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The three main marine depositional cycles of the Neogene of Portugal

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RESUMO

Palavras-Chave: Miocénico; Pliocénico; Estratigrafia; Paleogeografia; Tectónica; Plataforma costeira do Algarve; Bacia do Sado; Bacia do Baixo Tejo; Bacia do Mondego.

O modelo apresentado corresponde a uma síntese do estado actual do conhecimento relativo aos trabalhos estratigráficos e paleogeográficos que têm vindo a ser realizados nas regiões, de norte para sul: (1) Bacia do Mondego (litoral oeste de Pombal - Caldas da Rainha), (2) região vestibular da Bacia do Baixo Tejo (Península de Setúbal), (3) Bacia do Sado e litoral vicentino e (4) bordadura meridional algarvia. Nele se correlacionam as principais sequências sedimentares do Neogénico marinho português tendo em vista o seu enquadramento tectono-eustático regional, no "*onshore*" e no "*offshore*".

O modelo considera três ciclos deposicionais principais, para o Neogénico marinho português, equivalentes a sequências sedimentares de 2ª Ordem, com duração entre 5 e 8 Ma.

O I Ciclo está completamente representado apenas na região vestibular da Bacia do Baixo Tejo. As sequências atribuídas a este ciclo são, essencialmente, de idade burdigaliana (Miocénico Inferior) e terão sido, provavelmente, originadas por subsidência isostática local. A acentuada variabilidade das suas fácies sugere a existência na região de Lisboa de um ambiente de transição, de pequena profundidade, durante o Miocénico Inferior. Instabilidade tectónica desta bacia pode ter estado na origem de rápidos episódios regressivos, de expressão mais ou menos localizada. As associações fósseis marinhas (sirénios, corais, malacofauna, macroforaminíferos bentónicos) traduzem acentuado carácter termófilo.

O II Ciclo está muito bem representado na região vestibular da Bacia do Baixo Tejo, na plataforma costeira do Algarve e no litoral vicentino. Terá, ainda, influenciado a sedimentação no litoral ocidental estremenho, mas de modo pouco significativo. A sedimentação é essencialmente de idade languiano-serravaliana (Miocénico Médio) e terá sido desencadeada pelo acentuado eustatismo positivo global que caracterizou este intervalo temporal. Atingiu maior expressão batimétrica na Bacia do Baixo Tejo, como o atestam a maior uniformidade e extensão lateral das suas fácies e das suas associações de micro e macrofósseis. A análise de lito e biofácies dos sedimentos associados ao II Ciclo sugerem ter existido acentuado gradiente térmico das massas de água entre a bordadura meridional (fácies fortemente carbonatadas com macroforaminíferos bentónicos) e a fachada ocidental (fácies detríticas). Este ciclo termina com importante fase compressiva bética que se manifesta a partir do final do Serravaliano, tendo resultado em importante lacuna de deposição de sedimentos marinhos, ao longo de todo o território nacional, correspondente a cerca de 2,5 milhões de anos.

O III Ciclo tem expressão geográfica semelhante ao anterior mas o início da sedimentação marinha, condicionada por abatimentos tectónicos diferenciados em cada bacia, migra de sul para norte, ao longo do tempo. As primeiras unidades deste ciclo marinho iniciaram a sua deposição, no sotavento algarvio (Formação de Cacela), no decurso do Tortoniano Superior (primeira fase) enquanto que, mais a norte, na região de Pombal, a base deste ciclo (Formação de Carnide), data do Pliocénico Superior, Placenciano (terceira fase). Este facto está provavelmente relacionado com a rotação dextrogira da Bacia de Guadalquivir e consequente migração da deformação (subsidência) de sul para norte, ao longo do território português.

ABSTRACT

Key-words: Miocene; Pliocene; Stratigraphy; Paleogeography; Tectonics; Algarve Basin; Sado Basin; Lower Tagus Basin; Mondego Basin.

The present work follows a stratigraphic model for the marine Neogene of Portugal based on the definition of three main marine sedimentary cycles. Conceptually the I, II and III Neogene Cycles can be defined as 2nd order sedimentary sequences with duration ranging from 5 to 8 Ma. The I Neogene Cycle is fully represented only in the Lower Tagus Basin. Ranging from the Early Aquitanian to the Late Burdigalian the I Neogene Cycle testify a transgressive episode in the region of Lisbon and Setúbal Peninsula. Rapid lateral facies variations suggest a shallow marine basin. This cycle ends with an important Late Burdigalian tectonic compressive event expressed by uplift of the surrounding areas and deformation affecting the Early Miocene deposits of the Arrábida Chain.

