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A geotraverse through the south and central sectors of the Ossa-Morena zone in Portugal (Iberian massif)

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Abstract: The Ossa Morena Zone (OMZ) corresponds to the southernmost tectonic and paleogeographic unit of the Autochthonous Iberian Terrane and is bounded towards the Southwest by the South Iberian Variscan Suture Zone. The structure of the South and Central sectors of this major unit is dominated by two earlier deformation evens, related with a synchronous process of obduction/subduction, during the closure of the Variscan Ocean. Detailed structural mapping along the Guadiana Valley (almost perpendicular to the variscan trending) shows clearly a polarity on the metamorphic grade and deformation, decreasing both from southwest to northeast. The main units crossed by this traverse includes an accrecionary prism and an ophiolitic sequence in the vicinity of the suture, a tectonic mélange above the southern part of OMZ (including tectonic slices of ophiolites and high pressure rocks) and autochthonous lower deformed palaeozoic sequences, towards the northeast. In this paper we discuss the meaning of the main metamorphic and structural features of all these units.

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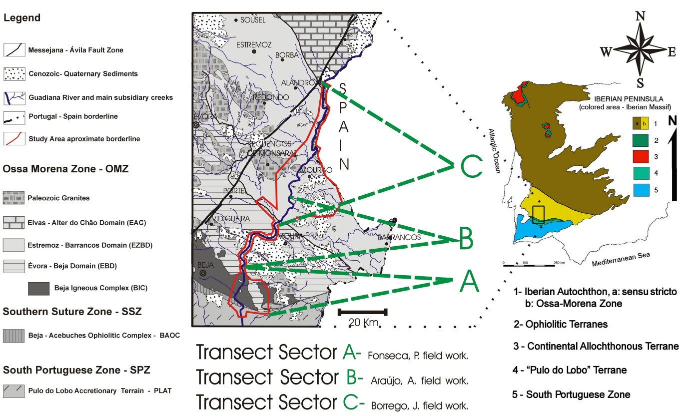
Introduction and geological setting

The Iberian Massif (IM) in the western half of Iberian Peninsula represents the largest and one of the most complete and continuous exposures of Variscan Belt in Western Europe (Figure 1). The arcuate shape of Variscan Belt in Western Europe result from a continent-continent collision between an Ibero-Aquitanian indentor (western Gondwana) (Matte and Ribeiro, 1975; Dias and Ribeiro, 1995; Brun and Burg, 1982; Matte, 1986; Burg et al., 1987) and a northern continent (Báltica? - N. America) (Ribeiro et al., 1990; Quesada et al., 1994). This process is responsible for the formation of the Ibero-Armorican arc by differential collision, which has produced crustal imbrication in frontal areas, left-lateral transpression in Iberia and right-lateral transpression in Armorica. It has been proposed (Crespo Blanc and Orozco, 1988; Fonseca, 1995; Fonseca et al., 1999) that a major ocean (Rheic ocean) was closed by subduction/obduction towards the inner part of the arc, leaving some remainder ophiolitic slices: the Lizard suture in SW England and the Beja Acebuches suture zone, respectively in the northern and southern branches of the Ibero Armorican Arc.

Figure 1. Tectonostratigraphic Terrane Map



Tectonostratigraphic Terrane Map of the Iberian Massif and geological map of the southern portuguese sector of the Iberian Massif (adapted from the Geological Survey map of Portugal, 1/500.000 scale).

The IM represents the ancient substratum of the Iberian Peninsula. It covers one third of the emerge territory of Iberia and supposed be stable since late Palaeozoic ages. It has been subdivided in several zones (Chacón et al., 1983; Julivert & Martinez, 1983; Julivert et al., 1974; Lotze, 1945) and one of these zones is the Ossa Morena Zone (OMZ). The IM has been considered peripheral to Gondwana, during almost all of the Palaeozoic, located very near the boundary of this continent to Laurentia (San José et al., 2004). The final result is due to the amalgamation of several tectonic terranes one of them the OMZ (Keppie & Dallmeyer, 1989). The connections between these tectonic terranes sometimes were very well expressed, underlined by suture zones with oceanic affinities like in other orogenic belts (Coney et al., 1980; Dewey & Birth 1970; 1971; Keppie & Dallmeyer, 1989. The Beja-Acebuches Ophiolitic Complex (BAOC) represents the Variscan suture in southwest of Iberia Peninsula, accreted to the OMZ substratum (Fonseca and Ribeiro, 1993; Fonseca et al. 1999; Fonseca, 1995). The BAOC separates the OMZ and the South-Portuguese Zone (SPZ – comprising Iberian Pyrite Belt and Pulo do Lobo Sequence), which is regarded as an exotic terrane originated from south and accreted, to Iberian Autochthon, during the Carboniferous times. Recently new dismembered ophiolitic slices have been found in the OMZ (Internal Ossa-Morena Zone Ophiolitic Sequences – IOMZOS), witch corresponds to allochthonous klippen on top of lower Palaeozoic sequences (Araújo et al. 1993; Fonseca, 1995; Pedro, 2004).

The Guadiana River is nearly perpendicular to the variscan structures and represents the best transverse, crossing the south variscan fold belt in Portugal (Figure 1). In fact, the well-exposed outcrops in this valley allow detailed structural mapping and, during the last years, several PhD theses on structural geology were achieved, enclosing distinct sectors of the Guadiana Valley, in Ossa-Morena and South Portuguese Zones (Silva 1989; Araújo, 1995; Fonseca, 1995; Piçarra 2000; Borrego in prep.)

The aim of this work is (1) to present unpublished geological mapping, (2) to make a review of the geometrical and kinematical structural data and (3) to make a global interpretation of a segment of the Guadiana Valley, covered by three contiguous PhD theses (Araújo, 1995; Fonseca, 1995; Borrego in prep.). Finally, we propose a general interpretation of the structure, on the basis of a geological cross section, from the suture zone to the central sector of the Ossa-Morena Zone.

The main domains along the Guadiana transverse

The Beja-Acebuches Ophiolitic Complex and the South Variscan Suture Zone

The Beja Acebuches Ophiolitic Complex (Figure 1 , sector A) is a continuous (about 130 km long) thin amphibolite serpentinite metamorphic belt (about 1500 m thick) extending from the surroundings of Torrão - Alcácer do Sal (Southwest Portugal) to Acebuches (Aracena: Southwest Spain) (Crespo Blanc, 1989; Quesada et al., 1994; Fonseca, 1995; Fonseca et al., 1999). This ophiolite complex is tectonically superposed over Paleozoic sequences of OMZ by obduction phenomena's, along the southern boundary of the Iberian Autochthon, and is bounded towards the North, mainly by latter variscan intrusions of Beja Igneous Complex or Beja Massif (BIC/BM). This limit is frequently reworked by semifragile sinistral thrusts. Towards the south, the Ferreira-Ficalho thrust separates the ophiolitic sequence from the Pulo do Lobo metassedimentary deformed sequence. The metamorphic grade in BAOC range from greenschist-amphibolitic facies through amphibolitic facies in metabasalts, to low-pressure granulitic facies in metagabbros (Quesada et al., 1994; Fonseca, 1995).

Along the Guadiana Valley, the best BAOC exposure, from S to N (and top to bottom), we can recognise, fine-grained greenschists (locally pillowed metabasalts containing cherty intercalations (Figure 2), amphibolites s.l. (corresponding locally to sheeted dyke or multiple dyke intrusions in flasergabbros), flaser gabbros (metagabbroic cumulates with minor meta-trondhjemitic intercalations), and scattered serpentinite bodies (Fonseca, 1995; Fonseca et al, 1999, fig.3).

