The evolution of the Lower Tagus basin (Lisbon and Setúbal Peninsula, Portugal) from Lower to early Middle Miocene*

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Évolution du bassin du Bas Tage (Lisbonne et Péninsule de Setúbal, Portugal) du Miocène inférieur au début du Miocène moyen

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Mots-clés : Burdigalien, Langhien, Faune foraminifère, Faune ostracode, Faune mammifère, Paléo-climat, Stratigraphie séquentielle, Flore, Palynomorphes, Eustatisme, Bassin du Bas Tage, Portugal.

Abstract

This study represents an integrated approach in order to define accurately the sequence stratigraphy of Lower to Middle Miocene in the Lower Tagus basin, as well as to characterize the palaeoenvironmental and palaeoclimatological changes that took place during this geological time span, and to establish comparisons with the global eustatic curve.

Planktonic foraminifera, ostracoda and mammals provide accurate datation for the units defined by Cotter (1956) in the Lower and Middle Miocene of the Tagus basin. They also allowed a better understanding of the relationships between marine units and intercalated progradant continental units in Lisbon and Almada. Marine character is more marked on the left bank of the Tagus.

The stratigraphic position of planktonic foraminifera and mammals show that there are some problems concerning correlations between mammal-units (Steininger et al., *1990; De Bruijn* et al., *1992, Van der Meulen and Daams, 1992), the planktic foraminifera zones (Berggren* et al., *1985), and the geomagnetic time scale (Cande and Kent, 1992).*

Interpretations concerning continental environments are provided on the basis of plant macro- and microremains and on mammals. Curves on temperature and moisture were defined taking also in account data concerning other vertebrates (Crocodylia, Squamata, Testudines, fishes) and molluscs.

Benthic foraminifera and ostracoda allowed the characterization of marine paleoenvironments. A local sea level variation curve has been worked up on this evidence: four sea level variation cycles were recognized.

Four sedimentary eustatic controlled sequences were recognized [B1 (≈19-17.5 Ma), B2 (≈17.5-16.2 Ma), L1 (≈16.2-15.1 Ma) and S1 initial (≈15.1-?)]. They are bound by regional disconformities in correspondance to transgressive surfaces.

Similarities were found between local sea level changes and global eustatic 3rd order cycles 2.1 to 2.4. However eustatic fall at the end of the 2.1 cycle seems more important in the Tagus basin, while the 2.2 cycle fall is less marked. The available data are still not enough for a satisfactory explanation of these differences. Data on subsidence rate changes, on sedimentation and on climate evolution suggest that the difference concerning the 2.1 cycle is mainly due to continental uplift. The 2.2 cycle eustatic fall may otherwise be explained through basin subsidence. This balanced the influx of sediments (related to a warm and moist climate, as well as to strong reliefs) and the eustatic fall.

In an annex a discussion on mammalian faunas is presented as well as their

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composition. This provides a basis for correlation to continental basins.

Version française abrégée

Le bassin du Bas Tage présente un assez complet remplissage de dépôts miocènes, où des sédiments marins prédominent sur quelques intercalations continentales. La série miocène fournit d'excellentes possibilités pour l'étude des variations eustatiques et des changements climatiques, aussi bien que de l'évolution écologique et environnementale.

Cette étude est un essai de synthèse ayant pour objectifs la définition précise de la Stratigraphie séquentielle concernant le Miocène inférieur et le début du Miocène moyen du bassin du Bas Tage ; on établit des comparaisons avec la courbe eustatique globale.

On a fait attention, en particulier, à l'obtention de datations encore plus précises par rapport aux datations déjà connues, aux différences de lithofaciès entre les aires de Lisbonne et la rive gauche du Tage (qui ont souvent difficulté des corrélations), ainsi qu'aux changements eustatiques.

Des foraminifères planctoniques, des ostracodes et des mammifères ont permis une datation fine des unités (I, II, III, IVa, IVb, Va1, Va2, Va3, Vb, Vc et Vla) définies autrefois par Cotter (1956) dans le Miocène inférieur et moyen du bassin du Bas Tage. A la lumière des nouvelles données obtenues à la suite de l'étude des coupes de Cristo Rei et de Quinta das Rosas (voir logs, références aux principaux fossiles dont des végétaux, foraminifères, ostracodes et mammifères, et interprétations paléoenvironnementales correspondantes, figs. 1 à 6 du texte) on a pu comprendre mieux les rapports entre les unités à faciès marins et les unités continentales progradantes, intercalées, affleurant à Lisbonne et à Almada (rive gauche du Tage). Le caractère marin est plus accentué sur la rive gauche.