The II Neogene Cycle includes thick sedimentary sequences covering Paleozoic and Mesozoic formations in the Algarve and Alvalade-Melides regions and it extends as far north as Santarém in the Lower Tagus Basin. Mainly controlled by global eustasy, it was generated by the important positive eustatic trend that characterized the Middle Miocene worldwide to which the Portuguese continental margin acted more or less passively. This cycle ended with a second and the most important compression event starting after the end of the Serravallian affecting the entire Portuguese onshore and shelf areas. This led to an important depositional hiatus of marine sediments for more than 2.5 Ma.

During the Early and the Middle Tortonian occurred the clockwise rotation of the Guadalquivir Basin. The thick marine units deposited afterwards in this basin produced a litostatic load, which seems to have induced subsidence farther west resuming the Neogene marine sedimentation in the Cacela region (Eastern Algarve), during the Late Tortonian. This marks the beginning of the III Neogene Cycle. To the north, in the Sado Basin (Alvalade-Melides region), a similar depositional sequence starts its sedimentation during the Messinian. Further north, in the Pombal - Caldas da Rainha region, marine sedimentation started during the Late Pliocene (Piacenzian). The migration in time, from south to north for the beginning of the marine sedimentation of this cycle is interpreted as reflecting a visco-elastic propagation of the deformation from the Betic chain northwards.

INTRODUCTION

For almost two centuries extensive stratigraphic and paleoecological studies have been published about the Neogene of Portugal mainly focusing on the Lower Tagus Basin (see Antunes *et al.*, 1999). However, still few works try to approach the entire Portuguese marine sedimentary sequences, their correlation and paleogeography in a single framework. Cunha (1992a, 1992b) proposed Tertiary alostratigraphic units which related continental and marine Neogene sequences from the Lower Tagus Basin northwards, distinguishing depositional episodes and tectono-sedimentary stages. In this same year the entire marine Neogene of Portugal is integrated on a synthesis of the paleogeographic evolution of the Western coast of France, the Iberia and the Betic-Rifian realms (Alvinerie *et al.*, 1992). The present work proposes a synthesis for the marine Neogene units of Portugal following the stratigraphic model proposed by Cachão (1995), which is here updated. Based on a compilation of the available data the paleogeographic evolution of the marine units of the Neogene of Portugal is described and some of its stratigraphic and tectonic implications are discussed. Already attempted by previous authors (Bourcart & Zbyszewski, 1940; Zbyszewski, 1964), the definition of major marine sedimentary cycles, herein designated the I, II and III Neogene Cycles, is important in order to filter local intra-basin facies variations from regional depositional sequences, this way enabling inter-basin correlation. Conceptually these marine Neogene Cycles can be defined as 2nd order sedimentary sequences (*sensu* Einsele & Rickens, 1991) and should be viewed as a step towards a full integration into a single Sequence Stratigraphy framework.

MAIN DEPOSITIONAL CYCLES

The I Neogene Cycle

The I Neogene Cycle is fully represented only in the Lower Tagus region. Lithostratigraphic units I to III of Cotter (1956), ranging from the Early Aquitanian to the Burdigalian (Antunes *et al.*, 1999) testify a small scale transgressive sequence in the region of Lisbon and Setúbal Peninsula (Fig. 1, 2). In this last region there is evidence of rocky shores on the western side of the Arrábida region based on the bioeroded surface of Foz da Fonte (Silva *et al.*, 1999) most probably related with cretaceous tectonic activity around the Sesimbra diapiric structure (see Kulberg *et al.*, 1995b; Kullberg & Kullberg *in press*). Maximum marine incursion during this cycle seems not to extend beyond the localities Alverca (A) and Vila Franca (VF) (Fig. 2). The Neogene unconformably overlies thick sequences of endorreic Paleogene continental deposits (Benfica and S. Caetano Formations; Azevêdo, 1998) and other Mesozoic units. This cycle ends with the regressive facies of the units IVb, Va and Vb defined for the Lower Tagus Basin by Cotter (1956), which dates range from the Late Burdigalian to the Early Langhian according to Antunes *et al.* (1999). Although isotopic ages compatible with this time interval have been registered (Antunes *et al.*, 1999) in the Algarve platform stratigraphical evidences are still contradictory (see Cachão, 1995, Cachão *et al.*, 1998).

Despite important thickness, rapid lateral facies variations testify that this marine basin was quite shallow at this time. Antunes *et al.* (this volume) interpret this as related to continuous tectonic subsidence during this long time interval. Other authors suggest that during the Early Miocene marine sedimentation inside the Lower Tagus Basin may have been possible due to the isostatic re-equilibrium that followed the uplift of the surrounding areas during the Late Cretaceous and the Paleogene (Kullberg & Kulberg, *in press*). However, the Lower Miocene depositional sequence includes several smaller sedimentary sequences (DS A, DS B0, DS B1 and DS B2 of Antunes *et al.*, 1999), which may reflect 3rd order parasequences (*sensu* Vail *et al.*, 1991). One such case is the erosional paraconformity that separates units II and III of Cotter (1956), which has minor temporal expression (intra CN3a biozone of Okada & Bukry *in* Gibert *et al.*, 1998). In some places (e.g. Cristo-Rei to Portinho da Costa sections), above this paraconformity fossil shell layers display what may be interpreted as load-induced sinsedimentary deformation along an erosional surface carved upon sand waves formed during an early stage of the Burdigalian marine estuary.

