Tectonic and Stratigraphic Description and Mapping of the Santa Susana Shear Zone (SSSZ), the SW Border of Ossa Morena Zone (OMZ), Barrancão – Ribeira de S. Cristóvão Sector (Portugal): Theoretical Implications

Descripción y cartografía tectónica y estratigráfica de la Zona de Cizalla de Santa Susana (ZCSS), límite SW de la Zona de Ossa Morena (ZOM), sector Barrancão – Ribeira de S. Cristóvão (Portugal): Implicaciones Teóricas

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RESUMEN

Se ha realizado una cartografía de la Cuenca de Santa Susana (Vestfalialiense D – Estefaniense A), situada en el limite SW de la ZOM con la Zona Sur Portuguesa (ZSP). Esta región se caracterizada por una frontera tectónica de orientación N-S entre la ZOM (este) y la ZSP (oeste). La Zona de Cizalla de Santa Susana (ZCSS) está relacionada con la generación de cuencas en pull-apart, con un estilo tectónico transtensivo dextrógiro, seguido por un régimen progresivo y diacrónico, afectando secuencias sedimentarias contemporáneas. Esta importante zona de cizalla evidencia similitudes geométricas, cinemáticas y temporales, con la estrutura tardi-varisca de Porto-Tomar-Ferreira do Alentejo.

***Key words**: Late variscan tectonics, transtension, pull-apart basins, diachronic regime.*

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Introduction

In this area it is recognized Ossa Morena Zone (OMZ) as well as South Portuguese Zone (SPZ) terrains. In this sector, the OMZ includes the Santa Susana Basin (SSB) (Almeida *et al*., 2006; Fernandes, 1996) and the Toca da Moura Vulcano-Sedimentary Formation (TMF) (Almeida *et al*., 2006; Carvalhosa and Zbyszewsky, 1994; Gonçalves, 1983; Pereira and Oliveira, 2006; Ribeiro *et al*., 1996). It is identified in the SPZ the Undifferentiated Pulo do Lobo Group (PLG) (Carvalhosa and Zbyszewsky, 1994), represented by Ferreira Ficalho Group (FFG) (Almeida *et al*., 2006; Carvalhosa and Zbyszewsky, 1994). From the base to the top of FFG sequence it is identified the Pulo do Lobo (PLF), Ribeira de Limas (RLF), Santa Iria (SIF) and the Horta da Torre (HTF) Formations (Pereira *et al*., 2006; Oliveira *et al*., 1986; Oliveira, 1990) (Table I). The SPZ – OMZ northwards contact (western and eastern blocks, respectively) is due to a right-handed transtensive shear zone (the SSSZ), that generates the Late Carboniferous SSB in a pull-apart regime (Almeida *et al.*, 2006).

The stratigraphic ages of these different Formations are presented in Table I according to the available bibliography.

Lithostratigraphy

The reason for the chosen lithostratigraphy is due to the necessity to: (a) understand the behaviour of the SSSZ in the SSB surrounding area and its structural implications; and (b) determinate the outcrop patterns of the SPZ near the SSSZ. For this reason the HTF composed by schists and quartzites (the top unit of SPZ in this region) has been separated from other Formations. The quartzites occur in boudins without internal deformation along the So\\S1 planar fabric (Almeida *et al*., 2006).

Ossa Morena Zone

In this area the OMZ is composed by two distinct units, the TMF and SSB (Almeida *et al*., 2006). The TMF consists in basic, intermediate (?) and acid volcanic rocks intercalated with sedimentary detritical episodes, in a shallow sub-aquatic basin (Gonçalves, 1983; Pereira and Oliveira, 2006), contemporaneous of the Cabrela Formation and Iberian Pyrite Belt (Pereira and Oliveira, 2006). The SSB is an alluvial fan sedimentary basin, due to the subsidence provoked by a dextral pull-apart tectonic regime, and it's characterized by a rhythmic sequence of conglomerates, sandstones and argillites, with the sediments of different provenience (OMZ and SPZ), with the carbonization of vegetable material in the finest levels, indicating a boggy environment in a arid to sub-arid climate (Almeida *et al*., 2006; Fernandes, 1996).

