Universidade do Porto - Faculdade de Ciências
Museu e Laboratório Mineralógico e Geológico
Memória nº 4, p. 263-267, 1995 ISSN 0871-1607

GEODYNAMICS OF THE EASTERN SECTOR OF THE ARRÁBIDA CHAIN (W PORTUGAL)

M.C. Kullberg [1], J.C. Kullberg [2], A. Ribeiro [1], S. Phipps [3]

1 Departamento de Geologia da Fac. Ciências da Univ. Lisboa, Ed. C2, 5º piso, Campo Grande, 1700 Lisboa
2 Centro de Estratigrafia e Paleobiologia / UNL, Quinta da Torre, 2825 Monte de Caparica
3 Department of Geology, University of Pennsylvania, Philadelphia, PA, USA 19104-6316

Abstract

The Arrábida chain – located in the southern segment of the Lusitanian basin – is a S-wards directed fold and thrust belt of Miocene age of deformation. ENE-WSW striking frontal ramps and associated folds are connected to sinistral NNE-SSW and N-S striking lateral ramps, that show left-lateral and SE-wards reverse movements. Both frontal and oblique ramps form imbricate duplexes. Constriction increases SE-wards due to the presence of a basin boundary fault (Setúbal-Pinhal Novo fault) that acts as a buttress to the oblique thrust movement. Kilometre scale transpressive structures can be observed along the basin boundary fault. A map scale sheath fold like structure can be observed at the Viso anticline, which is a consequence of a strong anisotropy contrast of the Mesocenozoic strata.The Arrábida chain thrusts migrated backward, i.e. to the north, according to an overstep model. Detailed geometrical reconstruction and kinematic analysis of the structures of the eastern region of Arrábida (Formosinho, Viso and Serra de S. Luis anticlines) show that a thin-skinned tectonic model (Ribeiro, A. *et al.*, 1990) fits very well with the geometry of the strutures of the Arrábida chain.

In this paper a tectonic model for the eastern sector of the Arrábida chain is proposed, based on field work and aerial photo-interpretation of the eastern pericline of Formosinho and anticlines of Viso and Serra de S. Luis.

Arrábida chain has a 3D imbricated structure, formed by imbricated S-wards directed ENE-WSW striking thrusts and oblique to the thrusts, sinistral lateral ramps striking NNE-SSW to N-S. The age of deformation is Miocene.

Important contributions to the understanding of the geometry of Arrábida chain structures, as well as their tectonic interpretations, were made by P. Choffat (1904-07; 1908), H. Seifert (1963), G. Zbyszewski (1964), A. Ribeiro and M. Ramalho (1986) and A. Ribeiro *et al.* (1990).

P. Choffat in 1908 described for the first time the geology of the Arrábida belt, outlining the existence of three "lines of dislocations" (now called thrusts), the first of which is located to the south of the chain (under the sea, cf. Ribeiro, A. *et al.*, 1990) and the second and third "line of dislocations" correspond to the Formosinho-Viso anticlines and Serra de S. Luis anticline, respectively.

This still on-going study aims to produce a qualitative and quantitative tectonic model of the Arrábida chain, based on the unusually good outcrop conditions of the region. Such a model will have important implications on the determination of the overall geometry of the inversion structures in the Lusitanian basin.

The interplay between lateral and frontal ramps in this part of the Arrábida chain is ductile, i.e. the thrusts strike at more or less 90º to the lateral ramps far from them and gradually merge into the lateral ramps as they approach them (**Fig 1**).

Striae always plunge to the north; they plunge more or less 10º-15º on the lateral ramps and are close to dip slip on the thrust planes.