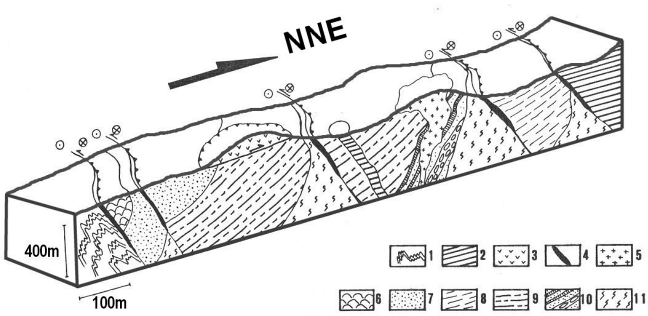
Figure 2. Outcrop

Outcrop of non-deformed pillowed meta basalts near the Guadiana River

Towards the north, the OMZ also include klippens of several internal ophiolitic sequences (Araújo et al., 1993) and high-pressure metamorphic rocks (eclogite/blueschist) (Fonseca et al., 1993; 1999; Fonseca, 1995; Pedro, 2004). These klippens were together emplaced, contemporaneously whit the obduction of BAOC, and occur as dismembered tectonic slices imbricated within the OMZ volcano-sedimentary sequences (Araújo et al., 1993; Fonseca et al., 1993; Araújo, 1995; Fonseca, 1995; Pedro, 1996; 2004; Moita, 1997; Pedro et al., 1998; Fonseca et al., 1999).

All these tectonic units were intruded by the BIC (Fonseca, 1995); the BIC hosts xenoliths (Figure 4) of several regional tectonic units, including previously deformed metamorphic rocks from the BAOC (Fonseca and Ribeiro, 1993) and the BIC emplacement is clearly latter then D1 unconformity (Andrade, 1979,1983 and Fonseca, 1995).

Figure 3. General 3D schematic



General 3D schematic cross-section along the Guadiana river, with the pseudo stratigraphic sequence.

1. Pulo do Lobo metassediments;
2. Beja Igneous Complex-BIC;

3. very deformed gneissic lithologies;
4. complex carbonates (listwaenitic like);
5. leucogabbros and metaplagiogranite lithologies ;
6. metabasalts, locally pillowed;
7. amphibolites s.l.;
8. metagabbros and flaser gabbros;
9. granulitic gabbros;
10. mafic-ultramafic cumulates;
11. serpentinezed peridotites.

Figure 4. Outcrop of xenoliths

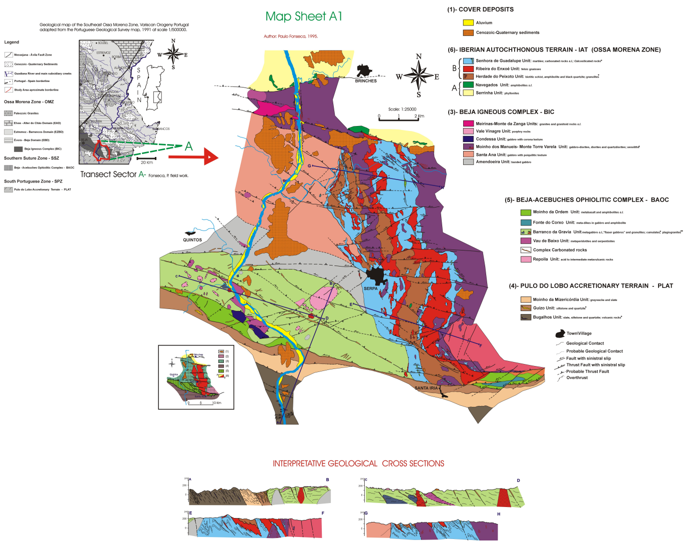
Outcrop of xenoliths in the Beja Igneous Complex. The xenoliths are essentially very deformed amphibolites from the BAOC.

The BIC is a typical layered gabbroic complex grading upwards from a peridotite-gabbro assemblage to an anorthosite-gabbro assemblage. On top of this sequence one can find dolerites and basalts. Poor exposure prevents the observation of the contact between these rocks and the BIC.

In what concerns the structure, the igneous rocks of the BAOC underwent intense Variscan deformation and metamorphism (Bard, 1969; Munhá et al., 1986; Fonseca, 1995, Fonseca et al., 1999). Original textures and mineralogy have been generally almost completely destroyed and replaced. These facts simultaneously with the disruption of the original lithological sequence, makes it very difficult to recognise the original ophiolitic lithostratigraphic sequence (Figure 3).

The metamorphic grade within the ophiolite (s.s) is variable, increasing very fast towards the north but also along strike in the ESE direction, towards the central part of the belt (Fonseca et al., 1999; Quesada et al., 1994). Metamorphic textures are dominantly nematoblastic and reflect the deformational history of the BAOC; three variscan phases of deformation are recorded and preserved in the footwall rocks of the BAOC (Fonseca, 1995; Fonseca et al., 1999). These three phases are responsible for the present dismembered configuration sketch of the suture between OMZ and SPZ. Structural mapping of a cross section along the Guadiana River shown an imbricated and folded sequence (Figure 5 , map A)

Figure 5. Map A



Map A

The first phase of deformation (D1), which is well identified at all scales, is associated with the basal rock units of the ophiolitic sequence [including granulite/amphibolite facies dikes in gabbro, flaser gabbros with associated plagiogranitos/leucogabbros and (serpentinized) ultramafics]. In thin section, sigma asymmetric tails on retrograded recrystallized grains of brown hornblende from dikes in gabbro indicate thrust shear to the north or NNE (Fonseca, 1995). This agrees with the presence of a macroscopic mylonitic cleavage with an associated stretching lineation and related shear criteria, indicating top towards N-NNE. D1 thrusts are mainly sub-horizontal or gently dipping to the S in the SW. This deformation phase is related to the obduction and ophiolite emplacement upon the crystalline footwall of the OMZ (Fonseca, 1995; Fonseca et al., 1999).

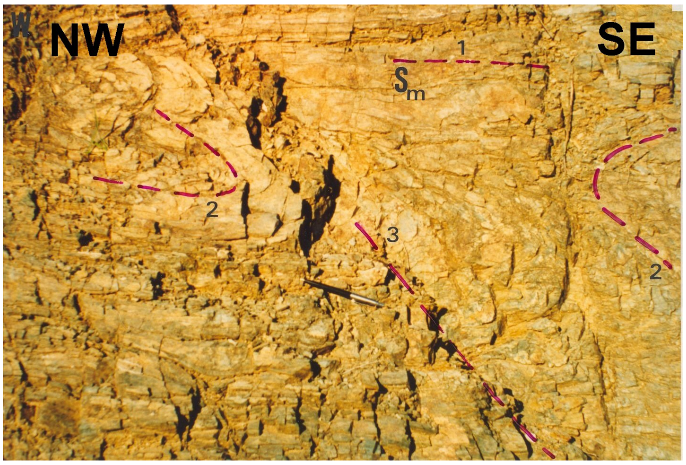
Crossing the Ferreira-Ficalho Thrust, the sedimentary units associated with the Pulo do Lobo sequence show the same deformation as the ophiolite (s.s) (Fonseca and Ribeiro 1993; Fonseca et al., 1999, Figure 6) The most important deformation feature of the Pulo do Lobo Formation is a penetrative cleavage that contains a stretching lineation D1 (Fonseca, 1995). This stretching lineation and shear criteria indicate sense of shear towards S-SSE, with sheath folds indicating the same sense of movement (Fonseca et al., 1999: Fonseca 1995). Moreover, microscopic examination of felsic metavolcanic rocks in D1 thrust faults shows bookshelf sliding of feldspars in a ductile matrix; the displaced hard grain in a ductile matrix implies a shear zone with sense of shear to the south. This advice that the Pulo do Lobo metasedimentary deformed sequence corresponds to an accrecionary prism affected by SSE vergent structures, (synthetic to subduction), synchronous with the obduction of the BAOC to the NNE (antithetic to subduction). The Pulo do Lobo very deformed sequence is discordantly covered by a flysh (Santa Iria Unit) with latte Devonian age (Giese et al, 1989; 1994).

Figure 6. Outcrop of the Pulo do Lobo unit

Outcrop of the Pulo do Lobo unit, showing at the least tree main deformation phases verging to the South.

