La Berrona (Fe); 27.- La Valera (Fe); 28.- Los Eloys (Fe); 29.- La Hinchona (Cu); 30.- Chocolatero (Au); 31.- Guijarro (Au); 32.- Monesterio (Cabra Alta) (U-(Ni-Co)); 33.- Pallarés (Cu-Ba); 34.- Sultana (Cu-(Au-Bi)); 35.- Cala (Fe-(Cu)); 36.- Teuler (Fe); 37.- Aguablanca (Ni-(Cu-PGE)); 38.- Cazalla de la Sierra (Fe); 39.- Constantina-Huéznar (Au); 40.- Novillero (Fe-(Cu); 41.- Villanueva del Fresno (Cabra Baja) (U-REE); 42.- Aroche (wollastonite) 43.- Maria Luisa (Cu-Zn-(Pb)); 44.- Fuenteheridos (Zn-Pb-Ag); 45.- Aracena (Zn-Pb-Ag-Ba).

and Chocolatero-Guijarro (Au, orogenic). The only mine currently (2002) in production is Cala (Fe-skarn), operated by PRESUR SA. Moreover, the recently discovered Aguablanca deposit will start its operation soon.

Despite the economic interest, little scientific work has still been done on the OMZ ore deposits, a fact which contrasts with the major effort done at clarifying its stratigraphy, structure, metamorphism and magmatic record. In this work, we present an overview of its major mineral deposits, including for the first time both the Portuguese

Metal association	Morphology	Host and related rocks	Style	Age	Examples
I. North Eastern Belt (NAB)					
Zn-Cu-Pb	Stratabound	Calc-alkaline, bimodal volcanic and sedimentary rocks	vhms	U. Proterozoic	Puebla Reina
W-(Bi-Sn)	Veins	Shales. Epizonal peraluminous leucogranites and pegmatites	intra-&perigranitic veins	U.Carboniferous	San Nicolás
Bi-(Co-Ni)	Veins	Sandstones & shales adjacent to epizonal leucogranites	perigranitic veins	U.Carboniferous	Espiel
Cu-(Zn-Pb-Ag)	Veins	Shales & sandstones adjacent to peraluminous epizonal biotite granites	intra-&perigranitic veins	U.Carboniferous	El Soldado, Las Morras
Sn	Stratabound, veins	Shales, sandstones, limestones. Veins in quartzites.	perigranitic replacement	U.Carboniferous	Oropesa
U	Veins	Granitoids	veins	Late Variscan-Alpine	Los Pedroches
II. Arronches-Córdoba Belt (ACB)					
Cu-(-Pb)	Disseminated, stratabound	Felsic migmatitic metavolcanics and gneisses	vhms?	Proterozoic	Tinoca, Azeiteiros
Zn-Pb	Stratiform	Shales and sandstones	sedex	Proterozoic?	Usagre
Au	Veins, stockworks	Metasediments & metavolcanic rocks	orogenic gold	Prot? Variscan?	S.Martinho, ANM
Zn-Cu-Pb-(Au)	Stratabound	Calc-alkaline, bimodal high K volcanic and related sedimentary rocks	vhms	E.Carboniferous	Nava Paredón
Fe	Stratiform	Rhyolites in calc-alkaline bimodal high K volcanic rocks	exhalative	E.Carboniferous	Las Berazas
Zn-(Pb-Cu)	Stratabound	Calcic skarns in carbonate rocks, calc-silicate hornfelses	skarn	U.Carboniferous	Los Arenales
Pb-Zn-(Ag)	Veins	Gneisses	shear-related veins	Late Variscan	Azuaga-Berlanga
Ba-F-(Zn-Pb-Ag)	Veins	Granitoids	basement-cover veins	U.Carboniferous – Permian?	Cerro Muriano
III. North Central Belt (NCB)					
Cr	Irregular	Serpentinites	alpine podiform	Proterozoic	Calzadilla
Cu	Irregular & veins	Calc-alkaline epizonal quartz-monzonites	porphyry	U.Proterozoic	Ahillones
Ba	Stratiform	Limestones, volcaniclastic shales	sedex	U. Proterozoic	Llerena
Cu-Zn-Pb	Irregular	Volcanosedimentary sequence	?	Cambrian	
Cu, Ba	Veins	Schists	syn-tectonic veins	Variscan	Pallarés
Fe	Tabular	Gabbro	magmatic	Variscan?	Alter do Chão
U-REE	Irregular	Syn-metamorphic granitic pegmatites	pegmatites	Carboniferous	Sierra Albarrana, Villanueva del Fresno
W(-Sn)	Veins & greisen	Granites	intragranitic veins & replacements	Variscan	Santa Eulália
Hg-(Pb-Cu-Ba-Au)	Stratabound, irregular, veins	Limestones, shales	epithermal replacements	Variscan	Mariquita
Fe	Strata bound	Limestones	skarns	Varican(?)	Alagada
Zn-Pb	Veins	Limestones	periplutonic veins	Varican(?)	Torre das Figueiras
IV. Olivenza-Monesterio Belt (OMB)					
Fe	Stratabound	Volcaniclastic sub-alkaline to alkaline dacites	(sub)-exhalative	Cambrian	Bilbaína, Bóveda, Bismark
Mn	Stratabound, veins	Volcaniclastic sub-alkaline to alkaline dacites	(sub)-exhalative	Cambrian	Zahínos
Fe	Irregular	Dacites with pervasive albitisation	replacement	Cambrian-Variscan?	Berrona, Alfredo
Au	Veins, irregular	Deformed metavolcaniclastic rocks	orogenic gold	Variscan	Guijarro, Chocolatero, Constantina-Hueznar
Cu, Zn-Pb	Veins	Shales, sandstones	syn-tectonic veins	Variscan	Hinchona
Ni-(Cu-PGE)	Pipe	Mafic & ultramafic cumulates, calc-alkaline gabbros	ultrabasic-related	Variscan	Aguablanca

Fe-(Cu-Au)	Stratabound, Irregular	Limestones, granitoids, gneisses	replacement	Variscan?	Colmenar, Monchi
Fe-(Cu-Au)	Stratabound, irregular	Limestones, calc-silicate hornfelses, diorites to leucogranites	skarn	Variscan	Cala, Teuler
Vermiculite	Irregular	Dolostones with magnesial skarn	skarn	Variscan	Garrenchosa
Cu-(Au-Bi)	Veins	Shales, calc-silicate hornfelses, calc-alkaline tonalites	peri-&intragranitic veins	Variscan	Sultana, Abundancia
W-(Sn-Bi-Au)	Veins, irregular	Epizonal peraluminous monzonites to leucogranites	peri-&intragranitic veins & greisens	Variscan	Virgen de Gracia, Mari Juli
Au	Veins	Peraluminous calc-alkaline epizonal leucogranites	intragranitic veins	Variscan	Burguillos
U-(Ni-Co)	Veins	Migmatitic gneisses	basement cover veins	Post Variscan	Cabra Alta
V. South Central Belt (SCB)					
Cu, P, Fe-Mn	Stratiform	Black shales	early diagenetic	Ordovician-Silurian	
Cu, Zn-Pb, Fe	Veins	Shales, sandstones and turbiditic sedimentary rocks	late-tectonic veins	Late to post-Variscan	Aparis, Novillero
Cu	Disseminations, veins	Felsic sub-volcanic intrusives and related breccias	?	Silurian?	Defesa das Mercês
U-REE	Disseminations, veins	Albitic leucogranites	magmatic	Variscan	Villanueva del Fresno
VI. The Evora-Aracena Belt (EAB)					
Fe	Massive,stratabound	Retrograded amphibolites and metalimestones	vhms+skarn?	L.Cambrian-Ordovician, Variscan?	Monges, Orada
Zn-(Cu-(Pb-Ag)	Stratiform (stratabound?)	Metavolcanic-sedimentary sequence with abundant metadolostones	vhms, sedex–Irish type?	Proterozoic-L. Cambrian?	Enfermarias, Maria Luisa, Aracena, Fuenteheridos
Au-Cu-(Pb)	vhms				
Au-Bi	Veins, stockworks	Metasedimentary and metavolcanic rocks	mesothermal	Proterozoic? Variscan?	Chaminé-Casas Novas-Braços
Fe	Massive, irregular	Marbles adjoining Beja Igneous Complex	skarn	Variscan	Alvito
Fe-Zn	Stratabound	Metalimestones, calc-silicate hornfelses	skarn	Variscan	Aracena
wollastonite	skarn	Limestones	skarn	Variscan	
graphite	Irregular	Schists	metamorphic	Variscan	
Cu	Veins, diaclase infillings	Quartz-diorite intrusions, aplite-pegmatite veins, and micaschists	periplutonic veins	Variscan	Azaruja
Cu	Veins	Metavolcanic-sedimentary sequence (Ordovician?)	late-tectonic veins	Late to post-Variscan	Rui Gomes
VII. S. Cristovão-Beja-Serpa Belt (SCBSB)					
Fe-Ti-V	Irregular masses	Gabbros of the Beja Igneous Complex	magmatic	U. Devonian?	Odivelas
Cu-(Ni)	Veins, stockworks	Gabbros of the Beja Igneous Complex	late-magmatic	U. Devonian?	Castelo Ventoso
Cu-(Ag-Au)	Veins, stockworks	Porphyry rocks of the Beja Igneous Complex	periplutonic veins. epithermal?	Carboniferous?	Caeirinha
Sb, Cu(As-Au)	Veins	Metasedimentary rocks	late-tectonic veins	Late to post-Variscan	Ventosa
VIII. Beja Acebuches Ophiolite Complex (BAOC)					
Cr	Dissemination, bands	Strongly serpentinised and metamorphosed peridotites	magmatic	Devonian?	Mombeja-Ferr. Alentejo
Ni-Cu-(Co)	Dissemination, bands	Deformed and metamorphosed wehrlite-troctolite rocks	magmatic	Devonian?	Palmeira
Cu	Dissemination, bands	Carbonatized domains of regional shear zones	syn-tectonic veins	Variscan	Mombeja

Table 1.- Major styles of mineralisation in the Ossa-Morena Zone
Tabla 1.- Principales tipos de mineralización en la Zona de Ossa Morena

and the Spanish ones. Also, an integrated model of ore evolution in time and space is proposed.

General features of the geology of OMZ will not be repeated here because they are reviewed in detail elsewhere in this volume. In this work, the southern boundary of the OMZ is taken to be the major structural contact with the Pulo de Lobo Terrane and the South Portuguese Zone (Figs 1 and 2). The northern boundary is set to be the Pedroches batholith and its westward extension in Portugal. Mineral deposits located between the Tomar-Córdoba Shear Zone (TCSZ) and the Pedroches batholith are included here because they show lead isotope signatures similar to those of the OMZ and distinct to those the Central-Iberian Zone (Tornos and Chiaradia, 2004).

The metallogeny of the OMZ is a record of the different geological processes related with a complex geodynamic evolution since the Cadomian through the Variscan orogenic cycles (Quesada *et al.*, 1987; Eguíluz *et al.*, 2000, and references therein). In this context the OMZ represents an exceptional place to test how magmatic and hydrothermal systems evolved through time, and to ascertain the effects that orogenic rejuvenation had on old metallic provinces.

The division of the OMZ which is followed here, into ore belts parallel to the trend of the orogenic belt is based on Oliveira (1986) and Locutura *et al.* (1990), with some modifications. The reference list includes the more significant papers published in the last ten years and some key earlier references. For a more complete overview the reader is referred to the earlier general overview of Locutura *et al.* (1990) and the metallogenic synthesis of Thadeu (1965), Schermerhorn (1981), Quesada *et al.* (1987) and IGME (2004).

2. Ore deposits description

The distribution of ore deposits and showings shows a clear pattern consisting of successive WNW- ESE-trending ore belts (Figs 1 and 2), modified after Oliveira (1986) and Locutura *et al.* (1990), and that broadly coincide with the major tectono-metamorphic domains (e.g., Apalategui *et al.*, 1990). The description of the ore deposits is organised into eight ore belts. Only the most significant styles of mineralisation and individual deposits are discussed here. Deposits within each belt are ordered according to known or supposed age.

2.1. North Eastern Belt (NEB)

This metallogenic belt occupies the NE part of the OMZ, between the Pedroches batholith and the Hornachos-Villaharta Fault (Fig. 1). This domain is characterised by a Paleozoic sedimentary sequence with Central Iberian Zone affinities which overlies a Proterozoic sequence typical of the OMZ. Shallow marine Carboniferous synorogenic basins are abundant in the area (Gabaldón *et al.*, 1985). A variety of mineral deposits occur, mainly hydrothermal veins related to the Pedroches batholith.

Volcanic-hosted Zn-Cu-Pb mineralisation (Upper Proterozoic-Lower Cambrian)

The **Puebla de la Reina** (1; Fig.1) deposit represents a typical Cu-Zn-Pb volcanic- hosted massive sulphide orebody (Conde *et al.*, 2001). It was discovered by the IGME in 1981 and consists of several stratiform lenses up to 9 m thick and 150 m long set in syn-Cadomian felsic volcaniclastic sandstones and massive dacites, with minor massive andesites, shales and limestones. The footwall and hanging wall of the deposit show a pervasive hydrothermal alteration which is strongly dependent on the type of protolith. Felsic volcanic rocks are chloritized and sericitized and strongly silicified adjacent to the orebody. Disseminated sulphides are common in the altered zones. Mafic rocks only show irregularly distributed chloritization. The mineralisation consists of pyrite, chalcopyrite, sphalerite and galena, with trace amounts of tetrahedrite and arsenopyrite, besides minor carbonates, quartz and illite. The absence of both a stringer zone and of preserved sedimentary structures, along with some textural evidence suggest that the mineralisation resulted from hydrothermal replacement of the volcanics. Conde *et al.* (2001) argued that the process involved mixing of a deep hot metal-bearing fluid with sub-surficial waters which carried reduced sulphur of marine derivation. Fluids were focused along extensional structures and major permeable/reactive horizons, largely vitriclast-rich and porous volcaniclastic sandstones.

These deposits probably formed in an arc or back-arc setting (Sánchez Carretero *et al.*, 1990) and share many features with those of Kuroko-type, i.e., the bimodal-felsic type of deposits (Barrie and Hannington, 1999).

W(-Bi-Sn) veins related to epizonal leucogranites (Late Variscan)

In the southern margin of the Pedroches batholith there are some bodies of leucogranite that show related tin-tungsten mineralisation (Ovtrach and Tamain, 1977). Cassiterite, wolframite and scheelite with accessory molybdenite and bismuth minerals occur disseminated in quartz-muscovite-topaz greisens. Perigranitic pegmatites are also found, with cassiterite, wolframite, scheelite and REE-bearing minerals.

The **San Nicolás** (2, Fig.1) leucogranitic cupola and the enclosing Devonian shales are host to a vein field consist-

Name	Substance	Age	Size & grade	Situation	Reference
Puebla de la Reina	Cu-Zn-Pb	Pr	0.5 Mt @ 1.6%Cu, 11.0%Zn, 1.2%Pb, 32 g/t Ag	Evaluated	Conde et al. (1999)
San Nicolás	W-(Sn-Bi)	V	0.36 Mt @ 3% WO_3 and 0.25% Bi	Mined (1912-1990)	Gumiel (1988)
Oropesa	Sn	V	18 Mt @ 0.28%Sn	Evaluated	Locutura et al. (1990)
El Soldado	Pb-(Zn-Ag)	V	2 Mt	Mined	Ovtrach & Tamain (1977)
Nava Paredón	Zn-Cu-Pb	V	0.25 Mt @ 2%Cu, 10.9%Zb, 4.7%Pb, 183 g/t Ag	Explored	Tornos et al. (2000)
Alfredo	Fe	C	2.3 Mt @ 54%Fe	Mined (1959-1968)	Dupont (1979)
Mariquita-Sultana	Hg-(Cu-Pb-Ba)	V	0.11 Mt @ 5-7%Hg, 2%Cu	Mined (1631-1971)	Tornos & Locutura (1989)
Calzadilla de los Barros	Cr	Pr	<0.03 Mt, 25.1%Cr	Explored	Arriola et al. (1981)
Llerena	ba	C	0.7 Mt 50%barite	Mined (1970-1990?)	Miras (1991)
Azuaga-Berlanga ore field	Pb-(Ag-Zn)	V		Mined (1848-1950)	
Cerro del Hierro	Fe	post V	50-52%Fe	Mined	
Sierra Albarrana	U- (REE)	V	12 Mt	Mined	González del Tánago (1991)
Las Herrerías	Fe-(Cu)	C	12 Mt @ 44%Fe, 0.28%Cu	Mined	IGME (1994)
La Bóveda	Fe	C	43.9%Fe	Mined (-1982)	Dupont (1979)
Oliva de la Frontera (Mari Juli,Virgen de Gracia)	W-(Bi-Au)	V		Mined (-1970)	Gumiel et al. (1987)
La Bilbaína	Fe-(Cu-Au)	C	7.85 Mt @ 52.5%Fe; 0.11%Cu	Mined (1910-1968)	Dupont (1979)
Monchi	Fe (Co-REE-U)	C-V	66%Fe	Mined (1953-1978)	Arribas (1963)
Colmenar-S.Guillermo-Sta Justa	Fe-(Cu)	C-V	31 Mt @ 35.3%Fe	Mined (1910-1978)	Dupont (1979), Sanabria (2001)
La Berrona	Fe	V?	23.6 Mt@ 24.8%Fe	Evaluated	IGME (1994)
Cabra Alta (Monesterio)	U-(Ni-Co)	post V	0.065 Mt @ 1.5% U_3O_8	Mined (1956-1965)	Arribas (1963)
Sultana	Cu-(Au-Bi)	V	<1 Mt 3.15% Cu, 15 g/t Au	Mined (1903-1919)	Tornos & Velasco (2003)
Cala	Fe-(Cu)	V	50 Mt @ 40%Fe, 0.4%Cu	Working (1901-)	Velasco & Amigó (1981)
Teuler	Fe	V	3 Mt	Mined	Vázquez (1989)
Aguablanca	Ni-(Cu-PGE)	V	31 Mt @ 0.62%Ni, 0.5%Cu	Feasibility	Tornos et al. (2001)
Aroche	wollastonite	V	1.8 Mt @ 22.3%wo	Evaluated	IGME (2002)
Maria Luisa	Cu-Zn-(Pb)	Pr	1.5 Mt @0.8%Cu, 3.0%Zn, 0.5%Pb, 50 g/t Ag	Mined (-1979)	Vazquez (1972)
Fuenteheridos	Zn-Pb-Ag	Pr?	4.0 Mt @ 2.0%Zn, 0.2%Pb, 80 g/t Ag	Evaluated	Fernandez Caliani et al. (1989)
Aracena	Zn-Pb-Ag-ba	Pr?	2-3%Zn, 0.4%Pb, 50 g/t Ag	Explored	Arribas et al. (1990)
Tinoca	Cu-(Pb)	Pr	0.025 Mt @ 2.5-5%Cu	Incipiently mined (1907-1934)	Oliveira (1986); Beck (1997)
Defesa das Mercês	Cu	S?	480 t (total exploited ore)	Mined (1896-1898)	SIORMINP (2002)
S. Martinho-Portalegre	Au	Pr? V?	1-2.5 g/t Au	Explored	Oliveira *et al.* (1995, 2001), Inverno (1997)
Monges	Fe	C?-V	1-2 Mt @ 30-66% Fe	Incipiently mined (1865-1905)	Goinhas & Martins(1986); Carvalho (1976)
Orada	Fe	O?-V	2 Mt @ 40%Fe	Mined (1955-1971)	Carvalho (1971, 1976)
Alvito	Fe	V	0.7 Mt @ 44%Fe	Mined (1884-1929)	Carvalhosa & Zbyszewski (1972), Carvalho (1976)
Enfermarias	Zn,Pb(Ag-Sb-Au)	C?	0.6 Mt @ 2.6% Zn, 0.8%Pb	Prospect	Oliveira & Matos (1992)
Chaminé-Casas Novas-Braços	Au-As-Bi	Pr? V?	4.45 Mt @ 2.81ppm Au	Evaluated	Ribeiro et al. (1993), Inverno (1997), Faria (1997)
Odivelas	Fe-Ti-V	D?	<10%TiO2; < 1% V_2O_5	Prospect	Silva (1945); Jesus (2002)
Castelo Ventoso	Cu-(Ni)	D?	<0.14%Cu, 0.02%Ni	Prospect	Jesus (2002)
Mombeja-Ferr. Alentejo	Cr	D?	<0.1% Cr (in bands)	Prospect	Mateus & Figueiras (1999 a,b)
Mombeja	Cu	V	< 1.5%Cu	Prospect	Mateus *et al.* (1998c)
Caeirinha	Cu(-Ag-Au?)	V?	< 1.5%Cu	Prospect	Relvas (1987)
Ventosa	Sb,Cu(As-Au)	V	< 30% Sb; < 1% Cu	Prospect	Mateus *et al.* (1998c)
Alagada	Fe	V	1.82 Mt @ 27%Fe	Prospect	Gonçalves & Assunção (1970)
Santa Eulalia	Sn-(W-F)	V	0.12 Mt of alluvial/elluvial ore	Prospect	Thadeu & Aires-Barros (1973), Oliveira (1986)
Aparis	Cu	Late-post V	0.02 Mt @ 2.75%Cu	Mined	SFM Internal Reports (1951, 1965)

Table. 2.- Tonnages and grades of the most significant ore deposits C: Cambrian; D: Devonian; O: Ordovician; Pr: Proterozoic; S: Silurian; V: Variscan;. Total tonnage includes estimated extracted + resources. Grades in % except Au and Ag in ppm. py: pyrite; wo: wollastonite

Tabla. 2.- Tonelaje y leyes de los depositos minerales más importantes de Ossa Morena.

ing of several wolframite-bearing quartz veins up to 50 cm thick. Aside from wolframite they contain significant amounts of cassiterite, scheelite, pyrite and chalcopyrite with quartz, muscovite, fluorite and topaz (Gumiel, 1988). Rocks near the vein field underwent pervasive greisenisation and tourmalinisation that was particularly intense in the granite.