The TMF basic rocks are characterized by extrusive and shallow intrusive events in a sub-aerial to sub-aquatic environment (Almeida *et al*., 2006; Gonçalves, 1983; Pereira and Oliveira, 2006). The intermediate and acid rock shows vesicles suggesting

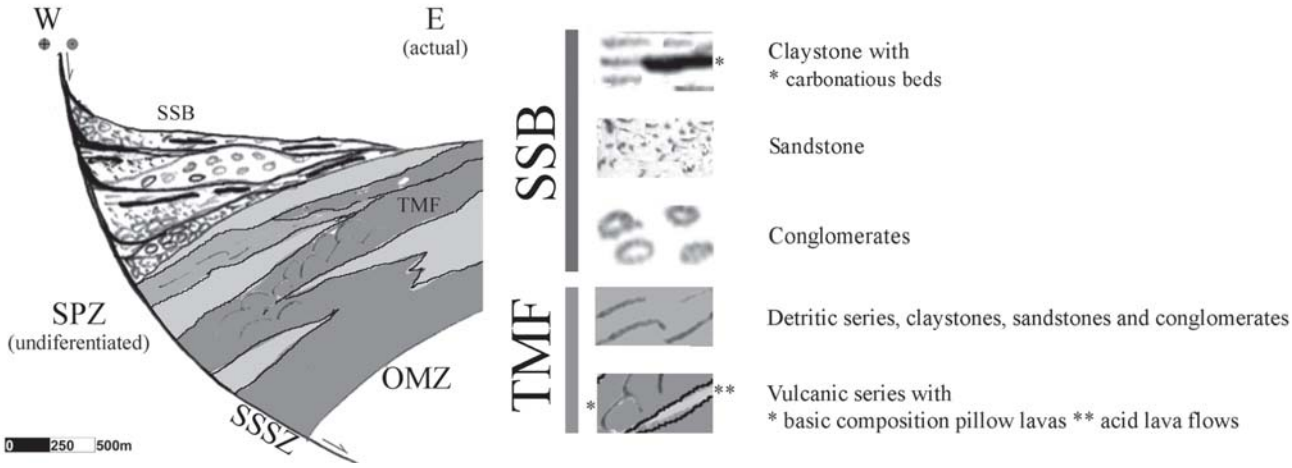

Fig. 1.- Structure in hemi-graben in witch occur the deposition of the unities of the SSB, in relation with the transtensive N-S shear zone and the opening of N60ºE tractive faults, witch limit the Northern part of the SSB. This event provokes an asymmetrical tilting of the basin, with the western part more tilted (60ºE) than the eastern (~30º-50ºW), with its depocentre located NW (adapted from) Almeida *et al.*, 2006.

Fig. 1.- Estructura en hemi-graben dónde se depositan las unidades de la BSS, en relación con la zona de cizalla transtensiva N-S con la apertura de fallas tractivas N60ºE, que limitan la parte norte de la BSS. Este evento provoca el basculamiento de la cuenca, con la parte oeste mas inclinada (60ºE) que la este(~30º-50ºW) con el depocentro localizado en el NW (adaptado de) Almeida* et al.*, 2006.

shallow underwater volcanism (Almeida *et al.*, 2006). The extrusion of acid lava of this complex shows intercalated riolitc domes with crioclastitic rocks and acid tuffs of different aspects, showing diverse volcanic episodes (Almeida *et al.*, 2006; Gonçalves, 1983). The detritic sedimentation produces an arrangement of fine layered greywackes and argillites with marine and palinological content and volcanic clasts (Almeida *et al.*, 2006; Pereira and Oliveira, 2006). This group is tilted 50ºW in the direction of the N-S SSSZ.

