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EVOLUCIÓN TECTONO-METAMÓRFICA DEL DOMINIO DE ALTO GRADO DE LA BANDA METAMÓRFICA DE ARACENA

Departamento de Geodinámica y Paleontología
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Lo único seguro es
que quién sabe

Julio Cortázar

A Sara, María y Antonia, por supuesto

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ABSTRACT

TECTONO-METAMORPHIC EVOLUTION OF THE HIGH-GRADE DOMAIN OF THE ARACENA METAMORPHIC BELT (SW IBERIA)

CHAPTER 1.- INTRODUCTION

The boundary between the Ossa-Morena zone (OMZ) and the South Portuguese zone (SPZ), which are two of the main units of the Iberian Massif, is marked by the presence of a tectono-metamorphic terrain known as the Aracena metamorphic belt (AMB). The AMB was first defined and divided into domains by Bard (1967a, b; 1969). These studies dealt mainly with geochemical and metamorphic features of the belt. Later on, several publications by Bard (1970; 1977), Bard and Moine (1979), Dupuy et al. (1979), Apalategui et al. (1983; 1984; 1990), Barranco et al. (1983), Munhá et al. (1986), Crespo-Blanc (1987; 1991), Crespo-Blanc and Orozco (1988; 1991), Ábalos et al. (1991), Fonseca and Ribeiro (1993), Quesada et al. (1994), Giese et al. (1994a, b) and Castro et al. (1996a, b; 1999) contributed to a better understanding of the structure and metamorphism in different areas of the AMB.

The AMB is a high-grade metamorphic band, some tens of kilometres wide and more than 100 km long that outcrops from Beja, in Portugal, to Almadén de la Plata, in the Seville province (Spain), whose limits lay parallel to the main regional structural trends. The AMB underwent a high-temperature/low-pressure (HT/LP) metamorphic event during the Variscan orogeny at the Upper Palaeozoic (e.g., Bard, 1969; Crespo-Blanc, 1991; Castro et al., 1996a, b; 1999). This work has focused on the central sector (between the villages of Cortegana and Santa Ana La Real, in the Huelva province) of a high-grade band located at the southern boundary of the AMB. The mentioned studies comprise field, petrographic, mineral chemistry and whole-rock geochemistry, which have been dedicated to the analysis of structure, metamorphism, magmatism and isotope geochronology of the AMB.

CHAPTER 2.- LITHOSTRATIGRAPHY AND PETROGRAPHY

According to the division proposed by Castro et al. (1996a, b; 1999a), which is based on lithological, geochemical, metamorphic and structural features, two different domains can be distinguished in the AMB: a southern oceanic domain (OD), and a northern continental domain (CD). The present research has focused on the highest-grade areas of the AMB, which are the high-grade zone of the CD and the Acebuches metabasites of the OD.

2.1. OCEANIC DOMAIN

Two groups of rocks are distinguished in the OD. In the northern part, the Acebuches metabasites define a series of amphibolites and mafic schists which, according to several geochemical studies (Dupuy et al., 1979; Munhá et al., 1986; Quesada et al., 1994; Castro et al., 1996b), are the result of the metamorphism of a former oceanic crust with MORB affinities. To the south of the Acebuches metabasites is located the Pulo do Lobo terrain, that has been interpreted by Eden (1991) as a part of an Variscan accretionary prism

The Acebuches metabasites outcrop in a long (> 100 km), narrow (around 1 km wide) band with a WNW-ESE direction and dipping to the north. This band is disrupted by late Variscan sinistral strike-slip faults, but shows a nearly constant thickness in the studied area (about 600 m). The Calabazares shear zone separates the Acebuches metabasites from the CD of the AMB, located to the north. The metabasite sheet overlies to the south, through the Southern Iberian shear zone (SISZ, Crespo-Blanc and Orozco, 1988), the Pulo do Lobo terrain.

The main rock types of the Acebuches series are amphibolites with minor amount of mafic schists and metadolerites. Taking into account the effects of the two main tectono-metamorphic events produced in the Acebuches metabasites, four main rock types have been defined in this series which, from the structural top to the structural bottom, are: (1) banded amphibolites with clinopyroxene, (2) banded amphibolites without clinopyroxene, (3) sheared amphibolites and (4) mafic schists. The different facies appear in parallel bands that follow the structural pattern of the OD. These bands can be repeated by means of inverse shear zones related to the SISZ. Additionally, in those areas of the lower half of the pile preserved from deformation and metamorphism, metadolerites with a relict igneous fabric have been found. The Acebuches metabasites present plagioclase and hornblende as the principal phases (> 90 % of the modal composition).