Marine fossil assemblages contain Sirenia mammals, corals, molluscs, benthic macroforaminifera all indicating the existence of subtropical warm waters at the latitude of Lisbon, during the Early Miocene (Antunes, 1971). During this cycle, the main depocentric area changed from Lisbon to the Charneca-Corroios region (Antunes *et al.*, this volume). Interpreted as due to a compressive block tectonics (*op. cit.*) we relate this to a deformation along a synclinal structure defined in the region of the Setúbal Península. In this basin a more rigid northern margin and a more deformable southern margin controlled the rate of the subsidence gradually shifting its depocentric area southwards along an asymmetrical synclinal with vergence towards the South.

This cycle ends with the onset of the important Late Burdigalian tectonic compressive event in the area. This event is expressed by deformation of the Lower Miocene deposits of the Arrábida Chain, south of the Formosinho thrust (Kullberg *et al.*, 1995a). It was dated from around 17 Ma, in the southern side of the Arrábida Chain, at Portinho da Arrábida – Anixa sector (Pais *et al.*, 1991; Antunes *et al.*, 1995). Uplift of the Iberian Meseta and the subsequent northeast to southwest progradation of terrigenous sedimentation by feldspatic sandstones pursued until the limit Burdigalian-Langhian inside the proximal areas of the Lower Tagus Basin. This led to strong lateral facies variations and possible diachronism of the limits of the lithostratigraphic units IV and V of Cotter (1956), between the Lisbon and the Setúbal Peninsula areas (Fig. 1). While the near proximal areas display thick sandstone units with terrestrial vertebrate faunas (Antunes *et al.*, 1996) the distal areas, south and west of the Cristo-Rei sector, always had shallow marine sedimentation, throughout this regressive interval.

Bourcart & Zbyszewski (1940) considered the litostratigraphic unit IVb of Cotter (1956; "Sands and clays with *Ostrea crassissima* and fossil plant remains of Quinta do Bacalhau") as correlative of the maximum of the regression associated to a first Miocene cycle, denominated "premier étage mediterranéen" following the terminology of Edouard Suess (*in* Bourcart & Zbyszewski, 1940). The age of this unit, around 18 Ma (Antunes *et al.*, this volume) may relate its deposition with the above-mentioned compressive event. Cunha (pers. commun., 2000) suggest that the correlative alostratigraphic unit SLD9 may end with the unit Va2 of Cotter (1956). However, the full extend of the consequences of this compression, inside the Lower Tagus Basin, namely the trend towards the most arid conditions (interpreted by other authors as a sequence of uncorrelated short-term climatic events; Antunes & Pais, 1984), is only achieved during the deposition of the litostratigraphic unit Vb of Cotter (1956; "Sands and sandstones with *Ostrea crassissima* of the valley of Chelas") which is here interpreted as the final depositional stage of the I Neogene Cycle.

In the Alentejo continental margin, an erosional surface detected between seismic units 4 and 5 is interpreted as related to this same compressive event (Alves *et al.*, this volume).

Due to the combination of all these local factors interacting with the positive eustatic trend of the Burdigalian, each of the small-scale events inside the Lower Tagus Basin, here integrated into the I Neogene Cycle, may result difficult to correlate with other regional basins. Only the entire I Neogene Cycle may allow successful correlations. However, the significant distance between this basin and the active Betic tectonic areas during the Aquitanian and Early Burdigalian (the opening of the Algerian and Provencal basins and the anti-clockwise rotation of the Corsica and Sardinia; see Sanz de Galdeano, 1997) may explain the lack of more evident and correlative tectonic structures controlling the sedimentation of the I Neogene Cycle inside the Lower Tagus Basin. The timing for the intra-Burdigalian compression event of Arrábida was probably related with the progressive westward advancement of the Betic-Rif deformation into the Western Mediterranean area by the end of the Burdigalian (see Sanz de Galdeano, 1997). At Arrábida, due to its westernmost Iberian position the tectonic efforts, related to the general compressive betic regime, led to the deformation of meso-cainozoic layers into several *en echelon* anticlines associated to a thrust belt with displacement towards SSE (Ribeiro *et al.*, 1979).