Sn replacements (Late Variscan)

A Sn-bearing stratabound replacive mineralisation was recently discovered in **Oropesa** (3; Fig.1), (Locutura *et al*., 1990). It is a rather large orebody (ab. 18 Mt @ 0.28% Sn with 8 Mt @ 0.4% Sn and up to 1% Cu). The mineralisation is surrounded by a large halo of pervasively hydrothermally altered rocks and is close to N-S subvertical faults. Host rocks consist of strongly silicified Late Carboniferous felsdpatic sandstones, slates, conglomerates and limestones that were deposited in a pull-apart basin, a geological setting similar to that of Nava Paredón massive sulphides (see below). Ore minerals, including arsenopyrite, cassiterite and chalcopyrite occur in veins, stockworks or disseminations. No feeder zone has been recognised at Oropesa. It could be however represented by the abundant tin-rich (up to 11% Sn) quartz veins set in the nearby Ordovician basement, here consisting of quartzites and shales. However, the two orebodies are separated by a fault. A hidden granitic cupola was probably the source of metals, fluids and heat, in an scheme similar to that of Renison Bell in Tasmania (Patterson *et al*., 1981).

Cu-Zn-Pb(-Ag) veins in granites (Variscan)

These veins are set within or near the Pedroches batholith, and constitute one of the largest vein ore fields in Europe. As a whole, the vein field displays a normal metal zoning with Cu veins inside the pluton (mostly biotite granites), and Pb-Zn(-Ag) veins near the contact or within the host Lower Carboniferous shales and sandstones (Ovtrach and Tamain, 1977). Pb-Zn veins are very abundant in the **Linares-La Carolina** district, in the eastermost exposures of the batholith and outside the limits of the Ossa-Morena Zone. Some major veins also occur in the southern part of the batholith.

Trends of vein swarms are WNW-ESE, NNE-SSW, NE-SW and E-W, and are probably related to normal and dextral strike slip faults (Asensio *et al*., 1997). The veins consist of quartz, carbonates (ankerite-calcite), chalcopyrite or galena-sphalerite, and always contain pyrite.

The more significant mines on the south of the batholith are **El Soldado-Las Morras** (4; Fig.1) group, set in Carboniferous turbidites (Culm Group) that show contact metamorphism probably due to a hidden granite cupola. The veins are short but thick, with an "echelon" arrangement and NE-SW and NNE-SSW trends. Hydrothermal breccias and cockade structures are common. This group has produced more than 2 Mt ore (Ovtrach and Tamain, 1977).

These veins are apparently related to the granites and metal zoning probably resulted from thermal gradients set up during the cooling of the batholith. Fluid inclusion data (Asensio *et al*., 1997) and geochemical considerations suggest that hydrothermal fluids probably were meteoric and that metals were scavenged from the regional sedimentary rocks and the granites. Fluid flow was enhanced by regional fracturing in late Variscan times. These veins are hardly distinguished from the barite-fluorite (-Zn-Pb-Ag) veins of the nearby Arronches-Córdoba Belt which could be as young as Early Alpine (see below).

Bi(-Co-Ni) veins and shear zones (Variscan)

South of the Pedroches batholith some poorly known quartz-carbonate veins exist that are hosted by Carboniferous turbidites near to leucogranite bodies. The veins trend is N20-45ºE, and they are 300-1200 m long and 4-30 cm thick. Ore zones within the veins are lenses about 4 m thick. The ore consists of native bismuth, bismuthinite, calcite and quartz, as well as minerals belonging to the Cu-Pb-Sn-W-Ni-Co-As-Ag system (Vázquez, 1989).

Uranium vein mineralisation (Late Variscan-Alpine)

Uranium-bearing quartz veins are found in the easternmost part of this belt, within or near the Pedroches batholith. The veins show a polyphase filling with quartz, chalcopyrite and pyrite as primary minerals, and a superimposed low-T alteration (chlorite-sericite-quartz). Most of the uranium mineralisation (pitchblende, coffinite and abundant oxidised species) was laid down during a late oxidising stage (Arribas, 1964) of unknown age. The uranium mineralisation formed by reduction of meteoric fluids at depth (down to 200 m). Pitchblende intergrowths with sulphides address to a protracted hydrothermal activity with shifts in the redox boundary.

2.2 The Arronches-Córdoba Belt (ACB)

This belt includes the Tomar-Córdoba Shear Zone (Fig.1) (e.g., Apalategui *et al*., 1990) as well as the neighbouring regions, north and south of it. In the Portuguese part of the OMZ this zone is equivalent to the Arronches-Campo Maior (Au, Cu, Pb, (Ag)) belt of Oliveira (1986). The major structural feature of this belt is a first order shear zone, believed to be a Cadomian cryptic suture by some authors (Abalos *et al*., 1991; Quesada *et al*., 1991), that underwent protracted activity during the Paleozoic. The Tomar-Córdoba shear zone exerted a strong control on sedimentation, magmatic activity, metamorphism and structural evolution of the area.

Volcanic-hosted massive sulphides (Proterozoic)

NW of Campo Maior, the **Tinoca** and **Azeiteiros** (2; Fig. 2) volcanic-hosted massive sulphide Cu mineralisation was mined since Roman times. They are hosted by Proterozoic rocks -a gneiss-migmatitic complex-, within the Tomar-Córdoba Shear Zone. At Tinoca, a stratiform mineralisation 1000 m long and 55 m thick, is set in amphibole- and/or biotite-bearing felsic migmatitic gneisses. Mineralisation consists of (semi-)massive magnetite with interstitial chalcopyrite and pyrite. Moreover, disseminations or irregular veins of chalcopyrite, pyrite and magnetite are set in a granoblastic quartz-rich rock. Felsic metavolcanic rocks (felsic gneiss) are interpreted as the mineralisation footwall. Both mineral assemblages at Tinoca are set in rocks that underwent silicification, chloritization and muscovitization, and also contain accessory sphalerite, argentiferous galena and gold (commonly above 0.5 g/t Au).

The Azeiteiros semi-massive and disseminated chalcopyrite and pyrite mineralisation (2.2% Cu) occurs in a 20-40 m thick, N110-120ºE-trending shear zone and is hosted in magnetite-bearing meta-rhyolites adjacent to amphibolites (Oliveira, 1986; Beck, 1997; SIORMINP, 2002).

Sedimentary-exhalative Zn-Pb mineralisation in the Azuaga Formation (Proterozoic?)

Some intriguing Zn-Pb stratiform mineralisation (**Retín** and some nearby prospects) occurs in the allegedly Late-Proterozoic syn-orogenic (Cadomian) Azuaga Formation. This formation consists of several thousand metres of a monotonous low-grade metamorphosed flysch sequence (Quesada *et al.*, 1987). The mineralisation consists of small lenses of massive sphalerite with minor galena and traces of chalcopyrite, pyrite and pyrrhotite with some barite, hosted by weakly chloritized schists of the flysch sequence. Discontinuous beds of volcano-sedimentary calc-alkaline rocks as well as of garnet-bearing Mn-rich quartzites - probable exhalites- are also found within the flysch sequence (Urbano, 2001, pers. com.). Veinlets and disseminations of sphalerite and galena and, sometimes, chalcopyrite, are common in these rocks.

High Zn/Cu ratios, the relationship to fine-grained siliciclastic sediments and the absence of a stringer zone all suggest that this type of mineralisation could be sedimentary-exhalative (Locutura *et al.*, 1990). Lead isotope ratios suggest sources with high U/Pb ratios, typical of terranes with a long-lived upper crustal evolution; model ages are Upper Neoproterozoic (Tornos and Chiaradia, 2004).

Orogenic gold mineralisation (Proterozoic? Variscan ?)

Orogenic gold mineralisation occurs in the Portalegre area, in **S. Martinho** (4; Fig.2) and **Algueireiras-Nave de Grou-Mosteiros** (A-N-M) (72; Fig. 2), south and north of the Tomar-Cordoba Shear Zone, respectively. Both styles of mineralisation are found near small shear zones within the pre-orogenic (Cadomian) Serie Negra sequence and underwent amphibolite and greenschist facies regional metamorphism, respectively. Gold mineralisation occurs typically in the transition metasedimentary/metavolcanic rocks, namely quartz-biotite slates and schists/amphibolites (and amphibolite gneisses) or felsic metavolcanic rocks. Small felsic-intermediate porphyritic intrusions and felsic-intermediate metavolcaniclastic rocks are commonly present close to the gold mineralisation. Hydrothermal alteration consists of silicification, chloritization, sericitization and carbonatization. The last is pervasive in the case of A-N-M where Fe-dolomite, accompanied by disseminated fuchsite, alters felsic metavolcaniclastic rocks. The mineralisation is found as disseminations, quartz veins, veinlets and stockworks, and can also be stratabound. It consists primarily of pyrite and pyrrhotite, with variable amounts of arsenopyrite; other accessory minerals include löllingite, chalcopyrite, gold, ilmenite, realgar, barite and tourmaline. Grade is 1-2.5 g/t Au at S. Martinho and not above 1 g/t Au at A-N-M (Inverno *et al.*, 1995; Inverno, 1997).

At **S. Martinho** (4), two gold generations were recognised; the first is related to early quartz I veinlets parallel to foliation containing arsenopyrite, pyrite, chalcopyrite and gold I. This low-Au mineralisation was deposited from metamorphic fluids, either aqueous-carbonic (H_2O-CO_2-CH_4), low saline (avg. 10 wt% NaCl equiv.) with Th of 245-521ºC fluids or lower temperature (Th = 112-162 ºC), H_2O-NaCl-Ca(Mg)Cl_2 fluids, with 1-18 wt% NaCl equiv. salinity. Quartz II discordant veinlets contain a later generation of arsenopyrite, pyrite and chalcopyrite with trace proportions of löllingite, pyrrhotite and gold II. This main gold mineralisation is interpreted as related with the circulation of magmatic, late stage hypersaline (32-62 wt% NaCl equiv.) H_2O-NaCl (also Mg/K/Fe chlorides, $CaCO_3$) fluids, homogenising between 270 and over 550 ºC (Oliveira, 2001; Oliveira *et al*, 2001a and 2001b).

Volcanic-associated Zn-Cu-Pb(-Au) and iron oxide mineralisation (Lower Carboniferous)

The Carboniferous sedimentary rocks of this belt are restricted to WNW-ESE-trending pull-apart basins. They constitute a siliciclastic-carbonate sequence deposited in a shallow marine to continental environment (Gabaldón *et al.*, 1985). Bimodal, high K calc-alkaline volcanic rocks

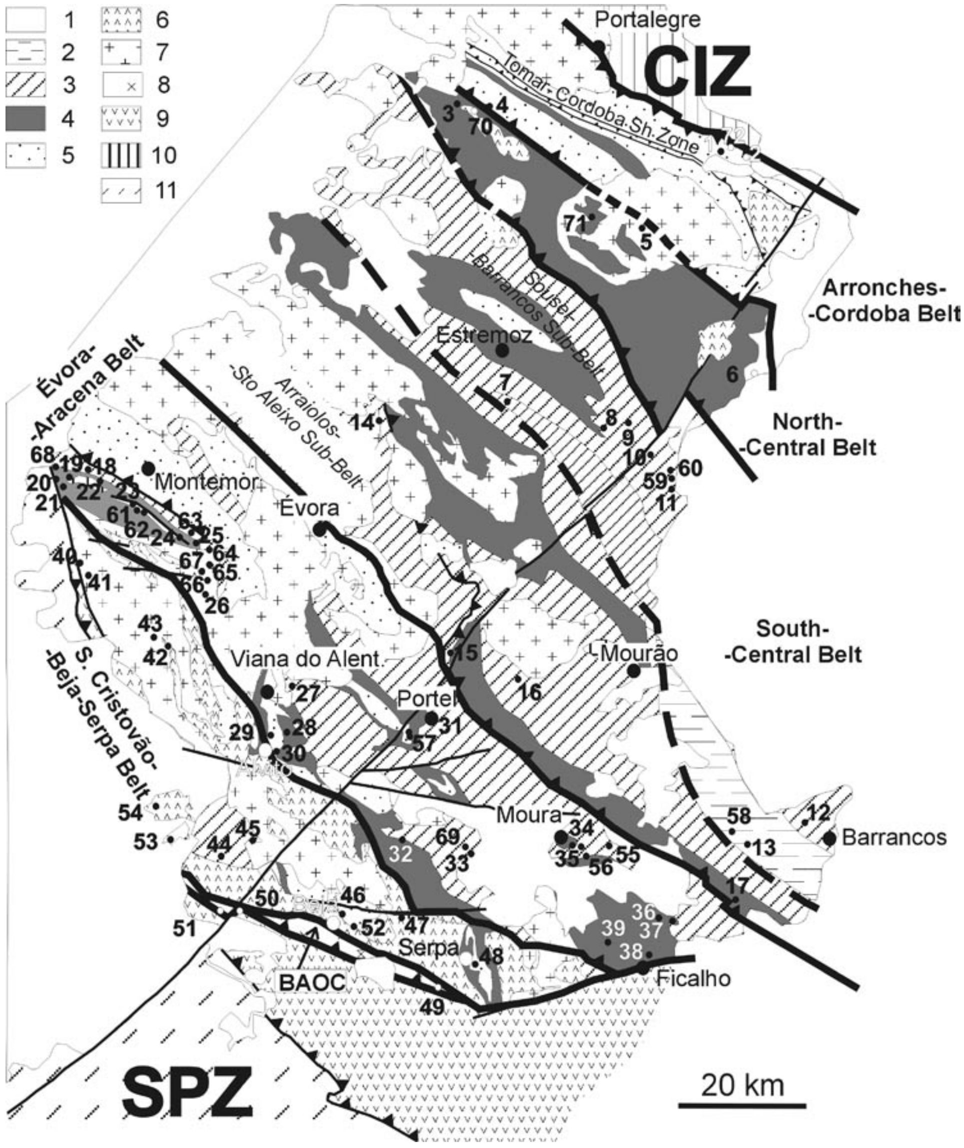

Fig. 2.- Synthetic geologic map of the Ossa-Morena Zone in Portugal showing the metallogenic belts and the location of the major deposits and districts described in text. Adapted from Geological Map of Portugal, scale 1:500000, 1992 – J.T. Oliveira and E. Pereira, compilers. Geology: 1. Cenozoic sedimentary cover. 2. Metasedimentary sequences of Late Devonian age. 3. Metasedimentary and metavolcanic sequences of Ordovician-Silurian age. 4. Metasedimentary (including metadolostones) and metavolcanic sequences of Cambrian age. 5.Metasedimentary and metavolcanic sequences of Proterozoic age. 6. Gabbros (and diorites) and ultramafic rocks (Lower Paleozoic to Variscan). 7. Undifferentiated Variscan and Late-Variscan granitoid rocks. Oceanic exotic Terranes: 8. Beja-Acebuches Ophiolite Complex (BAOC). 9. Pulo do Lobo Group (metasedimentary and metavolcanic rocks). 10. Central-Iberian Zone metasedimentary rocks. 11. South Portuguese Zone metasedimentary and metavolcanic rocks. Deposits and occurrences: *Arronches-Cordoba belt*: 1 - Balôco (Pb); 2 - Tinoca/Azeiteiros (Cu(Pb)); 4 - S. Martinho (Au(As)); 72 – Algueireiras-Nave de Grou-Mosteiros (Au). *North Central belt*: 3 - Alter do Chão (Zn, Cu, Ba);; 5 – Sta. Eulália (Sn, W); 6 – Alagada (Fe); 70 – Alter do Chão-Este (Fe, V); 71 – Torre das Figueiras (Monforte) (Zn, Pb). *South Central belt: a) Sousel-Barrancos sub-belt*: 7 – Mostardeira (Cu); 8 – Miguel Vacas (Cu); 9 – Zambujeira (Cu); 10 – Bugalho (Cu); 11 – Mociços (Cu); 12 – Defesa das Mercês (Cu); 13 – Aparis (Cu); 58 – Botefa (Cu); 59 – Urmos (Cu); 60 – Minancos (Cu); *b) Arraiolos-Sto. Aleixo sub-belt*: 14 – Azaruja (Cu); 15 – Monte do Trigo (Cu); 16 – Reguengos (Cu); 17 – Sto. Aleixo (Cu). *Évora-Aracena belt*: 18 - Courela do Conde (Cu); 19 - Safira (Cu, As, Au); 20 – Courelinha (Cu); 21 – Palmas (Sb, Au); 22 - Gouveia (As, Cu, Au); 23 - Monges (Fe, Py); 24 – Nogueirinha (Fe, Py); 25 – Chaminé (Au, As (Bi)); 26 – Alcalainha (Cu); 27 – Sobral/Ganhoteira (Cu); 28 – Água de Peixes (Pb, Zn); 29 – Alvito (Fe); 30 – Alvito (Cu); 31 – Portel-Algares (Zn, Cu, Pb); 32 – Vale de Pães (Fe); 33 – Orada (Fe); 34 – Enfermarias (Zn, Cu, Pb); 35 – Sto. André (Fe); 36 – Preguiça (Pb, Zn); 37 – Vila Ruiva (Zn, Pb); 38 – Ficalho (Pb, Zn); 39 – Louzeiras (Pb, Sb, Ag); 55 – Rui Gomes (Cu); 56 – Carrasca (Fe, Zn (Pb)); 57 – Portel-Balsa (Zn, Pb (Ag)); 61 – Monfurado (Au); 62 – Banhos (Au (As)); 63 – Casas Novas (Au, As (Bi)); 64 - Ligeiro (Au); 65 – Caras (Au, As); 66 – Braços (Au, As); 67 – Covas (Au, As); 68 – Caeira (Au (Cu)); 69 – Azenhas (Fe); *S. Cristóvão-Beja-Serpa belt*: 40 – Corte Pereiro (Cu, Pb, Zn); 41 – Caeirinha (Cu, Pb, Zn); 42 – Alcácovas (Entre Matas) (Cu); 43 – Alcácovas (V. Nogueira) (Cu); 44 – Asseiceiras (Cu); 45 – Peroguarda (Cu, Fe); 46 – Corujeiras (Fe); 47 – Baleizão (Cu); 48 – Serpa (Cu); 52 – Ventosa (Sb, Cu (As, Au)); 53 – Castelo Ventoso (Cu (Ni)); 54 – Odivelas (Fe, Ti, V); *BAOC*: 49 – Palmeira (Ni, Cu (Co)); 50 – Mombeja-Ferr. Alentejo (Cr); 51 – Mombeja (Cu).

