High temperature – Low pressure tectonites from the Boa Fé Fault Zone (Évora Massif, Ossa Morena Zone, Portugal): Evidences for transtensional tectonics

"Tectonitas de Alta Temperatura-Baja Presión en la Zona de Falla de Boa Fé (Macizo de Évora, Zona de Ossa-Morena, Portugal): Evidencias de una Tectónica Transtensional"

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ABSTRACT

Partial melting in the Évora Massif (Ossa-Morena Zone) occurred contemporaneously with non-coaxial deformation in a transcurrent regime.
An example of this fact has been taken from studied partially melted biotite-sillimanite-K-feldspar-andalusite-cordierite tectonites from the Boa Fé Fault Zone. These HT-LP (~ 2.5-3.5 kbar and 550º-750ºC) mylonitic rocks characterized by a steeply dipping to SW foliation (N30º-55ºW, 70º-80ºSW) and gently dipping to SE stretching lineation (10º-20º to SE) associated to sinistral sense of movement. Transtensional tectonics is suggested to explain how the Évora High-grade Metamorphic Terrain migmatites were exhumed in parallelism with the orogen-trend.

Key-words: *Ossa-Morena Zone, Évora Massif, Boa Fé Fault Zone, HT-LP tectonites, transtensional tectonics.*

RESUMEN

La fusión parcial en el Macizo de Évora (Zona de Ossa-Morena) fue contemporánea con el desarrollo de deformación no-coaxial en un régimen transcurrente.
Un ejemplo de este proceso procede del estudio de las tectonitas parcialmente fundidas con paragénesis de biotita-silimanita-feldespato potásico-andalucita-cordierita de la Zona de Falla de Boa Fé. Estas rocas miloníticas de alto grado metamórfico (~ 2.5-3.5 kbar y 550º-750º C) se caracterizan por una foliación N30º-55ºW, 70º-80ºSW y una lineación de estiramiento 10º-20º al SE asociada con un movimiento sinestrorso. Para explicar la exhumación de los Terrenos de Alto-grado Metamórfico de Évora se propone una tectónica transtensiva paralela con la dirección del orógeno.

Palabras clave: *Zona de Ossa-Morena, Macizo de Évora, Zona de Falla de Boa Fé, tectonitas de alta temperatura y baja presión, tectónica transtensiva*

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Introduction

It is now a well-established fact that exist a close relationship between shear zones and exhumation processes of high-grade metamorphic terrains.

In the last decade, extensional tectonics associated to ductile shear zones and migmatization, resulting in plutono-metamorphic complexes, have been referred from the Spanish cartographic extent of the Ossa-Morena Zone (e.g. González del Tánago, 1995; Apraiz, 1998; Apraiz and Eguiluz, 1996, 2002). Recently, in Portugal, tectonic studies (Pereira and Silva, 2002; Pereira *et al.*, 2003) have being focused on the high-grade metamorphic terrains and associated granitoid plutons in order to examine the tectonothermal conditions required for crustal deformation and the presence of a large amount of partially molten rocks.

Included in the Évora Massif (EM, Carvalhosa, 1983; Quesada and Munhá, 1990), the Boa Fé Fault Zone (BFFZ) is a NW-SE trending narrow band (0.1 – 1 km width) of strong brittle-ductile deformation that extends along 18 km in the boundary between two contrasting tectonic units (e.g. Pereira *et al.*, 2003): (1) the Évora High-grade Metamorphic Terrains (EHMT), at North, and (2) the Montemor-o-Novo Shear Zone (MNSZ), at South (Fig. 1).

Fieldwork, based on 1:2.500 scale geological mapping of the Boa Fé-Casas Novas area, and detailed sampling along the São Brissos riverside, enabled the description of structural and metamorphic features of this complex fault zone. The main purpose of this work concerns: (1) a redefinition of the structural meaning of the BFFZ as the EHMT / MNSZ boundary, and (2) a

characterization of the relationship between microstructures and metamorphism in the BFFZ tectonites.

Geological setting

According to the proposal of Carvalhosa and Zbyszweski (1994) the EM have been subdivided, from a stratigraphic point of view, on: (1) a Proterozoic volcano-sedimentary succession (Serie Negra, black metacherts and schists, felsic and basic metavolcanic rocks, uppermost Escoural Formation, to described amphibolitic facies rocks, and lowermost Escoural Formation, to include migmatitic rocks), (2) a lower Paleozoic succession made, at the base, by felsic volcanics and carbonate rocks of probably lower Cambrian age (Monfurado Formation or volcano-sedimentary complex), and towards the top, by basic volcanics and minor carbonate and pelitic rocks (Carvalhal Formation) with probable Ordovician and/or Silurian? age, and (3) an uppermost mostly detritic series with bimodal volcanics (Cabrela Formation) and minor carbonate rocks (Pedreira de Engenharia Formation) of Devonian-Carboniferous age.