The II Neogene Cycle

The II Neogene Cycle, in contrast with the previous one, is represented in a vast region of the southern and western coastal areas of Portugal. From South to North it includes: (1) the thick sedimentary sequences of the Lagos-Portimão Formation in the Algarve Basin, (redefined *in* Cachão, 1995); (2) the "*Calcarenito de* Melides" unit (Cachão, 1995) and the Alcácer do Sal Formation (Antunes *et al.*, 1986) in the Sado Basin (Alvalade-Melides region); and (3) the lithostratigraphic units Vc, VI and VII of Cotter (1956) in the Lower Tagus Basin, corresponding to the depositional sequences L1 (partially), S1, S2, T1 and T2 of Antunes *et al.* (this volume) (Fig. 1). Already Bourcart & Zbyszewski (1940) recognized that the units V, VI and VII of Cotter (1956) could be globally related to a same depositional sequence, which these authors denominated as "deuxième étage méditerranéen".

North of Lisbon, the marine sedimentation was most probably reduced to small and shallow local gulfs developing north of Sintra (Choffat, 1950; Madeira *et al.*, 1983-85), at Marinha Grande (M. T. Antunes *in* Ribeiro *et al.*, 1979; Antunes & Pais, 1993) and at Figueira da Foz (Teixeira *et al.*, 1958). None of these deposits, however, allow precise intra-Neogene specific stratigraphic positioning. We tentatively interpret the lacustrine facies of some of the clay and sandstone upper layers of the Amor Formation (Antunes & Mein, 1981) as reflecting the near proximal sedimentary facies associated to these deposits.

The II Neogene Cycle resulted from a large transgression that covered Palaeozoic and Mesozoic basements over a polygenic erosional unconformity in the Algarve region (see Cachão, 1995) and extended as far as Santarém in the Lower Tagus Basin (Bourcart & Zbyszewski, 1940; Antunes & Pais, 1993). Facies uniformity throughout the Lower Tagus Basin and the interpreted deeper paleobatimetries derived from the macrofossil assemblages (e.g. fishes, Antunes & Jonet, 1969-70) of the unit VI of Cotter (1956) clearly demonstrates the importance of this transgressive event (Alvinerie *et al.*, 1992). The transgression and the subsequent inshore coastline retreat led to a deficiency in sedimentation in the distal areas of the basin such as the region of Penedo (southwest of Setúbal Peninsula), expressed by condensed sections with glauconite (isotope K-Ar ages ranging from 15 to 12.5 Ma *in* Antunes *et al.*, 1999).

There is a change in facies from south to north, along the Portuguese margin, during this cycle. In the Algarve, at the south, the litofacies are more heavily calcified while further north, in the Lower Tagus Basin, the correlative litotypes tend to be less cemented by calcium carbonate. Fossil assemblages also seem to indicate the existence of a thermal gradient in the waters along the Portuguese shelf already during the Middle Miocene (see discussion *in* Cachão, 1995).

These trangressive sequences are interpreted as being mainly controlled by global eustasy reflecting a response to the important positive eustatic trend that characterised the Middle Miocene worldwide (cycles 2.3-2.4 of Haq *et al.*, 1988). During this phase the Portuguese continental margin acted passively to the transgressive motion with the exception of the Lower Tagus Basin, which continued behaving as an important depocentric area.

This cycle ended with a second and the most important compression event, which started after the end of the Serravallian. This tectonic phase affected the entire Portuguese onshore and shelf areas. In the onshore distal areas of the Lower Tagus Basin uppermost marine units revealed that marine sedimentation had been significantly reduced or even finished around this age, although biostratigraphic evidences are still controversial. The co-occurrence of *Helicosphaera walbersdorfensis* and *H. stalis* in the Calcareous nannofossil assemblages from the uppermost section of Foz do Rego (Costa da Caparica) indicate that the marine sedimentation ended in this distal sector of the Lower Tagus Basin during biozone NN7 of Martini / CN5b of Okada & Bukry (Cachão, 1995), between 11.8 and 11 Ma of Berggren *et al.* (1995), latest Serravallian. On the other hand, planktonic Foraminifera seem to indicate that the marine sedimentation persisted until the limit N15/N16 of Blow (earlymost Tortonian, Delgado *et al.*, 1993; Legoinha, 1993).

During the Lower Tortonian, in the Betic region, compressive efforts led to the westward movement of the Alboran's microplate (Tapponier, 1997) and to the development of olistrostrome deposits over the abyssal planes of the Cadiz and Horseshoe Golfs (Boninn *et al.*, 1975) most probably by gravitational placement (Sanz de Galdeano, pers. commun., 2000). Meanwhile, over the entire Portuguese margin, a generalized emergence was produced followed by intense erosion. Continental de posits (endorreic alluvial fans) formed in relation to major tectonic accidents define the SLD11 allostatigraphic unit (Cunha 1992a, 1992b, Cunha *et al.*, this volume). Karsts developed in the coastal areas south of Melides, previously subjected to higher calcification during the Middle Miocene (Cachão, 1995). This led to an important stratigraphic hiatus of more that 2.5 Ma (Fig. 1) that may be tracked from the Algarve region to the Iberian Abyssal Plane. It is well defined in all ODP Leg 149 sites, in particular Site 900 (Fig. 1), located 250 km west of Aveiro and at the present day depth of around 5 000m (Kaenel & Villa, 1996) (Fig. 2). According to Kaenel & Villa (1996) this hiathus correspond to the biozonal interval NN9-NN10 of Martini (1971) (CN7-8 of Okada & Bukry, 1980, aprox. between 10.5 and 8.6 Ma, of Bergreen *et al.*, 1995), equivalent to the entire cycle 3.1 of Haq *et al.* (1987).