→

(Sánchez Carretero *et al*., 1990) are scarce and confined to some magmatic alignments within the Benajarafe-Matachel basin. Despite the high metallogenic potential of this type of geological setting, ore deposits are rare in this basin and equivalent ones in the OMZ. The major deposit is **Nava Paredón** (5; Fig.1) a polymetallic volcanic-hosted massive sulphide deposit that was mined by the Romans and rediscovered by the IGME in the late 1970′ (Baeza *et al*., 1981). Recent work (Tornos *et al*., 2000) has shown that the mineralisation occurs at a well-defined stratigraphic horizon, between pervasively devitrified massive rhyolites and the overlying immature-derived polymictic mass flows. The age of the lithostratigraphical sequence is Upper Tournaisian to Lower Visean (Gabaldón *et al*., 1985; Sánchez Carretero *et al*., 1990). Rhyolites are thought to form subaerial to shallow marine domes whilst the overlying volcaniclastic sedimentary rocks probably formed in a fault scarp during syn-sedimentary faulting and deepening of the basin.

Rhyolites show a pervasive hydrothermal alteration consisting of texturally destructive silicification, sericitization and K-alteration synchronous to devitrification; hydrothermal dolomite can be locally important. These altered rocks contain abundant disseminated sulphides and are enriched in Cu and Au but a clear stringer system has not been found. The lowermost volcaniclastic rocks underwent equivalent alteration as the rhyolites. Upwards in the sequence, chloritization, silicification and K-alteration become more irregular.

The massive sulphides occur in five, 1 to 4 m thick lenses, with grades of about 30-35% Zn+Pb, 1.6% Cu, 600 g/t Ag and 1.9 g/t Au, that are enclosed in highly altered rhyolites. The mineralisation is dominantly sphalerite and galena, with minor amounts of pyrite, chalcopyrite, Ag-bearing tetrahedrite, pyrrhotite, bornite, bismuthinite, boulangerite and native gold. A semi-massive to disseminated mineralisation occurs in the volcaniclastic unit above. Here, sulphides, in the more altered zones, selectively replaced some of the silicate fragments or make up the cement of conglomerates and sandstones. The grades here are about 9% Zn+Pb and 2% Cu.

Sulphur isotope values ($\delta^{34}S$) of sulphides range from -0.2 to 6.5‰. Disseminated pyrite in the altered footwall has close to 0‰ values, while overlying massive sulphides have values of 1.3 to 6.5‰. This suggests that sulphur in the stockwork was mainly of igneous origin, probably leached out from the host rhyolites. Massive sulphides sulphur shows however a significant sedimentary component, and was probably derived from the biogenic reduction of seawater in an open system. Lead isotope signature of sulphides ($^{206}Pb/^{204}Pb = 17.93\text{-}17.95$; $^{207}Pb/^{204}Pb = 15.54\text{-}15.57$; $^{208}Pb/^{204}Pb = 38.10\text{-}38.18$; Tornos and Chiaradia, 2004) suggests an evolution close to the average growth curve and well below that of the radiogenic massive sulphides of the Iberian Pyrite Belt (Marcoux, 1998).

Geologic and geochemical features suggest that massive sulphides formed underneath the seafloor, both replacing reactive glassy rhyolites and cementing poorly consolidated sediments, at depths of more than 100 m, probably near syn-sedimentary faults (Tornos *et al*., 2000). Deep fluids, carrying metals probably leached out from the rhyolites, but with low sulphur contents, were focused into the fault zones. Mixing of these upwelling fluids with sulphur-bearing strata-contained waters confined to the major lithologic contacts, led to sulphide deposition.

In the same area as Nava Paredon, there also exist some

Fig. 2.- Mapa geológico sintético de la Zona Ossa Morena en Portugal, mostrando los cinturones metalogénicos y la situación de los principales distritos y depósitos minerales descritos en el texto. Adaptado del Mapa Geológico de Portugal, escala 1:500.000, 1992 – compilado por J.T. Oliveira y E. Pereira. Geología: 1. Cobertera sedimentaria cenozoica. 2. Secuencia metasedimentaria del Devónico Superior. 3. Secuencias metasedimentaria y metavolcánica del Ordovícico-Silúrico. 4. Secuencias metasedimentaria (incluyendo metadolomías) y metavolcánica del Cámbrico. 5. Secuencias metasedimentaria y metavolcánica del Proterozoico. 6. Gabros (y dioritas) y rocas ultramáficas (Paleozoico Inferior a Varíscico). 7. Rocas graníticas indeferenciadas de edad Varíscica y tardi-Varíscica. Terrenos oceánicos exóticos: 8. Complejo ofiolítico Beja-Acebuches (BAOC). 9. Grupo Pulo do Lobo (rocas metasedimentarias y metavolcánicas). 10. Zona Centro Ibérica, rocas metasedimentarias. 11. Zona Sudportuguesa, rocas metasedimentarias y metavolcánicas. Depósitos e indicios minerales: *Arronches-Cordoba belt*: 1 - Balôco (Pb); 2 - Tinoca/Azeiteiros (Cu(Pb)); 4 - S. Martinho (Au(As)); 72 – Algueireiras-Nave de Grou-Mosteiros (Au). *North Central belt*: 3 - Alter do Chão (Zn, Cu, Ba);; 5 – Sta. Eulália (Sn, W); 6 – Alagada (Fe); 70 – Alter do Chão-Este (Fe, V); 71 – Torre das Figueiras (Monforte) (Zn, Pb). *South Central belt: **a)** Sousel-Barrancos sub-belt*: 7 – Mostardeira (Cu); 8 – Miguel Vacas (Cu); 9 – Zambujeira (Cu); 10 – Bugalho (Cu); 11 – Moços (Cu); 12 – Defesa das Mercês (Cu); 13 – Aparis (Cu); 58 – Botefa (Cu); 59 – Urmos (Cu); 60 – Minancos (Cu); ***b)** Arraiolos-Sto. Aleixo sub-belt*: 14 – Azaruja (Cu); 15 – Monte do Trigo (Cu); 16 – Reguengos (Cu); 17 – Sto. Aleixo (Cu). *Évora-Aracena belt*: 18 - Courela do Conde (Cu); 19 - Safira (Cu, As, Au); 20 – Courelinha (Cu); 21 – Palmas (Sb, Au); 22 - Gouveia (As, Cu, Au); 23 - Monges (Fe, Py); 24 – Nogueirinha (Fe, Py); 25 – Chaminé (Au, As (Bi)); 26 – Alcalainha (Cu); 27 – Sobral/Ganhoteira (Cu); 28 – Água de Peixes (Pb, Zn); 29 – Alvito (Fe); 30 – Alvito (Cu); 31 – Portel-Algares (Zn, Cu, Pb); 32 – Vale de Pães (Fe); 33 – Orada (Fe); 34 – Enfermarias (Zn, Cu, Pb); 35 – Sto. André (Fe); 36 – Preguiça (Pb, Zn); 37 – Vila Ruiva (Zn, Pb); 38 – Ficalho (Pb, Zn); 39 – Louzeiras (Pb, Sb, Ag); 55 – Rui Gomes (Cu); 56 – Carrasca (Fe, Zn (Pb)); 57 – Portel-Balsa (Zn, Pb (Ag)); 61 – Monfurado (Au); 62 – Banhos (Au (As)); 63 – Casas Novas (Au, As (Bi)); 64 - Ligeiro (Au); 65 – Caras (Au, As); 66 – Braços (Au, As); 67 – Covas (Au, As); 68 – Caeira (Au (Cu)); 69 – Azenhas (Fe); *S. Cristóvão-Beja-Serpa belt*: 40 – Corte Pereiro (Cu, Pb, Zn); 41 – Caeirinha (Cu, Pb, Zn); 42 – Alcácovas (Entre Matas) (Cu); 43 – Alcácovas (V. Nogueira) (Cu); 44 – Asseiceiras (Cu); 45 – Peroguarda (Cu, Fe); 46 – Corujeiras (Fe); 47 – Baleizão (Cu); 48 – Serpa (Cu); 52 – Ventosa (Sb, Cu (As, Au)); 53 – Castelo Ventoso (Cu (Ni)); 54 – Odivelas (Fe, Ti, V); *BAOC*: 49 – Palmeira (Ni, Cu (Co)); 50 – Mombeja-Ferr. Alentejo (Cr); 51 – Mombeja (Cu).

semi-massive lenses of pyrite with stockworks and gossan outcrops (Las Erillas).

Minor stratabound iron oxide mineralisation also occurs in the rhyolitic domes that host the massive sulphide orebodies (Baeza *et al*., 1978). It consists of some metre-thick lenses of massive hematite which overlie pervasively chloritized rhyolites. This mineralisation is interpreted as contemporaneous to the massive sulphides, but formed through exhalative processes in an oxidant basin. Nearby magnetite and hematite-rich sandstones probably represent the dismantling products of the iron oxide mineralisation.

Barite-fluorite(-Zn-Pb-Ag) veins (Late Variscan?)

These veins are of the same age and genesis as those of the Pedroches region (North Eastern Belt) referred to above, but are characterised by higher fluorite and/or barite contents. They can be grouped into several vein ore districts, the most significant being **Los-Arenales-Cerro Muriano** (NW Córdoba; 6, Fig.1), the syn-Cadomian Ahillones pluton and nearby host rocks and those in the Variscan Villaviciosa-Ojuelos-La Coronada plutonic-volcanic complex. The first ore district consists of several veins located east of Los Arenales intrusion, in an area of about 8x2 km^2; the mineralisation here is related to large alpine faults with NE-SW, N-S and WNW-ESE trends, that probably reactivated earlier Variscan structures. The mineral assemblage consists of fluorite with trace amounts of pyrite, pyrrhotite, chalcopyrite, tetrahedrite, sphalerite and galena, disseminated or crustiform in quartz-chalcedony, fluorite and calcite. The N-S veins show sulphides concentrations, that are not found in the other vein systems (Delgado *et al*., 1978). The largest veins (up to 2.3 km long) are Perseverancia and Chaparral, on a WNW-ESE trend. Locally, the fault zone can be 30-120 m thick and hosts several fluorite shots up to 3.5 m-thick (Delgado *et al*., 1978). Furthermore, there exist some barite-rich veins with minor sphalerite, pyrite and galena. Aside to extensive silicification, especially when the host rock is highly deformed, hydrothermal alteration also produced sericitization. In the Pedroches batholith region, barite-bearing veins akin to those described here apparently formed in the shallowest part of vertically zoned vein system with Cu- and Zn-Pb-rich zones at depth.

Fluorite-barite deposition took probably place by fluid mixing in open fractures of deep hot reduced fluids that had interacted with basement rocks, and oxidised brines of surficial origin. Modelling suggests that mixing of such fluids can produce a vertical zoning of hydrothermal minerals with quartz in the bottom, fluorite in the intermediate zone and barite in the uppermost part of the system (Tornos *et al*., 1991). Sulphides would precipitate at any depth, but particularly in the quartz zone. Veins of this type can form by perigranitic hydrothermal activity, but can also be the consequence of regional hydrothermal events related to faulting, and independent of magmatism. In fact, in the Iberian Peninsula, veins of this type have been dated as either Late Variscan, Mesozoic (Spanish Central System - Galindo *et al*., 1994; Pyrenees - Johnson *et al*., 1996) or even Cenozoic (Roig and Canals, 1994). Absence of well constrained ages for the Arronches-Córdoba Belt veins precludes a correct interpretation.

Fluid inclusion data obtained by Asensio *et al*. (1997), show that fluids involved in these systems were rather hot (145-380ºC) and low saline (1-8 wt % NaCl equiv.). Few fluid inclusions with low homogenisation temperatures but high salinities (up to 33 wt % NaCl equiv.) are consistent with mineral deposition by fluid mixing.

Zn(-Pb-Cu) calcic skarns (Late Variscan)

Near **Los Arenales-Cerro Muriano** (6; Fig.1), Late Variscan subvolcanic leucogranite and related porphyritic dykes, there exists some base metal mineralisation (Zn-(Pb-Cu)). It is found in skarn-type replacements in interbedded limestones, dolostones, calc-silicate hornfels and schists of Lower Cambrian age. The prograde skarn minerals are either calcic (idocrase-grossular) or magnesian (diopside-humite) depending on protolith. They were subsequently replaced by amphibole, epidote, calcite, magnetite, fluorite, sphalerite, chalcopyrite and galena with traces of many other sulphides and sulphosalts (Delgado *et al*., 1978). These skarns share many features with distal Zn-rich type of skarns (Einaudi *et al*., 1981). The granite nearby was epizonal and water- and volatile-rich, as suggested by miarolitic cavities and the presence of abundant tourmaline and fluorite.

Pb-Zn(-Ag) quartz veins (Late Variscan)

As referred to above, the **Azuaga-Berlanga** ore field (13; Fig.1), was one of the leading lead producers of the world, standing as the most significant historical mineralisation in OMZ. Here, there literally exist hundreds of small mining workings in short and thick quartz-carbonate lensoidal veins within a NW-SE-trending corridor, roughly coincident with the Tomar-Córdoba Shear Zone. The veins developed in the more competent rocks of the shear zone, such as ultramylonites, gneisses, quartzites and amphibolites, all of Proterozoic age (e.g., Abalos *et al*., 1991 and references therein). However they are discordant to the shear zone trend suggesting that they formed during brittle reactivation of the latter in late Variscan times (Upper Carboniferous). The mineralisation occurs in highly discontinuous veins, about 40-500 m long and 0.5-3 m thick, that trend N20-45ºE, N70-80ºE and N120-130ºE. Host rocks to the vein system show a restricted but pervasive K-feldspar-type and sericite-quartz-type alteration. Vein mineral assemblage consists of galena and sphalerite with minor amounts of pyrite, chalcopyrite, Ag-bearing tetrahedrite, linneite, pyrargirite, pyrrhotite and some sulphosalts in a gangue of quartz, calcite and some barite and fluorite that can be locally abundant. Veins exhibit rather monotonous textures typical of the epithermal environment, including vuggy crustiform infillings and hydrothermal breccias with fragments of hydrothermally altered host rocks supported by quartz and carbonates with cockade texture. Chacón *et al*. (1981) briefly studied these orebodies. Fluid inclusions are low salinity and homogenise at temperatures below 200ºC. All the evidence suggests that hydrothermal flow was episodic and that was accompanied by generalised boiling in a shallow environment. These veins share structural and mineralogical features with the adularia-sericite type of epithermal systems. Nevertheless, there is no metal zoning and no relationship whatsoever with igneous rocks could be established. Only at **Santa Marta** (7; Fig. 1), where a small Late Variscan granodioritic intrusion exists, nearby veins might be plutonic related.

Lead isotope data (Tornos and Chiaradia, 2004) show that the metals were probably scavenged from rocks with an average Ossa Morena composition. However, veins near the Santa Marta intrusion show a pristine less radiogenic signature, suggesting that more juvenile lead was involved in this case. Lead isotope signatures show depletion in ^{207}Pb/^{206}Pb relative to equivalent mineralisation types of the Iberian Variscan Belt, and plot near the field of Variscan feldspars; this suggests that the age of mineralisation is pre-Mesozoic and probably Late Carboniferous-Early Permian, an approximation consistent with the age of the late movements along the Tomar-Córdoba Shear Zone.

In Portugal the galena-bearing quartz veins of Balõco might be equivalent to this type of mineralisation.

2.3 The North Central Belt (NCB)

This large belt includes the region comprised between the Arronches-Córdoba Belt and the northern flank of the Olivenza-Monesterio antiform. This region includes the Albarrana Domain and the North Central Belt of the Apalategui *et al*. (1990) subdivision of the OMZ. In Portugal it is equivalent to the Alter do Chão-Elvas belt of Oliveira (1986).

Ophiolite-related chromitites (Proterozoic)

Small (<10 km^2) bodies of serpentinites are found as small tectonic slices within the Malcocinado synorogenic formation near **Calzadilla de los Barros** (Badajoz; 11; Fig. 1). These rocks are interpreted as corresponding to olistholiths of alpine-type ophiolites within large andesitic volcaniclastic mass flows (Arriola *et al*., 1981; IGME, 1985). They consist of strongly retrograded harzburgites consisting of serpentine and talc with minor chlorite, magnetite and carbonates. They preserve some remnants of primary pyroxene, amphibole and olivine. Chromitites occur as decametric sized monotonous, semi-massive lenses less than 1.5 m thick, made of coarse-grained (>2 mm) Cr-spinel with cumulate textures. The two known showings have been systematically explored with negative results. Only one small lens was found, with 25.1% Cr and 0.4% Ni. Maximum values of Au, Pd and Pt are 1.7 g/t, 0.03 g/t and 0.01 g/t, respectively. Geological evidence suggests that they are Alpine-type chromitites (Arriola *et al*., 1981).

Sediment-hosted copper (Upper Proterozoic)

Some scarce copper mineralisation, including chalcopyrite, pyrite and bornite, is found as disseminations or concentrated in organic matter-rich layers within the lenses of black quartzite of the Serie Negra (Neoproterozoic). These rocks also show high geochemical background values of lead and zinc and are perhaps enriched in gold. These ore showings are anecdotal and probably represent minor metal concentrations in anoxic sediments. They have been traditionally interpreted as the source of gold and other metals for the vein-like deposits found nearby (Canales and Matas, 1992).

Porphyry copper mineralisation (Upper Proterozoic)

Small subvolcanic intermediate intrusions, mostly quartz-monzonites, interpreted as deep equivalents of the Cadomian synorogenic volcanic complex, host small copper occurrences (e.g., Ahillones-Los Parrados, El Mosquil). Chalcopyrite, pyrite and minor magnetite occur as disseminations, in stockworks or large quartz lodes within the intrusions. The host granitoids have a pervasive hydrothermal alteration, with replacement of the primary mineral assemblage by quartz, sericite, chlorite and epidote, besides minor carbonates and barite. This mineralisation has been interpreted as broadly equivalent to porphyry copper deposits (Locutura *et al*., 1990), and formed in the same volcanic arc as the afore-mentioned massive sulphide deposits. The hydrothermally altered host rocks could be equivalent to the propylitized rocks found in porphyry-like systems, but no more intense alteration products have been described.