Recent studies, based on structural geology and relationships between metamorphism and deformation, suggested that this stratigraphic subdivision in distinct formations is not directly applicable to this region with an evident structural complexity (Pereira *et al.*, 2003). In fact here, a strong syn-metamorphic S-L fabric has overprinted former stratigraphic limits, which as consequence, were affected by heterogeneously distributed shearing and associated folding. This interpretation explains the coexistence of large-scale open fold geometries, as the Cabrela-Carvalhal syncline, with macro- to minor-scale tight fold geometries, such as the development of structural associations of anticlines and synclines with strong stretched limbs, on the Neoproterozoic Serie Negra Succession and overlying lower Cambrian volcanic and sedimentary rocks. Pereira and co-workers (2003) have also suggested that variation in the style of deformation and structures can be explained by a single continuous non-coaxial deformation event progressing from zones dominated by orogen-parallel transcurrent movements to others dominated by shortening at an higher angle to the translation.

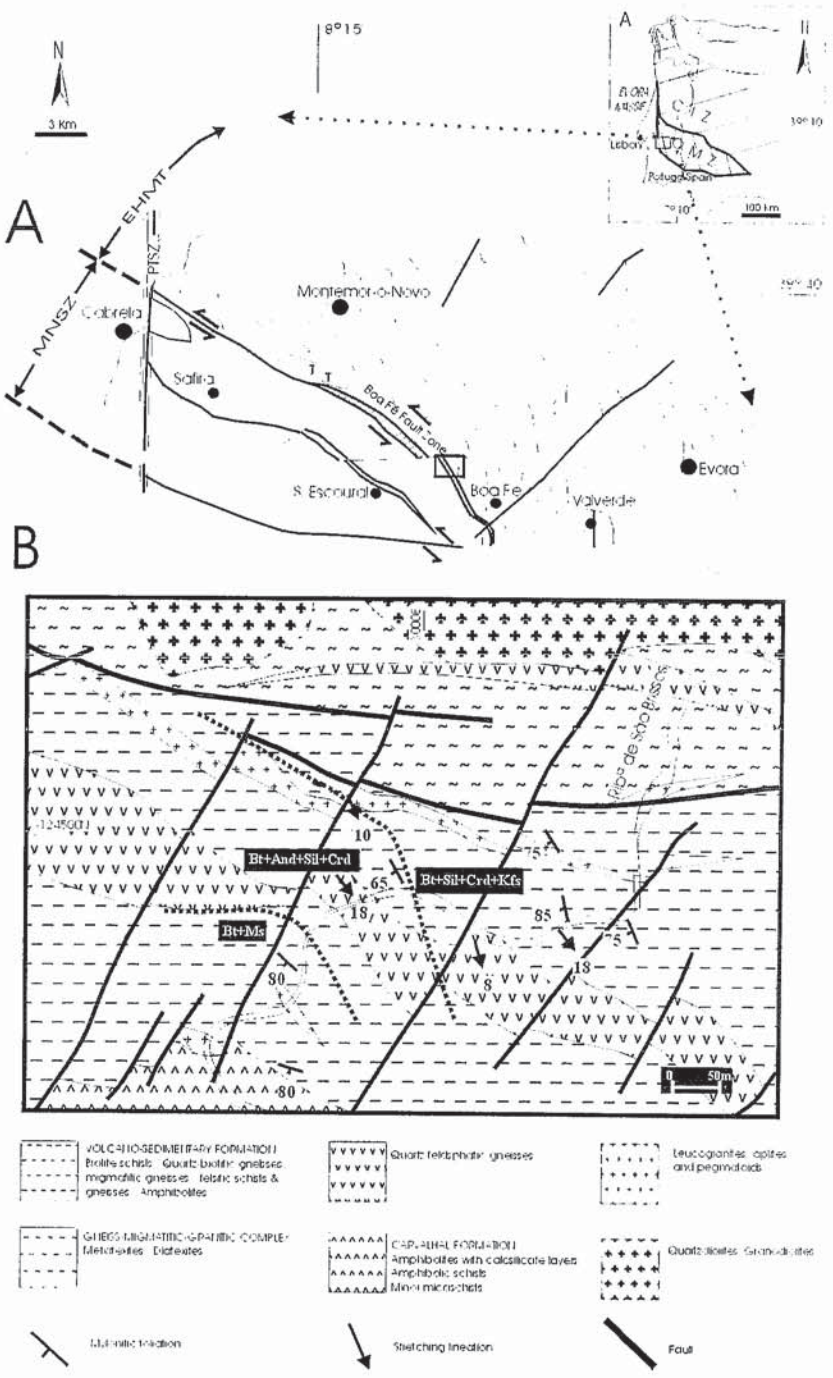

Fig. 1.- (A) Geological sketch of the Évora Massif with major structural subdivisions (Adopted from Pereira *et al.*, 2003) and (B) detailed geological map of Casas Novas area included in the Boa Fé Fault Zone (Tectonic boundary between the Evora High-grade Metamorphic Terrains (EHMT) and the Montemor-o-Novo Shear Zone (MNSZ)).

Fig. 1.- (A) Mapa esquemático de las principales subdivisions estructurales del Macizo de Évora (Adaptado de Pereira* et al., *2003) y (B) Mapa geológico detallado del area de Casas Novas incluida en la Zona de Falla de Boa Fé (Límite tectónico entre los Terrenos de Alto grado Metamórfico de Évora (EHMT) y la Zona de Cizalla de Montemor-o-Novo (MNSZ)).