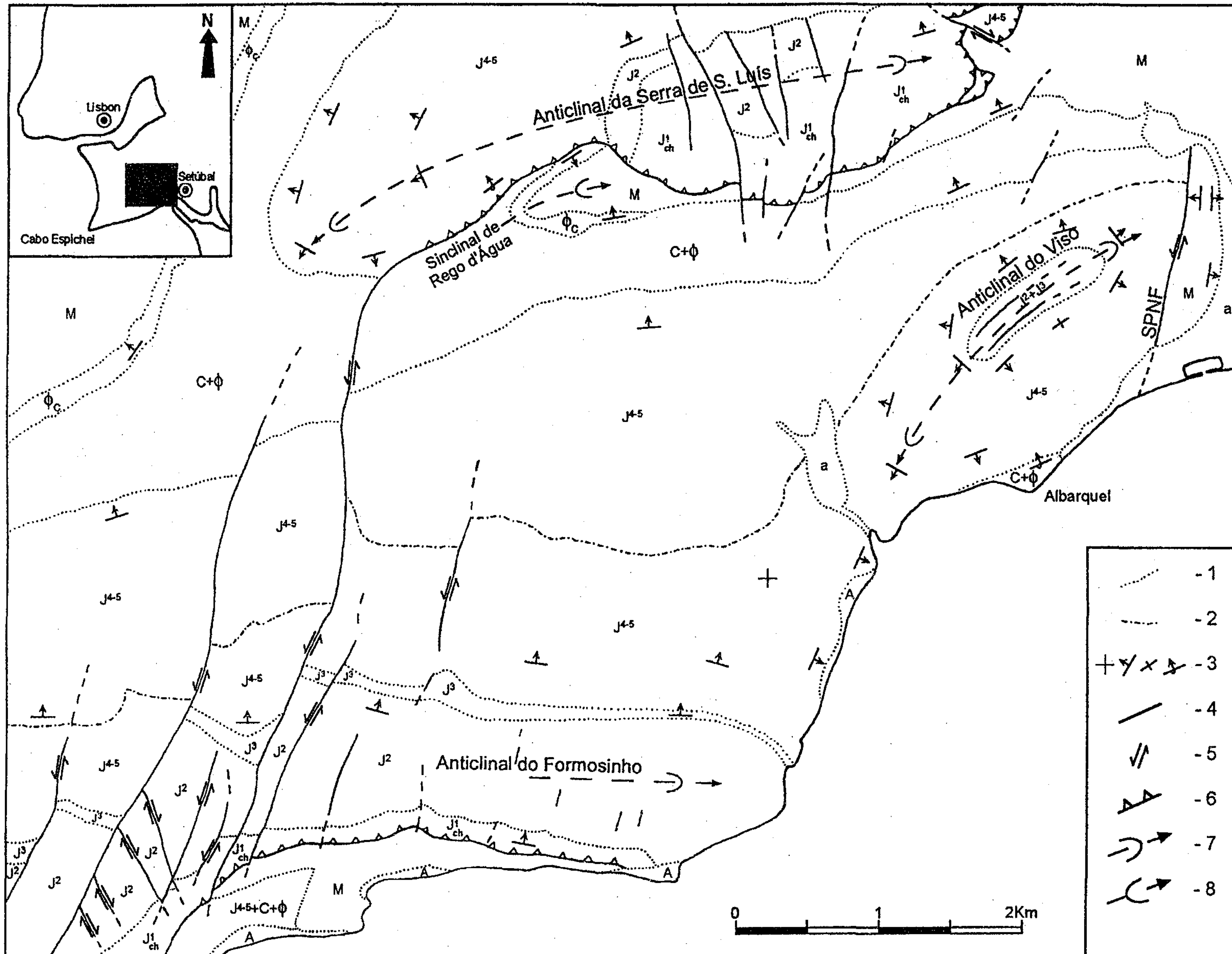

Fig 1 - Structural map of the eastern sector of the Arrábida chain, with location inset. Stratigraphic units are based on G. Zbyszewski (1964) (see fig 2 caption). 1- Geological limit; 2- Intra J^{4-5} photogeological marker; 3- Bedding simbols; 4- Fault; 5- Strike-slip fault; 6- Thrust fault; 7- Anticlinal hinge; 8- Synclinal hinge; SPNF - Setúbal-Pinhal Novo Fault.

Folds are tighter in the foot-walls of thrusts. Usually, the hanging-wall anticlines do not have reverse limbs. The geometry of fold axes is sigmoidal and periclinal. This sigmoidal shape is related to the ductile shear along the lateral ramps and the pericline geometry can approach that of a sheath fold.