Stratabound sedex barite (Upper Proterozoic)

Stratabound barite mineralisation occurs near **Llerena** (12; Fig.1) in the Spanish part of the NCB. It is hosted by the syn-orogenic (Cadomian) Neoproterozoic-Lower Cambrian Loma del Aire Fm., broadly equivalent to the Malcocinado Fm. It consists here of fine-grained sandstones, siltites, shales and limestones overlain by Cambrian limestones. This mineralisation probably represents the largest concentration of barite in Spain and was extensively studied by Poole *et al*. (1990), Miras (1991) and Hernández and Miras (1993). The mineralisation occurs as: a) stratabound massive to laminated barite, 1-3 m thick and some kilometres long, including scarce galena, chalcopyrite, cinnabar and pyrite as well as trace amounts of quartz, illite and ankerite-siderite; it is locally associated with cherts; b) equivalent horizons in limestones and shales, 1-2 m thick and less laterally extensive; the host carbonate rocks have significant amounts of barite as disseminations and nodules; c) karstic infillings of unknown age in the limestones, with iron oxides, illite, quartz and some pyrite and chalcopyrite; and d) NE-SW to ENE-WSW-trending near-vertical veins of massive barite crosscutting all previous rock types as well as Cadomian and Variscan granitoids; in these veins barite coexists with quartz, fluorite, carbonate and some sulphides. Barite-rich veins are typically located near both the Cadomian Ahillones granitoid and many other metamorphic and plutonic rocks of the area.

The relation to limestones and fine-grained volcaniclastic sedimentary rocks suggests that the stratabound barite deposits formed in low temperature (<150ºC), oxidised, iron- and manganese-poor brine pools at shallow to intermediate depths, due to the up-flow of hot deep brines, that mixed with seawater in a rather quiescent setting, as suggested by the presence of shales, well bedded barite and stratiform cherts.

Cu-Zn-Pb mineralisation related to volcanic rocks (Early Cambrian?)

Small Cu, Pb and Zn occurrences (e.g., **Alter do Chão;** 3, Fig. 2) associated with intermediate to felsic Early Cambrian metavolcanic rocks (incl. breccias), are also known from this belt (Oliveira, 1986).

U and REE in syn-metamorphic pegmatites (Variscan)

Complex pegmatites of granitic composition with uranium and rare earth mineralisation are found in the **Sierra Albarrana -Villaviciosa de Córdoba** area (Fig.1), where they form large pegmatite fields. Pegmatites which are for the most part of the muscovite type (muscovite, quartz, feldspar) (Ortega *et al*., 1992) form irregular to massive internally zoned veins some hundred metres long and less than 3 m thick, parallel to the Variscan structures. These veins show complex relationship to the host rocks, with the pegmatite accessory mineralogy controlled by the metamorphic grade; those located within the internal, high grade metamorphic core of the Sierra Albarrana Domain have a complex mineral assemblage including tourmaline, uraninite, brannerite, beryl, garnet, sulphides, xenotime, Nb-tantalite, allanite, complex phosphates, monazite and zircon (González del Tánago, 1991; González del Tánago *et al*., 1991; Ortega *et al*., 1992). These pegmatites have been interpreted as para-autochthonous pegmatites formed by partial melting of the host rocks (e.g., Ortega *et al*., 1992).

W(-Sn) greisen and vein-like mineralisation (Variscan)

The subvolcanic, Late Variscan **Santa Eulália** (5; Fig. 2) granitic massif (309-290 Ma), hosts, mostly within the non-porphyritic inner facies of the massif central monzonite, a subvertical N40º to 50ºW-trending swarm of quartz veins with greisenised (including fluorite) selvages. Quartz veins, up to 15 cm thick, exhibit cassiterite, wolframite, scheelite, base metal sulphides, arsenopyrite, pyrite, muscovite, fluorite and apatite. Cassiterite, with minor sulphides, predominates in the SE whilst wolframite (ferberite) and sulphides are more abundant in the NW. Moreover, small greisens formed at the intersection of N40º to 50ºW and NE-SW-trending fractures contain exclusively cassiterite and scheelite as ore minerals. Alluvial and elluvial deposits containing cassiterite and ilmenite, and subsidiary wolframite and rare earth minerals were mined in the same area (Thadeu and Aires-Barros, 1973; Gonçalves *et al*., 1975; Inverno, 1975; Oliveira, 1986).

Magmatic-related magnetite mineralisation (Variscan)

A distinct iron mineralisation occurs immediately east of Alter do Chão (70; Fig. 2), in the NW body of the mafic-ultramafic Alter do Chão (Lower Paleozoic?) massif, in the form of a 1400 m-long, gabbro-hosted, semi-massive magnetite layer, with 0.5% V_2O_5 (Beck, 1996), genetically analogous to the magmatic vanadiniferous magnetite deposits of the Bushveld Complex.

Iron skarns (Variscan?)

In Portugal, the Early Cambrian carbonates host the **Alagada** (Porto Xico) iron skarn (27-40% Fe) in its contact with the Elvas Variscan(?) granite, near the north-western tip of the OMB (6; Fig 2). This deposit, 400 m long and 2.7-9.5 m thick, is covered by 10 m of Quaternary alluvium. It consists dominantly of magnetite lenses parallel to bedding, with pyrite, pyrrhotite and scheelite as minor minerals (Gonçalves and Assunção, 1970; Oliveira, 1986; SIORMINP, 2002).

Shear- and vein-hosted Cu and barite mineralisation (Variscan)

In the **Pallarés** area (33; Fig.1) there is a large N-S, 10 km long and 3-5 km wide, brittle-ductile shear zone/fault between the Cadomian Pallarés granodioritic pluton and the host Neoproterozoic siliciclastic metasedimentary rocks. The latter are black schists and minor quartzites and ortho-amphibolites. The rocks within this structure underwent strong syn-tectonic hydrothermal silicification and sericitization postdating a major cataclasitic event. Quartz-dolomite-barite veinlets with disseminated chalcopyrite and galena, are common within and near the fault zone.

Accomodation of strike-slip faulting around the Pallarés granodiorite generated a dilational zone that promoted major hydrothermal activity. However, the absence of effective ore-forming processes inhibited the precipitation of significant amounts of sulphides that occur mostly in N45ºE-trending tensional fractures or as replacements in the nearby limestones (IGME, 2004).

Zn-Pb quartz veins (Variscan?)

Zn-Pb sulphide mineralisation associated with milky-quartz veins hosted in the Early Cambrian carbonate rocks are known in several Portuguese areas, although they remain to be investigated. That is, for instance, the case of mineralised veins at Torre das Figueiras (Monforte) developed in the contact zone with the Santa Eulália granitic massif (Oliveira, 1986).

Epithermal Hg-(Pb-Cu-Ba-Au) replacements in limestones (Variscan)

A small ore field characterised by a complex epithermal mineralisation (Hg-Pb-Ba-Cu-Sb) is found near Usagre. Thick chert-rich black limestones with minor slaty intercalations of Lower Cambrian age are host to the mineralisation, which seems to be related to WNW-ESE strike slip faults, which in turn enclose diabase and Late Variscan porphyry dykes. The mineralisation is younger than dykes. Sulphides, either massive or disseminated, occur as irregular or stratabound masses always surrounded by a halo of pervasively silicified rock.

The most important deposit of this type is at **Mariquita** mine (9; Fig. 1), an Hg-rich deposit worked intermittently from the Middle Age to 1971. The mineralisation is found as discordant massive bodies, up to 3 m thick. Cinnabar is associated with pyrite, Hg-rich sphalerite, chalcopyrite, Hg-rich tetrahedrite, galena, realgar and, locally, gold with ankerite, barite and quartz. The ore formed at temperatures between 250 and 320º C involving brines with 19-24 wt% NaCl equiv. (Tornos and Locutura, 1989). It is remarkable that host limestones contain a stratabound barite mineralisation that includes galena and traces of mercury, and that could well be the source of the epithermal ore metals. This type of hydrothermal mineralisation formed at very low depths after significant exhumation of the orogen. Regional faults focused both convective heat flow and small magma intrusions, which in turn promoted replacement of limestones and fracture fillings at places of strong fluid-carbonate interaction and/or mixing with surficial oxidised waters.

2.4 The Olivenza-Monesterio Belt (OMB)

This is the most diverse metallogenic belt and corresponds to the long known Olivenza-Monesterio antiform. This structure wedges out toward Portugal. A Proterozoic basement consisting mainly of shales and black quartzites of the Serie Negra is exposed in the core of the antiform and is overlain by an Early to Middle Cambrian succession of platform sediments –mainly carbonates- and volcanics. A key feature of this belt is the presence of abundant intrusions of different age (Cadomian and Variscan) and tectonic setting (Quesada *et al*., 1987; Sánchez Carretero *et al*., 1990).

Iron oxide deposits related to felsic magmatism (Lower Cambrian)

Discontinuous lenses up to 100 m long and 3-8 m thick of stratabound to stratiform iron oxide ores are found interbedded with hydrothermally altered massive dacites and volcaniclastic rocks of Lower to Middle Cambrian age. These volcanics overlie Early Cambrian massive limestones (Dupont, 1979). Most showings are located in the western part of the Olivenza-Monesterio antiform (e.g., **La Bóveda**, **Bilbaína, Las Herrerías, Bismark**; Fig.1). The ore lenses consist of massive to banded magnetite with some pyrite and chalcopyrite and trace amounts of arsenopyrite, galena, tetrahedrite, pyrrhotite and gold; fluorite can be locally important. The volcanics show pervasive hydrothermal and /or metamorphic alteration consisting mainly of actinolite, albite, quartz, chlorite and sericite. When the host rock to the mineralisation is the Early Cambrian limestone, ores bodies are concordant or discordant and consist of magnetite and siderite. Tourmalinites –probably exhalites- are locally found interbedded with the volcaniclastic rocks (e.g., **La Bóveda,** (18; Fig. 1)). Small mafic and felsic intrusive bodies can be locally common.

These deposits have long been interpreted as broadly syngenetic and resulting from exhalative submarine processes (Dupont, 1979; Locutura *et al*., 1990). Major orebodies such as la **Bilbaína** (22; Fig. 1) and **Bóveda** probably formed slightly underneath the seafloor by the early diagenetic replacement of the volcanic and carbonate rocks. However, some of the deposits of the Valuengo area (Bismark) might have been formed as true sediments by the exhalation of reduced low temperature (<150ºC) hydrothermal fluids ponding into shallow oxidised third order basins (Tornos *et al*., 2003). Sm-Nd isotope composition of magnetite from the **Bilbaína** mine have provided an age of ca.500 Ma and εNd_i values of -3.7 to 0.0, suggesting that relatively juvenile Nd was involved in the ore forming fluids (Darbyshire *et al.*, 1998). Moreover preliminary sulphur isotope values ($\delta^{34}S$= +3.6 - +12.4‰) suggest that sulphur was mostly derived from the thermo-reduction of seawater sulphate to H_2S with a minor but variable input of biogenically derived sulphide in an open system.

Scattered plugs of leucotonalite/dacite some tens of metres in diameter, could be the roots of the volcanics (e.g., La Valera, Los Eloys; Coullaut *et al.*, 1980). They show pervasive albitisation and brecciation, with tonalite/dacite fragments cemented by coarse-grained magnetite. Magnetite can also occur here either as massive ore, breccia fragments or disseminated in the altered host rock. Late replacements and veining including pyrite, chlorite, ankerite, fluorite and adularia are common.

Magnetite can also occur as disseminations (30-50% volume) within fine-grained volcaniclastic rocks. Moreover, evidence of detrital magnetite seems to be locally addressed (e.g., Aurora, Feria) by preserved structures within the ore, that might be sedimentary (e.g., ripple marks or graded bedding) . These showings could correspond to the erosion products of the primary ores.

As a whole, the Coullaut *et al.* (1980) model for these ores seems still to be valid. The leucotonalite / dacite plugs were the feeder conduits whilst the stratabound and stratiform orebodies represent lateral hydrothermal (sub-)exhalative and redeposited deposits.

Subsequent Variscan deformation and metamorphism modified some of the original features of this mineralisation. This is the case at the Bilbaína mine. This mine is near the western contact of the Brovales pluton and both are within a major syn-plutonic shear zone (Fig. 2). The mineralisation shows high temperature ductile deformation, accompanied by replacement of tremolite by talc and of hematite by magnetite. The combination of shearing and proximity to the pluton probably is the cause of copper and gold enrichment (up to 2.9 g/t Au; IGME, 2004) relative to that of other nearby deposits. In fact, textural evidence suggests that most of the sulphides and related gold precipitated during at this stage.

A last type of Fe-oxide ore consists of clays and iron oxide that fill paleo-karsts in limestones such as at the Cerro del Hierro Mine; karstification age is unknown.

Iron oxide deposits associated with albite granite stocks (Cambrian?, Variscan?)

Some large Fe-oxide deposits (e.g., La Berrona, Alfredo) are found within albite granite epizonal intrusions of unknown age and are thus apparently independent of volcanism. These plutons are elongated and roughly concordant and can crosscut thrusts (e.g., to the east of the Valuengo area; IGME, 1980). Often show weak foliation. Geochemically however these felsic rocks are similar to the Early to Middle Cambrian volcanics (Dupont, 1979). One case is **La Berrona** deposit (26; Fig. 1) which is a flat near cylindrical body within a foliated albite granite (IGME, 1980). The mineralisation has sharp but irregular replacive contacts towards the host rock and consists of albite, actinolite-hornblende, ferrosalite, carbonates, quartz and apatite with massive, semi-massive and banded magnetite and minor pyrite, pyrrhotite and chalcopyrite.

The **Alfredo** mine (8; Fig. 1) is a different case. It is located in the SW part of the Feria pluton which consists of massive fine-grained hastingsite syenites and albite granites (Dupont, 1979). The mineralisation, for the most part magnetite, is found within the albite granites and in the host Early Cambrian shales and limestones. The main orebody is stratiform and overlies the carbonate rocks a few hundred meters from the pluton. Lens-shaped orebodies are also found within the pluton. Moreover stockworks, breccias and dykes are common both within the granite and in the host rocks (Dupont, 1979). Minerals accompanying magnetite are hematite, actinolite-tremolite, ankerite, albite and quartz with traces of pyrite and chalcopyrite. The pluton has been dated at 311±15 Ma (K-Ar, whole rock; Dupont, 1979), i.e., Upper Carboniferous, which opens the possibility that at least stockworks, breccias and dykes might be of this same age or younger.

Manganese stratabound mineralisation (Cambrian)

In the **Olivas-Zahinos** area (17, Fig. 1), southwest of the main Cambrian volcanic exposures, there outcrop some volcanic-related ore deposits containing abundant Mn mineralisation. They were described by Ruiz de Almodóvar and Galán (1984) and Jiménez Millán *et al.* (1992), who recognised a wide variety of Mn-bearing hydrothermal assemblages including spessartine-bearing quartzites (cuticules) presumably derived from Mn-rich exhalites, thin (<1 cm) continuous layers of braunite and haussmanite, Mn-bearing jasper lenses and abundant showings of Mn oxides cementing or replacing volcaniclastic rocks; barite is fairly abundant and trace amounts of base metals are also common. Iron oxide mineralisation is restricted to some lenses of magnetite and hematite. The mineralisation is probably related to diffuse, low temperature exhalation of deep fluids into unconsolidated seawater-saturated rocks. The enrichment of Mn relative to Fe can result from differential oxidation of a deep ascending fluid, manganese being transported under more oxidising conditions than iron. West of the Oliva–Zahinos area some Cu-Zn-Pb occurrences probably represent a more reduced, H_2S-rich depositional environment.

Variscan regional metamorphism led to recrystallisation of manganese minerals, giving rise to a complex association of secondary minerals such as rhodonite, pyroxmanganite, tephroite or piamontite (Jimenéz Millan *et al*., 1992).

Orogenic gold mineralisation (Variscan)

Gold mineralisation was recognised during a regional geochemical survey by PRESUR SA in the central OMZ (Coma *et al*., 1988; Canales and Matas, 1992). The mineralisation is found within major Variscan SSW-verging WNW-ESE thrusts and shear zones tens of kilometres long and tens of metres wide. Several gold anomalies were discovered, the more representative being those in the **Guijarro** and **Chocolatero** areas (30 & 31; Fig. 1) (Canales and Matas, 1992) within the Monesterio thrust, which is a major structure in the Olivenza – Monesterio Belt (Quesada, 1992). Gold enrichment is found at the intersections of the thrust with black shales of the Tentudía Formation (Neoproterozoic) or with shales, metasandstones, metavolcaniclastic rocks and subvolcanic metadacites and metarhyolites of the Cadomian synorogenic complex (Malcocinado Formation).

Richest zones are hydrothermal breccias, minor brittle-ductile N-135-E shear zones and N-S to N-60-E extensional fractures, particularly their intersections. Mineralised zones show pervasive sericitization and chloritization and irregular but intense, sometimes texturally destructive silicification, with local tourmalinisation, albitisation and K-feldspar growth. Sulphides are scarce. Arsenopyrite and traces of pyrite, pyrrhotite and chalcopyrite with submicroscopic gold are disseminated in the more altered rocks or are related to vein quartz. Magnetite concentrations can be of local importance (Canales, 2000, pers.comm.).

Gold showings similar to those of the Guijarro – Chocolatero area, are also found in the **Constantina – Hueznar** area, in the easternmost Olivenza – Monesterio Belt (nº 29; Fig. 1). They are found within a WNW-ESE shear band about 15 km long (Ordoñez *et al*., 1992; Urbano, 1994) and are hosted by subvolcanic gabbros and gabbrodiorites of the Cadomian synorogenic volcanic complex or by shales and slates. In the first case gold is found in thin quartz veins, with carbonate and silicic alteration products, and in highly sheared and altered (epidote-sericite-quartz-chlorite-amphibole) rocks. In the second case, the mineralisation occurs in NNE-SSW thick quartz veins only. In both cases the ore assemblage includes minor sulphides, pyrite, arsenopyrite, pyrrhotite and chalcopyrite.

Preliminary research suggests that these gold deposits might be of economic interest (Canales and Matas, 1992). The high Au/Ag ratio (ab. 0.1), the low sulphide content and the geological setting are similar to those of the gold-only or orogenic gold veins located in metamorphic orogenic belts (e.g, Hogdson, 1989; 1993; Kerrich and Wymann, 1990), that formed at intermediate to shallow crustal depths (Groves, 1993). The mineralisation was probably laid down from hydrothermal/metamorphic fluids that leached disseminated gold contained in the Proterozoic sequence. Precipitation was probably caused by fluid depressurisation and immiscibility in extensional fractures.

Syn-metamorphic Cu and Pb-Zn veins (Variscan)

Small Cu and Pb-Zn lodes are widespread in the Serie Negra of the Olivenza – Monesterio Belt. They occur as subvertical veins less than a hundred metres long and a metre thick, filled by quartz with massive and brecciated textures, and disseminated chalcopyrite, galena and sphalerite. Hydrothermal alteration was negligible in the host shales/slates and restricted to local silicification. Most veins are concentrated near the Monesterio migmatitic core.

A special case is **La Hinchona** quartz – siderite vein (29; Fig.1), NW of Monesterio and close to the Salvatierra granodiorite to tonalite pluton. This is the largest known deposit of this category, about 0.5 km long and up to 2 m thick. A complex hydrothermal history is recorded by this vein that includes several stages of brecciation and vein infilling, from high temperatures down to epithermal ore precipitation. An early assemblage of arsenopyrite, pyrrhotite and pyrite, was replaced by chalcopyrite and, later on, by sphalerite, galena and tetrahedrite. Minor amounts of gold seem related to late low temperature silica (jasper).