Des données sur la position stratigraphique des foraminifères planctoniques et des mammifères dans l'aire en étude font ressortir quelques problèmes concernant des corrélations entre des échelles ("mammal units") basées sur les mammifères (Steininger et al., *1990; De Bruijn* et al., *1992; Van der Meulen et Daams, 1992), les foraminifères planctoniques (Berggren* et al., *1985) et, d'autre part, l'échelle géomagnétique (Cande et Kent, 1992).*

Les interprétations concernant les environnements continentaux sont basées sur les macro- et micro-restes végétaux et les mammifères. Des courbes sur l'évolution des températures et de l'humidité ont été élaborées en tenant compte également des données fournies par d'autres vertébrés (Crocodiliens, Squamata, Chéloniens, Poissons) et Mollusques.

Les foraminifères benthiques et les ostracodes ont permis la caractérisation de paléoenvironnements marins. On a pu produire une courbe concernant les variations du niveau de la mer à l'échelle de la région. Quatre cycles de variation du niveau de la mer ont été reconnus.

L'étude stratigraphique séquentielle a permis de mieux caractériser et dater quatre séquences sédimentaires contrôlées du point de vue eustatique [B1 (≈19-17.5 Ma), B2 (≈17.5-16.2 Ma), L1 (≈16.2-15.1 Ma) et début de S1 (≈15.1-?)]. Elles sont séparées par des discontinuités régionales correspondant à des surfaces de transgression.

En ce qui concerne des changements du niveau de la mer, on a vérifié qu'il y a des ressemblances entre les changements à l'échelle régionale et les cycles eustatiques globaux de 3e ordre 2.1 à 2.4. La chute eustatique vers la fin du cycle 2.1 semble la plus importante dans le bassin du Bas Tage, tandis que la chute à la fin du cycle 2.2 est moins accentuée. Les données disponibles sont encore insuffisantes pour expliquer d'une façon satisfaisante les différences en cause. L'ensemble des données concernant les changements des taux de subsidence, la sédimentation et l'évolution du climat semblent indiquer que la différence observée pour le cycle 2.1 est due surtout au soulèvement du continent. Par contre, celle qui concerne le cycle 2.2 peut être expliquée comme une conséquence de la subsidence du bassin, en compensation de l'afflux de sédiments (en rapport avec un climat chaud et humide, et avec des reliefs accentués) et la chute eustatique.

En annexe on présente une discussion concernant les faunes de mammifères non marins jusqu'au Langhien compris et leur composition, ce qui fournit une base pour des corrélations avec des basins continentaux.

Toute information est présentée en synthèse (voir fig. 6).

Introduction

In the Lower Tagus basin there is a fairly complete Miocene sedimentary infilling of predominant marine deposits, along with some continental intercalations. The Miocene series provides excellent opportunities for the study of eustatic variation, climate changes and related ecological and environmental evolution.

There are still several points that require a better understanding. Insufficient lithostratigraphic and other data useful for even more accurate dating, as well as lithofacies differences between the Lisbon area and the left bank of the Tagus in the Setúbal Peninsula often obscured correlations.

Much less attention was paid to other aspects of the evolution of Lower Tagus basin, i.e. to eustatic changes and subsidence. These are among the main topics of this paper, along with a synthesis based on recent developments on stratigraphy, paleontology, isotopic geology, paleoenvironments, and climatic changes.

Lower and Middle Miocene units. General data

Cotter (1956; J. C. Berkeley Cotter died in 1919) units concerning the Miocene of Lisbon (Lower Tagus Basin) were defined on empirical grounds: stratigraphic characters coupled with paleontological features long before concepts as sedimentary cycles and sequences were developped.

It is therefore not surprising that the succession and limits of this units do not match with the boundaries that would result from sequential viewpoints.

In the Lisbon area these units may be easily recognized in the field. They were taken into account in geologic mapping and are time consecrated by use. So Cotter's units are useful as informal lithostratigraphic units. We will deal with the units that correspond to the Lower Miocene and earliest Middle Miocene.

Unit I : "Argilas e calcários com *Venus ribeiroi*"

Age still is not very well known. Glauconite K/Ar ages for the same bed (in a very low position) were obtained: 24±1 Ma and 21,1±0,5 Ma. The corresponding environments are not in favour of the obtention of good biostratigraphic indicators as planktic foraminifera. This holds in special for the most conspicuous beds, *i. e.* coral fringe reefs. The invertebrate macrofauna seems to point out to an Aquitanian age (Zbyszewski, 1954; 1962). Ostracoda (Nascimento, 1988) also suggest an Aquitanian age. Mammalian fauna is poorly represented by sirenian remains, and a small mammal assemblage from the Km 10 locality (Antunes and Mein, 1992) at the lowermost marine levels in the NE part of the Lisbon region. Marine waters flooded into that area somewhat later than in Lisbon. The Km 10 small mammals may be ascribed to MN 2 (upper part) (Iberian zone Z) mammal unit, Latest Aquitanian, without entirely excluding MN3, lower part, Early Burdigalian (Antunes and Mein, *loc. cit.*; Antunes 1993-1995).