However, on the shelf of the Setúbal Canyon only small-scale erosional features seems to testify this compressive phase (Coppier & Mougenot, 1982).

The above-mentioned characteristics of this cycle allow the establishment of correlations within a broader regional scale. The already mentioned progression of the Betic-Rif deformation towards West (see Sanz de Galdeano, 1997) allows the establishment of a more direct structural and paleogeographic correlation between the Portuguese Iberian Margin and the Betic Chain. This may explain why the compressive efforts that can be recognized in the Arrabida and Sintra regions (see Kullberg & Kullberg, *in* press) are much more intense by the end of the II Neogene Cycle than during the end of the I Neogene Cycle, as it was already recognized by other authors (A. Ribeiro, pers. commun., 2000).

The III Neogene Cycle

During the interval of time in which the marine sedimentation completely ceased along the entire Portuguese margin, the persistence of the deformation on the Betic chain led to the development of an important foreland depocentric region. Related to a fault (Ribeiro *et al*, 1990) or to flexural deformation (Sierro *et al.*, 1990) an elongated foredeep basin, the Guadalquivir Basin, started to receive thick and deep marine sediments (Sierro *et al.*, 1990). The tectonosedimentary depositional sequences of the Gualdalquivir Basin (Olmo *et al.*, 1984 *fide* Sierro *et al.*, 1990) show evidences of a clockwise rotation with the northwestward translation of its depocentre taking place during the Early/Middle Tortonian transition (Sanz de Galdeano & Vera, 1991). Further west this rotation led to ulterior litostatic-induced subsidence and to the beginning of the marine sedimentation in the Algarve region, associated to the III Neogene Cycle.

The III Cycle sedimentation starts with micaceous fine poorly cemented sandstones, the *areolas* facies (Cachão & Freitas, 1998). In the Cacela region (Eastern Algarve),