The second phase of deformation (D2) can be identified essentially on the upper units of the ophiolitic sequence, such as metabasalts in the greenschist facies and amphibolites (s.l.). Kinematic indicators, which include shear bands and rotated porphyroclasts of hornblende are very abundant in these units and are especially well developed in the amphibolitic unit, where well-preserved shear bands show clearly the sinistral component of shear with thrust movement towards NW (Figure 7). In the serpentinized peridotite unit it is also possible to see C-S band structures at the outcrop as well as at thin-section scales showing sense of shear to NW (Fonseca 1995; Fonseca et al., 1999). These rocks (serpentinites) show a dominant stretching lineation of relict minerals associated with a ductile sinistral shearing of NW-SE direction. In the metabasalts unit this shearing is related to a strong mylonitic cleavage generally sub-horizontal or gently dipping to ESE and to a stretching lineation, usually associated to sheath folds, indicating a movement towards NW which is also detectable at thin-section scale (Fonseca and Ribeiro, 1993; Fonseca et al., 1999). These facts indicate the same sense of shear. We consider that these structures represent the second phase of the ophiolite emplacement (Fonseca, 1995).

Figure 7. Outcrop of a very deformed sector of metabasalts unit



It is possible to observe the tree main impulses of D2 deformation event.

1. mylonitic foliation_ Sm
2. folding of D2 mylonitic foliation;
3. Generation of thrust faulting to the WNW following the folding.

Some latter D2 WNW-ESE sinistral faults, presently filled with hydrothermal complex carbonates - listwaenite (representing metassomatic carbonatized serpentinites) (Fonseca et al., 1999; Mateus et al., 1999), dismembered and pulled apart the original structures. These faults are responsible for the presence, side by side, of rock types corresponding to very different metamorphic grades.

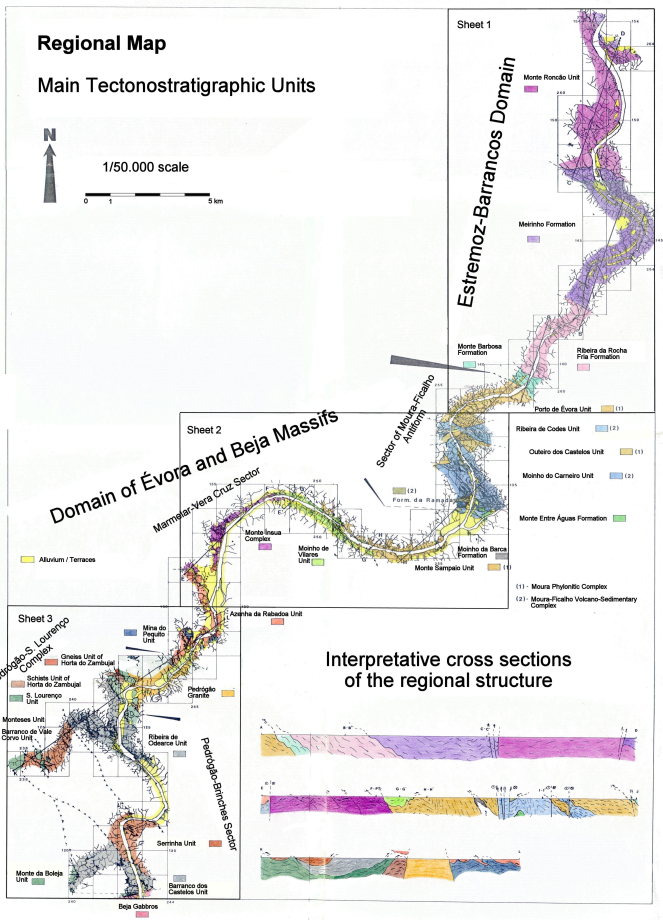
These faults have been reactivated during D3, usually as sinistral thrusts towards SW with a cleavage WNW-ESE strongly dipping to NNE, and, along the Guadiana Valley, they become more brittle with thrusting to SW with a sinistral component (this movement is well represented in the Ferreira-Ficalho ductile-brittle shear zone).

SW sector of the Ossa-Morena Zone – The Évora-Beja Domain

The Guadiana traverse, crossing all Évora-Beja Domain (EBD) and the southernmost part of Estremoz-Barrancos

Domain (EZBD), was mapped by Araújo (1995) at 1/5000 scale. All the area covered by this work is presented on Figure 8 (map B) at 1/50000 scale. This map only includes the main geological subdivisions defined by this author. The detailed geological mapping of the areas indicated as sheet 1, sheet 2 and sheet 3 is shown respectively in the maps B1, B2 and B3 (figs. 9, 10 and 11), at 1/20.000 scale, where detailed cross sections at 1/10000 scale are also presented.

Figure 8. Map B

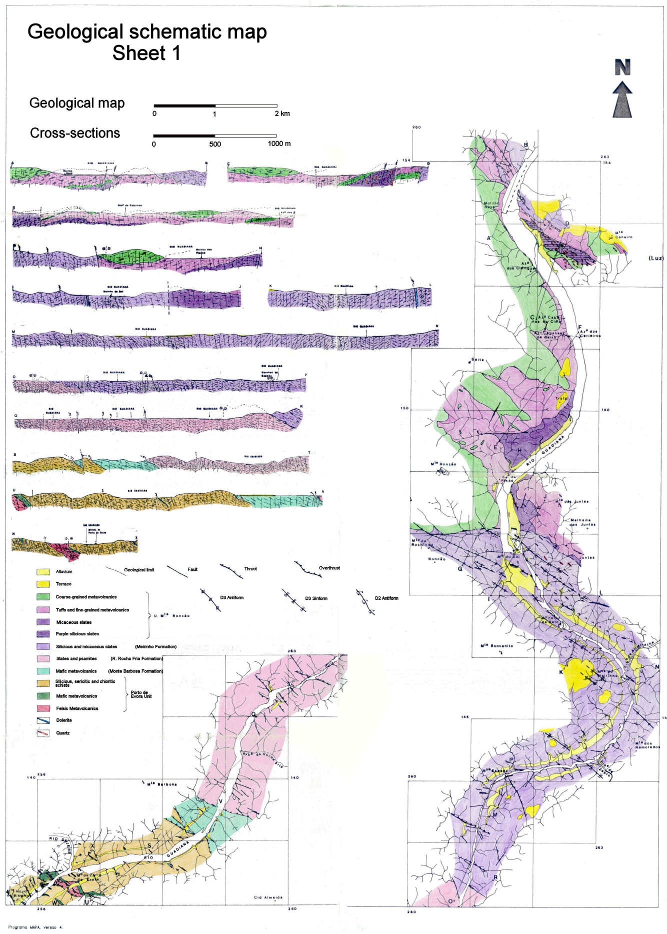


Map B

Tectonostratigraphic sequence

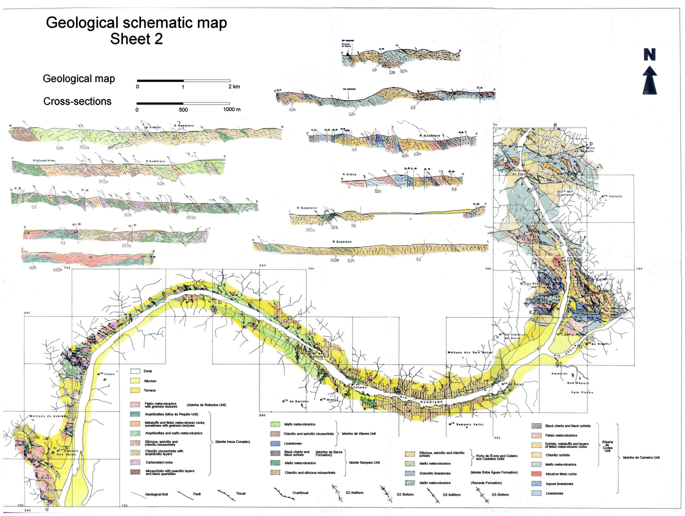
The structure of the EBD is characterized by multiple sub-horizontal earlier thrusting, often associated to kilometric recumbent folds, frequently refolded by a latter deformation event. These structural complexities always make difficult the correlation among different geological units. Nevertheless, along the Guadiana Valley the tectonostratigraphic sequence could be resumed as shown in Figure 12 .