The Cu and Pb-Zn veins display an apparently zoned distribution, Pb-Zn veins east of the pluton and Cu veins west of it. The current model involves circulation of hydrothermal/metamorphic fluids during Variscan times, that leached metals from the host metasedimentary rocks and precipitated the ore by simple cooling and fluid mixing. No evidence of boiling has been found. Differences between Cu and Pb-Zn veins are probably due to contrasting precipitation temperatures, chalcopyrite forming in the deeper and hotter parts of the system and galena and sphalerite in the shallower and cooler ones.

Ni-(Cu-PGE) in mafic to ultramafic intrusions (Variscan)

The **Aguablanca** Ni-Cu magmatic mineralisation is hosted by mafic and ultramafic rocks of the Aguablanca stock (37; Fig.1). This orebody was found in 1993 after the recognition of a strong stream geochemical anomaly. Its discovery represented a milestone in the mining exploration of the area, since no previous major Ni mineralisation had ever been found in SW Europe. Rio Narcea Recursos SA is currently evaluating the deposit and the exploitation is scheduled to start in late 2004.

The Aguablanca stock contacts with the Santa Olalla Main Pluton (SOMP), a Variscan high-K, calc-alkaline reversely zoned intrusion formed by diorites tonalites and granodiorites (Casquet *et al*., 2001; Tornos *et al*., 2001). The SOMP was dated at 332±3 Ma (^{207}Pb/^{206}Pb zircon age; Montero *et al*., 2000) and 354 ± 17 Ma (Rb-Sr whole rocks; Casquet *et al*., 1999). The Aguablanca stock consists of mafic rocks, namely (quartz-)diorites, gabbros and gabbronorites. Isotope geochemistry of the Aguablanca rocks is consistent with that of the SOMP, suggesting that they were consanguineous and broadly contemporaneous (Casquet *et al*., 2001). However, dating of the Aguablanca stock and the mineralisation was unsuccessful because of a strong crustal contamination and hydrothermal alteration (see below). Host rocks to the SOMP and the Aguablanca are Late Proterozoic to Early Cambrian dark shales (Serie Negra), limestones, volcanic rocks and sandstones, that underwent high-grade contact metamorphism near the intrusions. Limestones were converted into marble and skarn, largely barren garnet-rich skarns (Casquet, 1980). Relics of an earlier coarse-grained plagioclase-amphibole/pyroxene igneous rock (dioritoid) are locally found along the contacts of limestones with the plutons. These rocks probably formed by assimilation of limestones by dioritic magma (Casquet, 1980). Skarns and dioritoid are barren.

The Ni-(Cu-PGE) ore is found in a breccia pipe hosted by mafic rocks of the Aguablanca stock. The pipe is subvertical and ellipsoidal in cross section. It consists of heterometric fine- to coarse-grained fragments of ultramafic rocks (ortho- and clinopyroxenites and minor peridotites), gabbros-gabbronorites and fragments of the plutons host rocks (limestones, skarns, hornfels) supported by a gabbroic and gabbronoritic matrix (Barren Breccia). However, in the pipe core, the breccia is supported by sulphides (Ore Breccia). Massive orebodies with subordinate silicate inclusions (coarse-grained pyroxenites) are also found in the pipe core. The metallic assemblage consists of intercumulus to massive pyrrhotite, chalcopyrite and pentlandite. Disseminated mineralisation is found in the Barren Breccia and in the host mafic rocks. No spatial zoning of the Ni/Cu ratios was recognised but the Ore Breccia and the massive sulphides have significantly higher Ni grades that the disseminated mineralisation.

Widespread hydrothermal alteration, which can be locally intense, converted the magmatic silicates into clinoamphibole, sericite, phlogopite, talc and epidote and also led to recrystallisation of the sulphides.

As a whole, the deposit shares many of the features of magmatic-hosted Ni-Cu deposits, but is located in a calc-alkaline gabbroic stock in an active margin setting. Very few deposits of this type have been described to date. Isotope (Nd, Sr and S) and trace elements geochemistry suggest that juvenile magmas intruded into the upper crust during oblique subduction of an oceanic crust (the Acebuches Ophiolite) previous to accretion of the South Portuguese terrane to the OMZ . An intracrustal magma chamber formed where combined assimilation and fractional crystallisation processes took place leading to sulphide magma immiscibility and silicate magma diversification and stratification (Casquet *et al*., 1999; Tornos *et al*., 2001; Casquet *et al*., 2001). Sulphur was added to the melt through assimilation of organic sulphur-rich rocks, probably from the Serie Negra. The relatively radiogenic lead isotope signatures (Tornos and Chiaradia, 2004), and the Au/Au* values (Tornos *et al*., 2001) reinforce this interpretation. Sulphide magma sunk to the bottom of the chamber and was subsequently intruded along with the mafic and ultramafic cumulates to form the Aguablanca stock. The intrusion was probably favoured by tectonic structures such as the nearby strike-slip Cherneca fault.

Alternative models have been proposed to explain the Aguablanca Ni-(Cu-PGE) mineralisation. Lunar *et al*. (1997) and Ortega *et al*. (2001) suggested that the Aguablanca stock is an old, pre-Variscan layered complex that was verticalised during the Variscan orogeny. Quesada *et al*. (2002) invoked a skarn process, and Marcoux *et al*. (2002) described it as a massive sulphide.

Shear zone and plutonic-related iron-rich Feox(Cu-Au) skarns and replacements (Variscan)

Most orebodies of this category are found in the region including the Burguillos, Brovales and Cala areas, NE and SE of the Jerez de los Caballeros township. Here skarn-type, stratiform and vein-type magnetite mineralisation is found, although not exclusively, along the contacts of Variscan plutons with Early Cambrian metasedimentary and metavolcanic rocks. Emplacement depth of the plutons was about 1.5 - 3 km (Velasco and Amigó, 1981; Casquet and Tornos, 1991). Variscan igneous rocks range in composition from gabbros to granodiorites and have ages of 352±4 Ma to 332±3 Ma (Dallmeyer *et al*., 1995; Casquet et *al*., 1998; Pin *et al*., 1999; Montero *et al*., 2000).

The most important iron mines are of this type. This is the case of the **Monchi** mine (23; Fig. 1), at the western contact of the Burguillos del Cerro plutonic complex and the **Santa Barbara** and **El Colmenar** mines (Cuervo *et al*., 1996; Sanabria, 2001), at the eastern contact of the Brovales pluton (24; Fig. 1). Another large magnetite mineralisation is still mined at **Cala** (35; Fig. 1), adjacent to the small Cala granite outcrop (Velasco and Amigó, 1981). Skarns are common at these localities but are small. The long alleged relationship between skarn-forming processes and magnetite is nowadays being reconsidered.

Skarns formed in general by replacement of limestones and calc-silicate hornfelses (exoskarns). Most are calcic Fe-skarns. A case is the skarn at the Santa Barbara mine. Here a small (ferro-)salite-grandite exoskarn is variably replaced by a retrograde assemblage of actinolite-hornblende, minor epidote, scapolite and plagioclase (Casquet, 1980, Casquet and Velasco, 1978; Velasco and Amigó, 1981; Casquet and Tornos, 1991; Cuervo *et al*., 1996). The ore, consisting of magnetite with minor amounts of pyrite, chalcopyrite, other sulphides (pyrrhotite and bornite) and ilvaite, is intergrown with the retrograde skarn. Late sulphide-bearing chlorite + quartz + calcite veins are common. Endoskarns developed on plutonic rocks are small and consist either of a garnet skarn, or more commonly a low-T actinolite + epidote + feldspar assemblage. Skarns and skarn-type magnetite bodies are of local extent compared to the large stratiform magnetite bodies mined at the same localities referred to above. They consist almost exclusively of magnetite, with some accessory pyrite (Table 1).

The **Cala** mine (35; Fig. 1) is a remarkable case of this type of mineralisation. The mine lies at the fault contact of a small (<1 km^2 on outcrop) biotite granite stock (Casquet and Velasco, 1978; Velasco and Amigo, 1981) with Early Cambrian carbonate rocks and calc-silicate hornfelses. A metasomatic wollastonite zone developed on limestones away from the tectonic contact, followed by an inner grandite zone. In turn, calc-silicate rocks were replaced by a pyroxene skarn. Dolostones remained unaltered. No significant endoskarn has been recognised. The mineralisation occurs as two subvertical lenses (Vázquez *et al*., 1980) within the grandite zone and near the faulted contact with the granite. These lenses probably formed at dilatational structures within the fault. The ore consists of coarse-grained magnetite intergrown with actinolite, and late pyrite and chalcopyrite; the copper concentrate has about 4 g/t Au. A retrograde skarn of actinolite, epidote and calcite is locally found away from the fault. Major faults as in the case of Cala, were important controls in ore deposition as they focused most of the regional fluid flow. At the Cala mine the close spatial association of ore and garnet skarn has long been taken as a proof for a common origin. However, barren garnet skarns are widespread in the area (e.g., Casquet and Velasco, 1978; Casquet, 1980). Some small copper-rich skarns distal to the iron ones have also been recognised in the area (IGME, 2004).

The **Teuler** deposit 4 km SE of Cala (36; Fig. 1), is the only known magnetite mineralisation related to a magnesian skarn. Magnetite, with accessory pyrite and chalcopyrite, is interbedded with vermiculite and serpentine in a sort of contorted rhythmic layering. The orebody is stratiform and lies within marbles and calc-silicate rocks. Sills and dykes of biotite leucogranite are widespread.

Another apparently fault controlled mineralisation is found at the **Sta Barbara - El Colmenar** group of mines, at the western contact of the Brovales pluton (24; Fig. 1). Here, aside to the Santa Bárbara skarn, referred to above, there is a discontinuous stratiform mineralisation, about 2 km long and 2-20 m thick, strikingly different from the volcano-sedimentary and skarn-related ores. The assemblage consists of banded to massive actinolite, magnetite and albite with minor proportions of adularia, ferrosalite, biotite, quartz, carbonates and titanite (Cuervo *et al*., 1996). The more internal zone consists of massive coarse-grained magnetite with interstitial actinolite, ilvaite and sulphides, including chalcopyrite, pyrite, pyrrhotite, millerite and cobaltite, besides significant amounts of titanite, allanite, zircon and apatite. The mineralisation is replacive on felsic volcaniclastic and volcanic rocks, calc-silicate hornfels and limestones of Early Cambrian age, and is older than skarns. Sm-Nd dating of magnetite (334±32 Ma; Darbyshire *et al*., 1998) and preliminary lead isotope data (Tornos and Chiaradia, 2004), are consistent with a Variscan age for the ore-forming process. The Sta Barbara – El Colmenar mineralisation is but one of a string of magnetite lenses that extend eastward away from the Brovales pluton (e.g., Sta Justa, El Soldado, Aurora or Bismark mines) at an apparently similar stratigraphic position. This has long led to discussion about the exact origin of this mineralisation, either skarn (Coullaut, 1979; Cuervo *et al*., 1996) or volcanic-related (Vázquez and Fernández Pompa, 1976; Dupont, 1979). However the Variscan age of magnetite and textural evidence speaks in favour of a tectonically controlled hydrothermal replacement.

The **Monchi** Mine (NE of the Burguillos pluton; 23, Fig. 1) exploited five high-grade (66% Fe) magnetite lenses some tens of metres long and few metres thick located at the contact between calc-alkaline granodiorites and diorites of the Burguillos del Cerro plutonic complex and the host pelitic hornfelses, marbles and calc-silicate rocks. This contact is a major syn-magmatic shear zone (Casquet *et al*., 1998). The ore lenses consist of massive magnetite-vonsenite and minor ilvaite. The ore is foliated and variably recrystallised at places. Moreover it can be found as enclaves within the granodiorite. Fine grained uraninite-bearing allanite-rich hedenbergite-plagioclase rocks are also found at this mine. These rocks are stratiform and apparently independent of magnetite lenses; their significance remains uncertain. They are brecciated and injected by K-feldspar + amphibole ± axinite ± quartz pegmatite veins. Discordant veins of massive, coarse-grained magnetite with actinolite-hornblende constitute a late generation of magnetite ore. Metallic minerals at the Monchi and nearby mines, are scarce and irregularly distributed.

They are however unusual. We record here the following: pyrrhotite, cobaltite, chalcopyrite, pyrite, arsenopyrite, Co-gersdorffite, safflorite, löllingite and bismuthinite, molybdenite, scheelite and gold. Allanite from a fine grained hedenbergite-rich rock was dated by the U-Pb method at 338±1.5 Ma (Casquet *et al.*,1998). This age is consistent with that of the Burguillos pluton and other calc-alkaline intrusions in the area (350-330 Ma).

As a whole, most of the deposits in this district share geologic features with the hydrothermal iron oxide (Cu-Au) (U-REE) style of mineralisation (e.g., Hitzman *et al.*, 1992), including the widespread presence of an albite-actinolite-magnetite hydrothermal assemblage, the variable but relatively high contents of scapolite, apatite, fluorite and B-bearing minerals (vonsenite, axinite, tourmaline), and the close association with major crustal discontinuities (Tornos *et al.*, 2003). No fluid inclusion data are available, but few oxygen isotope data from magnetite and amphibole (Cuervo *et al.*, 1996; Spiro and Tornos, unpub. data) suggest that the ore precipitated at high temperatures (>500ºC) from isotopically heavy fluids ($\delta^{18}O_{SMOW}$ between 9 and >12‰) of probably magmatic or metamorphic origin. Galindo *et al.* (1995) and Darbyshire *et al.* (1998) reported Nd and Sr isotope data for magnetite from El Colmenar mine. However the interpretation is not straightforward. εNd_i and $^{87}Sr/^{86}Sr_i$ values of -7.6 to -4.5 and 0.7093-0.7137, respectively, probably represent those of the ore-forming fluid and suggest a crustal source for part of the metals in solution.

Most iron oxide mineralisation referred to above have low and irregular Cu-Au contents (Table 2); in fact, high-grade Cu-Au deposits in the OMZ are only found away from the ironstones (see below). However, significant Cu-Au grades are also found within stratiform magnetite deposits in shear zones or adjacent to Variscan granitoids (Bilbaína, Colmenar, Cala). This suggests that earlier magnetite acted as a geochemical trap for Cu – Au transported by late hydrothermal fluids, probably of igneous origin.

Vermiculite related to Mg-skarns (Variscan)

Small forsterite and diopside/spinel Mg-skarn developed at the contact of Early Cambrian dolomitic marbles with gabbros of the Aguablanca stock, at La Garrenchosa. Vermiculite formed by low temperature alteration of earlier phlogopite-rich veins within the skarn (Velasco *et al.*, 1981). Size of vermiculite crystals can be up to 20 cm.

Cu(-Au-Bi) veins (Variscan)

Quartz - ankerite - chalcopyrite veins are scarce in the OMZ, and are restricted to two small ore fields, NE of the Burguillos pluton and N of the Santa Olalla del Cala pluton, respectively. These veins can host minor amounts of Zn-Pb sulphides.

The Burguillos ore field is represented by the large **Abundancia** Mine (19; Fig.1), and some nearby lodes. The veins (NNE-SSW trending) are hosted by black shales and sandstones of the Late Precambrian Serie Negra, within the contact metamorphic aureole of the Burguillos del Cerro pluton. Veins consist of quartz and dolomite with chalcopyrite and variable amounts of calcite, pyrite, arsenopyrite, tennantite, sphalerite, gersdorfitte and freibergite. Hydrothermal brecciation and other features indicative of boiling are common (Tornos and Velasco, 2002). $\delta^{34}S$ values near 0 ‰, suggest that sulphur source was nearby igneous rocks.

Sultana mine, NW of the Santa Olalla pluton (34; Fig.1), probably is the richest gold deposit in Spain with an average grade near 3.1% Cu and 15 g/t Au, with ore shoots of up to 800 g/t Au (Tornos and Velasco, 2002). The deposit consists of a Late Variscan, low to moderately dipping (20 to 60ºW) N160ºE vein system with an *en échelon* pattern, hosted by Variscan tonalites and Late Precambrian to Early Cambrian calc-silicate hornfels, schists and metavolcanic rocks. The ore is mostly chalcopyrite, bismuthinite and maldonite, together with an assemblage of quartz, ankerite and sericite; vein selvages exhibiting strong sericitizacion and ankeritization, and local tourmalinisation are well developed. Fluid inclusion studies indicate that hydrothermal fluids were complex H_2O-CO_2-CH_4-NaCl-$CaCl_2$-KCl brines with salinities up to 30 wt % NaCl equiv. (Velasco *et al.*, 1995), that underwent several stages of immiscibility. Deposition temperature of the Cu-Au assemblage was 290-380ºC. $\delta^{18}O$ values of quartz and carbonates (+4.7 - +7.5‰) suggest equilibrium with deep fluids (Tornos and Velasco, 2002); the heavy sulphur isotope signatures ($\delta^{34}S$ = 10.4-15.6 ‰) are indicative of sulphur leaching from the host sedimentary rocks. The ore assemblage (Cu-Bi-(Au-Te)) and fluid composition of the Sultana veins are strikingly similar to those reported from Tennant Creek (Australia), where Cu-Au ores are hosted by an iron formation (Zaw *et al.*, 1994; Stoltz and Morrison, 1994). This suggests that the Sultana deposit might be correlated with the late Cu-Au stage of the ironstones at shear zones and granite contacts.

A key question is why, in spite of many similarities, the gold content is larger at Sultana mine whilst Abundancia mine is barren. Sulphur and lead isotope data suggest that in both cases metals were derived from the same sources, probably the Serie Negra shales and igneous rocks near the vein systems. The cause probably lies in the process of polyphase immiscibility of saline CO_2-rich fluids, only recognised in Sultana.

Leucogranite-related W(-Bi-Au) veins (Variscan)

Veins of this type are scattered over a large area near Oliva de la Frontera; however only two mines came into operation, the Virgen de Gracia and Mari Juli. Veins are hosted by Early Paleozoic volcanic and siliciclastic rocks. No large plutonic bodies outcrop; however the presence of contact metamorphic effects, hydrothermal alteration and granitic dykes suggest the existence of a hidden intrusion (Ruiz de Almodóvar *et al*., 1984; Gumiel *et al*., 1987).

At **Virgen de Gracia** mine (21; Fig.1), quartz veins are subhorizontal as in Panasqueira (Portugal), where they formed by decompression consequent to crystallisation of an underlying granite (Kelly and Rye, 1979). At **Mari Juli** mine (20; Fig. 1) however, quartz veins are small and subvertical. Alluvial deposits related to the vein field have produced up to 6 kg/m^3 WO_3.

Vein filling consists of quartz and some muscovite (at the veins edge), tourmaline and siderite. Wolframite is found at the selvages and chalcopyrite, pyrite, arsenopyrite, molybdenite, fahlore, bismuthinite and enargite in the vein cores; at Mari Juli mine veins are richer in scheelite, and contain some gold. Host rocks are strongly tourmalinised and greisenised. When host rock to the veins is a mafic rock then scheelite instead of wolframite is found.

The La Bazana pluton, few kilometres East of this vein field is remarkable on this respect. It is formed by muscovite bearing granites. Zones of intense greisenisation, with up to 4% WO_3, are found near the pluton´s edge (Coma *et al*., 1988). It is tempting to correlate the La Bazana granitic event with the W(-Bi-Au) veins.