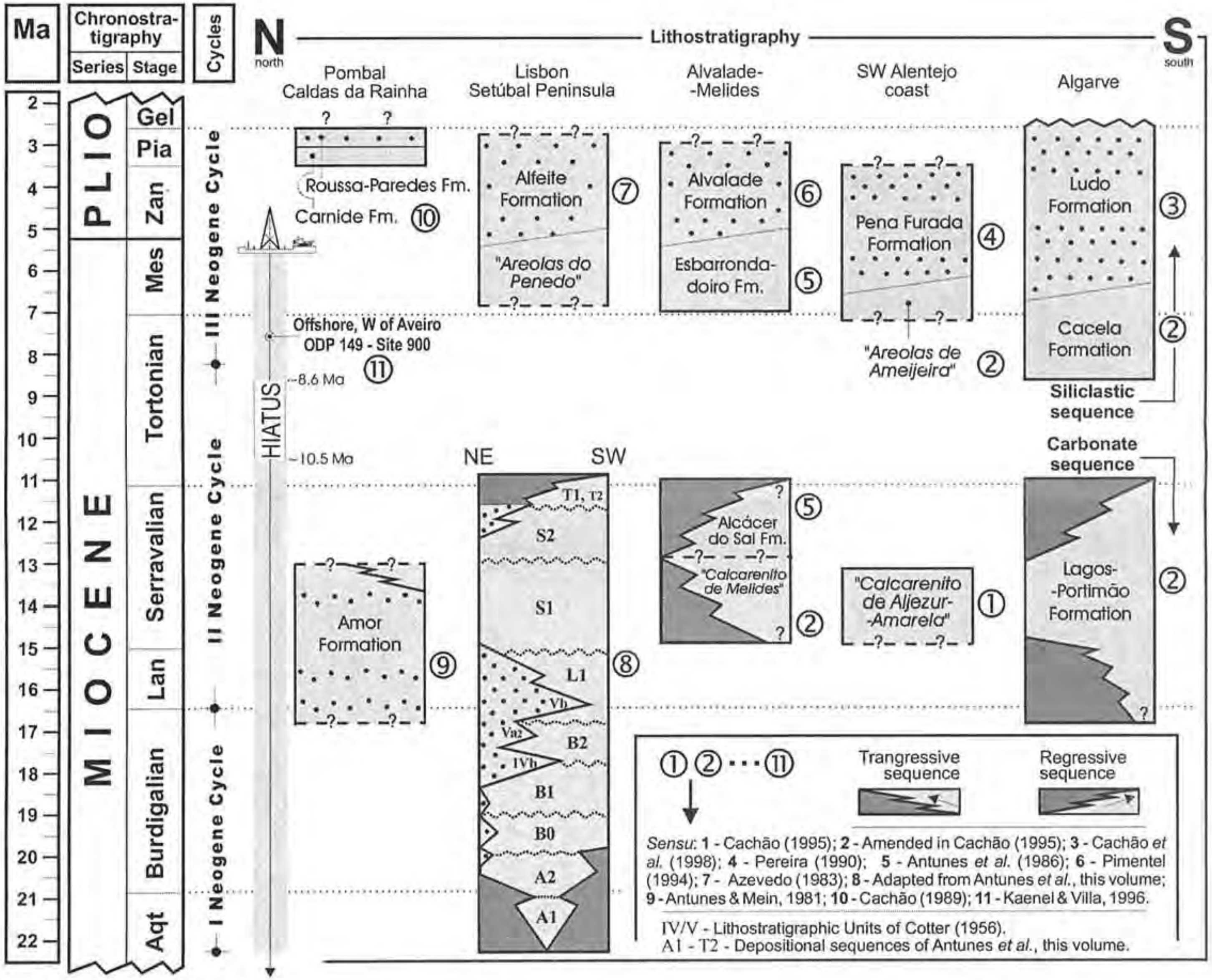

Fig. 1. Stratigraphic framework of the depositional sequences of the Neogene of Portugal (Adapt. Cachão, 1995).

the *areolas* lower levels of the Cacela Formation enclose rich macrofossil and microfossil assemblages allowing its stratigraphic positioning in the beginning of the Late Tortonian (CN9a Okada & Bukry, 1980 *in* Cachão, 1995) (Fig. 1). So, marine sedimentation in the Algarve Basin resumes immediately after the CN7-8 hiatus detected at the Iberia Abyssal Plain by Kaennel & Villa (1996).

The external location of the Algarve region relative to the Guadalquivir basin explains the short vertical development of the Cacela Formation, correlative of the thick units A to D of the Guadalquivir Basin (see discussion *in* Cachão, 1995). The common occurrence of condensed sections with glauconite (Antunes *et al.*, 1984) is in agreement with this deficiency in sediments (Cachão, 1995). At Central Algarve (Oura region) the Cacela Formation overlays the karsified upper units of the Lagos-Portimão Formation. This unconformity is well marked by a bioeroded marine abrasion surface that cuts an already litified substratum, testifying the important time gap that separates these two units (Silva *et al.*, 1999; Domènech *et al.*, 1999). The Cacela Formation, together with the overlying siliciclastic Ludo Formation (Cachão *et al.*, 1998) defines the first phase of sedimentation associated to the III Neogene Cycle (Fig. 2).

To the north, in the Sado Basin (Alvalade-Melides region), a similar depositional sequence, initiating with the Esbarrondadoiro Formation, starts its sedimentation shortly afterwards, during the Messinian (Antunes *et al.*, 1986). In the Lower Tagus Basin (Setúbal Peninsula), overlaying the fossiliferous levels of the II Neogene Cycle, a transitional sequence previously recognized and denominated "Sobreda sands" (Dollfus & Cotter, 1909) or "Sobreda layers" (Bourcart & Zbyszewski, 1940) was subsequently interpreted by T. Antunes (*in* Ribeiro *et al.*, 1979) as a result of the calcium carbonate dissolution of the uppermost Miocene layers of the units VII of Cotter (1956). However, there is an unit, herein designated "*Areolas do Penedo*" (Fig. 1), that overlays fossiliferous Middle Miocene (II Neogene Cycle) layers at the Penedo region by means of an unconformity erosional surface. Although the existent stratigraphic data are still imprecise, this unit seems to testify a short-term shallow marine incursion in the Setúbal Peninsula that is assumed to be correlative of the Esbarrondadoiro Formation. Together, the two units are considered as an evidence of a small-scale marine episode, the second phase of the III Neogene Cycle in the Sado (Alvalade-Melides) and Lower Tagus basins (Fig. 2). Shortly afterwards this phase ended by transitional to fluvial regressive sequences represented by the Alvalade Formation, in the Sado Basin (Pimentel, 1994) and the "*Série arenosa do Alfeite*" in the Lower Tagus Basin (Azevêdo, 1983).