Figure 9. Map B1



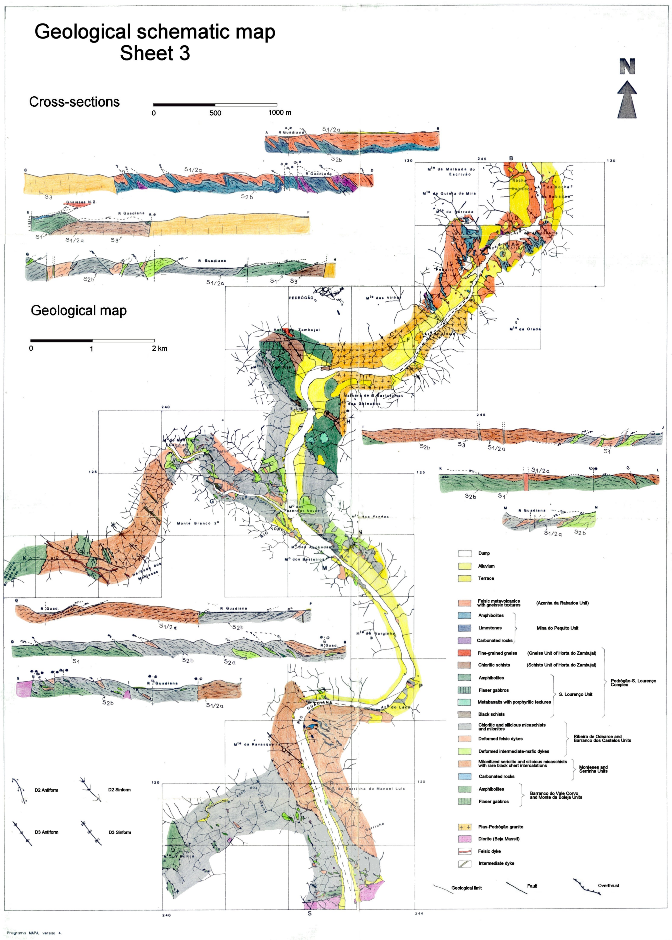
Map B1

Figure 10. Map B2



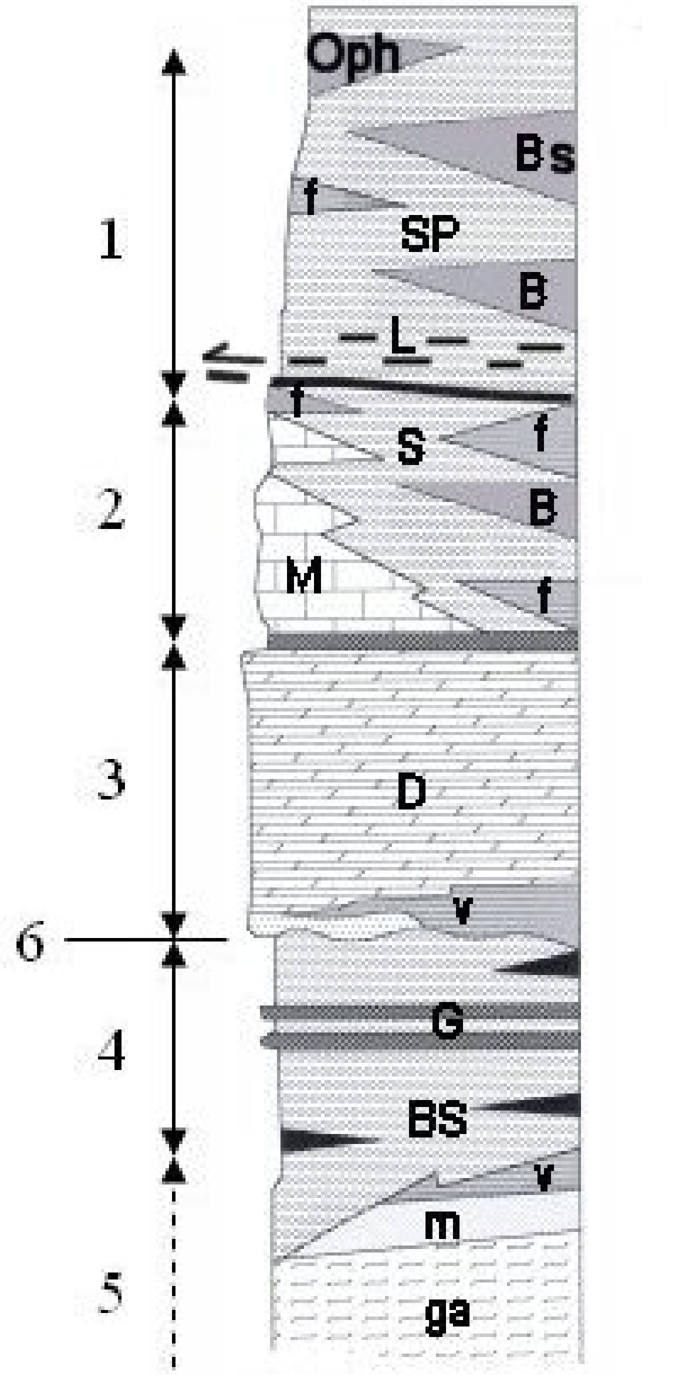
Map B2

Figure 11. Map B3



Map B3

Figure 12. Tectonostratigraphic sequence



Tectonostratigraphic sequence of the Évora-Beja Domain (adapted from Oliveira et al., 1991 and Mateus et al., 2005):

1. Moura Phylonitic Complex (alochthonous), schists and psamites (SP), lidites (L), blueschists (Bs), ophiolitic slices (Oph), mafic (B) and felsic (f) metavolcanics;

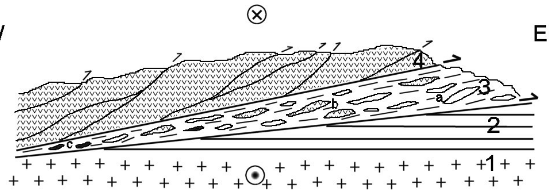
2. Moura-Ficalho Volcanic-sedimentary Complex (Middle Cambrian – Silurian?), calcitic marbles (M), schists (S); mafic (B) and felsic (f) metavolcanics;
3. Dolomitic Formation (Lower Cambrian), dolomites (D, locally silicified), felsic metavolcanics (v) and basal conglomerates;
4. Águas de Peixe Formation, black schists (BS), greywackes (G), black cherts (black); 5 – Escoural Formation, micaschists (m); felsic metavolcanics (v), amphibolites and gneisses (ga).

The upper tectonic unit (Moura Phyllonitic Complex - MPC) is mainly represented by micaschists and corresponds to a strongly imbricated complex, involving several layers of autochthonous sequences (mainly volcano-sedimentary rocks), but it also includes dismembered and scattered slices of ophiolites. The widespread greenschists facies overprint an earlier high-pressure metamorphic event (blueschists in the Guadiana Valley and eclogites in the western sector of EBD, Fonseca et al., 1993). According to the geochemical signature, MPC includes amphibolites ranging from N-MORB to T/P-MORB (ophiolitic slices, Araújo et al., 1993, Fonseca et al., 1999, Pedro, 2004) and mafic alkaline and peralkaline metavolcanics (autochthonous slices).

Macrocospic analysis, at the all EBD scale, indicates that the MPC truncates the units that are geometrically beneath: to the East, in Moura-Ficalho region, the MPC overlaps formations with Silurian or Lower Devonian ages (Piçarra, 2000); to the West, in Viana do Alentejo-Alvito region, it even overlaps Precambrian formations. This cartographic pattern is considered as an evidence of a major first phase overthrust, that limits the MPC from the underlying autochthonous sequences.

The overall evidences (tectonic, metamorphic and geochemical) leads to the interpretation of MPC as an obduction related “mélange” (Araújo et al., 2005), induced by the first deformation phase, between the southern boundary of the OMZ and the ophiolitic nappes (Figure 13).