Unit II : "Areolas com *Chlamys pseudopandorae* da Estefânia"

This regressive unit is mainly composed of fine sands and silts associated to clays, sometimes with oysters. The boundary between I and II is but conventional. Clays at Horta das Tripas, yielded a MN3 (lower part) faunula with *Brachyodus* and rhinoceroses; no Proboscideans are known (Antunes, 1984). These clays have been ascribed to the Unit I (uppermost part), but it is probably better to include them in the unit II.

A little higher in the II unit, there are mostly fine sands with ostreids and vertebrates: marine fishes, crocodilians and mammals (Antunes and Mein, 1986); small mammals have been reported to MN3 (lower part) mammal unit (Iberian zone Z), Lower Burdigalian.

Units III and IVa : "Banco Real" and "Argilas do Forno do Tijolo"

The major Burdigalian transgression took place then. There is a disconformity that may be regarded as a transgressive surface between the units II and III. The last unit grades upwards into the IVa (pyrite-rich, bluish euxinic silts and silty clays). The upper part of the IVa shows that depth and salinity were decreasing (plant macrofossils, *Cerithium* and other molluscs more or less tolerant to lower salinities). Planktic foraminifera point out to N5-6 for the Cotter's IVa unit.

Unit IVb : "Areias da Quinta do Bacalhau"

This progradant unit includes fluviatile, feldspathic sands in Lisbon and mostly estuarine sands in Setúbal Peninsula. Large mammals from the fluviatile sands comprise gomphotheres but still no Prodeinotheres (Antunes, 1990), rhinoceroses and specially the last *Brachyodus*; MN4, Lower part (Iberian zone B) mammal unit (Burdigalian).

Units Va1, Va2, Va3 and Vb : "Calcários com *Chlamys scabrella* de Casal Vistoso", "Areias com *Placuna miocenica*", "Calcários com *Chlamys scabriuscula* de Musgueira" and "Areias do Vale de Chelas"

Although corresponding to a rather brief span in time these units are specially interesting. Two depositional cycles are represented: the first one corresponding to Va1 (shallow marine sandstones biocalcarenites/algal fringe reefs with *Lithothamnium*) and Va2 (fluviatile sands, followed up by fine, in part eolian, sands associated to thin clay layers that may correspond to littoral dunes in the Lisbon area) and the second to Va3 (shallow marine, coarse sandstones) and Vb (fluviatile, feldspathic sands). The transgressive surfaces are placed, respectively, at the bottom of the shallow marine sandstones Va1 and the Va3 units.

Lisbon is the type area for the Cotter's units. In Setúbal Peninsula, Va2 and Vb fluviatile sands are not represented but there are correlative deposits that always show a marine littoral character. The age of Va1 and Va3 units is not yet accurately established although it has generally been ascribed to Late Burdigalian. In Lisbon a Langhian age has been accepted for the Vb unit (Antunes *et al.*, 1973).

Units Vc and VIa : "Calcários com fósseis espáticos e *Anomia choffati* da Quinta das Conchas" and "Argilas azuis de Xabregas"

A new set of transgressive deposits (Vc) is represented by shallow marine conglomerates with a large proportion of oyster valves, followed up by sands and fine deposits (silty biocalcarenites in alternance with silty clays). In the Almada area (Setúbal Peninsula), supposedly correlative sediments have a stronger marine character (shallow marine sandstones alternating with shelf mudstones). The Vc unit represents the early stades of the most important transgression (Serravallian), whose apogee corresponds to the deepest facies known in the Lower Tagus basin and to the VIa unit (alternating pyritous, bluish euxinic silty clays with somewhat more carbonated mollusc beds).

Sequential stratigraphy of the basin infilling has been hampered by difficulties in accurate dating and in correlating sedimentary units from both margins of the Tagus (Lisbon vs. Setúbal Peninsula). In order to reach a better understanding of these problems two sections were studied at Cristo Rei and Quinta das Rosas (Almada area). Deposits regarded as equivalent to the IVa, IVb, Va1, Va2, Va3, Vb and Vc (Lower to Middle Miocene) outcrop there. Foraminifera, ostracoda, small mammals and plant macroremains were studied. Results are compared to (and completed by) already known data.

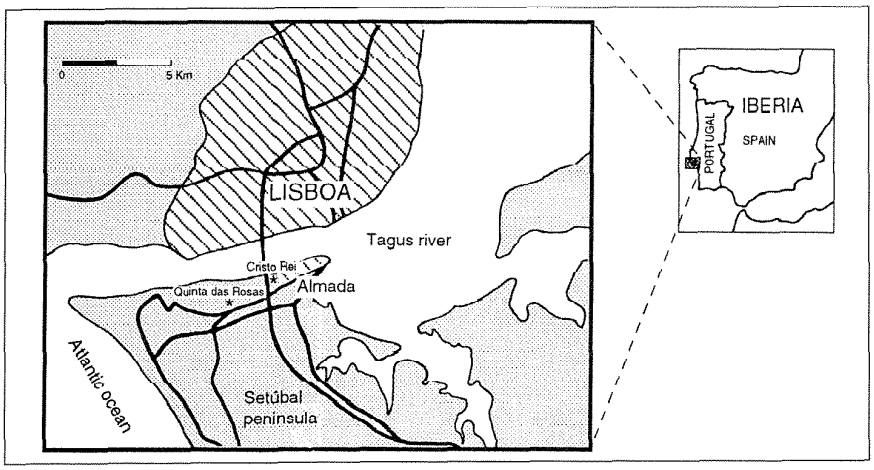

Fig. 1. – Location of the studied sections (*).