Structural style of the BFFZ

Pereira and co-workers (2003) have described for the MNSZ three main high shear strain sub-planar features: 1) the southern border of the MNSZ where outcrops the strong mylonitized Alcaçovas gneisses 2) the Santiago do Escoural Fault Zone, located within the MNSZ, including the stretched Monfurado Syncline, and 3) the BFFZ at the northern border with the EHMT.

The BFFZ represents a N65°W-trending narrow steeply dipping to

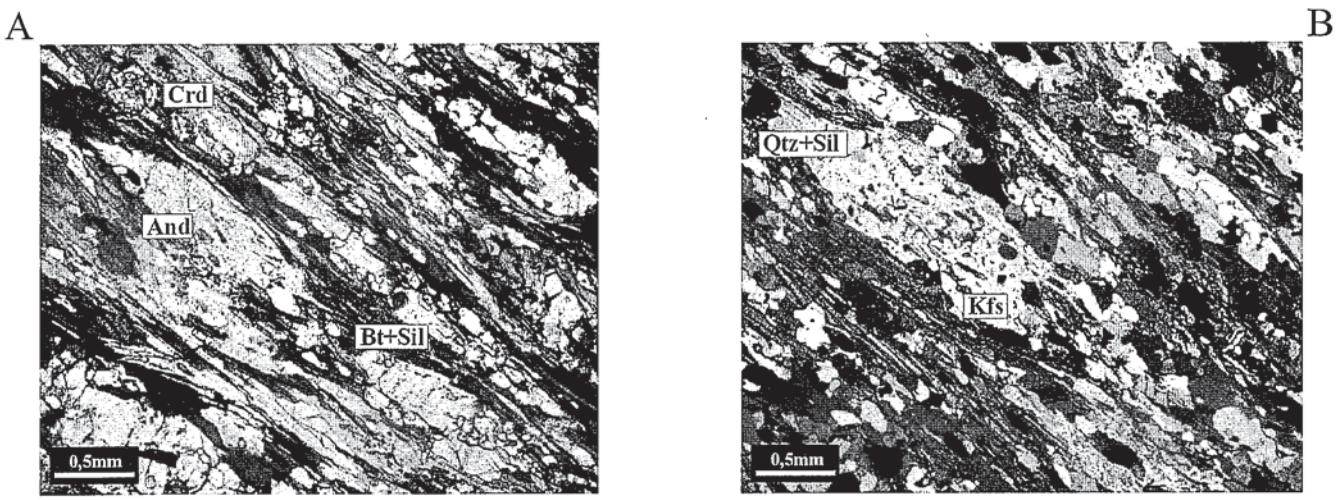

Fig. 2.- HT-LP tectonites from the Boa Fé Fault Zone: (A) Eyes-shaped andalusite-biotite-cordierite-quartz nodules surrounded by aligned biotite-fibrolitic sillimanite intergrowths. (B) Poikiloblastic K-feldspar enclosing aligned biotite;

Fig. 2.- Tectonitas de alta temperatura y baja presión de la Zona de Falla de Boa Fé: (A) Intercrecimientos orientados de biotita y fibrolita alrededor de microestructuras nodulares de andalucita-biotita-cordierita-cuarzo, (B) Porfiroblasto de feldespato potásico con textura poiquiloblástica e inclusiones de cristales orientados de biotita.

subvertical corridor, that extends from SW of Montemor-o-Novo, where the very-low metamorphic grade upper Paleozoic rocks (Cabrela Formation) are in contact with the EHMT migmatites, towards the SE nearby of Nossa Senhora da Boa Fé, where lower Paleozoic sequences under affected by amphibolitic metamorphic conditions also contact with the EHMT migmatites (Fig.1). At South of the Boa Fé – Casas Novas area the general strike of the BFFZ suffers a flexure and changes to N15°-30°W, what is yet poorly understood.