The SSB is composed by sediments created through the erosion process that affected surrounding terrains, in a semi arid to arid environment. From base to top these sediments include positive grading rhythmic sequences of conglomeratic sandstone, middle to fine grain sandstone and manganese rich carbonaceous argillite. These rocks show an immature and badly sorted matrix, suggesting a short and turbulent transport, typical of the generation of small and thick alluvial fans in a sin-tectonic regime (Almeida *et al.*, 2006). The asymmetrical and rhombic geometry of this basin support the assumption of sin-tectonic subsidence and rhythmic deposition of the alluvial fans (Fig. 1). The presence of carbon material in argillite indicates an oxygen dewlapped environment typical in swampy regions.

South Portuguese Zone

The SPZ in this area is composed by two main units, the PLG and the HTF. The PLG is distinguished from HTF by the absence of ortoquartzite (Almeida *et al.*, 2006). It's characterized by intercalations of psamite, quartzite and schist with exudation quartz, extremely deformed and boudinated. In this group we can observe a gradual passage of pelito-psamitic with flysch characteristics, presenting low deformation and metamorphism rates (Almeida *et al.*, 2006; Pereira *et al.*, 2006; Oliveira *et al.*, 1986; Oliveira, 1990). From the top to the base of this sequence it can be observed psamites apparently with no internal deformation; quartzite with sub-horizontal stretching lineation parallel to the axis of cylindrical folds; extremely deformed philyte-quartzite rocks in medium metamorphism grade with intense exudation quartz dynamically recristalized and stretching lineation parallel to the folding axis. This group shows a more intense deformation than the upper Formations of the SPZ. This suggests a deformation style in different structural levels characterized by isoclinal cylindrical folding with stretching parallel to their axis (Almeida *et al.*, 2006).

In this area the HTF is the most recent unity of the SPZ (Pereira *et al.*, 2006; Oliveira *et al.*, 1986),(Oliveira, 1990). It's characterized by the presence of schist with orthoquartzite intercalation (Almeida *et al.*, 2006; Pereira *et al.*, 2006; Oliveira *et al.*, 1986; Oliveira, 1990). The So//S1 orientations measured near the N-S SSSZ are Nº20W and passes gradually to the regional orientation N60ºW in the westernmost part of this zone.

The gradual transition observed between the HTF and the PLG suggests stratigraphic continuity. The contact with the lower formation is identified by the

Geostructural Domains	Lithostratigraphy (from Bibliography)	Lithostratigraphy (present work)	Chronostratigraphic Epoch and Age
Ossa Morena Zone (OMZ)	Santa Susana Basin (SSB)	Santa Susana Basin (SSB)	Upper Carboniferous (Westephalian D – Eastephanian A)
Ossa Morena Zone (OMZ)	Toca da Moura Formation (TMF)	Toca da Moura Formation (TMF)	Early Carboniferous (Tournesian CM - Visean NM)
	Horta da Torre Formation (HTF)	Horta da Torre Formation (HTF)	Upper Devonian (Upper Famenian)
South Portuguese Zone (SPZ)	Santa Iria Formation (SIF)	Pulo do Lobo Group (Undifferentiated) (PLG)	Upper Devonian (Upper Famenian)
	Ribeira de Limas Formation (RLF)		middle to upper Devonian (Frasnian or upper)
	Pulo do Lobo Formation (PLF)		Early (?) Devonian

Table I.- Lithostratigraphy and Chronostratigraphic Epoch and Age (adapted from Almeida *et al.*, 2006 and actualized from Oliveira *et al.*, 1986, Oliveira *et al.*, 1990).