The banded amphibolites appear in the upper half of the Acebuches series, and they show a characteristic centimetric to decimetric granulometric layering, which is parallel to a metamorphic foliation defined by the preferred orientation of amphibole prisms. The contacts are sharp and there are not significant differences in composition between bands (Castro et al., 1996b). The banding is best developed near the top of the series, in the Hb-Cpx zone. On the contrary, the banded amphibolites of the Hb zone are medium-grained, lack the largest grain size bands and their banding is, therefore, less evident.

In the coarse-grained banded amphibolites leucosomes with subhedral to euhedral amphiboles as well as euhedral zoned plagioclases have been observed. This texture, along with a typical tonalitic mineral assemblage suggests that these leucosomes could have been originated by partial melting of the amphibolite. Experimental melts obtained by dehydration melting of the Acebuches amphibolites are also tonalitic in composition (López and Castro, 2001).

The lower half of the Acebuches series comprises sheared amphibolites and mafic schists. Both rock types are fine-grained and show a penetrative mylonitic foliation as well as a stretching lineation, which seem to be due to the deformation produced in the SISZ.

In this work, only the schists and quartzites from the upper limb of the Pulo do Lobo antiform, which are in contact with the Acebuches metabasites through the SISZ, are studied.

2.2. CONTINENTAL DOMAIN

To the north of the Acebuches metabasites is located the CD of the AMB which, according to its metamorphic grade has been divided into a high-grade zone, near the contact with the OD, and a low-grade zone to the north of the former (e.g., Castro et al., 1996a, b; 1999a). The high-grade zone coincides with the Cortegana antiform (see Bard, 1969; Giese et al., 1994a). The southern overturned limb, dipping to the north, overthrusts the OD. The Cortegana-Aguafría shear zone (CASZ) constitutes the northern boundary of the high-grade zone of the CD. The low-grade zone of the CD overthrusts the high-grade zone through the CASZ.

The subdivision proposed for the high-grade zone is based on (1) stratigraphic correlations with lower grade zones of the AMB (Bard, 1969; Crespo-Blanc, 1991; Giese et al., 1994a), (2) compositional differences between lithologies and (3) field relationships. Two main rock series have been defined: the aluminous and the calc-magnesian series. According to Crespo-Blanc (1991), the aluminous series would correspond with the Precambrian La Umbría series, the marbles located at the base of the calc-magnesian series are correlated with the lower Cambrian Aracena dolomitic series and, finally, the calc-magnesian series would coincide with the bimodal volcano-sedimentary formation of Cambrian age.

The aluminous series is composed mainly of high-grade metapelitic gneisses, with subordinate intercalations of graphite rich quartzites, calc-silicate rocks and marbles. These rocks were partially molten giving rise to migmatites. According to different proportions of partial melt, stromatic migmatites, agmatic migmatites and nebulites have been defined. The contacts between different types of migmatites, although not always appear clearly, seem transitional (Castro et al., 1999a). Differences in composition of the original protolith, as well as in the partial melting reactions gave rise to different rock types, which have been defined in base of the minor phases present in melanosomes (see also El-Biad, 2000). In this sense, biotitic (± Sil), cordieritic (Crd ± Grt ± Sil), amphibolitic (Amp ± Cpx ± Crd) and charnockitic (Crd + Opx ± Sil) migmatites have been defined. Throughout the series, leucosomes can be granitic (s.s.), trondhjemitic or tonalitic in modal composition. In stromatic and agmatic migmatites, the foliation is defined by alternative milimetric layers of leuco- and melanosomes. This migmatitic layering is parallel to the regional foliation and is pervasively folded at the outcrop scale. In some stromatic migmatites, the limits between leuco- and melanosome layers are diffuse, suggesting a continuous variation in the melt fraction between bands. Frequently, leucosomes appear in veins injected through a set of fractures crosscutting all the previous structures but connected with the concordant leucosome layers. Migmatitic layering embraces enclaves of quartzites, amphibolites or calc-silicate rocks. Leucosomes can be isotropic or, alternatively, they can present a weak foliation defined by the preferred orientation of isolated blasts and biotitic aggregates defining a schlieren fabric. In all leucosomes, a relict sequential igneous texture is observed.