Fig. 1. – Localisation des coupes en étude (*).

New data: Cristo Rei and Quinta das Rosas sections

In this chapter the description and additional data concerning two typical sections in the left bank of the Tagus (Fig. 1), where deposits are mainly marine, will be presented.

Cristo Rei

This section is at the cliff on the left bank of the Tagus close by the Cristo Rei monument (Figs. 2, 3) (UTM coordinates 29SMC852813).

Lithostratigraphy, palaeontology and paleoenvironments

All Burdigalian units (Cotter,1956) are well exposed. Lower to middle Burdigalian units (II, III and IVa) may be seen at the lower half of the section. Our study is mainly focused at IVa (top), IVb, Va2 and Vb at the upper half of this section (Figs. 2 and 3):

IVa unit

Lithology: bluish siltstones with *Pitar islandicoides*, *Flabellipecten expansus* and beautiful *Pereiraia gervaisi* (among other fossils) and silty clays rich in marine microfossils (thickness, ca. 35 meters).

• *Foraminifera*

Plentiful *Globigerinoides* and especially *Catapsydrax unicavus*, *Globigerinoides altiaperturus*, *Globigerinoides obliquus* and *Globorotalia peripheroronda* indicate Blow's N5/N6 zones (Burdigalian). *Globorotalia mayeri* and *Globoquadrina* are abundant (Fig. 2).

Benthic foraminifers are small-sized. The genera *Ammonia*, *Cancris*, *Cibicides*, *Reussella* and predominant *Nonion*, *Lenticulina*, and *Uvigerina* are represented. This assemblage as well as the planktic/benthic relationships are compatible with infralittoral to circalittoral environments (Fig. 3).

• *Ostracoda*

Ostracod distribution along this unit has been reported (Nascimento, 1988).

Marine environments were ascribed to the infralittoral stage. Ostracods (Fig.3; Pl. I and II) show that marine environments corresponding to IVa unit were the deepest ones that ever occurred in the Lower Miocene of the Lower Tagus basin. Circalittoral stage may have been attained elsewhere (Nascimento, *id.*).

Ostracod fauna is typically a warm-water one, even if somewhat less warm conditions may have occurred.

Several species from this section are common in Burdigalian and Aquitanian beds, where they are in association with termophile forms as *Cnestocythere* and *Pokornyella* (Nascimento, 1978; 1983; 1988; 1989; 1990). This corroborates data about the frequency of hermatypic corals in the Lower Miocene of the Tagus basin, a situation that never occurred later (Antunes and Chevalier, 1971; Chevalier and Nascimento, 1975) even if warm waters and salinity were adequate (Va1 unit, at least) but requirements were not then be met as far as turbidity and highly detritical sedimentation were concerned.

• *Palynology*

Spores (Bryophyta, Polypodiaceae, Pteridaceae, Gleicheniaceae, Schizeaceae) are most frequent. Gymnosperms are not as common as at early Burdigalian. Angiosperms are quite abundant; *Bombax* and Sapotaceae reach their apogee. *Engelhardtia*, *Myrica*, Araliaceae, *Diospyros*, *Alnus*, *Corylus* and *Castanea/Castanopsis* are well represented (Pais, 1981; 1986).

The maximum occurrence of dinoflagellates occurs in the first third of the unit.

IVb unit

Lithology: Composed mainly of sands with intercalated oyster banks and lenticular argilaceous bodies containing abundant plant macroremains at the top. The uppermost sand levels yielded some small mammals.

• *Small mammals*

The small mammal assemblage not including any Cricetidae points out to Lower MN4 (Iberian zone B) (see Addendum).

• *Plant macroremains*

Abundant, more or less well preserved but without cuticle; on plant macroremains the following *taxa* were recognized (Pais, 1989):

Lygodium gaudinii
Comptonia acutiloba
Myrica cf. *lignitum*
Populus serrulatus
Ulmus bronii
Zelkova zelkovaefolia
Sapindus falcifolius
Magnolia oedipa
Daphnogene polymorpha
Cf. *Engelhardtia orsbergensis*
Gleditschia knorrii

This plant assemblage is interpreted as indicating a warm to subtropical tem-

perate climate. Predominance of non-entire leaved plants suggest marked seasons, with probably one dry season, and high moisture (6%-leptophyll; 22%-nannophyll; 61%-microphyll; 11% notophyll).