Further north, in the Pombal - Caldas da Rainha region, an also similar depositional sequence may be observed (Cachão, 1989). The marine sedimentation started with the deposition of the Carnide Sandstones (Barbosa, 1983) during the Lower Upper Pliocene (the Carnide Formation, Piacenzian, CN12a Okada & Bukry, 1980 *in* Cachão, 1990). This unit is in depositional continuity with an upper siliciclastic unit, the Roussa-Paredes Formation, which contains palinological assemblages indicative of Reuverian age (ante-Praetiglian) (*i.e.* Piacenzian) (Diniz, 1984). These two units evidence a delayed third phase of marine sedimentation within the III Neogene Cycle (Fig. 2).

Onshore, during the III Neogene Cycle, the marine sedimentation initiated in the south of Portugal propagated northwards to the Tagus Basin and further north towards the west coast of Estremadura. This seems to suggest migration of crustal subsidence from south to north in a visco-elastic rheological regime (Ribeiro, pers. commun., 2000). The change in the relative orientation between the southern E-W elongated depocentric area of Algarve and the northern N-S elongated depocentric area of Pombal-Caldas da Rainha may reflect a rotation in the orientation of the maximum compressive regime from the Upper Miocene (NNW-SSE) to the Pliocene (WNW-ESE) (Ribeiro *et al.*, 1996).

The marine sedimentation on the Portuguese sector of the Iberian Margin seemed to have been progressively more controlled by tectonic deformation, particularly during this last cycle. This seems to be in agreement with a most accepted hypothesis for the Neogene tectonic structuration of the Betic-Rif chain, by which there was a progressive translation of the deformation from the inner zones of the chain towards West (Sanz de Galdeano, 1997).

CONCLUSIONS

A new paleogeographic model for the evolution of the marine sedimentary units of the Neogene of Portugal is described based on the definition of three main marine depositional sequences. Defined as 2nd order sedimentary sequences the I, II and III Neogene Cycles have durations ranging from 5 to 8 Ma.

The I Neogene Cycle is represented in the Lower Tagus Basin. Lithostratigraphic units I to III of Cotter, ranging from the Lower Aquitanian to the Burdigalian testify a transgressive sequence which maximum incursion not extended beyond Alverca-Vila Franca localities. Rapid lateral facies variations testify for a shallow marine basin. This cycle ends by an important Late Burdigalian tectonic compressive event that induced terrigenous sedimentation inside the Lower Tagus Basin induced by uplift of the proximal surrounding areas and deformation affecting the Early Miocene deposits of the Arrábida Chain. This led to the progressive change of the paleoenvironment of the region of Lisbon towards more terrestrial and arid conditions reaching its maximum during the Burdigalian-Langhian limit (unit Vb of Cotter). It may be concluded that the I Neogene Cycle resulted from the combination of local subsidence conditions probably induced by isostatic crustal re-equilibrium associated to the with the positive eustatic trend of the Burdigalian.

The II Neogene Cycle, represented in a larger region, includes thick sedimentary sequences in the Algarve, the Sado and the Lower Tagus Basins (units VI and VII of Cotter). North of Lisbon, the marine sedimentation was