The aluminous series also includes kinzigitic gneisses which crop-out in decametre-scale bodies located near the contact between the CD and the OD, and show a mineral assemblage with Crd ± Grt ± Kfs ± Hc + Sil ± Pl ± Ilm ± Bt ± Qtz (see also El-Biad, 2000). Cordierite appears either as subhedral megacrysts with crenulated fibrolite aggregates in the core or as dynamically recrystallised blasts. Hercynite crystals show a skeletal habit and are associated with fibrolite and rims of plagioclase. The kinzigitic gneisses present a rough and irregular compositional layering, defined by dark cordierite-rich layers and light layers with K-feldspar and almandine-rich garnet. The mineral assemblage and the fabric suggest a restitic origin for these rocks.

The calc-magnesian series comprises different rock types such as leucocratic gneisses, calc-silicates rocks, amphibolites and marbles, whose common protolith could have been a bi-modal volcano-sedimentary series of upper Cambrian-middle Ordovician age (Bard, 1969; Apalategui et al., 1983; 1984; Crespo-Blanc, 1991).

Leucocratic gneisses are mainly composed of quartz and feldspar and both granitic and trondhjemitic have been found. According to the predominant minor phase, biotitic, amphibolic, pyroxenic and, to a lesser extent, garnet-rich and graphitic leucocratic gneisses have been found. Alternating layers formed by different types of leucocratic gneisses and, also, lateral transitions between them are common. These compositional layering is parallel to a metamorphic foliation defined by trails of the ferro-magnesian minerals. Usually, a mineral lineation defined by the preferred orientation of amphibole and clinopyroxene is observed on the foliation planes. When deformed at shear zones, a very penetrative mylonitic foliation, which embraces feldspar porphyroclasts, and an associated stretching lineation are observed.

Calc-silicate rocks and marbles occur as discontinuous bands and lenticular bodies. The marbles can either outcrop as hectometric, pervasively folded sheets located at the base of the calc-magnesian series or intercalated within the calc-silicate rocks. In both cases, marbles are characterised by coarse-to-medium-grained granoblastic textures. The main foliation of these marbles is defined by a compositional layering and a metamorphic foliation defined by trails of ferro-magnesian minerals. Additionally, calc-silicate and amphibolite bands, which have been interpreted as intercalated volcanic layers in the primitive carbonate series (Crespo-Blanc, 1991), appear as boudins parallel to the main foliation of the dolomitic marbles. These boudins usually show nearly rectangular sections with occasional development of fish-mouth limits. Chocolate-tablet structures have been also observed.

Calc-silicate rocks comprises a wide variety of rock types, with strong differences in both textural relations and mineral composition, that reflect the effects of a HT/LP metamorphic event that affected a wide range of sediments and volcanic rocks with a variable proportion of carbonates.

The continental amphibolites that outcrop in the high-grade zone appear usually related to calc-silicate rocks, near the contact with the OD. Occasionally, the main structures of marbles and calc-silicate rocks appear crosscut by amphibolitic dikes. The continental amphibolites show important variations in grain size along with a consistent mineral assemblage (Pl + Hb ± Cpx). The most characteristic continental amphibolites of the high-grade zone are coarse and very coarse-grained amphibolites (defined as El Rellano amphibolites by Castro et al., 1996b), which appear intercalated within calc-silicate rocks and marbles. These amphibolites were not affected by the main deformation event of the CD (they crosscut previous structures of surrounding calc-silicate rocks), and can either present a typically metamorphic granoblastic or a dominant igneous texture. The fine-grained amphibolites usually show a well-developed granoblastic texture, although subhedral zoned plagioclases suggest an igneous origin for these rocks.

In the northern limb of the Cortegana antiform medium-grade rocks, equivalent to the high-grade rocks of the southern limb, crop-out. The contact between both domains is marked by the Cortegana-Aguafría shear zone (CASZ, see also Crespo-Blanc, 1991). The main rock-types of this medium-grade series are leucocratic gneisses, calc-silicate rocks, marbles, amphibolites and schists. The most conspicuous formation of the medium-grade domain is the so-called La Corte series (Bard, 1969), constituted by alternating bands of amphibolites and schists. The La Corte amphibolites are fine- to medium-grained and present a penetrative foliation, defined by amphibole prisms, plagioclase ribbons and epidote-rich layers. This foliation is of mylonitic character when these amphibolites are affected by the CASZ. The mineral assemblage (Pl + Hb + Act ± Cum + Ep ± Chl ± Qtz + opaques) is typical of the greenschists facies. The La Corte schists comprise feldspathic micaschists and quartz-schists, are mostly muscovite-rich and the highest-grade mineral assemblages contain andalucite. These schists show a metamorphic foliation defined by alternating quartz-rich and mica-rich layers, as well as by the preferred orientation of phyllosilicate blasts. Evidences for a previous foliation are observed in microlithons within less deformed schists.