At the Formosinho anticline, the lateral ramp connecting this structure with the Serra de S. Luis frontal ramp anticline is duplicated, forming a duplex. Inside this duplex, distributed shear movement is partially accomodated by sinistral NNW-SSE striking riedel (R) strike-slip faults.

A spectrum of deformation from brittle to ductile behaviour can be observed at the Viso and Serra de S. Luis anticlines, where the Lower/Middle Jurassic (J^{1-2-3}) dolomites and limestones behave very brittly and the more clayish Upper Jurassic (J^{4-5}), Paleogene and Miocene units behave in a ductile and semi-ductile way.

The Viso structure

The Viso anticline is one of the most interesting structures of the belt. In map view (**Fig 1**) the Middle Jurassic outliers form a core around which the Upper Jurassic beds, rotate 360°. The Middle Jurassic unit in this area consists of mechanically competent limestones that acted as a rigid block and indenter to the Upper Jurassic incompetent marly-conglomerate complex (**Fig 2**).

This rigid block had a vertical displacement larger than that of the surrounding Upper Jurassic unit that deformed mostly by flattening. The differential vertical displacement of the two mechanical units was probably caused by expulsion of the central rigid block due to constriction, enhanced by an inherited horst geometry of the Middle Jurassic block, probably with basement involvement.

This interpretation is also supported by gravity data worked out by Azevedo e Silva, E. (1992), where the Bouguer anomaly map of the eastern sector of the Arrábida chain displays a strong positive anomaly above the Viso structure.

It is here suggested that the strong deformation observed at the Viso anticline was caused by the formation and progression of the Serra de S. Luis younger thrust located to the north.

Constrictional deformation in the Arrábida belt is inferred from the above described Viso anticlinal structure and also by the geometry of the Serra de S. Luis anticline axis. The axis of this fold is gently folded due to contraction parallel to the fold axis.