Va1 unit

Lithology: shallow marine sandstones rich in mollusc casts (*ca.* 5 meters). At the bottom there is a disconformity interpreted as a transgressive surface. Sandstones infill bioturbations on the top of the IVb sands.

Va2 unit

Lithology: marls alternating with sandstone beds (*ca.* 21 m).

Exposure is not good at this part of the section. Mollusc casts occur. However we did not find the typical species of this unit, *Placuna miocenica* - a further good warm water indicator.

• *Foraminifera*

Planktic foraminifera are very scarce. Shells are poorly preserved. Benthic foraminifera are frequent, although broken and recrystallized. *Ammonia* is abundant; *Nonion*, *Elphidium* and *Cibicides* are rare. This assemblage indicates a littoral environment (Fig. 3).

The occurrence of *Globigerinoides sicanus* in the lower part of Va2 (Antunes *et al.*, 1973) points out to N8.

• *Ostracoda*

Two samples were collected. The lower sample yielded *Cytherella (Cytherelloidea) jonesiana* and *Cytheretta (Cytheretta) rhenana rhenana*. The

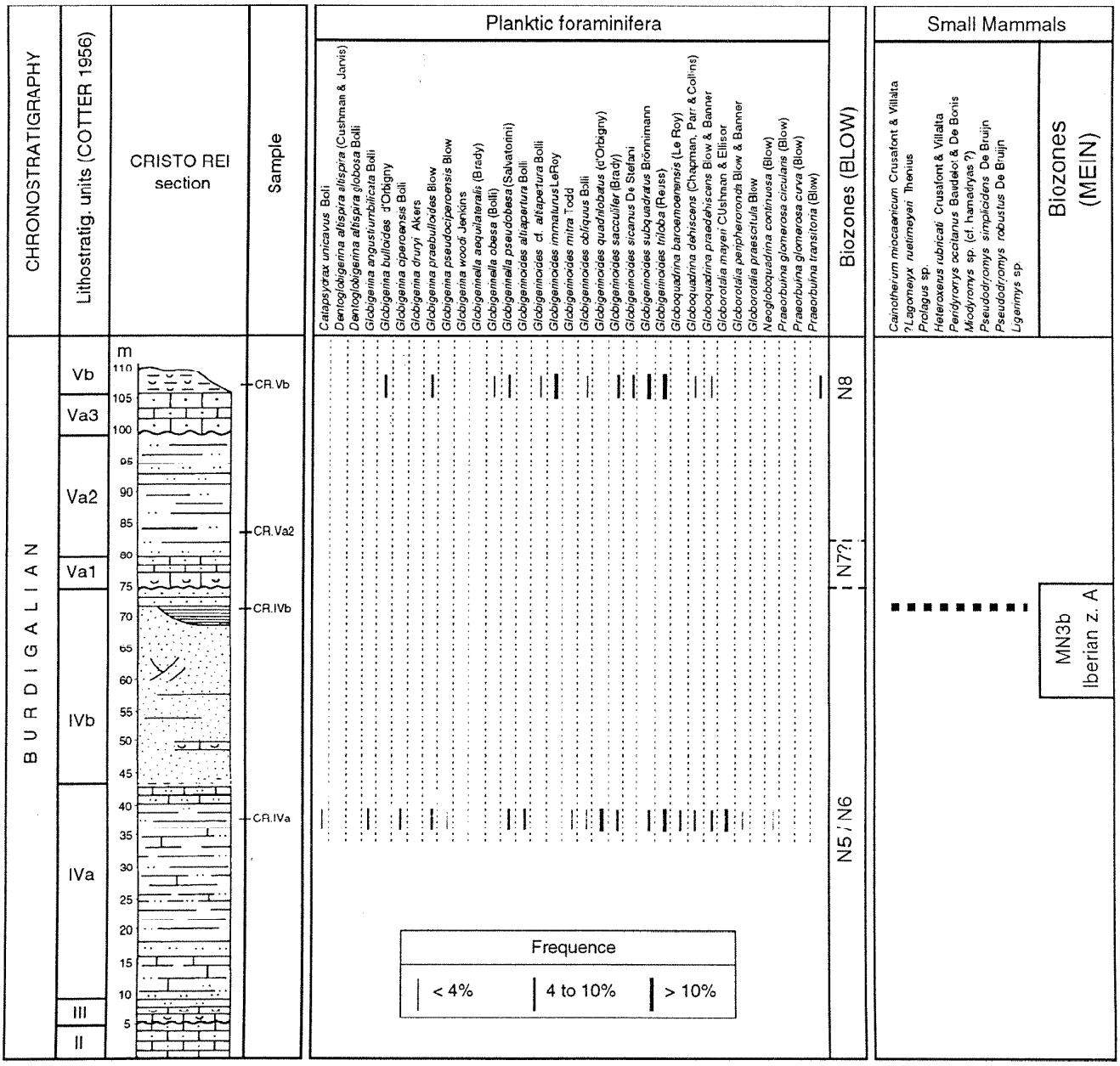

Fig. 2. – Cristo Rei section. Planktic foraminifera and small mammal distribution and biostratigraphy.