Basic intrusions parallel to the main structures of the high-grade zone of the CD have been reported (Bard, 1969; Castro et al., 1996a, b; El-Hmidi, 2000). Ambiguous relationships between the intrusions and their host rocks have been interpreted by El-Hmidi (2000) as an evidence of the syn-metamorphic character of these intrusions. Post-kinematic intrusions are also observed in the high-grade zone of the CD. Intermediate-to-basic intrusions comprise gabbros, diorites, quartz-diorites, and subordinate tonalites and norites. Also, small plutons of meta-aluminous leucocratic granites have been found.

CHAPTER 3.- STRUCTURE

The main structures in the AMB are E-W to WNW-ESE oriented and dip to the north. One of the most remarkable geological features of the AMB is the striking difference between the OD and CD in their structural configuration and tectonic evolution (see also Castro et al., 1996a).

3.1.- OCEANIC DOMAIN

In this work the description is focused in the structure on the Acebuches metabasites. The Acebuches metabasites are WNW-ESE oriented and dip consistently between 40° and 50° towards the NE. Three deformation phases have been identified in these rocks (Castro et al., 1996b). The OD-D1 is associated with a high-grade metamorphic stage, and affected the entire metabasite sheet. The main fabric developed during this phase is a foliation defined by the preferred orientation of amphibole and plagioclase crystals (OD-S1). Other structures include a lineation (OD-L1) marked by the alignment of amphibole crystals and S-C' structures (Ponce de León and Choukroune, 1980) defining an anastomosing pattern. The OD-S1 is best developed at the top of the amphibolite sheet where it is parallel to a prominent banding in the amphibolites. This banding has been interpreted by Castro et al. (1996a) as a result of the high-grade metamorphism of the upper part of the amphibolitic pile. The kinematic criteria appearing in the upper part of the amphibolites indicate the activity of a predominantly non-coaxial deformation history for OD-D1. Considering the high pitch shown by the OD-L1, the kinematic criteria consistently indicate a top-to-the south sense of movement, with a minor component of sinistral strike-slip movement.

The second deformation phase (OD-D2) corresponds to the activity of the Southern Iberian shear zone (SISZ). Coeval to the movement along the SISZ is a retrometamorphism of the amphibolites towards greenschist facies. The SISZ mainly affected the lower half of the amphibolite sheet and the upper part of the Pulo do Lobo metasediments. However, its geometry is quite intricate in detail, with many minor shear zones kinematically linked to the floor shear zone, defining an imbricate fan. A prominent S-L fabric was formed in association with the activity of the SISZ. OD-S2 is mylonitic and it is marked by the preferred orientation of amphibole prismatic blasts, plagioclase ribbons and millimetre-scale bands of epidote, actinolite and chlorite. Statistically, the orientation of the OD-S2 is very similar to that of OD-S1. The OD-L2 stretching lineation is defined by plagioclase ribbons and elongated amphibole blasts. OD-L2 strikes NW-SE, with moderate plunges towards SE and NW. A fundamental fact is that OD-L2 plunging towards SE are the more common in the amphibolite band, with opposite plunges dominating only in specific areas (see also Crespo-Blanc, 1991). This spatial distribution of lineations with changing plunges is explained as a consequence of the SISZ acting as a transpressive zone, according to the model of Lin et al. (1998). In this way, the areas with NW-plunging lineations are supposedly due to the influence of a more intense pure shearing component, when compared to the areas with SE-plunging lineations. Kinematic criteria consistently indicate a sinistral strike-slip movement for the simple shearing component in the SISZ.

Finally, the OD-D3 phase is limited to the effects of the Calabazares shear zone. The thickness of this band is of no more than 5 m, and affects the northern contact of the amphibolite sheet with the CD. Deformation within the Calabazares shear zone is highly heterogeneous, with the formation of a mylonitic foliation (OD-S3) and a stretching lineation (OD-L3) that also affect the rocks in the overlying continental domain. The spatial arrangement of these fabrics, and the kinematic criteria associated with them indicate a top-to-the-SSE sense of movement. This implies that the Calabazares shear zone can be considered as a thrust, and it is kinematically comparable with the structures resulting from the CD-D4 phase of deformation in the continental domain.

