Neogene and Quaternary tectonic evolution of the South Portugal margin

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Palavras-chave: Tectónica neogénica, Inversão Tectónica, Neotectónica, Bacia Algarvia, Fronteira Açores-Gibraltar, Estado de tensão

Resumo: Discutem-se o desenvolvimento da Bacia Algarvia, a tectónica, o soerguimento e subsidência da mesma durante o Neogénico e Quaternário com base em reinterpretações de perfis sísmicos de reflexão, análise geomorfológica e estrutural. Conclui-se que a Bacia Algarvia evoluiu em regime tectónico compressivo constritivo durante o Quaternário mas que os movimentos verticais positivos e negativos são fundamentalmente flexurais, possivelmente associados a um mecanismo litosférico profundo. A existência de um limite de deformação Guadiana-Vidigueira é proposto. Discutem-se ainda propostas de 350 m de soerguimento da Serra do Algarve e 1.5 km de subsidência máxima da área imersa.

Key-words: Neogene Tectonics, Tectonic Inversion, Neotectonics, Algarve Basin, Açores-Gibraltar Plate Boundary, Stress Field

Abstract: Basin development, tectonics, uplift and subsidence during the Neogene and Quaternary are discussed with the aid of newer interpretation of seismic reflection data, geomorphological and structural data of the onshore and offshore of the Algarve Basin. It is concluded that the Algarve Basin evolved in a constrictive compressive stress field during the Quaternary but its positive and negative vertical movements are mainly flexural, possibly associated with deep located lithospheric mechanisms. Existence of a Guadiana-Vidigueira deformation boundary is proposed. 350 m of uplift of the Serra do Algarve and 1.5 km of subsidence of the offshore depocentre are discussed.

BASIN DEVELOPMENT AND TECTONICS DURING THE NEOGENE AND QUATERNARY

Neogene and Quaternary basin development and tectonics of the southern Portuguese margin are still poorly understood. In order to try to organise ideas about the evolution of this region during this time interval the following data and results are listed below:

i) the offshore Neogene and Quaternary has a maximum total thickness of 1.8 sec TWT (approximately 1.8 km of sediments), presently lying approximately 1100 m below sea level,

ii) marine sediments of Middle Miocene and Pliocene age were uplifted 350 m in the northern Algarve mountains since Late Pliocene, and the total thickness of the onshore Neogene and Quaternary probably does not surpass 200 m;

iii) the Miocene unconformity (**M**) truncates the Paleogene unconformity (**P**); Miocene sediments lie directly on top of Lower Cretaceous (or older sediments) even in areas of the basin which are presently approximately 2900 m below present day sea level;

iv) the Miocene through Quaternary sediments onlap both towards the continental shelf (to the north) and towards the Guadalquivir Bank (to the south); the Lower Miocene shows southwards directed turbidite-like depositional structures towards the bottom of the paleo-continental slope

v) the post-M unconformity sediments are little affected by compression when compared with the earlier sediments; the few existent post-M unconformity **thrusts** are located to the north of the offshore basin depocentre axis and they consist of mild reactivations of earlier thrusts;

vi) the post-M unconformity faults located south of the Neogene depocentre and bounding the Guadalquivir Bank are NE-SW to ENE-WSW trending **extensional** faults, i.e. striking parallel to the onshore, shelf and slope thrusts;

vii) the N-S trending normal faults south of Olhão down throw consistently towards the E; some of their northern segments have strongly been inverted during the Quaternary;

viii) the strike of the onshore post-Middle Miocene through Quaternary reverse faults with observed offsets ranging from a few centimetres to 50 m (in Pliocene through Quaternary and Miocene sediments) varies from E-W to N-S; much larger offsets can be speculated on the basis of lack of Miocene sediments on the hanging-walls of the main onshore thrusts; however, the most important observed post-Miocene thrusts strike N-S;

ix) the earliest drilled offshore Neogene sediments are of Middle to Early (?) Miocene age;

x) the depocentres of the offshore Algarve Basin migrated NE-wards (MOUGENOT, 1989) from Middle Miocene to Quaternary;

xi) the Gibraltar olistostrome (of Tortonian age), which extends from the Gibraltar Strait westwards beyond the Gorringe Bank barely penetrates the areas located to the north of the Guadalquivir Bank, i.e. the offshore Algarve Basin;

xii) the Paleogene sediments were deposited in a shallow marine environment (MOUGENOT, 1989) on top of folded

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and thrust Early Cretaceous sediments truncated by the Paleogene unconformity **(P)**; the Paleogene is folded and eroded prior to the deposition of the Miocene (Fig. 1).