At a kilometric scale, and considering other mesoscale cartographic evidences, one can admit that the northern limit of the Cabrela-Carvalhal Syncline is characterized by strong ductile shearing and superposed brittle deformation. Due to this superposition of deformation regimes the BFFZ structural pattern is characterized by the presence of stretched tight units, bounded by imbricate and anastomosing shear bands, made of internally ductile deformed biotite schists/gneisses, quartz-feldsphatic orthogneisses, and amphibolites. Their limits are rotated by translation along E-W and NE-SW-trending brittle faults where cataclastic textures have been identified.

The São Brissos riverside cross section shows a strong increase of the metamorphic grade and shear strain, in a short distance with less than 500 m. It is possible to observe, from SW towards NE, that amphibolites with calc-silicate layers and micaschists give place to dominant gneissic mylonitic textures including a complex assemblage of biotite-rich micaschists, banded or partial migmatized paragneisses, banded quartz-feldsphatic para- and orthogneisses, migmatites, amphibolitic layers, granitoid segregations/veins and porphyritic intrusives. Of particular interest is the presence of a 1-6 m width poorly foliated N75°W-trending, leucogranitic dyke dipping to 40°-60°SSW that extends for approximately 600 m doing an angle of 35°-50° with the main foliation of the country-rocks. This granitoid dyke is spatially associated with gold and arsenic geochemical anomalies.

The location of high shear strain within the BFFZ is coincident with the occurrence of banded biotite-andalusite-sillimanite gneisses. These rocks are characterized by a well-developed steeply-dipping mylonitic foliation (N30°-55°W, 70°-80°SW) associated with a gently dipping stretching lineation (10°-20° to SE) and mesoscale C′-type shear band cleavage (E-W), indicating sinistral sense of movement.

Close to the migmatitic-granitic complex quartz-feldspar-rich venules become thicker (centimetric) and several vein generations can be distinguished. These wider veins are subparallel or disharmonic relatively to the foliation. Folded leucosomes normal to the foliation are cutted by the veins sub-parallel to the foliation and some of them show evidences of shearing and folding (intra-crystalline deformation of quartz and feldspars).

BFFZ tectonites: high-temperature/ low-pressure mineral assemblages

Along the BFFZ transverse, at the São Brissos riverside, it is clear the existence of a fast metamorphic gradation from SW towards the NE, in the direction of the EHMT migmatitic rocks. This progressive increase on metamorphic grade follows a sequence of distinct lithological types that include: amphibolites (Hbl + Pl ± Bt ± Opaq), micaschists (Bt + Ms + Qtz ± Pl ± Opaq), orthogneisses (Bt + Ms + Qtz + Sil + Pl) and paragneisses (Bt + Ms + Qtz + And + Sil + Crd ± Pl ± Opaq ± St), silicified partial migmatized gneisses (Bt + Ms + Qtz + Kfs + Sil + Crd + Pl ± Opaq) and a migmatitic-granitic complex.

The biotite-andalusite-sillimanite-cordierite mineral assemblage starts with the sudden appearance of brown-red biotite followed by xenoblastic andalusite and the fibrolitic sillimanite. Rare staurolite relics are preserved in micaschist, andalusite is residual (xenoblastic) and cordierite increases in banded paragneisses. The intergrowth between biotite and fibrolite-sillimanite is common. The sillimanite occurs as strong elongated clusters of fibrolite needles parallel to the stretching lineation or, more rarely, as isolated fibrolitic clots intergrowth with quartz and K-feldspar.

Paragneisses exhibit thin and rhythmic ondulated venules, subparallel to main foliation, essentially composed by quartz and small amounts of plagioclase. Their borders are regular and contact with the mesosome by cordierite-rich bands.

Eyes-shaped nodules of andalusite-biotite-cordierite are characteristic of this tectonites with the xenoblastic andalusite in equilibrium with red biotite + quartz, and rounded by strong pinnitised cordierite. These nodules are it self rounded by intergrowths of red biotite, fibrous sillimanite and quartz.