Fig. 2. – Coupe de Cristo Rei. Répartition des foraminifères planctoniques et des petits mammifères, biostratigraphie.

upper sample includes *Aurila* sp., *Miocyprideis fortisensis*, *Cyamocytheridea strigulosa*, *Olimfalunia* gr. *plicatula* (Fig. 3).

In the upper sample, *Miocyprideis fortisensis* represents more than 80% of the entire ostracod population. This points out to an oligohaline environment (Nascimento, 1988, 1993). *M. fortisensis* seems to be a local indicator of the end of the Burdigalian and probably of warm waters. This species remains unknown in post-Burdigalian levels.

• *Palynology*

The Va2 sediments are not rich in plant remains. *Riccia* is common. Polypodiaceae spores are scarce. The *Pinus* are common, as *Castanea/Castanopsis*, *Quercus*, *Engelhardtia*, Amaranthaceae/Chenopodiaceae, Compositae, Gramineae and *Armeria*. *Ephedra*, Sapotaceae, *Sparganium*, and Poligonaceae are rare.

The rather high frequence of *Armeria* can be interpreted as showing that the littoral was close by. *Engelhardtia* and Sapotaceae point out to a tropical climate (Pais, 1981, 1986).

Va3 unit

Lithology: shallow marine sandstones with mollusc casts (*ca.* 6 m).

Vb unit

Lithology: sandy marls with *Schizaster* fragments (exposed on about 4m).

• *Foraminifera*

Globigerinoides sicanus and *Praeorbulina transitoria* allow correlations with basal N8 (Upper Burdigalian). Scarce *Globigerinoides altiaperturus* occurs. *G. subquadratus* is abundant while *Globoquadrina* is rare. *Globorotalia* was not found (Fig. 2).

Benthic assemblage is characterized by plentiful *Ammonia* and *Nonion* and frequent *Elphidium*, *Cibicides*, *Lenticulina*, *Textularia* and *Bulimina* (Fig. 3).

Benthic foraminifera assemblage and the abundance of planktic foraminifera indicate an infralittoral, probably near circalittoral palaeoenvironment.

• *Ostracoda*

The observed forms are typical of sublittoral environments (probably close to the infralittoral/circalittoral transition).

The ostracoda association is quite different from the previous ones, and especially that from the IVa unit; in this section, in the Vb, four species appear