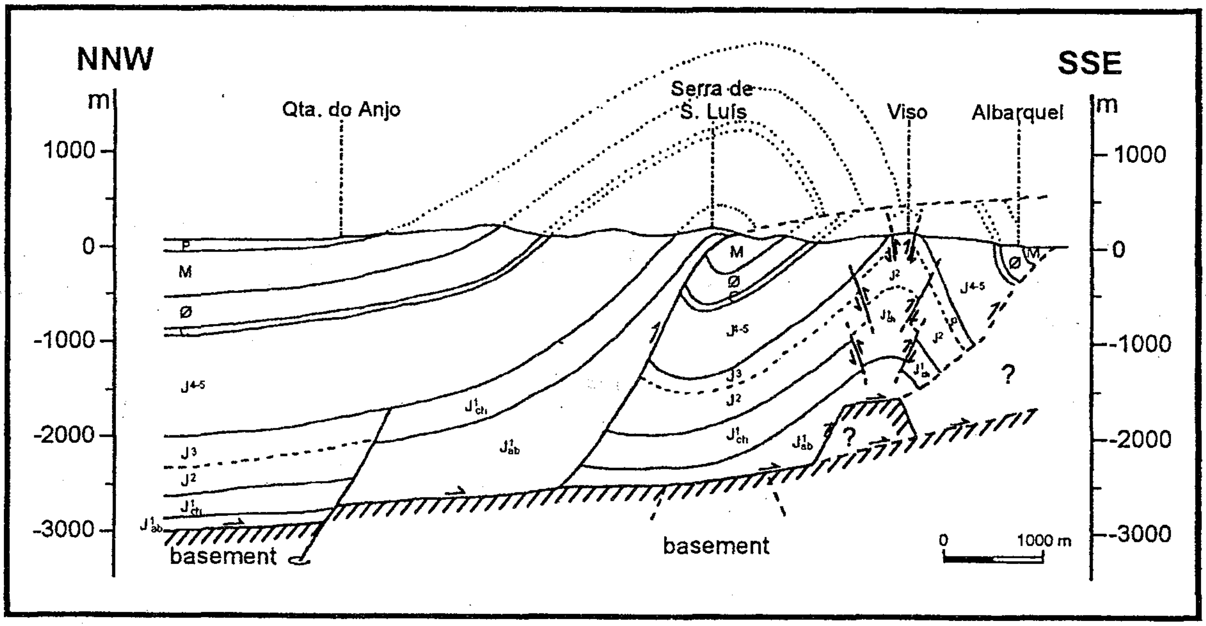

Fig 2 - Balanced geological cross-section of Serra de S. Luís and Viso structures, calibrated at the northern end by seismostratigraphy. Represented stratigraphical units are those of G. Zbyzsewski (1964), in Carta Geológica de Portugal, folha 38-B: Setúbal, scale 1/ 50 000, ed. S.G.P. **P**- Pliocene; **M**- Miocene; **ϕ**- Paleogene(Oligocene); **C**- Cretaceous; **$J^{4\text{-}5}$**- Upper Jurassic; **J^3**- "Lusitaniano"; **J^2** - Middle Jurassic; **$J^1{}_{ch}$**- Lower Jurassic; **$J^1{}_{ab}$**- Hettangian evaporite complex. Curved arrow = left lateral strike-slip faults (Jurassic normal faults) with movement oblique to this section.

Conclusions

1. The thin-skinned thrust model proposed by A. Ribeiro *et al.* (1990) to explain the Arrábida belt structures fits well with the observed structures that show thrusting and transport to the south and associated folding.

2. Comparison of geometries of thrust hanging-walls and foot-walls deformation structures shows a sharp contrast. Foot-wall synclines with reverse limbs are well developped, whereas the equivalent hanging-wall anticlines are generally absent or poorly developped. This suggests that the compressive structures started out as thrusts that later generated drag synclines on the foot-walls. This is opposed to the traditional model according to which the structures started as folds that were later cross cut by breaching thrusts.

3. The Viso sheath fold like structure (with sheared periclines along lateral ramps) and gentle folding of the Serra de S. Luis anticline axis (parallel to the axial direction) indicate an increase of convergence in the eastern part of the belt due to proximity of the basin boundary fault (Setúbal-Pinhal Novo fault). This constriction is a good explanation for the development of three thrust fronts in the eastern sector of the belt as opposed to only one in the western sector (Cabo Espichel, where no constriction is observed).

4. The stronger constrictional deformation observed in the Viso anticline compared to that of the Serra de S. Luis anticline is a structural evidence for the backward propagation sequence of the imbricated thrusts, as proposed in A. Ribeiro *et al.* (1990) but based on a stratigraphical evidence.

5. Backward thrust propagation was probably induced by the existence of an E-W striking basement horst block further south, that acted as a buttress to the sedimentary pile, during compression. This is indicated by wells that drilled basement at 1700 m below sea bed, to the south of Arrábida chain, whereas in the Arrábida chain itself, basement is at a depth of about 3 km.

This paper is a contribution to project MILUPOBAS, funded by the EC through contract GPEP/EC nº JOU2-CT 94-0348 .

References

Azevedo e Silva, E., 1992. Correlação Tectónica-Geofísica na orla Mesocenozóica ocidental. Relatório de Estágio Profissionalizante em Ciências Geofísicas, 105 p. Dep. Física, FCUL.

Choffat, P., 1904-07. Le Crétacique dans l'Arrabida et dans la contrée de Ericeira. Comun. Com. Serv. Geol. Portugal, T VI : 1-51.

Choffat, P., 1908. Essai sur la tectonique de la chaîne de l'Arrabida. Mem. Com. Serv. Geol. Portugal, 89 p. Imprimerie Nationale, Lisboa.

Ribeiro, A. & Ramalho, M., 1986. Estratigrafia e Tectónica da cadeia da Arrábida. Congr. Nac. Geol., 2nd (Univ. Lisboa). Field guide for Excursion B2/B3, 8 p.

Ribeiro, A., Kullberg, M.C., Kullberg, J.C., Manuppella, G. & S. Phipps, 1990. A review of Alpine tectonics in Portugal: foreland detachment in basement and cover rocks. Tectonophysics, 184 : 357-366

Seifert, H., 1963. Beiträge zur Geologie der Serra da Arrábida in Portugal. Geol. Jahrb., 81: 277-344.

Zbyszewski, G. , 1964. Carta Geológica de Portugal, folha 38-B : Setúbal. Scale 1/50 000, Serv. Geol. Port., Lisbon.