The disappearing of andalusite and the growing of K-feldspar blasts give rise to the highest metamorphic grade mineral assemblage defined in this zone (Bt+Sil+Kfs+Pl+Crd). The K-feldspar is poikiloblastic and grows over the aligned red biotite, forming symmetrical or slightly assymetrical "eyes-shaped" grains oriented parallel to biotite-sillimanite intergrowths (Fig.2b).

These gneisses tend to show venules of leucosomes with irregular borders (cuspate-shaped) with more frequent biotite-rich selvages (strongly chloritised biotite and opaques) around and inside veins irregularities.

BFFZ tectonites: microfabrics, strain and shear indicators

Strong orientated clusters of biotite-muscovite, fibrolitic sillimanite needles and bands of recrystallized quartz defined the main foliation of the BFFZ tectonites, where poikiloblastic texture of K-feldspar and plagioclase and xenoblastic (residual) andalusite are also representative features.

Strain fabrics and shear indicators along the lowest metamorphic grade tectonites (amphibolitic facies) are associated with subhorizontal stretching lineation and dominated by asymmetric textures (monoclinic symmetry), with the widespread development of S-C planes, C′-type extensional cleavage, asymmetric tails, mica-fish, indicating a sinistral sense of movement with a evident extensional component. In contrast in the higher amphibolitic facies tectonites the predominant fabrics tend to be more symmetric (orthorrombic symmetry), but there also exists minor preserved asymmetric structures. There exist a clear textural contrast between the microfabrics developed in tectonites at distinct metamorphic grades. The typical textures are grano-lepidoblastic (sometimes granonematoblastic), alternating with porphydoblastic (eyes-shaped andalusite-biotite-cordierite-quartz nodules, K-feldspar or plagioclase symmetric oval blasts). The leading microtextural feature in gneisses is the metamorphic compositional layering subparallel to the main foliation, where thin quartz venules, altern with cordierite-rich bands, granoblastic-polygonal textures in quartz-rich layers, and bands with biotite-sillimanite overgrowths.

Discussion and conclusions

The BFFZ is a NW-SE-trending steeply-dipping 0.1-1 km width zone of crustal weakness that separates two distinct tectonic units inside Évora Massif: the EHMT at North, from the MNSZ at South (Pereira *et al.*, 2003). Represent a complex band of strong deformation formed by an array of several imbricate and anastomosing shears bands and superposed brittle faults. The mechanical contrast between these two distinct tectonic units is suggested to be the cause to progressively accentuated the BFFZ "weak" character by the continuous reworked of structures at different structural levels during metamorphic processes, as suggested by the development of mylonitic textures (ductile to brittle-ductile regime) and cataclastic textures (brittle regime).

Strain fabrics and shear indicators on the steeply-dipping foliated BFFZ tectonites with a subhorizontal to SE gently-dipping stretching lineation, indicate a sinistral sense of transtensional shearing. The shear planes outlined by the intergrowths of red biotite and fibrolitic sillimanite indicate high-temperatures for the generation of these microfabrics. Boudinage of competent layers parallel to shear planes and pervasive C'-type shear band cleavage are also according with an extension regime with subhorizontal maximum finit elongation.

At Boa Fé-Casas Novas area is remarkable the rapid increase of the metamorphic grade from greenschist facies conditions (biotite zone) at SW, to upper amphibolitic facies conditions (sillimanite – K-feldspar - cordierite zone) at NE, in a short distance of approximately 500 m. The appearance of the biotite + andalusite + fibrolitic sillimanite + quartz + K-feldspar + plagioclase + cordierite mineral assemblage is related with the first stages of leucosomes and mesosomes differentiation and seems to be clearly associated with the highest strain gradients characterized by well-developed mylonitic textures. This fact means that the tectonic evolution of the BFFZ was intimately related with a prograde metamorphic event of high-temperature / low-pressure type, which acted as a trigger to the diffuse initiation of syntectonic migmatization processes. The high metamorphic grade beside the migmatic-granitic complex generated the dehydration melting reactions that could enhanced the generation of melts which have ascended along weakness planes, as pointed by the presence of leucogranitic dikes cutting the main foliation of the BFFZ tectonites.

Another evidence for high-grade metamorphic conditions is the presence of cordierite- sillimanite associate with feldspar blastesis. The quick variation in metamorphism deduced for this sector, as well as the garnet inexistence in pelitic rocks suggest a prograde evolution under low pressure conditions, reaching temperatures high enough to cause dehydration melting reactions (650-750°C). Thus, the high metamorphic "field" gradient defined for this sector, and the described microstructures, represents a strong argument to testify the orogen-parallel transtensional movements along the boundary between MNSZ and EHMT.

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