3.2. CONTINENTAL DOMAIN

The CD shows a very complex tectonic history (Bard, 1969; Apalategui et al., 1983; 1984; Crespo-Blanc, 1991; Giese et al., 1994a). Four different ductile deformation phases have been distinguished in the AMB. The structures resulting from the CD-D1 phase are almost completely erased by the more recent phases, especially by CD-D2. The CD-S1 foliation is only preserved as polygonal arcs of mica blasts, scattered rootless folds and crenulated fibrolite crystals included in cordierite porphyroblasts. At a large scale, the CD-D1 phase was associated, in the northern Ossa-Morena zone, with the formation of km-scale recumbent folds (Bard, 1969; Apalategui et al., 1983; 1984; Crespo-Blanc, 1991; Ábalos et al., 1991; Giese et al., 1994a; Apraiz, 1998).

The fabric due to DC-D2 is essentially planar (CD-S2), with subordinated L-tectonites. In fact, the CD-L2 lineation is only apparent along discrete, local shear zones that show a normal component of displacement. The analysis of the measured quartz c-axis fabrics, with predominant small circle girdles normal to the CD-S2, indicates that the strain ellipsoid was in the apparent flattening field, not far from the oblate ellipsoids line (e.g., Schmid and Casey, 1986). The short axis of this ellipsoid was located in a vertical position. The coeval activity of discrete normal shear zones and flattening with a vertical shortening axis points to an extensional collapse or gravity spreading as the most probable tectonic regimes for CD-D2. This deformation phase is contemporary with the high-grade metamorphic conditions in the southern part of the CD.

A third deformation phase (CD-D3) originated symmetric upright folds. Typical wavelengths for the main CD-D3 folds are of 1 to 2 km. A CD-S3 rough foliation is only apparent in the hinges of minor folds in marbles. The axial traces of the CD-D3 folds vary from the north of the CD, where they strike N-S, and are vertical, to the south of the CD, where they are WNW-ESE oriented, dipping towards the NNE.

CD-D4 is the last main phase affecting the CD. It is also the phase that contributed to a larger extent to the present map-scale structure of the CD. Two types of structures appear during this phase: large antiforms and ductile shear zones. Two antiforms essentially define the structure of the CD (Bard, 1969), the Fuenteheridos antiform to the north, and the Cortegana antiform to the south. Both show wavelengths of several km, and they are open folds moderately inclined towards the SSW. The superposition of these folds with those of the previous phases generated complex fold interference patterns. To the south of the CD, dominate the type 0 interference pattern (Ramsay, 1967), that is, redundant superposition. To the north of the CD the 3-D relative disposition of the several generations of folds originated patterns corresponding to the types C, E, F, G and I of Thiessen and Means (1980). No tectonic fabrics were developed in association with these large folds. The boundary between the Cortegana and Fuenteheridos antiforms is outlined by a major WNW-ESE oriented shear zone, the Cortegana-Aguafría shear zone (see also Crespo-Blanc, 1991). A very penetrative mylonitic foliation (CD-S4) appears within this shear zone, with an associated stretching lineation (CD-L4). CD-S4 dips 40°-45° to the north, and CD-L4 shows a large pitch. The kinematic criteria in this shear zone are scarce, but the quartz c -axis fabrics unequivocally indicate a top-to-the-SSW sense of movement. This implies an almost pure thrust displacement for the Cortegana-Aguafría shear zone. Similar structures, albeit of minor dimensions, have been found in other parts of the CD (see also Crespo-Blanc, 1991; Giese et al., 1994a). The Calabazares shear zone is kinematically comparable to these structures, and it might be considered as an equivalent of the Cortegana-Aguafría shear zone in the contact between the OD and the CD. CD-D4 is interpreted as a phase of crustal shortening accommodated by the displacement of large blocks along ductile shear zones acting as a thrust system. The antiforms are accordingly interpreted as thrust nappes or, given the low strain in the antiforms evidenced by the generalised absence of CD-D4 fabrics, as thrust accommodation folds.

CHAPTER 4.- METAMORPHISM

The AMB has been traditionally recognised as a high-temperature/low-pressure metamorphic belt (e.g., Bard, 1969; Miyashiro, 1973; Grapes and Graham, 1978). Nevertheless, few studies dealing with the metamorphism of this area have been carried out, including those by Bard (1967a, b; 1969; 1970), as well as later works by Castro and co-workers (Castro et al., 1996a, b; Díaz et al., 1997; El-Biad et al., 1997; El-Biad, 2000).