Figure 13. Interpretative section of major D1 structures



Interpretative section of major D1 structures, at full EBD scale (after Araújo et al. in prep.):

1. Precambrian basement;
2. Cambrian to Silurian/Lower Devonian autochthonous sequences;
3. Moura Philonitic Complex; a – autochthonous fragments; b - Ophiolitic fragments; c – High pressure rocks;
4. Ophiolitic napes.

Structural features

The first deformation event (D1) is preserved along the southernmost sector of the EBD and is correlated to D1 in the BAOC. This deformation phase is expressed by a mylonitic foliation, usually sub-horizontal. The related stretching develops a mineral lineation with NNE-SSW trending, and frequent shear criteria indicating top towards the north at meso and microscopic scales. The structures of this phase are considered a direct evidence of the ophiolitic obduction over the EBD. D1 is generally well preserved in the ophiolitic slices and in the upper tectonic levels of the MPC. The first deformation phase, although often overprinted by latter phases, is recognised until 30 kms north of the suture line materialized by the BAOC. The D1 deformation event is responsible by the main imbrication of allochthonous (ophiolites) and parautochthonous units, including high-pressure rocks (blueschists and eclogites).

The second deformation event corresponds to a thrust and recumbent fold system trending NS or NNW-SSE, with W facing and a penetrative axial plane cleavage. The stretching lineation is generally oblique or almost parallel to the fold axes and the shear criteria indicates top to the NNW. The geometry and kinematics of this phase result from a tangential transpressive regime (Araújo & Ribeiro, 1995). The D2 deformation is responsible for the accentuation of the structural complexity of the MPC. Some D1 thrusts show evidence of reactivation during this deformation event.

A third deformation phase induces a NW-SE folding with an associated steeply dipping crenulation cleavage, with vergence towards the SW. This cleavage sometimes is not axial planar and transect the coeval folds, showing the existence of a left lateral shear component related with the regional flattening. This event is clearly more brittle than the previous ones, and overprints the regional metamorphic peak in greenschists facies. The overall region is still cut by late variscan faults in several directions (mainly strike-sleep faults). Some of these faults were retaken during the alpine cycle.

OMZ central sector (Estremoz - Barrancos Domain)

The EZBD and the Elvas -Alter do Chão Domain (EAC, Figure 1) are both located in the central sector of OMZ and have a relatively well established litostratigraphic sequence. The region was mostly affected only by a singular low grade metamorphic event (low greenschist facies - chlorite zone). In these domains detailed biostratigraphic data helped to constrain the OMZ autochthonous stratigraphy (liñan et al., 1990) and hence the regional structural-tectonic framework.

The nature of the boundary between EZBD and EAC still remain controversial. According to several authors (Gonçalves, 1971; Ribeiro et al., 1979; Araújo et al., 1994) it corresponds to a major tectonic structure, the Juromenha overthrust. Silva (1997) minimizes the meaning of this structure, considering it only a discrete thrust zone. A different interpretation is proposed by Oliveira (1984) and Oliveira et al., (1991); for these authors this discontinuity is only a Cambrian -Ordovician unconformity. In this work we propose that the EZBD northeast limit is an overthrust, although we are aware that this interpretation needs to be supported by detailed complementary studies.

The Southwest EZBD boundary is established with the EBD, by a major polyphasic shear zone, the Santo Aleixo da Restauração shear zone (SAR-SZ). This main structure was considered a major overthrust (Araújo, 1995 and Araújo et al. 1995) with a sinistral shear component.

Tectonostratigraphy

A detailed geological and structural mapping was produced in the EZBD (Transect Sector C of Figure 1) in the vicinity of the Guadiana River valley, during 2001 to 2005 (map C and related interpretative cross-sections, figs. 14 to 17). This field work has provided an extensive review of the regional geological knowledge and led to some reinterpretation of the region, partially supported by recent biostratigraphic data (Piçarra, 2000). An almost complete and continuous Silurian-lower Devonian fossil record in the EZBD has been put in evidence, which is an important constraint to the tectono-stratigraphic and geodynamic evolution of OMZ; a lithostratigraphic sequence for all the region could than be proposed (Figure 18).

The Santo Aleixo da Restauração metabasites, with alkaline signature (Carvalho, 1987; L. Ribeiro et al., 1992), correlates this rocks with the initial Cambrian continental rift phase (Quesada, 1990) , followed by a general Ordovician-Devonian passive margin stage (unites 2 to 7).

The synorogenic unit 9 (and probably also unit 8) is a foreland flysch type succession, ca. 2 km thick infilling basin (Early Devonian), which display only one penetrative deformation episode, the regional D2. Towards the East, the unit 8 is a lateral equivalent of this flysch unit; it corresponds to a distal siliclastic platform facies, of the same sedimentary basin (Piçarra, 2000).

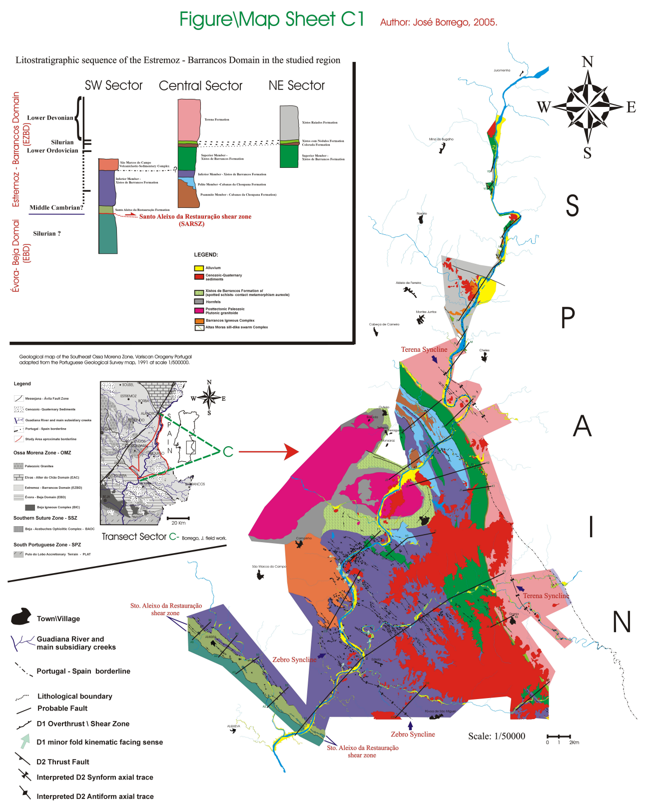
Structural Interpretation

From a structural point of view the EZBD was affected by two main penetrative and pervasive deformation phases - D1 and D2 (corresponding to D2 and D3 on the southwest sectors previously described). Both phases were generated under low grade metamorphism. The D1 event creates recumbent folds with the development of a co genetic sub horizontal axial plane slaty cleavage (S1). The D1 fold axes are scarcely recognized on a macroscopic scale, but very widespread in the outcrop scale. The trending orientation of these D1 axes is variably, but statistically there is a cluster nearby the N-S direction. This clear predominance of N-S direction locally shifts to NW-SE and could be the result of the superposition of the D2 shearing.

In some restricted areas the D1 folds show that the regional facing is towards the northern quadrant (inferred using sedimentary polarity control “way-up” criteria). Geometrically, L1 define metric folds with arcuate shape axes (sheath folds like?), mainly verging to NE, N and/or NW. The observed and mapped folds imply a structural kinematics during regional D1, that are not in accordance with some previous works (Simancas et al., 2001; Poyatos, 2002). The described scenario, approaching the Terena Syncline, is quite different; on SW limb the D1 small folds are scarce and mainly absent in the Northern limb.

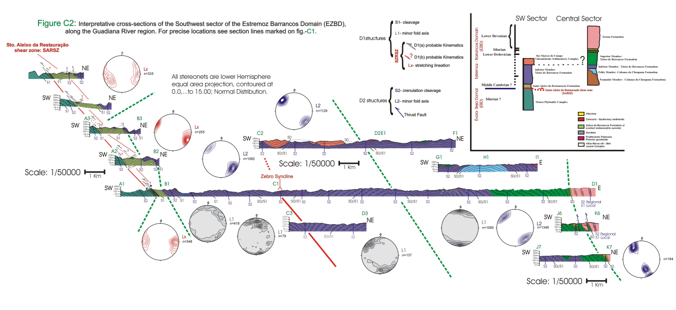
The D2 deformation event is also pervasive and has developed NW-SE folded structures observed at all scales, from kilometric folds to crenulation cleavage (Figure 17). D2 main structures includes some major folds as the Terena Syncline and Zebro Synform (Araújo, 1989, and Araújo, 1995), with steep axial planes striking NW-SE.