From the above it can be concluded that:

a) the base of the Miocene unconformity subsided more than 1.5 km from LatePaleogene-Early Neogene times until Present in the offshore Algarve Basin and it is possible that the present coastline (or shelf break) retreated between 70 and 100 km since Late Oligocene/Early Miocene times;

b) the simultaneous activity of basinwards directed thrusts (north of the basin depocentre) and extensional faults on the southern basin boundary and Horseshoe Abyssal Plain (MOUGENOT, 1989 and TERRINHA, 1998), both of which accommodate minor displacements when compared to theNeogene and Quaternary vertical movements suggest that the onshore and offshore mountain and basin reliefs are flexural;

c) the Miocene through Quaternary northeastwards basin depocentre migration and slight incursion of the Gibraltar olistostrome in the east of Algarve (offshore) indicates that Central and Eastern Algarve shared a slight flexural bending with the Guadalquivir basin, during orogenic transport of the External Betic nappes towards the N and NW; however,

d) the influence of the Miocene Betic orogenic tectonics does not appear to be the determinant factor in the structuration and development of the Neogene Algarve Basin, as shown by **i)** the lack of the Gibraltar olistostrome in the Algarve Basin and maintenance of a Middle Miocene-Upper Miocenedepocentre in the west (MOUGENOT, 1989), **ii)** the lack of important compressive structures of this age and **iii)** the simultaneous existence of shortening and extensional structures within the same basin;

e) an arcuate deformation boundary, striking NW-SE in the Gulf of Cadiz, rotating anticlockwise towards the north, separates areas with important Miocene shortening in central Portugal from areas almost un-affected by the Miocene shortening (southern Portugal and the Algarve), where most of the deformation was mostly accommodated by ductile flexuring. The southern segment of this "deformation boundary"- the Guadiana Fault - was probably a transfer fault during the Mesozoic extension and later during the Paleogene-Neogene compressive tectonics; the northen segment is parallel to the Vidigueira fault.

Based on the above exposed facts and ideas theNeogene Algarve Basin is classified as a flexural basin. However, its geometry, orientation of main structures and migration of depocentre with time does not allow a direct correlation with the emplacement of the Betic nappes, i.e. the Algarve Basin is not a foreland basin of the Betic orogen.

MODEL FOR THE FORMATION OF THE NEOGENE ALGARVE BASIN

A model for the formation of the Algarve Neogene Basin has to account for **i)** its flexural characteristics, geometry and thickness of its sedimentary infill, **ii)** the basinwards directed thrusts in the north (onshore and continental platform of the Algarve Basin) and **iii)** extensional structures in the south (basin domain and Guadalquivir Bank). The model should also take into account **a)** the adjacent tectonic setting, i.e. the type and location of the Africa/Iberia plate boundaries, structure and tectonic evolution of the Betic orogen and Gorringe Bank and **b)** the plate trajectories of Africa with respect to Iberia or Eurasia.

Considering that:

i) the Internal Betics were subjected to very intense compressive deformation during Late Cretaceous andPaleogene times and that the Algarve margin also recorded these deformation events and was probably an emerged strongly inverted basin during this time interval,

ii) the Neogene compression that caused the overthrust of the External Betics and contributed to the formation of the Gibraltar Arc was barely felt in the Algarve and

iii) the maximum compressive stress trajectories during Middle Miocene times were approximately NW-SE in Central Iberia,

it is suggested that

a) the Betic-Rif orogen accommodated most of the Africa-Iberia collision during Neogene times and the metamorphosed Internal Betics acted as a promontory or rigid block between the two colliding plates;

b) the maximum compressive stress trajectories are parallel to the plate movement trajectory (Africa with respect to Europe) only in non- or mildly deformed areas of Iberia, while in the southern Iberian margin these trajectories must have been controlled by the indentation of the Internal Betics (that acted as a rigid block)and formation of the Betic-Rif arc, which caused a radial pattern of the maximum compressive stress around the Gibraltar area, where theGuadiana fault acted as a major deformation boundary (buttress fault). Stress data from the World Stress Map (ZOBACK, 1992)

indicate a NE-SW oriented maximum compressive stress for NW Morocco which is compatible with this model;

c) the extensional faults in the south of the Algarve Neogene Basin (basin depocentre and Guadalquivir Bank) were probably caused either by secondary extension associated with radial compressive stress around the Gibraltar arc or

d) by a deep located origin, such as for the extension and subsidence of the Alborán Basin.