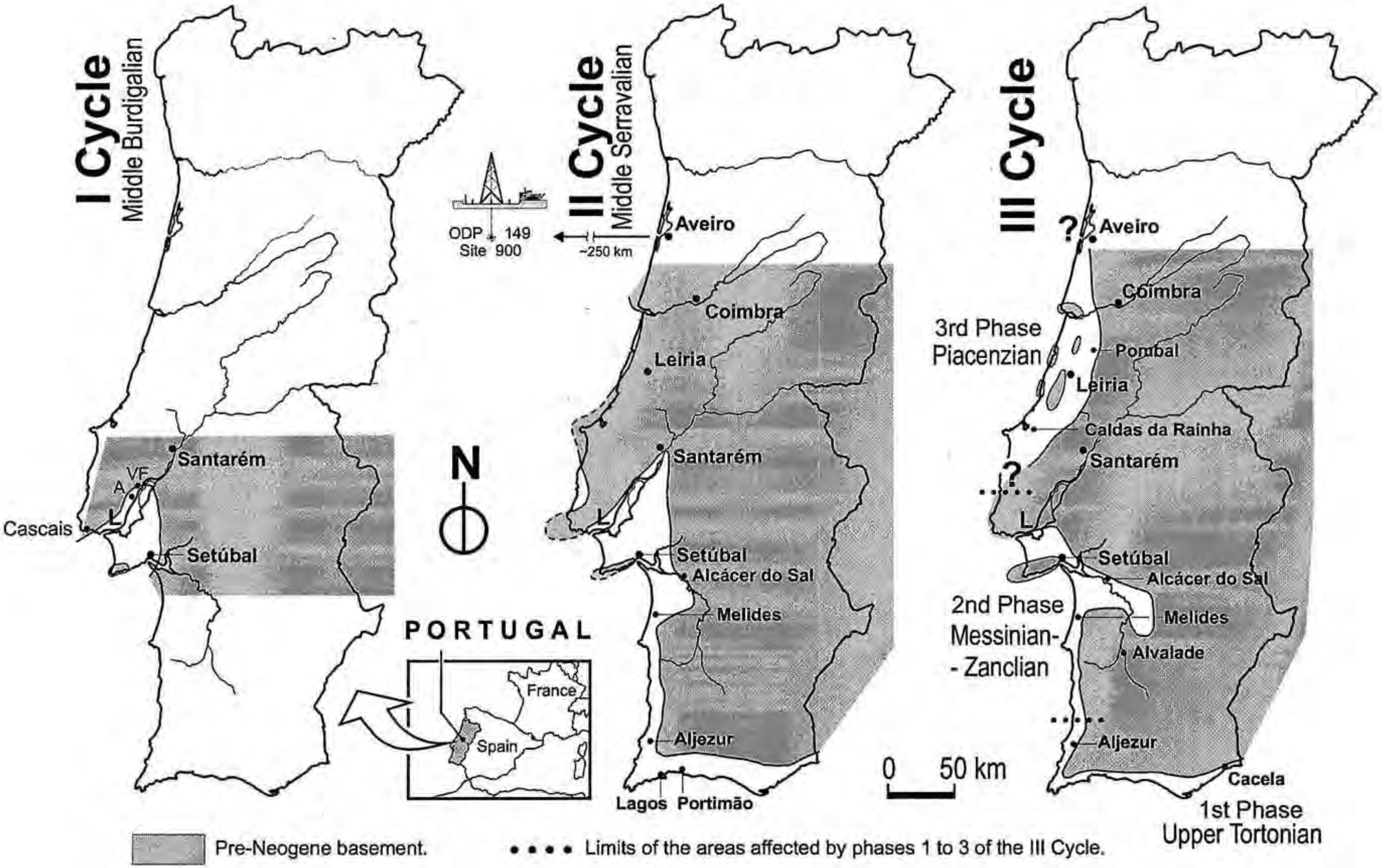

Fig. 2 - Paleogeographic maps of the maximum transgressive events of the Neogene of Portugal. Shaded sectors represent emerged areas surrounding the marine basins. I - I Neogene Cycle during the Middle Burdigalian; II - II Neogene Cycle during the Middle Serravallian; III - III Neogene Cycle during the Upper Tortonian in the Algarve region (1st phase), the Messinian-Lower Pliocene in the Alvalade-Melides-Setúbal regions (2nd phase), and the Upper Pliocene-Piacenzian in the Caldas da Rainha – Pombal region (3rd phase). Abbreviations: L – Lisbon; A – Alverca; VF – Vila Franca.

most probably reduced to small and shallow local gulfs. It was generated by the important positive eustatic trend that characterised the Middle Miocene worldwide (cycles 2.3-2.4 of Haq *et al.*, 1988). The Portuguese margin acted passively to the transgressive movement with the exception of the Lower Tagus Basin that behaved as an important depocentric area. This cycle ended with a second and the most important compression event starting after the end of the Serravallian and pursuing throughout the Lower and Middle Tortonian. This led to an important depositional hiatus of more that 2.5 Ma, which can be traced from the Algarve region to the Iberian Abyssal Plane (ODP Leg 149).

The clockwise rotation of the Guadalquivir basin between the Early and the Middle Tortonian moved the depocentric area closer to the Algarve region. The thick marine units deposited afterwards in this basin produced a litostatic load, which seems to have induced subsidence farther west resuming the Neogene marine sedimentation in the Cacela region (Eastern Algarve), during the Late Tortonian. This marks the beginning of the marine III Neogene Cycle. To the north, in the Sado Basin (Alvalade-Melides region), a similar depositional sequence starts its sedimentation during the Messinian giving evidence for a second phase of sedimentation associated to the III Neogene Cycle. Further north, in the Mondego Basin (Pombal - Caldas da Rainha region), a similar depositional sequence (the third phase) started during the Late Pliocene (Piacenzian). It can be concluded that during the III Neogene Cycle, the marine sedimentation started first in Algarve and then propagated northwards suggesting migration of crustal subsidence, in this direction. The change in the relative orientation between the southern depocentric area of Algarve Basin and the northern depocentric area of the Pombal-Caldas da Rainha may reflect a rotation in the orientation of the maximum compressive regime from NNW-SSE to WNW-ESE.

During the Neogene, the marine sedimentation on Portuguese sector of the Iberian Margin seemed to have been progressively more controlled by tectonic deformation. This seems to be in agreement with a most accepted hypothesis for the Neogene tectonic structuration of the Betic-Rif chain by which there was a progressive translation of the inner zones of the chain towards the West. While the most important deformation in the Betic region occurs between the Upper Oligocene till the Langhian, in the Portuguese margin the intensity of the tectonic deformation seems to increase along the Neogene, which may suggest a centrifugal transference of the deformation from the Inner Zone of the Betic-Rif region out and westwards.

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