Leucogranite-related gold veins (Variscan)

In the Burguillos area swarms of tourmaline-bearing muscovite peraluminous leucogranites cross-cut the gabbroic to granodioritic Burguillos plutonic massif and the tonalitic Brovales pluton. They were emplaced at moderate depths (3.5 km) and underwent pervasive albitic alteration associated with Au-bearing sulphide-poor quartz veins (Bachiller *et al*., 1997). Fluids responsible for this alteration were moderate to highly saline brines in the H_2O-CO_2-NaCl-KCl-$CaCl_2$-$FeCl_2$ system. High salinities and high $\delta^{18}O$ values (9.5-11.2‰) of the fluids suggest that they were magmatic in origin.

Uranium veins (Post-Variscan)

Some uranium deposits, such as **Monesterio** (Cabra Alta) (32; Fig. 1), are found along late- to post-Variscan fractures. Quartz-carbonate veins contain uranium (pitchblende), nickel (nickelite) and cobalt (smaltite-chloantite) along with safflorite, millerite and pyrite, with minor chalcopyrite and pyrite (Arribas, 1962b). The mineralisation disappears at depths over 60 m. Host migmatitic gneisses underwent pervasive low temperature alteration (chloritization, sericitization and silicification).

2.5 South Central Belt

This belt (Barrancos- Hinojales Domain of Apalategui *et al*., 1990) is characterised by the presence of a tightly folded thick sedimentary sequence of Ordovician to Devonian age deposited in a stable continental basin. Igneous rocks are poorly represented in Spain but are more abundant in Portugal. Regional metamorphism is low-grade. The boundaries with the neighbouring belts are a south-verging thrust to the north and a longitudinal strike-slip fault to the south. In Portugal this belt has been subdivided into the northern Sousel-Barrancos sub-belt and the southern Arraiolos-Sto. Aleixo sub-belt (Oliveira, 1986) (Fig.2).

Stratabound Fe-Mn, Cu and P prospects (Early Paleozoic)

Few stratabound prospects of oolitic iron oxides are found in small tectonic slices of this belt within a strongly imbricated area near **Cazalla de la Sierra** (38; Fig.1), and west of Cala, in Spain. Rocks are shales and sandstones of Early Ordovician age (Gutierrez Marco *et al*., 1984). The mineralisation, up to 1 m thick and of regional extent, shares many features with other stratigraphically equivalent mineralisation of Iberia. The ore assemblages consists of goethite and hematite but, in contrast with other deposits, do not contain magnetite or siderite. As elsewhere, ore genesis is correlated with the Lower Ordovician transgression and resulted from accumulation of iron oxides in small oxidised and shallow third order basins.

Scattered stratabound, centimetre thick concentrations of copper sulphides (chalcopyrite and covellite) and pyrite occur in the footwall of some quartzite layers of Silurian age. They are overlain by shales, black lidites and some felsic volcaniclastic beds that host lenses of chalcopyrite, pyrite, barite and manganese oxides. Few variscite replacements and veins are also scattered within the Silurian black shales in close association with chert and lidite beds (Moro *et al*., 1992). Replacement of the latter by variscite was early diagenetic and related to low temperature exhalative processes. Uranium also occurs locally within the black shales.

Iron- and base metal-bearing veins (Variscan)

The key metallogenic characteristic of the Sousel-Barrancos sub-belt in Portugal is the presence of abundant quartz and carbonate-bearing veins with N-S, ENE-WSW, NNE-SSW and WNW-ESE trends. They were mined extensively during the 19th century and first decades of the

20th century (Rhoden, 1956; Gomes et al., 1959; Mendes, 1967; Barros, 1968; Gaspar, 1968, Cerveira, 1972, 1975; Oliveira, 1984, 1986; Mateus et al., 1983). The old mines of **Aparis** (13; Fig. 2), **Botefa** (58), **Miguel Vacas** (8), **Mociços** (11), **Urmos** (59), **Minancos** (60), **Bugalho** (10), **Zambujeira** (9) and **Mostardeira** (7) are the biggest deposits of this type in Portugal. In Spain, the **Novillero** mine (40; Fig.1) is the more outstanding example. The veins are mainly near-vertical and related to strike slip faults trending NNW-SSE or, more commonly, NNE-SSW to NE-SW. They are composed of polyphase, variably brecciated, hydrothermal quartz + carbonate (ankerite, siderite and/or calcite) + chalcopyrite + pyrite ± tetrahedrite/tennantite ± arsenopyrite ± sphalerite ± galena ± barite infillings; they are usually hosted by thick and monotonous metasedimentary sequences with shales, greywackes and sandstones that underwent very restricted hydrothermal alteration. These veins do not show evident relationship to intrusions of any kind and are interpreted as a result of intense hydrothermal activity of Variscan age that remobilised sedimentary-diagenetic disseminations of metals in the host rocks. The precipitation along faults took place via boiling, cooling or fluid mixing processes at rather low temperatures (<250ºC) and depths. Supergene enrichment is common, leading to the development of mineral associations composed of iron (hydr-)oxides, malachite/azurite, cuprite, liebethenite, atacamite, chrysocolla and covellite.

There is a second group of mineralisation represented by the **Defesa das Mercês** old mine (12; Fig. 2). Here, chalcopyrite, pyrite and local gold (Defesa das Mercês-Ordem Lírio) occur as disseminations or represent an important part of the mineral infillings shown by different arrays of veinlets and veins within felsic subvolcanic intrusions and related breccias, although it is also possible to identify late, brecciated quartz-calcite lodes along strike slip faults trending from NW-SE to NE-SW (Silva, 1949; Oliveira, 1982).

Cu veins (Variscan)

Several Cu mineralisation occurrences, **Azaruja** (14; Fig.2), **Monte do Trigo** (15), **Reguengos** (16), and **Sto. Aleixo** (17), exist in the western part of this belt, i.e., the Arraiolos-Sto. Aleixo sub-belt in Portugal. Sto. Aleixo consists of a chalcopyrite-bearing quartz vein hosted in Silurian spilites (Carvalho and Oliveira, 1992). The remaining occurrences are set in syn- to post-Variscan quartz-dioritic intrusions, microgranite dykes and aplite-pegmatites veins usually emplaced in Cambrian-Early Ordovician? schists. The mineralisation consists of 0.4-1.5 m-thick, decametric (rarely hectometric), NW-SE -trending quartz veins within the intrusions or as masses infilling diaclases and fractures in microgranite dykes and aplite-pegmatite veins. Host rocks show a variable sericitization. Ore minerals are chalcopyrite, pyrite, occasionally galena and/or sphalerite. Calcite and barite are, at places, gangue minerals in the quartz veins (Goinhas and Martins, 1988). Zones of supergene enrichment with malachite, azurite and chalcocite were targets of Roman mining in Salvação do Índio (Azaruja). The development of the low-grade, primary Cu mineralisation seems to be related to the felsic-intermediate plutonism (Oliveira, 1986)

U in albite leucogranites (Variscan)

Rare albite-tourmaline gneisses and albite leucogranites (aplites) with some U, are found east of Villanueva del Fresno. Host rocks are thermally metamorphosed Ordovician metapelites of the Terena syncline. Contact metamorphism is probably related to a hidden intrusion. Ore mineral is davidite which is found along with pyrite and titanite in an aplite dyke, some tens of metres long and less than 1 m thick, hosted by tourmalinised and albitised gneisses (Arribas, 1963).

2.6. The Évora-Aracena Belt

This metallogenic belt, together with the S. Cristóvão-Beja-Serpa belt in Portugal, corresponds to the Évora-Aracena Domain of Apalategui *et al.* (1990), one of the major and more complex tectono-metamorphic areas of the OMZ. The geological formations belonging to this area have a rather unique stratigraphic sequence that is not easy to correlate with that of other areas of the OMZ (Crespo, 1987, 1989). It consists mostly of a Proterozoic-Lower Paleozoic succession containing schists (Riphean?) overlain by carbonate rocks and a bimodal metavolcanic sequence. The age of the last two is controversial and could be from Upper Proterozoic, and related with the synorogenic Cadomian sequence, to Early Silurian (Crespo, 1989, Oliveira *et al.*, 1991).

The belt includes significant stratabound Cu, Zn, Pb and magnetite orebodies, forming the so-called Magnetite-Zinc Belt (Schermerhorn, 1981; Oliveira, 1986). Most of these deposits show a strong tectonic deformation, often leading to complex imbricate sequences. The recognition and characterisation of the textural relationships, primary mineral assemblages, hydrothermal alteration and original relationships with the host rocks are therefore very difficult. However, according to the present state of knowledge it is possible to distinguish several stratiform and stratabound mineralisation types among other deposit types.

Magnetite-bearing Cu-Zn stratiform/ stratabound mineralisation (Lower Paleozoic? Variscan?)

Different iron oxide deposits, **Monges** (Montemor-o-Novo), **Orada** (Pedrógão) **and Vale de Pães** (Cuba) are known in this belt. They are commonly hosted in Early Cambrian-Ordovician? amphibolites associated with marbles and metavolcanic rocks of the same age. They contain strongly recrystallised (syngenetic or epigenetic?) disseminated and massive, stratiform (or stratabound) ores composed of magnetite and sulphides (pyrrhotite + pyrite ± chalcopyrite ± sphalerite). Magnetite is dominant in Orada, Vale de Pães and in the upper part of Monges and, although abundant, subordinate to pyrrhotite and pyrite in the deeper levels of Monges. The mineralisation was mined in **Monges** and **Orada**, as well as in other adjacent but minor orebodies (Silva, 1945; Neiva, 1952; Carvalho, 1971; Carvalho *et al*., 1971; Goinhas and Martins, 1986). The **Algares de Portel-Balsa** deposit is an equivalent mineralisation but is characterised by the presence of abundant sphalerite as well as the presence of many accessory phases such as galena, cubanite, different sulphosalts and arsenopyrite (Gaspar, 1967; Goinhas, 1971a; Carvalho, 1988).

The Early Cambrian (?) Monfurado Formation is the setting for the **Monges** deposit (23; Fig.2), already mined by the Romans. It is hosted by intermediate-basic and felsic metavolcanic and metalimestones, all folded in a Variscan anticline. The mineralisation, either stratiform or disseminated, is mainly hosted by amphibolite and amphibolite gneiss and, in the shallowest levels of the mine, by skarns formed on the interbedded limestones due to the intrusion of the syn-tectonic Variscan Escoural quartz-diorites. The ore assemblage includes magnetite, pyrite and pyrrhotite, and subsidiary chalcopyrite, sphalerite and sulphosalts. Iron-rich gossans occur on surface. Initial resources of the superficial portion (to 10 m depth) were about 1-2 Mt, with 30-66% Fe, 3.3-19% SiO_2 and 0.2-0.8% S. Mineralisation is known down to a depth of at least 200 m. The mineralisation is interpreted as syngenetic exhalative associated with Cambrian mafic volcanic rocks but modified by metamorphism and metasomatism induced by Variscan intrusions (Silva, 1948; Carvalho, 1976; Goinhas and Martins, 1986).

The **Orada** deposit (33; Fig. 2) occurs in an equivalent sequence of Ordovician(?) mafic and felsic metavolcanic rocks with some metalimestone lenses that overly the Cambrian metadolostones. The volcanic rocks (amphibolite or amphibolite gneiss) are the prime host of lenticular or disseminated mineralisation. Some of it also occurs in skarns formed as a product of contact metasomatism of the limestones related to the intrusion of the nearby two-mica, calc-alkaline, late-Variscan Pedrógão granite (308±4 Ma; biotite age). Mineralisation of this type can be traced along 6 km, in up to 10 m-thick and 100 m-long (max. 250 m) lenses. Specifically at Orada, 2 Mt of magnetite-pyrite ore was mined out of three main ore lenses. Accessory phases include pyrrhotite as well as hematite, calcite, chlorite, epidote, quartz, amphiboles and serpentinised olivine. Ore contains 39-46% Fe, 6-18% SiO_2, 2.5-4.5% CaO and is almost devoid of P (0.01-0.02%) an S (0.01-0.2%), but at places sulphides are abundant and the sulphur content is over 20% S. The genesis would have been similar to that of the Monges deposit (Carvalho, 1971; Carvalho, 1976).

In the equivalent **Vale de Pães** hidden deposit (32; Fig. 2), 17 km to the west of Orada, the magnetite mineralisation is hosted in the same Ordovician(?) amphibolite and amphibolite gneiss, associated with metavolcanic rocks and minor metadolomites and biotitic schist, intruded by Variscan(?) felsic-intermediate plutonic rocks. Mineralisation in the mafic metavolcanic rocks is either massive or disseminated and contains dominant magnetite and subsidiary pyrite and pyrrhotite, and minor epidote, quartz and carbonate. The deposit, that almost reaches the surface and extends to a depth of 180 m, contains 8.5 Mt with average grade of 42% Fe, 19% SiO_2 and 0.6-5.2% S. The genesis was similar to that of Orada (Carvalho, 1976; Oliveira, 1986).

As mentioned above, the current genetic model envisaged for this iron mineralisation involves contact metamorphism and metasomatism of previous syngenetic exhalative mineralisation, due to the intrusion of Variscan igneous rocks. However, a different origin was recently proposed for the iron mineralisation at Azenhas, near the Orada deposit (Mateus *et al*., 1999a). At **Azenhas** (69; Fig. 2), where minor magnetite orebodies were incipiently mined (Carvalho *et al*., 1971), recent studies (Matos *et al*., 1998; Mateus *et al*., 1999a) have shown that they occur exclusively within strongly metasomatized and imbricated sequences of amphibolite slices, immediately underneath a major WNW-ESE thrust zone. Here, carbonate and calc-silicate rocks (Lower Cambrian?) also occur but form a relatively narrow band apparently confined to another important near-horizontal thrust zone. The mineralisation comprises: 1) massive, fine- to medium-grained ores within non-carbonatised amphibolites; 2) banded, medium- to coarse-grained ores within carbonatised rock domains; and 3) brecciated ores, caused by late deformation of the massive ore near strike slip faults. Magnetite prevails in all these kinds of ores, with interstitial domains infilled usually by tremolite, often partly replaced by lizardite-amesite ± carlosturanite aggregates. Chemically, the ores have less than 62.50% Fe_2O_3 (as total iron), 15.03-21.31% SiO_2 and very low P_2O_5 contents (< 0.04%). Disseminated pyrite, pyrrhotite and chalcopyrite also occur but always along late fractures developed after magnetite formation. As a genetic mechanism, the rise of oxidising aqueous fluids, subsequently CO_2 enriched, under a significant reverse temperature gradient provided by the tectonic superposition of amphibolites over a relatively cold (lower greenschist facies) autochthonous sequence, would promote iron ore deposition.

This style of iron mineralisation is also found in Spain, mostly in the eastermost Aracena massif. However, some minor iron oxide-bearing deposits are found near the Zn-Cu-(Pb) massive sulphides (see below). They seem to be related to hydrothermal submarine replacements eventually associated with an important, epigenetic dolomitisation process of unknown age.

Zn-Cu-(Pb) volcanic-hosted massive sulphides (Proterozoic? –Cambrian?)

Some Late Proterozoic?-Cambrian? volcano-sedimentary sequences host a second style of mineralisation. It consists of stratiform massive sulphides chiefly composed of pyrite and sphalerite with variable proportions of galena and tetrahedrite. These ores occur almost exclusively within metavolcanic and metacarbonatic horizons belonging to thick volcano-sedimentary sequences, that are affected by strong, although heterogeneous, hydrothermal alteration.

In the Moura-Ficalho area, different Zn-Pb(-Ag-Sb-Au) deposits are known, namely those of Preguiça, Vila Ruiva, Carrasca, Sto André and Enfermarias (Goinhas, 1971b; Oliveira, 1986; Oliveira and Matos, 1992). The **Preguiça** (36; Fig.2) and **Vila Ruiva** (37) deposits correspond to very rich secondary Zn-ores located in metadolostones of Lower Cambrian age, due to strong *in situ* oxidation and supergene enrichment processes on previous sulphide mineralisation. Equivalent metadolostones host the **Carrasca** (56) prospect but only small amounts of disseminated sphalerite and galena were recognised (Aalten and Steenbruggen, 1997). Drilling in the eighties intersected the **Sto André** (35) and **Enfermarias** (34) orebodies, with Zn, Cu, Pb, Ag and Au contents up to 17.53%, 2.88%, 2.75%, 384 ppm and 3.2 ppm, respectively (Oliveira and Matos, 1992). The **Sto. André** orebody, showing somewhat different characteristics, is enclosed in the Ordovician metavolcanic-marble sequence and exhibits a very wide hydrothermal siderite alteration halo with abundant disseminated pyrite and arsenopyrite.

The **Enfermarias** orebody, hosted by a Lower Cambrian metavolcanic-metadolostone sequence, comprises massive and disseminated mineralisation that records a very long and complex evolution (Barroso, 2002, Martins, 2002). The rock sequence drilled at Enfermarias consists of felsic to intermediate-mafic metavolcanic rocks interbedded with silicate-bearing marbles, metadolostones, and different layers of metasomatic rocks. Primary mineralisation occurs mainly in strongly chloritized intermediate-mafic metavolcanics as semi-massive to massive lenses subparallel to the metamorphic banding; the ore assemblage consists mostly of pyrite and sphalerite with minor amounts of galena, chalcopyrite, magnetite, arsenopyrite and sparse Ag-bearing tetrahedrite (Barroso, 2002; Martins, 2002). The sphalerite, magnetite, arsenopyrite and most pyrite are pre-metamorphic and show evidence of strong recrystallisation and deformation.

The introduction of galena, chalcopyrite and Ag-bearing tetrahedrite, as well as the crystallisation of most of the gangue-forming minerals (actinolite-tremolite, talc, serpentine, biotite and chlorite), took place during the retrograde Variscan metamorphism. Late massive aggregates of magnetite and pyrite developed in metasomatic rocks, mostly consisting of chlorite/serpentine, actinolite/tremolite and talc, are related with late near-horizontal shear zones. The origin of this mineralisation is ascribable to the circulation of oxidised aqueous-carbonic fluids, progressively focussed along near-horizontal structural corridors after the Variscan deformation-metamorphic peak. These fluids were also responsible for partial remobilisation of the primary sulphide assemblage, and for late input of metals (Pb, Cu, Ag, As and Sb) in the system. Finally, there are quartz, chlorite, pyrite, chalcopyrite and pyrrhotite cementing fault breccias and infilling late veins; they are related to near-vertical strike slip fault zones and are interpreted as recording the effects of an independent Cu ore-forming system superimposed to a main, pre-existing, Zn-Pb(-Ag) geochemical halo.

The clear spatial relationship between the primary sulphide mineralisation and the metavolcanic rocks, the sub-parallelism between the sulphide layering and the metamorphic banding, and the preservation of some evidence for the pre-existence of a Fe-Mn carbonate halo around ore strongly suggest that the Enfermarias can be an example of a stratiform (and syngenetic?) deposit with miscellaneous characteristics of SEDEX and Irish-type categories, particularly if the silicate-bearing marbles are envisaged as metamorphic products of dolomitic shaly rocks. In this context, it is worth noting that the fabrics of the metadolostones hosting the nearby Carrasca prospect are polymodal and have red luminescence, usually taken as indicative of continuous nucleation from a chemically homogeneous fluid in a system with high water/rock ratio (Aalten and Steenbruggen, 1997). The O and C stable isotope data suggest that the dolomitisation process took place at low temperatures (40-55ºC), involving seawater as the main fluid type (Aalten and Steenbruggen, 1997). It is not clear yet, however, what is the chronological relationship between the dolomitisation process and the earlier mineralising events in the Enfermarias system.