If subsidence of the Algarve Neogene Basin has lithospheric origin, two processes can be proposed:

1) existence of oceanic crust in the southern margin of Iberia is suggested by the overlap of the two lithospheric plates in the palinspatic reconstructions of SRIVASTAVA *et al.* (1989); if this was the case it is possible that roll-back of the subducted slab was produced west of the Gibraltar arc during the formation of the arc and rotation of the main compression from N-S to NW-SE direction during the Middle-Late Miocene. Further subduction would then have occurred to the east of the Betic arc, which might be associated with the calc-alkaline volcanism of Sierra de Gata of Late Miocene age. The existence of a subducted slab underneath Iberia could explain the overlap between the African and Iberian plates suggested by SRIVASTAVA *et al.* (1989).

2) delamination of the lower lithosphere has been suggested by various authors to explain the Neogene subsidence and thinning of the Alborán Basin. There is a possibility that the southern Portuguese margin shared the same deep processes that caused the subsidence in the Alborán area.

PRESENT STRESS FIELD AND TECTONIC FRAMEWORK OF SOUTHERN PORTUGUESE MARGIN

The following observations carried out during field work and study of seismic sections may probably contribute to further development of the neotectonic models of this area, updated in RIBEIRO *et al.* (1996):

i) approximate E-W and N-S trending small scale reverse faults mapped in the area of Albufeira (Central Algarve Sector) indicate constriction in Pliocene-Quaternary sediments

ii) the N-S striking post-Upper Miocene thrust of Porto de Mós, which has been reactivated in the Quaternary and N-S striking Quaternary thrust south of Olhão indicate an approximate E-W trending main compressive direction on the coastline and shelf areas;

iii) the active extensional faults parallel to the Guadalquivir Bank suggest that the Neogene subsidence and thinning of this area is still active.

Inspection of data from World Stress Map (ZOBACK, 1992) shows a NE-SW main compression direction in NW Morocco, i.e. the area located to the south of the extensional faults of the Guadalquivir Bank. These data suggest that the stress trajectories around the Betic-Rif arc are probably radial with respect to it and that NNW-SSE oriented extension at the Guadalquivir Bank may be secondary, driven by indentation of the Betic-Rif arc. The constriction observed in the Central and Western Algarve Sectors is probably associated with the effect of buttress of the arcuate basement inversion anticline (Serra do Algarve). The Cabo de São Vicente Fault is considered to be a sinistral reverse fault, which could constitute the original fault for the northward propagating incipient subduction zone postulated by RIBEIRO *et al.* (1996). Three suggested alterations to the Present tectonic framework of SW Iberia proposed by RIBEIRO *et al.* (1996) are:

1- the Cabo de São Vicente Fault is a sinistral oblique-slip reverse fault;

2- the Guadalquivir Bank faults are extensional, possibly with a sinistral oblique-slip component on them and

3- the Guadiana Fault is a buttress fault to the compression of the Betic-Rif arc; this compression may be the cause for the sub-perpendicular extension at the Guadalquivir Bank.

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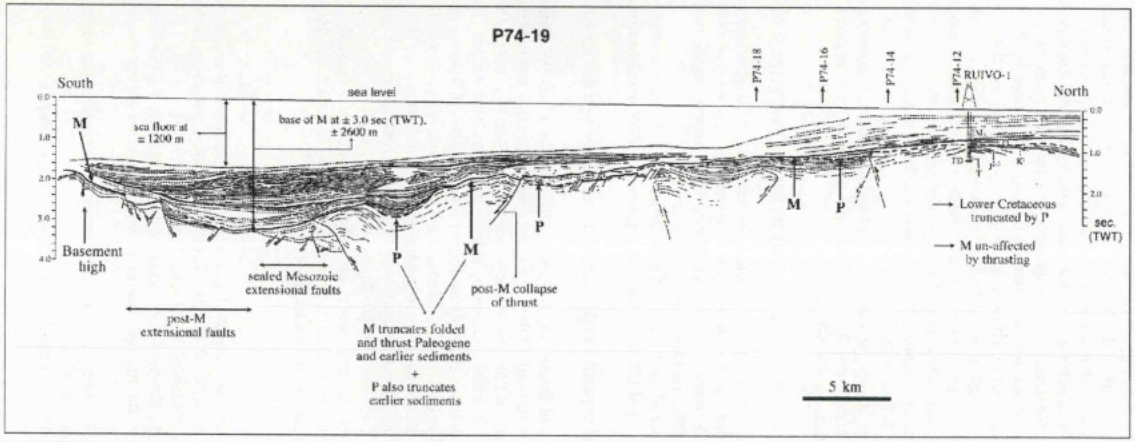

Fig. 1 - Basin evolution and subsidence during Neogene and Quaternary times. It is argued that the Lower Cretaceous and Paleogene sediments were deformed, exposed above sea level, truncated by erosion and covered by Neogene sediments during re-newed subsidence. **P** - Paleogene unconformity (probably of Eocene age); **M** - Miocene unconformity (Lower to Middle Miocene age). (Adapted from TERRINHA, 1998).