4.1.- OCEANIC DOMAIN

The study of the oceanic domain has been focused on the Acebuches metabasites. Associated with OD-D1, a HT/LP metamorphic event (OD-M1) affected the Acebuches metabasites. According to the present orientation of the structures, OD-M1 shows an inverted metamorphic gradient (Bard, 1969; Crespo-Blanc and Orozco, 1991; Castro et al., 1996b). In this sense, the structural top of the Acebuches metabasites reached the transition between the upper amphibolite and the granulite facies, and the metamorphic grade progressively decreases towards the structural bottom of the sheet. In the lower structural half of the Acebuches metabasite series, the observed inverted metamorphic gradient become steeper as these rocks were later affected by a retrograde event (OD-M2), related to the Southern Iberian shear zone, which was more intense at the base of the series. The banded amphibolites from the upper levels of the Acebuches metabasite series were not affected by OD-M2 and preserve the metamorphic assemblages and gradient due to OD-M1.

The medium-grained banded amphibolites show a typical hornblende zone mineral assemblage. The transition from the medium-grained to the coarse-grained amphibolites is marked by the clinopyroxene-in isograd, as well as anhydrous partial melting of the rock, as evidenced by the presence of leucosomes with tonalitic composition. The inverted sequence of the OD-M1 gradient is seeing as changes in the mineral chemistry of the amphiboles of the Acebuches metabasites as well as by geothermobarometers data (see also Castro et al., 1996b). In effect, towards the structural top of the series, the plagioclase is slightly more calcic and the amphibole becomes richer in Aliv and Ti, which indicate increasing temperatures (e.g., Raase, 1974; Grapes and Graham, 1978; Laird, 1980; Laird and Albee, 1981; Spear, 1981; Hynes, 1982). Thermometric calculations based on coupled substitutions in amphiboles and using the hornblende-plagioclase thermometer (Holland and Blundy, 1994) indicate that the peak temperature attained at the upper structural levels reached around 800 ºC whereas at middle levels in the amphibolites their peak temperature was slightly over 700 ºC. According to the geothermobarometers data, the banded Acebuches metabasites show a very steep field gradient (300-600 ºC/km). Furthermore, low NaM4 values in amphiboles from the Acebuches metabasites suggest low pressures for OD-M1 (Grapes and Graham, 1978; Laird and Albee, 1981; Ábalos et al., 1991). Also, semi-quantitative barometric calculations carried out by Castro et al. [1996b] point to a low-pressure (close to 4 kbar) nearly isobaric heating path.

The mineral assemblages in metabasites from the lower half of the Acebuches metabasites formed during OD-M2, a retrograde metamorphic event related to the activity of the Southern Iberian shear zone. Near the structural base, this retrograde metamorphic event reached P-T conditions corresponding to the transition between amphibolite and greenschist facies as indicated by mafic schists with actinolite, epidote and chlorite. Towards the top, the amphibolites, although affected by the deformation at the Southern Iberian shear zone, show a characteristic hornblende zone mineral assemblage, which is very similar to that of the medium-grained banded amphibolites. It seems likely that in the middle levels of the Acebuches series, the differences in P and T during the transition from OD-M1 to OD-M2 were not significant, and this accounts for a progressive transition between both events. The absence of albite and the coexistence of chlorite and epidote in the mafic schists suggest that pressure during OD-M2 was around 4 kbar (e.g., Hynes, 1982; Maruyama et al., 1983).

4.2.- CONTINENTAL DOMAIN

The CD underwent a high-temperature/low-pressure (HT/LP) metamorphic event (CD-M) that reached ultra-high-temperature conditions in some rocks (e.g., kinzigites, Patiño-Douce et al., 1997) located near the contact with the OD. The temperature rapidly decreases towards the north of the belt, defining a steep metamorphic gradient (see also Bard, 1969). The metamorphic evolution of the CD is constrained by pelitic migmatites in the aluminous series. The metamorphic evolution of calc-silicate rocks and marbles is similar to that of the aluminous rocks.