Figure 14. Map C



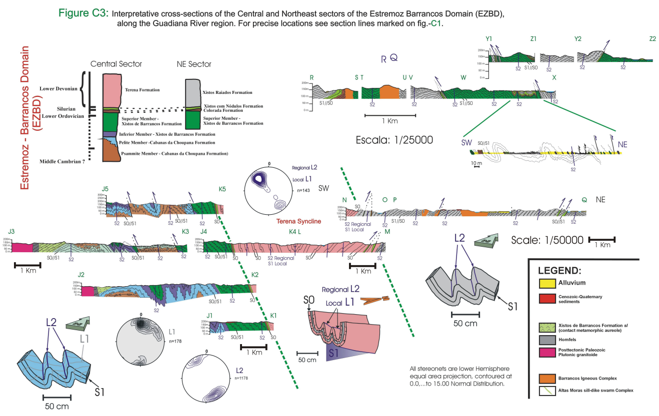
Map C

Figure 15. Cross-sections



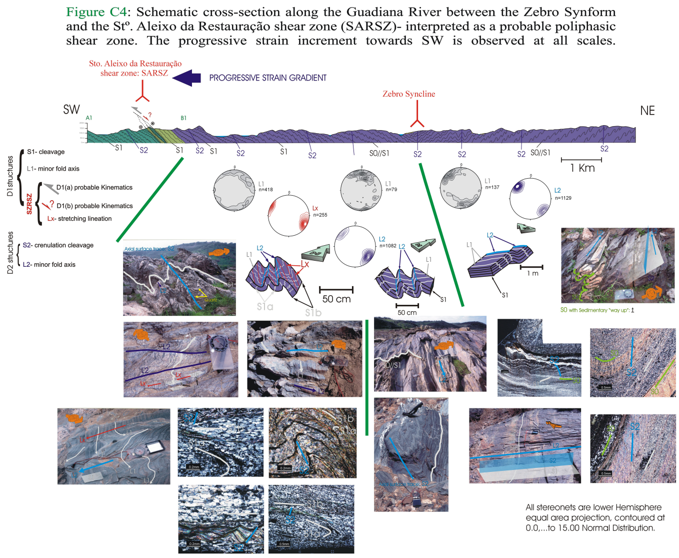
Cross-sections (see location on Figure 14)

Figure 16. Cross-sections



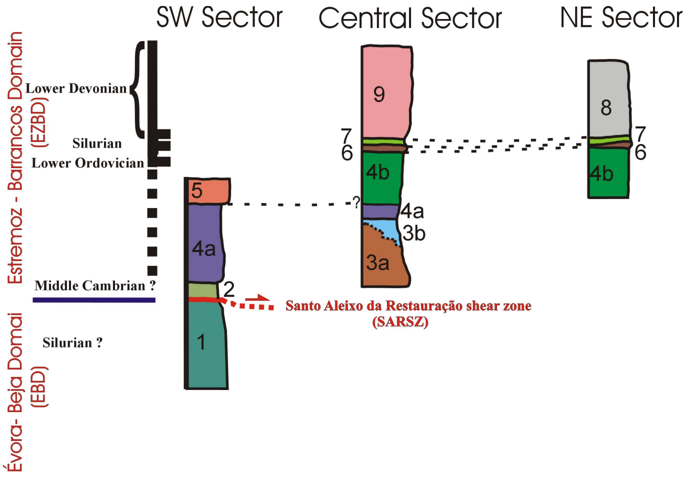
Cross-sections (see location on Figure 14)

Figure 17. Interpretative cross-section



Interpretative cross-section (see location on Figure 14)

Figure 18. Simplified litostratigraphic sequence

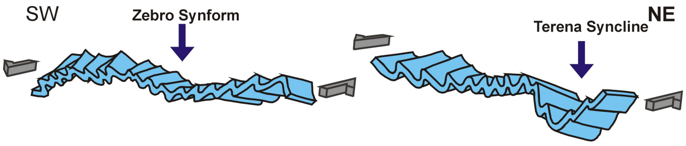


Simplified litostratigraphic sequence of the Estremoz-Barrancos Domain in the studied area (partially adapted from Piçarra, 2000):

1. Moura Phylonitic Complex (alochthonous): schists and psammites;
2. Santo Aleixo da Restauração amphibolite schist and metabasites (Middle Cambrian?);
3. Cabanas da Choupana Formation (Middle Cambrian ?), 3a- Psammite Member, greenish quartzwackes and very impure quartzwackes, 3b- Pelite Member, grey-blue to pink-brown slates with pink-brown siltstones intercalations;
4. Xistos de Barrancos Formation (Ordovician ?): 4a- Inferior Member, violet to grey and green slates and intercalated siltstones, 4b- Superior Member, green to grey slates and silts;
5. São Marcos do Campo Volcano-Sedimentary Complex (Ordovician ?), Volcaniclastic violet and green sediments (ranging in grain size from gravel to lutite, but predominantly sandy);
6. Colorada Formation (basal Silurian), quartzites and impure quartzites;
7. Xistos com Nódulos Formation (Silurian), euxinic black shales with minor black cherts;
8. Xistos Raiados Formation (Lower Devonian), grey shales and white siltstones ;
9. Terena Formation (Lower Devonian), mainly shales - greywackes alternations displaying turbidite characteristics (some deep sea fan facies may be recognized) , defining a Flysh sequence.

The variation in the minor folds axes dip (L2), suggests the actuation of a sinistral slip parallel to the D2 trending contemporaneous with the main shortening and suggesting the actuation of a sinistral transpressive regime. A similar model where proposed for other places in the EBZD, e.g. Lopes, 2003, for the Estremoz Anticline region (Figure 19).

Figure 19. Conceptual block diagram



Conceptual block diagram of D2 Variscan deformation in the EZBD, along the Guadiana River transverse.

To the south of the Zebro Syncline and towards the SARSZ there's a progressive increment of the D1 deformation, with the local development of a stretching lineation Lx; in the vicinity of the SARSZ, Lx affects the previous D1 folds axes (materialized by the intersection lineation L1), and locally develops a S1b cleavage (Figure 17).

Concluding Remarks

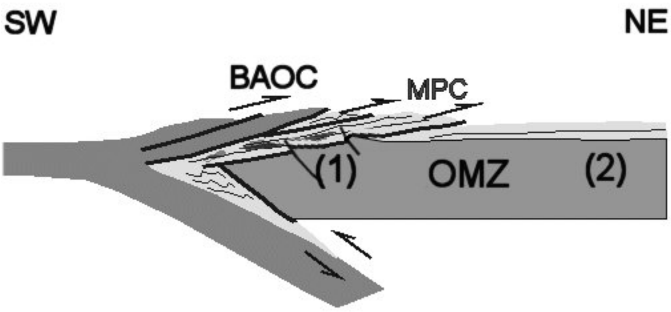
The Guadiana traverse along the south and central part of the OMZ clearly shows a strong polarity on the deformation and metamorphism. In the vicinity of the suture zone, in the southernmost sector of this traverse, the regional metamorphic peak reaches the amphibolitic facies, having a few local units in the granulitic (metagabbros in BAOC) and eclogitic facies (in the MPC). The high grade and high pressure metamorphic rocks are almost completed retrograded by a later tectonometamorphic event, in the greenschists facies. Towards the NE, the metamorphism decreases and in the EZBD there are no evidences of metamorphism higher than the greenschists facies. In this domain, towards the NE, the metamorphism still decreases and the schists are gradually replaced by slates.

Concerning the deformation, the three deformation phases displayed in the southern region, contrast with the EZBD, progressively less deformed towards the NE. In fact, along this traverse, the tectonic style range from refolded mylonitic foliations in the vicinity of the suture, to large sectors with only one slaty cleavage, in the northern part of the EZBD.