The **María Luisa** mine is near Aracena (43; Fig.1) and is set in medium to high grade metamorphosed and deformed volcaniclastic rocks. This metavolcaniclastic unit some 1500 m thick, includes metarhyolites and metadacites with basicity increasing upwards (Crespo, 1989). The age of this sequence is unknown because of structural complications. It might be older than marble beds which are correlated with the regional Early Cambrian carbonates. This possibility is consistent with a syn-Cadomian age for the volcaniclastic complex. On the contrary, Crespo (1989) proposed that the metavolcanic sequence overlies the marble beds and that in consequence it could be as young as Silurian . Recent lead isotope model ages however suggest that the mineralisation is Cadomian; in consequence the host rocks probably are a syn-Cadomian volcanic sequence (Tornos and Chiaradia, 2004).

In detail the mineralisation at María Luisa is hosted in quartz-sericite schists (probably altered metavolcaniclastic rocks) with some intercalations of amphibolites, calc-silicate hornfelses and metalimestones (Florido, 1993) that were strongly chloritized, silicified and skarnified. The orebody consists of several stacked lenses trending N120-140ºE. Underlying the ore lenses there is a small stockwork, with vein-like and disseminated mineralisation, affected by chloritization. Vázquez (1972) distinguished two types of ores: an early syngenetic ore, consisting of pyrite, arsenopyrite and sphalerite with minor magnetite occurs in the footwall and is overprinted by a late ore with magnetite, pyrrhotite, arsenopyrite, pyrite, sphalerite, chalcopyrite and galena with minor cubanite, tetrahedrite and bornite. The existence of a skarn-like assemblage (pyroxene, actinolite, epidote) in association with the second type of ore, suggests that this ore is probably metasomatic and the product of an hydrothermal activity related either to the Variscan metamorphism or to some small epizonal dioritic to quartz-dioritic stocks and dykes of unknown age that occur nearby. The strong deformation precludes any clear genetic interpretation for the first type of ore. However, the widespread evidence of replacement suggests that these massive sulphides formed by sub-seafloor processes. In fact, there exist also lenses of meta-exhalites with jasper and Mn-bearing minerals (pyrolusite, braunite, rhodonite) probably equivalent to the sulphides but formed in a more oxidised and cooler environment

Sulphur isotope data of sulphides from María Luisa range between 13 and 19.5 ‰ (Conde and Tornos, unpub. data), indicating that the source of sulphur is neither magmatic nor biogenic, but possibly resulting from the leaching of the host rocks, and ultimately derived from the thermo-reduction of seawater sulphate.

Some Zn-Pb-Ag-barite stratiform mineralisation is also found at Aracena east of Maria Luisa mine, along the contact between the felsic metavolcaniclastic sequence and the thick marble unit (Guillou, 1967; Fernández Caliani *et al.*, 1989; Arribas *et al.*, 1990). Some poorly known mineralisation within zones of silicified marble consist of galena, sphalerite and pyrite. Most of the ore at Aracena is interpreted by these authors as related to silicified carbonatic lenses that display syn-sedimentary brecciation and are interbedded with pervasively chloritized and silicified volcanic rocks. The mineralisation here occurs as disseminations, veinlets and semi-massive bodies including galena, barite, pyrite and sphalerite with lesser amounts of pyrrhotite and freibergite; barite-galena are more abundant in the silicified limestones. Guillou (1967) quotes a regional zonation with Cu and Ag in the core and Zn and magnetite in the outer zone.

Arribas *et al.* (1990) have stated that syn-sedimentary faults, slumps and neptunian dykes can be recognised at Aracena, in support for a syngenetic to early diagenetic model for the mineralisation. In this hypothesis, the ore formed in a sub-tidal environment by exhalative processes on the seafloor. This mineralisation is probably equivalent to the Maria Luisa mine, but has Pb-enriched zones and minor proportions of chalcopyrite. Moreover, the volcanic influence is lacking at Aracena.

Differences between the Maria Luisa and Aracena orebodies can be attributed to different depositional environments and temperatures, lower at Aracena. In this perspective, the Zn-Pb-barite deposits of Aracena probably represent a (sub-)exhalative mineralisation deposited in a tectonically unstable oxidising carbonate-dominated platform, probably through direct precipitation and shallow diagenetic replacement of the carbonates. The reaction of deep reduced H_2S-bearing brines with sulphate-rich alkaline waters at rather low temperatures (<150ºC) should promote the precipitation of sphalerite, galena and barite.

Some of these deposits, specially those hosted in carbonate rocks, show effects of strong supergene alteration that may be responsible for a significant metal reconcentration, as is the case of Ag in **Fuenteheridos** or Zn in Preguiça and Vila Ruiva gossans, that rendered these deposits economic in the past.

As a whole, these volcanic-related deposits share many features with those of Puebla de la Reina (see above). Lead isotope data suggest that they are broadly contemporaneous and of Upper Proterozoic-Lower Cambrian age. Moreover they are consistent with derivation of the metals from two different sources, i.e., a crustal reservoir, that could correspond to an evolved continental crust similar to that of the Central-Iberian Zone, and a more primitive source, probably mafic magmas generated by the Cadomian subduction (Tornos and Chiaradia, 2004). The tectonic setting of these massive sulphides might thus have been be a syn-Cadomian magmatic arc-basin system.

Orogenic gold mineralisation (Proterozoic? Variscan?)

Orogenic gold mineralisation occurs along 35 km in the NW sector (Montemor-o-Novo) of this belt. It has general characteristics, including the host rocks and the age (Proterozoic Escoural Formation), the alteration and the mineralisation similar to those of the Portalegre area gold deposits. At places, calc-silicate/skarnoid rocks and thin granite dykes can host minor mineralisation (Inverno, 1997). The gold concentrations occur in the vicinity of the Montemor-o-Novo NW-SE shear zone, and are hosted by sheared metamorphic rocks affected in part by a high grade metamorphism (Pereira *et al*., 2002).

According to Ribeiro *et al*. (1993) and Ribeiro (1994), gold mineralisation of **Chaminé-Casas Novas** (63; Fig.2) occurs in veins and lenses of variable thickness, developed within a major, near-vertical, NNW-SSE turning to N-S shear zone that affects mainly biotite schists of Proterozoic age. The mineralised structures consist of centimetre-wide quartz + arsenopyrite veinlets intersecting high grade decimetre- to metre-wide quartz veins parallel to the cleavage and often showing digitations into the country rocks. In the latter structures, three main stages of mineral deposition were identified. The first one comprises the development of quartz ± tourmaline ± ankerite + arsenopyrite + löllingite ± maldonite ± bismuth ± pyrrhotite ± pyrite. The second is responsible for the deposition of quartz + chlorite + ankerite + arsenopyrite + gold ± chalcopyrite ± pyrite, and the third stage involves the precipitation of quartz + chlorite + marcasite + covellite. The host rocks record the effects of intense hydrothermal alteration, particularly strong silicification and chloritization besides incipient sericitization and erratic dissemination of pyrite and arsenopyrite. These textural-chemical transformations confirm the epigenetic nature of the mineralising process and document well the polyphase character of fluid/rock interactions under decreasing temperature conditions between *ca.* 400ºC and 200ºC.

A total resource of 4.45 Mt at avg. 2.81 g/t Au is known in this area, 60% of which from the main deposits, Chaminé (1.2 Mt), Casa Novas (1.7 Mt) and Braços (0.1 Mt), 30% from nearby deposits (Banhos, Ligeiro, Caras and Covas) and the remainder from other deposits and occurrences in the area (Faria, 1997).

The 150 m-long, 25 m-thick **Braços** deposit (66), grading avg. 5 g/t Au, consists mostly of a silicified zone located along the thrust contact between Proterozoic schists with a sequence dominated by quartz-feldspar porphyritic intrusive rocks, amphibolites (and amphibolite gneisses) and felsic metavolcanic rocks. The eastern end of the deposit is disrupted by a normal late-Variscan N-S fault. Chlorite, either in quartz veins or in host rocks, and pervasive Fe-dolomite? alteration are at places present in the mineralised zones. Gold (at times visible) is accompanied by pyrite, arsenopyrite, löllingite, chalcopyrite, galena and barite (Inverno, 1997; SIORMINP, 2002).

In the western portion of this Montemor-o-Novo gold mineralised area, close to the Ferreira-Ficalho thrust, gold-bearing quartz vein mineralisation is also hosted in the same Proterozoic Escoural Formation. Here, the gold mineralisation is related to stibnite (e.g., **Palmas**; 21; Fig. 2) or pyrite and base metal sulphides, mostly chalcopyrite (e.g., **Caeira**; 68) (Goinhas and Martins, 1986). Some gold mineralisation, in quartz veins and disseminations, also occurs in silicified schists, felsic-intermediate metavolcanic and calc-silicate rocks of the Cambrian Monfurado Formation (central part of the area), accompanied by dominant pyrite (e.g., **Monfurado**; 61) (Faria, 1997).

Iron-rich skarns (Variscan)

Along with the skarn-like replacements superimposed to the mafic volcanic-related magnetite mineralisation (see above) there are some massive, calcic and magnesian iron-rich skarns, chiefly developed along the contact of marbles with diorite-gabbro intrusions of the Beja Igneous Complex (Silva, 1945; Neiva, 1952). The small **Alvito** iron deposit (29; Fig.2) occurs in Early Cambrian metalimestones in contact (through a N-S thrust) with diorites of the syn-Variscan Cuba gabbro-diorite. The mineralisation consists of irregular masses and stratiform lenses of magnetite with serpentine, olivine, asbestos, chlorite, garnet, diopside, amphibole and idocrase, or even calcite and dolomite. Pyrite, pyrrhotite, chalcopyrite, and rare galena also occur at places. There is a resource of 0.7 Mt at 44% Fe, 17% SiO_2 and 1.5% S. Though skarn development through metasomatism appears to be the main metallogenic process, it has been proposed that prior to it a volcanogenic process would have concentrated metals in Cambrian (?) volcanic rocks of the area (Silva, 1948; Carvalhosa and Zbyszewski 1972; Carvalho, 1976; SIORMINP, 2002)

Magnetite and sphalerite-rich skarnoids (Variscan?)

In the Aracena massif there are some small sphalerite-magnetite stratabound orebodies enclosed in skarn-like assemblages including garnet, pyroxene, clinoamphibole and epidote. They are probably bimetasomatic skarns formed by the reaction of metamorphic fluids with calc-silicate hornfels.

Wollastonite skarns (Variscan?)

Large lenses, up to 6-8 km long and 1 km wide, of calcic skarns with massive wollastonite are found in the Aroche area (Huelva) within the Aracena Metamorphic Band. They formed by the replacement of high grade marbles, interbedded with calc-silicate hornfelses, schists and different types of orthogneisses of Upper Proterozoic-Lower

Cambrian age. Discordant veins of leucogranite and quartz probably related to nearby Variscan granite and gabbro plutons were probably at the origin of these replacements (Fernández *et al*., 2002).

Graphite in metamorphic rocks (Variscan?)

In the proximity to the wollastonite mineralisation but interbedded with the amphibolite gneisses, quartzites marbles and calc-silicate hornfels, there exist some graphite-bearing lenses that were probably the product of high-grade metamorphism of organic matter-rich layers (Rodas *et al*., 2000). Small minable high-grade orebodies are located in veins or shear zones that transected the stratabound mineralisation.

Cu veins (Variscan)

There are several old mines and prospects that worked Cu- and Co-As-bearing lodes controlled by strike slip fault zones (Oliveira, 1986); minor Co-As occurrences with arsenopyrite and safflorite are found nearby. At **Rui Gomes** (55; Fig.2), the main mined lodes are heterometric tectonic breccias containing heterolithic fragments cemented by late and coarse-grained aggregates of siderite + ankerite ± calcite ± quartz, locally enriched in chalcopyrite and pyrite. The development of these epigenetic lodes is ascribable to the hydrothermal activity correlative of Late-Variscan strike slip faults formation and/or reactivation.

2.7. S. Cristóvão-Beja-Serpa Belt

The geological background of the S.Cristóvão-Beja-Serpa belt is largely dominated by the Beja Igneous Complex (BIC), a wide curved intrusive belt that can be followed for *ca.* 100 km in the westernmost domain of the OMZ southern border in Portugal, resulting from important synorogenic, Variscan magmatic activity developed from Frasnian-Famennian to Late Visean times. This belt can be divided into three major units: 1) the Beja Gabbroic Complex (BIC), mainly consisting of olivine-bearing gabbroic rocks, bordered by heterogeneous diorites resulting from variable extents of magma mixing or crustal assimilation at the margin of the intrusion; 2) the Cuba-Alvito Complex, comprising mostly granodiorites, diorites and gabbros; and 3) the Baleizão Porphyry Complex, a late, epizonal intrusion that includes different types of porphyry rocks (Andrade, 1974, 1983; Perroud *et al.* 1985; Santos, 1990; Santos *et al*., 1990; Dallmeyer *et al*., 1993; Quesada *et al*., 1994). The main known mineralisation is intimately related to the magmatic differentiation path (e.g. Fe-Ti-V), magma mixing and/or crustal assimilation processes (e.g. Cu(-Ni)) and the emplacement/cooling of late porphyry intrusions (e.g. Cu(-Ag-Au?)). Other, minor, mineralisation includes Fe-skarns (e.g. **Corujeiras;** 46; Fig.2) and Sb-Cu-(As-Au) veins (e.g. **Ventosa;** 53) related to the development and further reactivation of Late-Variscan strike slip faults (Mateus *et al*., 1998b). These prospects are similar to those found around or within the Variscan plutonic complexes in the Olivenza-Monesterio Belt.

Fe-Ti-V mineralisation (Variscan)

This mineralisation is well characterised in the **Odivelas** (54; Fig. 2) area. Detailed geological studies (Silva *et al.* 1970, Andrade 1983, Santos *et al.* 1990, Mateus *et al*., 2001b; Jesus, 2002) show that the outcropping rocks in the westernmost part of BIC are quite diverse and often layered, forming two main Series that show normal polarity and a gradual contact. The lower magmatic sequence embraces three main groups of layers. The lower group comprises essentially olivine leucogabbros, within which layers and lenses (and/or blocks?) of troctolitic rocks and of cumulates (olivine melanogabbros, wehrlites and websterites) can be recognised, besides irregular bodies of massive accumulations of coarse-grained magnetic oxides. These bodies, irregular in shape, at approximately right angles to the regional layering and of considerable size (up to an estimated 50 tons each - Silva, 1945), are mainly composed of vanadium-bearing titanomaghemite, ilmenite, and accessory maghemite (Mateus *et al*., 2001b, Jesus, 2002). The research carried out also shows that the magnetic anomalies are not limited to the small area surveyed for iron ores in 1944 (Silva, 1945) and that the mineralised bodies are quite enriched in titanium and vanadium (up to 10.05% of TiO_2 and up to 0.99% of V_2O_5); this interpretation agrees with the results previously obtained by Fonseca (1999) and Gonçalves *et al*. (2001) concerning the available geophysical and soil geochemistry data, respectively. No accurate reserve estimates are presently available.

Cu(-Ni) veins and stockworks (Variscan.).

Work recently carried out in the Odivelas-Ferreira do Alentejo area enabled the identification and the preliminary characterisation of a Cu(-Ni) mineralising system within the upper, outcropping layered gabbroic Series (Mateus *et al*., 2001a; Jesus, 2002). This Series consists mostly of olivine-pyroxene leucogabbros, olivine leucogabbros and gabbros that are strongly metasomatized and massive pyrrhotite+chalcopyrite+pyrite±pentlandite aggregates fill up anastomosed centimetre-thick vein arrays. The available whole-rock analysis data show that Cu and Ni contents of the massive sulphide aggregates may reach up to 14000 and 1500 ppm, respectively; no other in-formation is presently available. The development of this type of mineralisation is envisaged as a result of late fluid circulation within the fractured gabbroic Series, probably during the late stages of their cooling.

Cu(-Ag-Au?) epithermal systems (Variscan)

Epithermal mineralisation related to the late magmatic activity of BIC is known but poorly characterised in detail. The most important mineral occurrences are **Corte Pereiro** (40; Fig. 2), **Caeirinha** (41) and **Alcáçovas** (42) (*e.g.* Oliveira, 1986; Relvas, 1987; Massano, 1988; Mateus *et al.*, 1998b). These mineralising systems are characterised by several superimposed and crosscutting stages of pervasive fracturing and hydrothermal circulation and contain minor, but significant amounts, of Ag and in a few exceptional cases, also Au, Bi, Cu, Pb and Zn.

Sb-Cu(-As-Au?) veins (Variscan)

As referred to in Mateus *et al.* (1998b), the Ventosa prospect is representative of the mineralisation related to hydrothermal activity triggered by late reactivation of shear zones and/or by the development of Late Variscan strike slip fault zones. In this prospect, the lodes are controlled by a relatively complex array of structures that are subsidiary to a major WNW-ESE left-lateral shear zone. They are hosted in silicified metamorphic rocks, which sometimes show sulphide (pyrite)-rich disseminations. The ores, randomly distributed within a polyphase hydrothermal quartz-carbonate assemblage, comprise stibnite and tetrahedrite, as well as significant amounts of pyrite, arsenopyrite and berthierite and accessory amounts of chalcopyrite, marcasite and gudmuntite, famatinite-stibioluzonite, aurostibite, chalcostibite, chalcocite and covellite; poorly crystallised Sb and/or Fe-Sb oxides (such as schafarzikite and tripuhyite), besides kermesite and hematite/goethite, are the main products of ore weathering.

2.8. The Beja-Acebuches Ophiolite Complex

The Beja-Acebuches Complex (BAOC) is an extremely dismembered ophiolite sequence incorporated in the Variscan South Iberian Suture. The lower and intermediate sections of BAOC, to be found essentially in Portugal, comprise respectively peridotites (mainly harzburgites) and gabbroic rocks (gabbro-gabbronorites and minor troctolites). The upper sections of BAOC, well represented in Spain, consist essentially of amphibolites derived from basaltic lavas of tholeiitic nature; deep marine sediments and examples of sheeted dike complexes are almost absent (Munhá *et al.*, 1986, 1989; Crespo, 1989; Quesada *et al.*, 1994).

Cr mineralisation (Variscan)

Cr-spinel is an important accessory mineral phase in all of the metaperidotites and metawehrlites/troctolites included in BAOC, for which the whole-rock Cr content goes up to 3620 ppm. In the seventies, the Serviço de Fomento Mineiro drilled several, although very thin, banded chromitites within strongly serpentinised metaperidotites belonging to the Ferreira do Alentejo-Mombeja ultramafic domain. It is also worth noting that the PGE contents of BAOC peridotites are quite low (Mateus and Figueiras, 1999a, b).

Ni-Cu(-Co) sulphide dissemination (Variscan)

BAOC metagabbroic rocks comprise most times accessory amounts of sulphides, usually forming tiny and randomly distributed aggregates of irregular morphology, mainly consisting of pyrrhotite + pyrite ± chalcopyrite. Microscopic sulphide aggregates appear, however, to be characteristic of ilmenite-free rocks, namely of the metatroctolites found at **Palmeira** (49; Fig. 2) (Guadiana Valley), whose Ni+Cu+Co content average is in the order of 1050 ppm (Mateus *et al.*, 1998a). In these variably serpentinised rocks, sulphides occur: 1) as randomly disseminated irregular millimetric globules of pentlandite (and/or bravoite) + pyrrhotite ± chalcopyrite ± mackinawite; 2) as pentlandite (and/or bravoite) + pyrrhotite ± heazlewoodite aggregates within magnetite fringes surrounding altered Cr-spinel; and 3) as fine aggregates of bravoite within weakly disseminated awaruite ± pyrite. The sulphides are interpreted as magmatic.