The mineral assemblages observed in the aluminous migmatites of the CD record melting related to biotite breakdown. Relic grains of muscovite within K-feldspar poikiloblasts in some nebulites indicate that there has also been partial melting by muscovite breakdown (El-Biad, 2000). In addition, hydrous melting by plagioclase breakdown must have occurred since some leucosomes are granodioritic-tonalitic (i.e., plagioclase-rich) and then, originated from Ca-rich melts (Patiño Douce, 1996; Patiño Douce and Harris, 1998). The complete breakdown of muscovite and the onset of biotite break-down indicate that temperature reached, at least, 825 ºC (e.g., Vielzeuf and Holloway, 1988; El-Biad et al., 1999). Also, analyses on graphite within aluminous gneisses and nebulites also point to temperatures close to 800 ºC (Rodas et al., 2000). On the other hand, the temperature did not reach the biotite-out isograd which, at low-pressure, is crossed around 950 ºC (Patiño Douce and Johnston, 1991; Vielzeuf and Montel, 1994). The heating path could have been either isobaric or accompanied by a slight pressure increase. In any case, pressure was low as it is deduced by the absence of kyanite (Bard, 1969). The predominance of orthopyroxene and cordierite over garnet as peritectic phases in several migmatites from the CD supports LP metamorphic conditions (see Grant, 1985; Vielzeuf and Montel, 1994). P-T calculations carried out using TWEEQU (Berman, 1991), indicate that the charnockitic nebulites reached temperatures slightly over 900 ºC. The calculated pressure is between 4 to 6 kbar with a nearly isobaric path. Several observations suggest (cf., Clemens and Droop, 1998; Spear et al., 1999) that after the thermal peak, the aluminous migmatites of the CD followed a clockwise P-T path defined by decompression and subsequent isobaric cooling. These observations are: (1) abundant cordierite and scarce, partially reabsorbed, garnet; (2) quartz-biotite coronas around orthopyroxene porphyroblasts; and (3) textures (magmatic layering) indicating that these migmatites remained within the melt-present field long enough to deform while they were partially molten.

CHAPTER 5.- GEOCHEMISTRY

Whole-rock geochemistry analyses have been carried out on different lithologies of the AMB.

The La Corte amphibolites are similar to the Acebuches amphibolites, showing T-MORB affinity in both spider MORB-normalised and REE diagrams. However, significant differences (especially in Ba, Th, Gd, Er, Ho y Tm) have been found. Accordingly, the La Corte amphibolites could have generated in an oceanic ridge environment, influenced by an anomalous segment or by an oceanic island.

The meta-aluminous character of the late intrusive granites is shown by different geochemical diagrams, and is consistent with the absence of mica and the presence of amphibole, clinopyroxene, garnet and titanite as minor phases. In an ORG normalised spidergram (Pearce et al., 1984), the late granites of the CD show a pattern similar to that of the granites related to continental collision tectonic scenario. Moreover, in the R1-R2 diagram (La Roche et al., 1980) with the fields added by Batchelor and Bowden (1985), the meta-aluminous granites of the CD of the AMB plot in the late-orogenic granites field. These observations are in agreement with the late intrusion of these small granitic plutons during the last stages of the continental collision that gave rise to the AMB.

There are certain geochemical similarities between the trondhjemitic leucocratic gneisses and the oceanic ridge granites (ORG) defined by Pearce et al. (1984). In this sense, some trondhjemitic leucocratic gneisses, spatially associated with amphibolites, could represent the acid member of the bi-modal volcanism generated in a continental rifting environment.

The ORG-normalised spidergrams, the REE diagrams and the Rb-Sr data suggest that the leucosomes of Cortegana migmatites are disequilibrium melts and, therefore, they were rapidly segregated after formed. Also, the initial 87Sr/86Sr ratio point to a crustal origin for these melts. The isotopic age for this melting event is located between 325 ± 19 Ma and 313 ± 10 Ma, which is very similar to that obtained by Castro et al. (1999) for migmatites and nebulites of the CD of the AMB.