The tectonic complexity of the suture zone and the EBD probably result form a near synchronous process of obduction/subduction during the two first events, as showed in Figure 20 . In fact, a few outcrops in the EBD, seems to present contradictory interference patterns between D1 and D2 events. In these scarce situations, structures showing top to the north or northeast shearing, congruent with D1 kinematics, are superposed on D2 structures. Moreover, the strong obliquity between de trending of the D2 fold axes and the related stretching lineation (indicating top to the

NW or NNW) seems to be also an evidence of a synchronous process of subduction and obduction. According to this interpretation, towards the NE, these earlier deformation events become weaker and progressively later and they are not present in the northern part of the EZBD.

Figure 20. Schematic representation

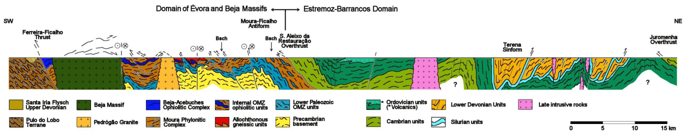


Schematic representation of the near contemporaneous D1 related obduction and D2 related subduction, affecting autochthonous and alochthonous units in the southern boundary of OMZ. BAOC – Beja-Acebuches Ophiolitic Complex; MPC – Moura Philonitic Complex;

1. Évora-Beja Domain;
2. Estremoz-Barrancos Domain.

The general structure of the fully described Guadiana traverse is represented on Figure 21 . D1 related obduction structures are only present in the Beja-Acebuches Ophiolitic Complex, in the MPC and in the related alochthonous units. Concerning the last deformation event (D3 in the suture zone and EBD and D2 in EZBD), the vergence change in the northern part of the studied sector (towards NE), could be an evidence of a latter pulse related with obduction kinematics.

Figure 21. Interpretative cross-section of all studied region



Interpretative cross-section of all studied region.

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References

Andrade, A. S. (1979) – Aspectos Geoquímicos do ofiolitóide de Beja. Com. Serv. Geol. Portugal, t. 64, pp. 39-48.

Aandrade, A. S. (1983) – Contribution à l'analyse de la suture hercynienne de Beja (Portugal). PhD INPL, Nancy, 137 pp.

Araújo, A. (1989) – Estrutura de uma geotransversal no rio Guadiana, entre Moura e Mourão. Prova de Aptidão Pedagógica e Capacidade Científica. Dep. Geologia da Faculdade de Ciências de Lisboa, 92 pp.

Araújo, A. (1995) - Estrutura de uma Geotransversal entre Brinches e Mourão (Zona de Ossa-Morena): Imphplicações na evolução geodinâmica da margem Sudoeste do Terreno Autóctone Ibérico. PhD Thesis, Dep. Geociências, Universidade de Évora, 200 pp.

Araújo, A., Lopes, L., PEREIRA, M.F., GONÇALVES, F., SILVA, J.B. & RIBEIRO, A. (1994) – Novos elementos sobre o Carreamento da Juromenha (Elvas). Anais da Universidade de Évora, 105-109.

Araújo, A.; Fonseca, P.& MUNHÁ, J. (1993) - Ossa-Morena Ophiolites. XII Reunião de Geologia do W Peninsular, Évora, 20-24 de Setembro de 1993. Terra Abstracts, supplement n. 6 to Terra Nova, vol. 5: 8.

Araújo, A.; Fonseca, P.; MUNHÁ, J.; MOITA, P.; PEDRO; P. and RIBEIRO, A. (2005). The Moura Phyllonitic Complex: An Accretionary Complex related with obduction in the Southern Iberia Variscan Suture. Geodinamica Acta, 18/5, pp 375-388.

Araújo, A. & Ribeiro, A. (1995) - Tagential Transpressive Strain Regime in the Évora-Aracena Domain (Ossa Morena Zone). Buletin Geológico y Minero, Vol. 106-2: 111-117.

Bard, J. P. (1969) – Le metamorphisme régional progressif des Sierras d'Aracena en Andalousie occidentale (Espagne). Sa place dans le segment hercynien sud-iberique. These Univ. Montpellier, 355 pp.

Borrego, J. (in prep). Cartografia Geológico-Estrutural de um sector da Zona de Ossa-Morena (Sector de Estremoz – Barrancos) e sua interpretação Tectónica. PhD Thesis, Dep. Geociências, Universidade de Évora

Brun, J.P. & Burg, J. P., 1982. Combined thrusting and wrenching in the Ibero-Armorican Arc: a corner effect during continental collision, Earth Planet. Sci. Lett., 61: 319-332.

Burg, J. P., Bale, P., BRUN, J. P. & GIRARDEAU, J., 1987. Stretching lineation and transport direction in the Ibero-Armorican Arc during the Siluro-Devonian collision, Geodynamica Acta, 1: 71-87.

Carvalho, J. (1987) – Estudo petrográfico e geoquímico de metavulcanitos da região de Santo Aleixo-Amareleja (Alentejo-Portugal). Relatório de Estágio Científico. Departamento de Geologia da Faculdade de Ciências da Universidade de Lisboa.

Chacón, J.; Oliveira, V.; Ribeiro, A. e Oliveira, J. T. (1983) - La estructura de la Zona de Ossa-Morena. Libro Jubilar J. M. Rios Geologia de España. tomo 1, pp. 490-504.

Coney, P.; Jones, D. L. e Monger, J. W. H. (1980) - Cordilleran Suspect Terranes. Nature, 288, pp. 329-333.

Crespo-blanc, A. 1989. Evolución geotectónica del contacto entre la Zona de Ossa-Morena y la Zona Surportuguesa en las sierras de Aracena y Aroche (Macizo Ibérico Meridional): un Contacto mayor en la cadena hercínica europea. Ph. D. Thesis. Dept. de Geo. y Min. - Univ. de Sevilha.

Crespo-blanc, A. & OROZCO, M. (1988) – The Southern Iberian Shear Zone; a major boundary in the Hercynian folded belt. Tectonophysics, 148, pp 221-227.

Dewey, J. F. e Bird, J. M. (1970) - Mountain belts and the New Global Tectonics. Journ. Geophys. Res., 75, pp. 2625-2647.

Dewey, J. F. e Bird, J. M. (1971) - Origin and emplacement of the ophiolite suite: Appalachian ophiolites in Newfoundland. Journ. Geophys. Res., 76, pp. 3179-3206.

Dias, R. & A. Ribeiro, 1995. The Ibero-Armorican Arc: A collision effect against an irregular continent? Tectonophysics, 246: 113-128.

Fonseca, P. (1995) – Estudo da Sutura Varisca no SW Ibérico nas regiões de Serpa-Beja-Torrão e Alvito-Viana do Alentejo. PhD Thesis, GeoFCUL, Univ. Lisboa, 325 pp.

Fonseca, P.; Araújo, A.; Leal, N. & Munhá, J. (1993) - Variscan Glaucophane Eclogites in the Ossa Morena Zone. XII Reunião de Geologia do Oeste Peninsular. Évora, 20-24 de Setembro de 1993, Terra Abstracts, supplement n. 6 to Terra Nova, vol. 5: 11-12.

Fonseca, P.; Munhá, J.; Pedro, J.; Rosas, F.; Moita, P.; Araújo, A. & Leal, N. (1999) – Variscan Ophiolites and High-Pressure Metamorphism in Southern Iberia. Ofioliti, n. 24 (2): 259-268.

Fonseca, P. and Ribeiro, A. 1993. Tectonics of the Beja-Acebuches Ophiolite: a major suture in the Iberian Variscan Foldbelt. Geol Rundsch, 82, Springer Verlag: 440-447.

Giese, U.; Reitz, E. e Walter, R., 1989. Contributions to the Stratigraphy of the Pulo do Lobo succession in Southwest Spain. Com. Serv. Geol. Portugal, vol. 74, pp.