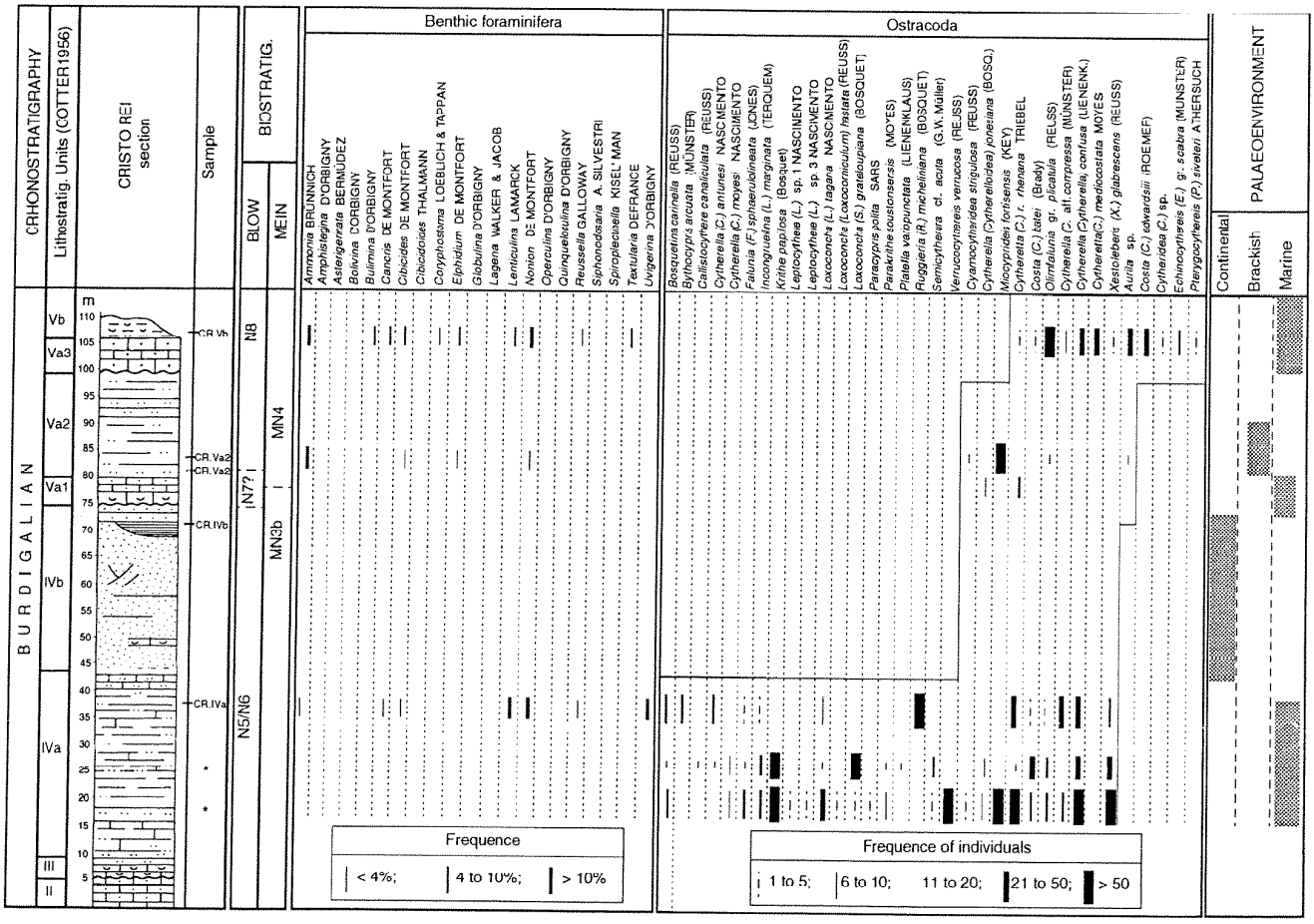

Fig. 3. – Cristo Rei section. Benthic foraminifera, ostracoda and paleoenvironment interpretation. (*), samples from Nascimento (1988).

Fig. 3. – Coupe de Cristo Rei. Foraminifères benthiques, ostracodes interprétation. (*), échantillons étudiés par Nascimento (1988).

for the first time; 12 are unknown; 7 are common to IVa and Vb units. Differences cannot be exclusively ascribed to bathymetric characters, but probably also to the Burdigalian to Langhian water temperature changes (Vergnaud-Grazzini and Rabussier-Lointier, 1980) (Fig. 3). Similar modifications of the ostracod assemblages are characteristic of the Burdigalian/Langhian transition in the Tagus basin.

Quinta das Rosas

Section exposed at Monte de Caparica (West of Almada) near the Instituto de Ciências da Saúde (Figs. 1, 4, 5). Beds outcrop on the road embankment and the building foundations (UTM coordinates 29SMC827801).

Lithostratigraphy, palaeontology and paleoenvironments

Vb unit

Lithology: sandy marls with thin shallow marine fossiliferous sandstones that grade up into sands (5 m). Upwards there is an unexposed part of *ca* 4 m. Over it, there is a shallow marine fossil-rich sandstone overlain by whitish marls that become brown towards the top (*ca* 5 m).

• *Foraminifera*

A sample (Az.Vb) collected at the lower levels (Fig. 4) yielded *Praeorbulina glomerosa*. This is the first occurrence of this species (critical for ascertaining the Burdigalian/Langhian boundary) in the Lower Tagus basin. As *Orbulina* does not occur the planktic assemblage may be ascribed to N8 (Langhian).