CHAPTER 6.- DISCUSSION AND CONCLUSIONS

The main geological characteristics of the Aracena metamorphic belt, which are presented in this work, are: (1) the presence of MORB-derived metabasites (the Acebuches metabasites) at the oceanic domain; (2) an inverted metamorphic gradient affecting the Acebuches metabasites, which is interpreted as a primary feature related to SW-verging thrusting (in the present geographic coordinates); (3) a complex unit interpreted as an accretionary prism (the Pulo do Lobo terrane) that was overthrust by the Acebuches metabasites through a transpressional shear zone (the Southern Iberian shear zone); (4) a calc-magnesian series in the CD, interpreted as derived from a bi-modal volcano-sedimentary series related to the opening of a continental rifting; (5) a HT/LP metamorphism with a nearly isobaric heating path that reached maximum temperatures of ca. 975 ºC at less than 6 kbar affected the CD; (6) the metamorphic peak was associated with the main deformational event affecting the CD (CD-D2), which records an extensional collapse between two contractional events; (7) the peak metamorphic temperature is located to the contact between the continental domain and the Acebuches metabasites and abruptly decrease towards the north; (8) peak temperatures were 150 ºC higher in the continental domain than in the oceanic domain (Acebuches metabasites); (9) a diachronous evolution of the metamorphism, that migrated from west to east along the belt (Castro et al., 1999); (10) contrasted structural evolutions of the continental and oceanic domains, that were juxtaposed at the end of their tectonic histories during sinistral oblique convergence and collision; and (11) the presence of near-trench syn-tectonic noritic intrusives in the continental domain that have a high-Mg andesite composition (Castro et al., 1996; El-Hmidi, 2000).

According to the mentioned features, different tectonic models have been suggested (e.g., Ábalos et al., 1991; Crespo-Blanc and Orozco, 1991; Bard, 1992; Quesada et al., 1994; Giese et al., 1994b; Simancas et al., 2003). In this work a ridge-trench interaction model, based on that proposed by Castro et al. (1996a, b), is presented to explain the tectonic evolution of the AMB:

1. Continental rifting, oceanic ridge and passive margin stages (Cambrian-Silurian). The oceanic basalt with T-MORB affinities was generated at the oceanic ridge, and constitutes the parental rock of the Acebuches metabasites.

2. Subduction of the leading oceanic plate (Devonian?). The oceanic lithosphere that evolved towards the NE of the ridge completely subducted beneath the northern continental margin (the current CD). The convergent motion between plates led to shortening in the CD, which can be identified as the CD-D1 phase. The presence of calc-alkaline magmatism in the western and central parts of the Ossa-Morena zone supports a subduction beneath the Iberian autochthonous terrain (Quesada, 1991)

3. Ridge subduction (Tournaisean-Visean). Once the leading plate was consumed, the oceanic ridge intersected the subduction zone generating a trench-trench-ridge (TTR) triple junction and a related slab-free window. This phenomenon provoked the upwelling of the underlying asthenosphere and a subsequent thermal rebound. This anomalous high temperature in shallow deeps of the continental crust gave rise to a HT/LP metamorphic event, as well as the partial melting of a metasomatised mantle wedge, which produced magmas with boninitic affinities. Isotopic ages suggest the triple junction migrated along the southern continental edge towards the east, which generated a long and narrow high-grade metamorphic belt (namely, the AMB). The subduction of the oceanic ridge induced a relaxation of the compressive stress (see Platt, 1986; Thorkelson, 1996). Although the cortical thickening was not significant, the tectonic scenario was in some way favourable for an extensional collapse, during which an axial shortening took place (CD-D2).

4. Subduction of the trailing plate (Visean-Namurian): Once the triple junction was passing by, subduction of the trailing plate begun beneath the northern continental edge, whose rocks had been

previously heated up. Therefore, the rocks located at the upper levels of the oceanic sheet were heated up by the CD, giving rise to the currently observed inverted metamorphic gradient of the Acebuches series. This subduction process induced a NNE-SSW oriented compression that affected both the continental (CD-D3) and the oceanic (OD-D1) domains.

5. Emplacement of the Acebuches metabasites (Namurian). As the temperature of the oceanic subducting slab rose, the rocks located at the upper levels become dehydrated and were accreted to the base of the continental margin. The process involved the downwards migration of the subduction plane towards more hydrated levels that favoured the shear deformation. Through this plane (namely, the present-day SISZ), the continental plate plus the upper levels of the oceanic slab overthrust the rest of the oceanic lithosphere (OD-D2 phase), which was totally subducted, as well as the accretionary prism (the Pulo do Lobo terrain). This process produced the uplift rate required to preserve the inverted metamorphic gradient (see Peacock, 1987).

6. Continental collision (Namurian-Westphalian). Once the trailing plate was completely consumed, the southern continental margin (the current SPZ) subducted beneath the northern continental margin and, subsequently, both continental plates collided. This continental collision took place in a transpressive regime (Crespo-Blanc and Orozco, 1988; 1991; Ábalos et al., 1991; Bard, 1992; Giese et al., 1994b) and promoted the last ductile deformation phases recorded in the AMB (CD-D4 and OD-D3) that generated SSW-verging km-scale antiforms and inverse shear zones.

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