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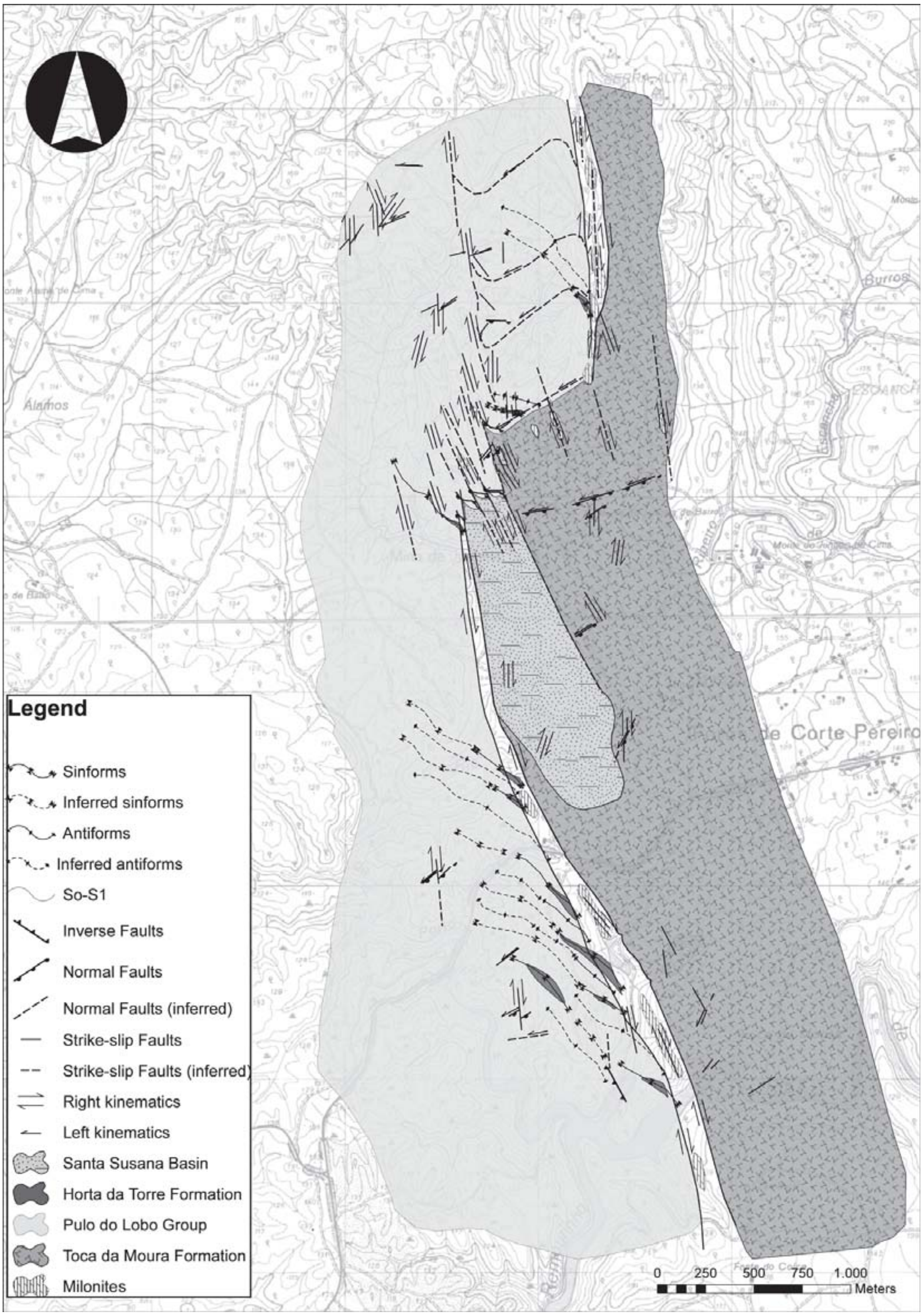

Fig. 2.- Santa Susana Basin and SSSZ structural mapping (1:12.500 scale). This major shear zone induce the virgation of the SPZ cleavage from N60ºW to N10º-30ºW, and the conservation of pieces of HTF in synclines of the SPZ, in a retail pattern, along the SSSZ. In the OMZ occurs the formation of pull-apart basins as the SSB. In the SW part of this transtensive basin there's also evidences of dragging movement, supporting the dextral movement of the SSSZ. Along the SSSZ occurs a late generation of metassomatic rocks (Upper Carbouniferous – Permic?) as a result of a metassomatic phenomenon of the OMZ and SPZ rocks, simultaneously with the late stages of this dextral shear regime (adapted from Almeida *et al.*, 2006).