Giese, U., von Heogen, R., Hoymann, K.H., Kramm, U., and Walter, R., 1994, The Palaeozoic evolution of the Ossa Morena Zone and its boundary to the South Portuguese Zone in SW Spain: geological constraints and geodynamic interpretation of a suture in the Iberian Variscan orogen: Neues Jahrbuch Geologie Paläeontologie Abhandl, v. 192, p. 383-412.

Gonçalves, F. (1971) – Subsídios para o conhecimento geológico do Nordeste Alentejano. Memórias Serviço Geológico Portugal, nova série, 18: 62 pp.

Harrison,T. M., 1981. Diffusion of 40Ar in hornblende, Contr. Min. Petrol., 78, 324-331.

Julivert, M. e Martinez, F. (1983) - Estructura de conjunto y vision global de la Cordillera Herciniana. Libro Jubilar J. M. Rios. Geologia de España, tomo 1, pp. 607-630.

Julivert, M.; Fontboté, J. M.; Ribeiro, A. e Conde, L. (1974) - Mapa Tectónico de la Península Ibérica y Baleares. Escala 1:1000000. IGME, 101 p.

Keppie, J. D. e Dallmeyer, R. D. (1989) - Tectonic map of Pre-Mesozoic terranes in circum-Atlantic Phanerozoic orogens. Scale 1:5 000 000. IGCP Proj nº 233, Terranes in Circum-Atlantic Paleozoic Orogens. Halifax, Canada.

Liñan, E. & Quesada, C. (1990) – Rift Phase (Cambrian) of the Ossa-Morena Zone (part V). In: Dallmeyer R.D. and Martínez García E. (eds.), Pre-Mesozoic Geology of Iberia. Springer Verlag, Berlin Heidelberg, 259-266.

Lopes, J. L. G. (2003) – Contribuição para o Conhecimento Tectono-Estratigráfico do Nordeste Alentejano. Transversal Terena-Elvas. PhD Thesis, Universidade de Évora, 542 pp.

Lotze, F. (1945). Zur Gliederung der Varisziden in der Iberischen Meseta. Geotekt Forsch 6, pp. 78-92.

Mateus, A.; Figueiras, J.; Gonçalves, M. and Fonseca, P. E. (1999) - Evolving fluid circulation within the Beja-Acebuches Variscan Ophiolite Complex (SE, Portugal), Ofioliti, 24/2, Sp. Iss., pp. 269-282.

Mateus, A.; Araújo, A.; Gonçalves, M. A., Matos, J. (2005) Variscan overthrusting, fluid flow and the genesis of magnetite ore-bodies at Azenhas area (Pedrógão, Ossa-Morena Zone, SE Portugal), Boletín Geológico y Minero, volume 116 nº 1 (accepted, November 2004)

Matte, Ph., 1986. Tectonics and plate tectonics model for the Variscan Belt of Europe, Tectonophysics, 126, 329-374.

Matte, Ph. and Ribeiro, A. (1975). Forme et orientation de l'éllipsoide de d´rformation dans la virgation hercynienne de Galice. Relations avec le plissement et hipothèses sur la génèse de l'arc Ibero-Armoricain. C. R. Ac. Sc. Paris, ser. D. 280, pp. 2825-2828.

Moita, P. (1997) – Caracterização petrográfica e geoquímica do metamorfismo de alta pressão no sector de Viana do Alentejo-Alvito (Zona de Ossa-Morena), MSc. Thesis, GeoFCUL, Univ. Lisboa, 158 pp.

Munhá, J.; Oliveira, J.T.; Ribeiro, A.; Oliveira, V.; Quesada, C. & Kerrich, R. (1986) – Beja-Acebuches Ophiolite characterization and geodynamic significance, Maleo, 2 (13), pp 31.

Oliveira, V. (1984) – Contribuição para o conhecimento geológico-mineiro da região de Alandroal-Juromenha (Alto Alentejo). Estudos, Notas e Trabalhos do SFM, 26 (1-4): 103-126.

Oliveira, J.T.; Oliveira, V. & Piçarra, J.M. (1991) – Traços gerais da evolução tectono-estratigráfica da Zona de Ossa-Morena em Portugal. Cuadernos Lab. Xeoloxico de Laxe, Vol. 16, pp 221-250.

Pedro, J. (1996) – Estudo do metamorfismo de alta pressão na área de Safira (Montemor-o-Novo) Zona de Ossa Morena, MSc Thesis, GeoFCUL, Univ. Lisboa, 69 pp.

Pedro, J. C. (2004) Estudo Geológico e Geoquímico das Sequências Ofiolíticas Internas da Zona de Ossa-Morena (Portugal) . PhD Thesis, Universidade de Évora, 225 pp.

Pedro, J.; Araújo, A.; Fonseca, P. & Munhá, J. (1998) – Litogeoquímica da sequência ofiolítica no sector de Oriola (Zona de Ossa Morena) e sua importância na reconstituição geotectónica do ramo SW da Cadeia Varisca. Actas V Cong. Nac. Geol. Comunic. Instituto Geol. Mineiro de Portugal, 84 (1): 138-141.

Piçarra, J.M. (2000) – Estudo estratigráfico do sector de Estremoz-Barrancos, Zona de Ossa Morena, Portugal. Litoestratigrafia e Bioestratigrafia do intervalo Câmbrico Médio?- Devónico Inferior. PhD Thesis, Universidade de Évora, 268 pp.

Poyatos, D. J. M. (2002) – Estrutura del Borde Meridional de la Zona Centro Ibérica y su relaión con el contacto entre las Zonas Centro Ibérica e de Ossa Morena. Laboratorio Xeolóxico de Laxe, serie Nova Terra, nº 18, Coruña, 295 pp.

Quesada, C. 1990. Introduction of the Ossa-Morena Zone (part V). In: Dallmeyer R.D. and Martínez García E. (eds.), Pre-Mesozoic Geology of Iberia. Springer Verlag, Berlin Heidelberg, 249-251

Quesada, C., Fonseca, P., Munhá, J., Oliveira, J. & Ribeiro, A., 1994. The Beja-Acebuches Ophiolite (southern Iberia Variscan Foldbelt): geological characterization and geodynamic significance. Boletin Geológico y Minero de España, 105-1: 3-49.

Ribeiro, A., Antunes, M.T., Ferreira, M.P., Rocha, R.B., Soares, A F., Zbyszewski, G., Moitinho de almeida, F., Carvalho, D. e Monteiro, J.H. – (1979). Introduction à la Geologie generale du Portugal. Serviços Geológicos Portugal, 114 pp.

Ribeiro, A., Quesada, C. & Dallmeyer, R.D., 1990. Geodynamic Evolution of the Iberian Massif. In: Dallmeyer,R.D. & Martinez Garcia, E. (Eds.) Pre-Mesozoic Geology of Iberia, Springer-Verlag, pp. 398-409.

Ribeiro, M. L., Mata, J. & Munhá, J. (1992) – Magmatismo do Paleozóico Inferior de Portugal. In Gutiérrez-marco J.C., Saavedra J. & Rábano I. (eds.), Paleozóico Inferior de Ibero-America. Universidad de Extremadura, pp 377-395.

San josé, M. A., Herranz, P. & Pieren, A. P. (2004) A review of the Ossa Morena Zone and its limits. Implications for the definition of the Lusitan-Marianic Zone. Journal of Iberian Geology, 30, pp 7-22.

Silva, J. B. (1989) – Estrutura de uma Geotransversal da Faixa Piritosa: Zona do Vale do Guadiana. PhD Thesis, GeoFCUL, Univ. Lisboa, 293 pp.

Silva, J. B. (1997) – Geodinâmica ante-Mesozóica do sector Oeste da Zona de Ossa Morena e regiões limítrofes: síntese com base em recentes observações. In ARAÚJO, A. e PEREIRA, F. (eds.), Estudos sobre a Geologia da Zona de Ossa-Morena (Maciço Ibérico), Livro de homenagem ao Prof. Francisco Gonçalves, Univ. Évora, pp 231-262.

Simancas, J.F., Poyatos, D.M., Expósito, I., Azor, A., Lodeiro, F. G. (2001) – The structure of a major suture zone in the SW Iberian Massif: the Ossa-Morena/Central Iberian contact. Tectonophysics 332: pp 295-308.