Cu sulphide disseminations (Variscan)

Polyphase hydrothermal activity along WNW-ESE shear zones led to the development of silica-carbonate infillings and of prominent alteration halos in the mafic and ultramafic host rocks (Mateus *et al.*, 1999b). Usually, the hydrothermal precipitates exhibit variable amounts of disseminated sulphides (mainly pyrite ± chalcopyrite ± sphalerite) or of their weathering products, besides several generations of carbonates. With few exceptions, the whole-rock base metal contents are typically low (< 500 ppm, on average). It should be noted, however, that the only real evidence for historical attempts of mineral exploitation in BAOC is represented by the abandoned trial workings for Cu in western **Mombeja** (50; Fig. 2) village, which are located along the hydrothermal infillings of a WNW-ESE shear zone adjoining strongly carbonatized ultramafic rocks (Mateus *et al.*, 1998c); in this particular case, Cu and Zn contents may reach 1.5% and 1200 ppm, respectively.

3. Discussion and conclusions

Ore deposits in the Ossa-Morena Zone can be grouped into very different types, some of them unusual worldwide. This is chiefly the result of a complex tectono-metamorphic evolution that gave rise to a variety of geological settings where very different ore-forming systems set in. Three main factors are responsible of this particular complex evolution. The first is the position of the OMZ between two contrasting terranes, the Central-Iberian Zone to the north and the South Portuguese Zone to the south. Both terranes experienced a different evolution. The South Portuguese Zone is characterised by a long-lived crustal evolution with minor orogenic input, whilst the OMZ is a polyphase terrane that behaved as an active magmatic arc during Cadomian and Variscan times (Quesada *et al*., 1987; Quesada *et al*., 1991; Eguiluz *et al*., 2000). The second key factor concerns the transpressional type of deformation that existed during the Cadomian orogeny (Liñán and Quesada, 1990), and particularly during the Variscan orogeny. Most present-day large structural features are Variscan; however many of them are rejuvenated older structures. This is the case of the many longitudinal transcrustal, W-E to WNW-ESE-trending faults that strongly controlled sedimentation, magmatism and hydrothermal activity since the Late Proterozoic (Quesada *et al*., 1987). These structures have probably controlled the deposition of many ore deposits in OMZ, as they focused magmatism, heat flow and hydrothermal activity particularly at local extensional zones such as pull-apart structures and releasing bends (Tornos *et al*., 2002). The third factor, has only been recently brought to light. Deep reflection seismic sounding (Simancas *et al*., 2003) has shown that a *ca.* 5 km thick body with the geometry of a sill exists at 10-15 km depth, underneath most of the Ossa-Morena Zone. Because of seismic properties and geometrical considerations this body is probably formed by mafic and ultramafic rocks and has to be of Variscan age. Many metallogenetic features of the OMZ might be related to this hidden mafic to ultramafic body. Its existence had been anticipated by Casquet *et al*. (2001) and Tornos *et al*., (2001) on the basis of geochemical and textural evidence from the Aguablanca stock and related Cu (-Ni) mineralisation. It might also be the explanation for the ^{207}Pb-depleted lead isotope signatures which are characteristic of the OMZ (Tornos and Chiaradia, 2004).

3.1. Metallogenic evolution

Pre-Cadomian metallogenesis

The Pre-Cadomian metallogenesis is not significant. In fact, only few deposits undoubtedly associated with Proterozoic ore-forming processes have been recognised. This is the case of some chromite-rich ultrabasic rocks and stratiform Cu deposits within the Serie Negra. This scarcity of mineralisation older than the Cadomian orogenesis has to be attributed to the strong deformation and dismembering of the pre-Cadomian terranes, which have not still been recognised in the OMZ, and to the fact that most of the rocks of the Cadomian cycle were deposited in a rather stable setting where hydrothermal processes are uncommon.

Mineral deposits of the Cadomian orogenesis

The OMZ was the site of a Cadomian magmatic arc formed during the southwards subduction of the Iberian Autochthonous Terrane (Central-Iberian Zone), which preceded collision with the OMZ (Sánchez Carretero *et al*., 1990; Quesada *et al*., 1991). Despite major tectonic dismembering, general features of a typical Andean-type magmatic arc have been claimed by Sánchez Carretero *et al*.(1990), particularly a calc-alkaline andesite-dacite volcanism and plutonism. Ore deposits clearly associated with this orogeny and the related magmatic activity are scarce. Although the partly submarine magmatic arc and related back arc basin had to be favourable settings for the development of a wide variety of ore-forming systems, no major deposits have been found to date. The more significant mineralisation consists of small (sub-)exhalative deposits. These include volcanic-hosted massive sulphides (Puebla de la Reina), sedex barite mineralisation (Llerena) and rare porphyry copper deposits (Ahillones). The Tinoca and Azeteiros deposits, hosted in felsic migmatitic gneisses, could be equivalent to the Puebla de la Reina mineralisation, but underwent higher grade metamorphism. No epithermal mineralisation has been recorded, as it would be expected on behalf of the abundant volcanic and subvolcanic rocks. A sedex-like mineralisation was recognised in the foreland basin, but is restricted to a small area (Retín).

Abundant Fe and Cu-Zn volcanic-hosted and Pb-Zn-Ag mineralisation exists both in the Evora-Aracenal Belt and the North Eastern Belt that bear many similarities, among other the stratigraphical setting and the lead isotope signatures. However, the age of these deposits is still unknown. Geological reasoning suggests that they could be Upper Proterozoic to Silurian. If this mineralisation were not related to the Cadomian magmatic arc, an equivalent tectonic setting had to exist at some other time during the Lower Paleozoic in the Evora-Aracena and North Eastern belt domains.

In the absence of absolute ages, it can be questioned whether orogenic gold mineralisation hosted in Proterozoic terrains formed during pre-Cadomian, Cadomian or Variscan times.

The post-Cadomian rifting stage

This stage is characterised by a (sub-)alkaline bimodal epizonal plutonism, and volcanism, and the formation of ubiquitous (sub-)exhalative iron deposits. Some small manganese-bearing orebodies also formed under more oxidising conditions. These deposits are variable from truly exhalative to sub-exhalative replacive and deeper metasomatic ones.

The stable platform stage

Only some minor ores without relevant economic interest can be related to this stage. They include several stratiform Cu, Pb and Fe-Mn oxide concentrations, probably linked to local exhalative or diagenetic processes. A few Cu concentrations closely associated with the Ordovician-Silurian volcanism can also be included within this style of mineralisation.

Mineral deposits related to the Variscan orogeny

Ore-forming events related in time and space to the Variscan magmatism, led to the formation of most of the ore deposits in the OMZ. Most are set within pull-apart structures, major shear bands and faults and plutons of variable composition (Tornos *et al*., 2002).

A key feature of the OMZ is the absence of a preserved significant Early Carboniferous volcanism. Moreover, Variscan syn-orogenic basins (e.g., Los Santos de Maimona basin of Visean age, Rodriguez *et al*., 1992; El Guadiato basin of Visean-Serpukhovian age, Cozar and Rodriguez, 1999; among others, Gabaldón *et al*., 1985) are not typical arc or back arc basins but, instead, seem to be narrow strike-slip fault related basins, mostly filled with shallow marine to continental sedimentary sequences. Synorogenic basins are the preferential loci for the volcanic-hosted massive sulphides deposits (e.g, Barrie and Hannington, 1999; Large and Blundell, eds., 2000); however, in Southwest Iberia most Variscan massive sulphides formed only in pull-apart basins located in the allochthonous South Portuguese Zone terrane (Iberian Pyrite Belt). The OMZ basins are almost devoid of submarine exhalative deposits. Only the Nava Paredon deposit, some minor prospects and several occurrences of iron oxide mineralisation occur in the OMZ.

Syn-metamorphic probably Variscan (and/or Proterozoic?) gold and base metal mineralisation is widespread in the OMZ. Gold deposits and prospects share many features with "orogenic gold", i.e., sulphide-poor, quartz-bearing veins and disseminations, such as mineral assemblages, hydrothermal type of alteration and fluid composition. They are known from the Montemor-o-Novo, Portalegre and Guijarro-Chocolatero areas. This gold mineralisation is always related to major shear zones and thrusts that crosscut the syn-Cadomian metavolcanic sequence or metasedimentary/metavolcanic rocks of the Late Proterozoic Serie Negra.

Minor regional structures were also controls to the abundant Cu, Fe and Pb-Zn syn-metamorphic veins, usually hosted in black shales belonging to either the Serie Negra or Ordovician-Silurian terrains. They are interpreted as the result of metal remobilisation from proto-concentrations by means of circulating metamorphic fluids and subsequent precipitation along local extensional zones. Re-deposition of metals was probably controlled by system temperature, with chalcopyrite forming at higher temperatures than sphalerite, galena and iron oxides. The deepest syn-metamorphic mineralisation is represented by anatectic pegmatites.

Variscan intrusions, dated between 350 and 330 Ma, i.e., Early Carboniferous, consist of a continuous spectrum of metaluminous rocks from gabbros to monzogranites, and minor peraluminous granites. They form large, usually epizonal, roughly zoned plutons (e.g., Casquet, 1980; Pons, 1982; Sánchez Carretero *et al*., 1990). A Ni-(Cu) magmatic mineralisation was recently discovered in the mafic cumulates of the Aguablanca stock. It probably resulted from combined crustal assimilation (of the Serie Negra) and fractional crystallisation processes in a predicted deep magma chamber (Casquet *et al*., 2001; Tornos *et al*., 2001). This chamber might be correlated with the recently discovered, probably mafic to ultramafic body (Simancas *et al*., 2003), which apparently spreads under most of the OMZ, in the middle crust. The Aguablanca deposit seems to be rather unique in that it is one of the few syn-orogenic Ni (-Cu) orthomagmatic deposits worlwide described so far. The Beja igneous complex is rather similar to Aguablanca and other Olivenza – Monesterio Belt plutons. It contains irregular and small Fe-Ti-V and Cu-(Ni) mineralisation that formed by processes similar to those invoked for Aguablanca. Some epithermal Cu(-Ag-Au?) prospects in the S.Cristóvao-Beja-Serpa Belt might be also related to late intrusions of the Beja igneous complex.

Early Cambrian carbonate rocks adjacent to the plutons can be host to typical calcic iron-rich skarns. However, the relative contribution of skarn-type metasomatism to the formation of iron oxide deposits has long been debated. Since Cambrian carbonates are overlain by volcanics that contain allegedly exhalative Fe ores, the question as to whether some large stratiform orebodies are Cambrian or Variscan remains open. However, systematic isotope data of magnetite from some of those orebodies (Galindo *et al*., 1995; Darbyshire *et al*., 1998) suggest that magnetite achieved isotope equilibrium with nearby Variscan igneous rocks. This in turn implies that fluids involved were equilibrated with the igneous rocks. An earlier stage of shear zone-related actinolite-albite alteration (with magnetite) similar to the hydrothermal iron oxide stage of the Fe-ox (Cu-Au) deposit type, has been advocated by Tornos *et al*. (2003). This iron oxide mineralisation might be indicative of a vertical magmatic-hydrothermal continuum.

Gold-copper mineralisation is related in space to the metaluminous plutons. This includes Cu-Bi-Au veins, Au-only disseminations within leucogranites, and reconcentration along shear bands. This mineralisation is always younger than the iron oxide type. Furthermore iron oxide were a preferential host rock for the Au-Cu ores. In fact, oxidised environments destabilise thiosulphide complexes, such as those of Cu, Bi and Au, but not chloride complexes, such as Zn, Pb or Ag.

Late orogenic peraluminous granodiorites to granites with poorly constrained ages between 310 and 280 Ma, are related to a different style of mineralisation. Cu-Pb-Zn perigranitic veins display intra- and peri-plutonic zoning with respect to the biotite granite type of the Pedroches plutonic massif (Ovtrach and Tamain, 1977). However, there is no evidence as to the involvement of igneous fluids in these systems. The pluton probably acted as a heat source only. Reduced meteoric water was involved in large convective cells around the pluton. The metals were leached out from the host rocks and precipitated in a temperature-dependent concentric pattern, with chalcopyrite in the inner part and galena in the outer part. The presence of barite and fluorite veins in the district suggests that mixing with cool, oxidising meteoric waters took also place near the surface.

Younger peraluminous leucogranites display characteristic hydrothermal alterations. Tungsten-rich vein fields are found near outcropping or hidden, granitic cupolas in the Pedroches, San Nicolás, La Bazana and Oliva de Frontera areas. They are similar to those found elsewhere in the Iberian Variscan Belt (Tornos and Gumiel, 1992). These vein systems are representative of different depths, from deep systems as at La Bazana, to veins related to hidden granites, such as those at Oliva de la Frontera. Distal Zn-rich skarns, bismuth-rich veins and Sn replacements might also be related to these late leucogranites.

Late Variscan wrench faulting and associated felsic-mafic magmatism were probably responsible for replacive and vein-like mineralisation in the Usagre area. Assemblages of Hg-, Sb-, As-, Pb- and Ba-bearing minerals, fluid inclusion data and regional alteration patterns, resemble those of epithermal deposits. Probably synchronous to the former are the widespread Pb-Zn veins near or within the Tomar-Córdoba Shear Zone. They formed from low temperature (<250º C) convective meteoric waters. Heat was apparently furnished by small intrusive bodies within the shear zone.

The Late Variscan –or younger- hydrothermal activity apparently unrelated to igneous activity of any kind is well established. Metals were extracted from either sedimentary-diagenetic disseminations in host rocks or earlier concentrations, and deposited along fault segments of variable direction through boiling, cooling or fluid mixing processes at rather low temperatures (<250ºC) and depths. The main metal associations of this stage are Cu(Zn-Pb) and Sb-Cu(-As-Au).

The post-Variscan hydrothermal activity

The onset of the Alpine rifting led to fracture reactivation and renewed hydrothermal activity. Minor barite and uranium vein-like mineralisation were formed at this stage.

3.2. Tectonic environment: A vertical continuum in an oblique setting

The strong dismembering induced by Variscan tectonics precludes any interpretation of the original relationship between the different pre-Variscan deposits. However, the study of the Variscan metallogenesis shows that there is a straightforward link between oblique tectonics and ore-forming processes. Such a relation of mineral deposits to transpressional deformation was first documented by Sanderson *et al*. (1991) north of the Tomar-Córdoba Shear Zone and has been recently proposed for the OMZ and South Portuguese Zone by Tornos *et al*. (2002).

In fact, it is possible to envisage a rather continuous vertical evolution of the hydrothermal systems during Variscan times. The common link between most of the Variscan mineralisation is its relation to extensional crustal domains associated with strike slip zones, including pull-apart basins and structures in the shallow portion of the system (approx. less than 1-3 km depth), or more subtle structures, such as bending zones, in the lowermost system counterparts. As a whole, the different mineralisation styles define a continuum from deep pegmatites and orogenic-type gold-only veins and replacements to exhalative massive sulphide or oxide deposits. Following a theoretical model, the deep pegmatites should be overlain by the orogenic-type gold deposits and the Cu, Pb-Zn and Fe syn-metamorphic veins. The epizonal metaluminous magmatism is related to skarn, iron oxide replacements, Ni-(Cu) magmatic pipes and Cu-Au mineralisation, while the peraluminous magmatism is associated with different base metal veins, W-Sn, greisens and replacements. Finally, the shallow hydrothermal systems should include epithermal-like Hg replacements and Pb-Zn veins, besides (sub)-exhalative massive sulphides and iron oxides.

3.3. The alternating mineralising zones

Perhaps the more intriguing feature of OMZ is the existence of several alternating Zn-Pb(-Cu) and Fe(-Cu) NW-SE to WNW-ESE belts some hundred km long and about 10-50 km wide, that are subparallel to the main Variscan structures. The North Eastern Belt, is characterised by a complex metallogeny, with very different styles of mineralisation, including Zn-Cu-Pb volcanic-hosted massive sulphides, Sn replacements and perigranitic W-(Sn), Cu, Zn-Pb, Bi-(Co-Ni) and barite-fluorite veins, all formed at small depths. Lead isotope data (Tornos and Chiaradia, 2004) suggest that metals were scavenged from a crustal source with an isotopic signature intermediate between those of the OMZ and the Central-Iberian Zone. This mixed signature was expected from geological models (e.g., Quesada *et al*., 1987). Thus, the Obejo-Valsequillo-Puebla de la Reina Domain has a typical OMZ basement, overlain by a Paleozoic sequence similar to that of the Central-Iberian Zone. The Arronches-Córdoba Belt contain Zn-Pb mineralisation, both as stratabound deposits of Proterozoic age as veins. Moreover significant orogenic gold mineralisation also occurs in the Portuguese part of this belt. Zn-Pb mineralisation is also common in the North Central Belt, largely as veins. The Olivenza-Monesterio Belt shows the largest variety of ore deposits of the OMZ. Most of the Fe-(Cu) orebodies of the area are found within this belt, including pre-Variscan and Variscan volcano-sedimentary ores, Variscan skarns, karst fillings and veins. Remarkable is the existence of syn-orogenic orthomagmatic Ni (-Cu) deposits related to the Variscan magmatic arc plutons. The South Central Belt contains few ore deposits, particularly stratabound Fe-Mn, Cu and P prospects. The Évora-Aracena Belt is dominated again by Zn-Pb-(Cu)-bearing orebodies, but orogenic-type Au mineralisation also occurs. Cu, along with other metals (Ni, Ag, Au, ...) regains importance in the S. Cristóvão-Beja-Serpa Belt. Finally Cr and Cu disseminations (along with Ni and Co) are of local importance in the Acebuches Ophiolite Belt.

Locutura *et al*. (1990) interpreted that differences among the ore belts reflected crustal heterogeneities within the OMZ. However, recent lead isotope data do not show significant differences among the various metallogenic belts (Tornos and Chiaradia, 2004). In consequence other variables had to play a role in explaining metal diversification. These might include variations in the composition of the metal reservoir, that could not be traced by lead isotopes, and distinct P-T conditions of transport and precipitation of the metals, Cu mineralisation usually forming at higher temperature than Zn-Pb ores.

The OMZ represents a somewhat unique group of different metallogenic belts, with a non-conventional metallogenesis and zoning that cannot be easily explained on the basis of current geotectonic ore evolution models. The pre-Variscan metallogenesis can be tentatively explained on the basis of an Andean-type active continental margin with a magmatic belt and related basin. This was followed by post-orogenic extension. However, Variscan metallogenesis although related again to a magmatic arc setting is dramatically different. Variscan mineral deposits include peculiar hydrothermal iron oxide, magmatic Ni-(Cu) or Sn replacements, but scarce volcanic-hosted massive sulphide deposits. According to the present state of knowledge, this metallogenesis in an active magmatic arc can only be satisfactorily explained by invoking dominant strike slip deformation and synchronous magma emplacement (Tornos *et al*., 2002). A distinct geological feature of Variscan age is the deep, probably mafic and ultramafic body, recognised through seismic work all beneath the OMZ (Simancas *et al*., 2003). It probably played a significative role in the genesis of some ore deposits, particularly some Fe orebodies and Cu-(Ni) mineralisation in the Olivenza-Monesterio Belt and San Cristovao-Beja-Serpa Belt. Why this hidden body was intruded in the middle crust during Variscan orogenesis is still uncertain. A transpressional regime of deformation during Variscan orogeny was characteristic in the OMZ both during subduction and further collision with the South Portuguese Zone.

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