Fig. 2.- Mapa estructural de la Cuenca de la Santa Susana e ZCSS (escala 1:12.500). Esta gran zona de cizalla induce la virgación de la esquistosidad de la ZSP de N60ºW a N10º-30ºW y la conservación de retazos de la FHT en sinclinales de la ZSP, a lo largo de la ZSSS. En la ZOM se forman cuencas en pull-apart. La parte SW de esa cuenca transtensiva evidencia también un movimiento de arrastre, apoyando el movimiento dextrógiro de la ZCSS. A lo largo de la ZCSS se generan rocas metasomaticas (Carbonífero Superior – Pérmico) como resultado de un fenómeno metasomático tardío de las rocas de ZSP y ZOM, simultaneamente con las fases finales de ese régimen de cizalla dextrógiro (adaptado de Almeida **et al.***, 2006).*

absence of orthoquartzite and the presence of psamitic rock with stretching lineation, identifying higher deformation rates on the lower PLG stratigraphic (PLF and RLF) units (Almeida *et al.*, 2006).

The emplacement of the SSSZ tectonic regime affects differently each side of the adjacent blocks. In the SPZ it induced the flexural slip of the previous tectonic fabric favouring the conservation of the HTF synclines with axis dipping SE mainly near the SSSZ. This produces a retailed outcrop pattern of HTF synclines with PLG rocks cropping out in the SPZ anticlines (Fig. 2).

Santa Susana Shear Zone Milonites

The Santa Susana shear zone is composed by heterometric carbonate, quartzite and intermediate milonitic rock with veins with the same composition. The occurrence of carbonates along the contact with the TMF indicates the influence of hydrothermal fluids that altered the basic rocks of TMF. The exudation quartz veins are related to the dissolution and precipitation processes that affected the rocks of the SPZ along the SSSZ (Almeida *et al.*, 2006).

Conclusions

The outcrop pattern revealed in Map 1 shows a complex disposition of the different geological aspects and indicates the evolution of a transtensive tectonic regime that affects previous rock fabrics such as bedding, cleavage and lineaments that exist in the wallrock. It also affects the sedimentation regime during the upper Carboniferous and it's distribution in the Santa Susana pull-apart Basin.

By the analysis of field data we conclude that the SSSZ was generated after the main deformation phase affecting the HTF, and ceased after the formation of the SSB. This can be demonstrated by the fact that the SSSZ affects the previous SPZ fabrics and by the apparent lack of milonitic rocks inside the conglomerates in the SSB suggesting that the carbonated milonites are formed after the sedimentation in this pull-apart basin.

The SSSZ truncates and locally drags the SPZ cleavage from regional N60ºW trending, to N20ºW. In the area near this shear zone the HTF is conserved in retails in synclines in the SPZ folded structure. In this sector the SPZ contacts with the OMZ by tectonic cutting and not as the inverse contact as shown in 1:500.000 SGP mapping (Almeida *et al.*, 2006). This tectonic event also provokes the tilting of the TMF (OMZ) and the installation of the SSB according to a strain partitioning style (Fig. 2) (Almeida *et al.*, 2006).

This structure shows kinematic and geometric similarities with the dextral late-variscan Porto-Tomar-Ferreira do Alentejo Fault, as well as with other faults in the Iberian Pyrite Belt that affects other Carboniferous formations, like the Corona Fault (Lousal Mine). In this sector the SSSZ creates a pull-apart basin of upper Carboniferous age, the Santa Susana Basin, allowing the determination of a minimum age for this tectonic regime.

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