The benthic foraminifera assemblage (Fig. 5) is characterized by abundant

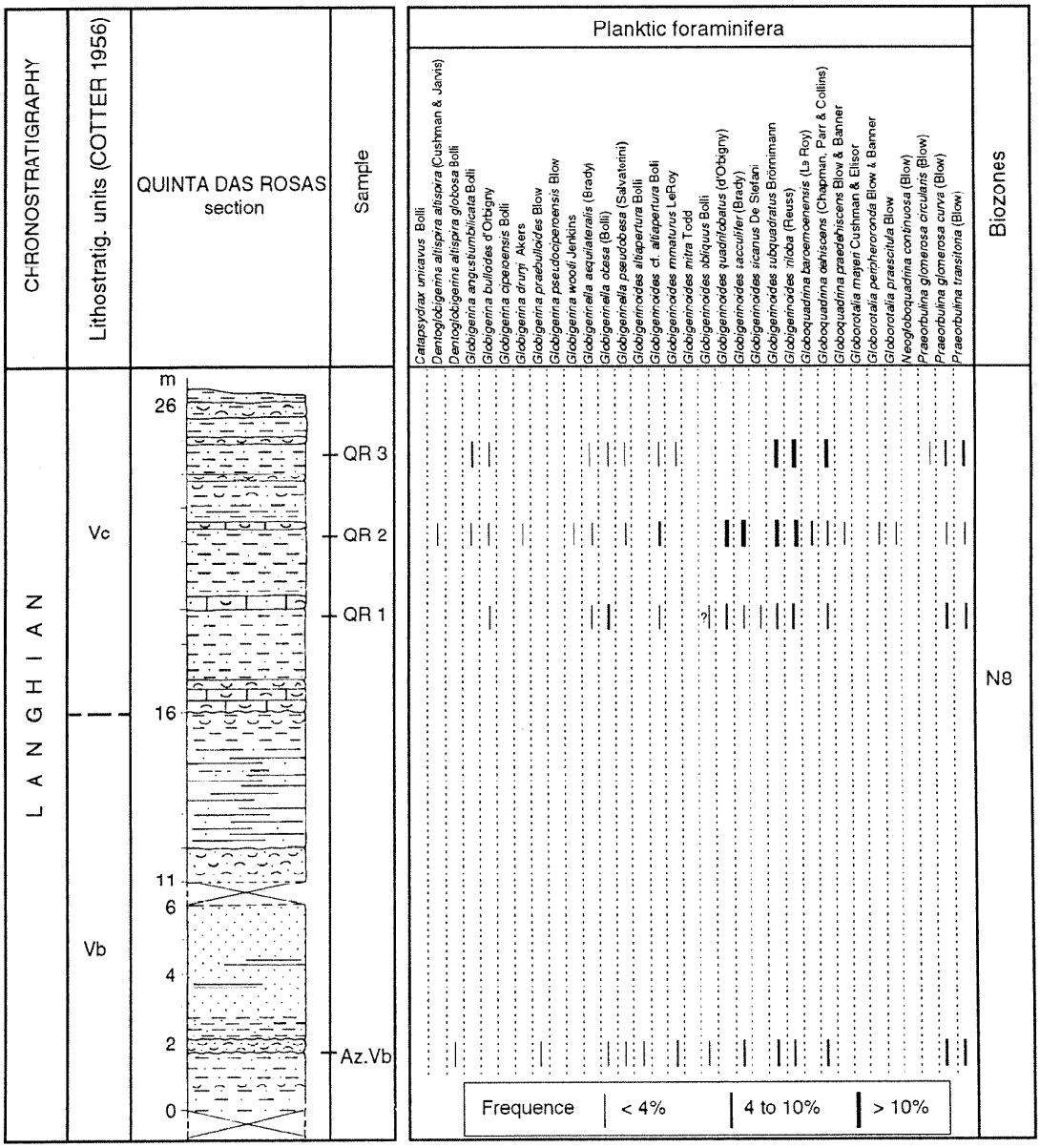

Fig. 4. – Quinta das Rosas section. Planktic foraminifera and biostratigraphy.

Fig. 4. – Coupe de Quinta das Rosas. Foraminifères planctoniques et biostratigraphie.

Textularia and frequent *Ammonia*, *Nonion*, *Quinqueloculina* and *Cibicides*. Predominance of *Textularia* is probably related to the nature of the sediment (coarse bioclastic material). Foraminifera shells show different stages of preservation; this can be regarded as a result of remobilization. This assemblage points out to an infralittoral palaeoenvironment.

• *Ostracoda*

For ostracods species from (AZ.Vb) see Fig 5. Ostracod assemblage indicate the infralittoral stage.

Vc unit

Lithology: shallow marine sandstones alternating with shelf mudstones (*ca.* 10 m).

• *Foraminifera*

Praeorbulina glomerosa curva, *Praeorbulina transitoria*, *Globigerinoides sicanus*, *Globigerinella aequilateralis*, *Globorotalia perpherororonda* and *Globorotalia praescitula* occur (Fig. 4). This assemblage still points out to N8. In the upper levels (sample QR 3), *Praeorbulina glomerosa circularis* was found; this is close to N9 zone. The absence of *Globorotalia mayeri* and the scarce occurrence of *Globigerinoides* cf. *altiapertura* are not well understood.

The benthic foraminifera assemblage from the lowest sample (QR 1) is less diverse when compared to the upper ones (QR 2 and QR3) (Fig. 5). *Ammonia* and *Nonion* predominate in all samples. *Elphidium*, *Amphistegina*, *Asterigerinata* and *Cibicides* from the lowest sample are indicative of an infralittoral environment. Abundant *Lenticulina* and frequent *Cancris* in sample QR 2 may be related to greater depth; abundant *Bulimina* and *Bolivina* may probably be correlated to high organic matter contents in the sediment and to anoxic conditions. Frequent *Cibicidoides* in the uppermost sample (QR 3) show circalittoral influence.

• *Ostracoda*

The QR3 sample (Fig. 5) yielded some species unknown in Lower Miocene, as *Aurila (Ulicznina) oblonga*, *Ruggieria (R.) nuda* and *Loxoconcha (Loxoconcha) ducasseae*. The fauna is closely related to Serravallian associations elsewhere in the same basin (Nascimento, 1988; 1989; 1990). The QR3 association suggests sea water temperatures higher than those corresponding to Vb

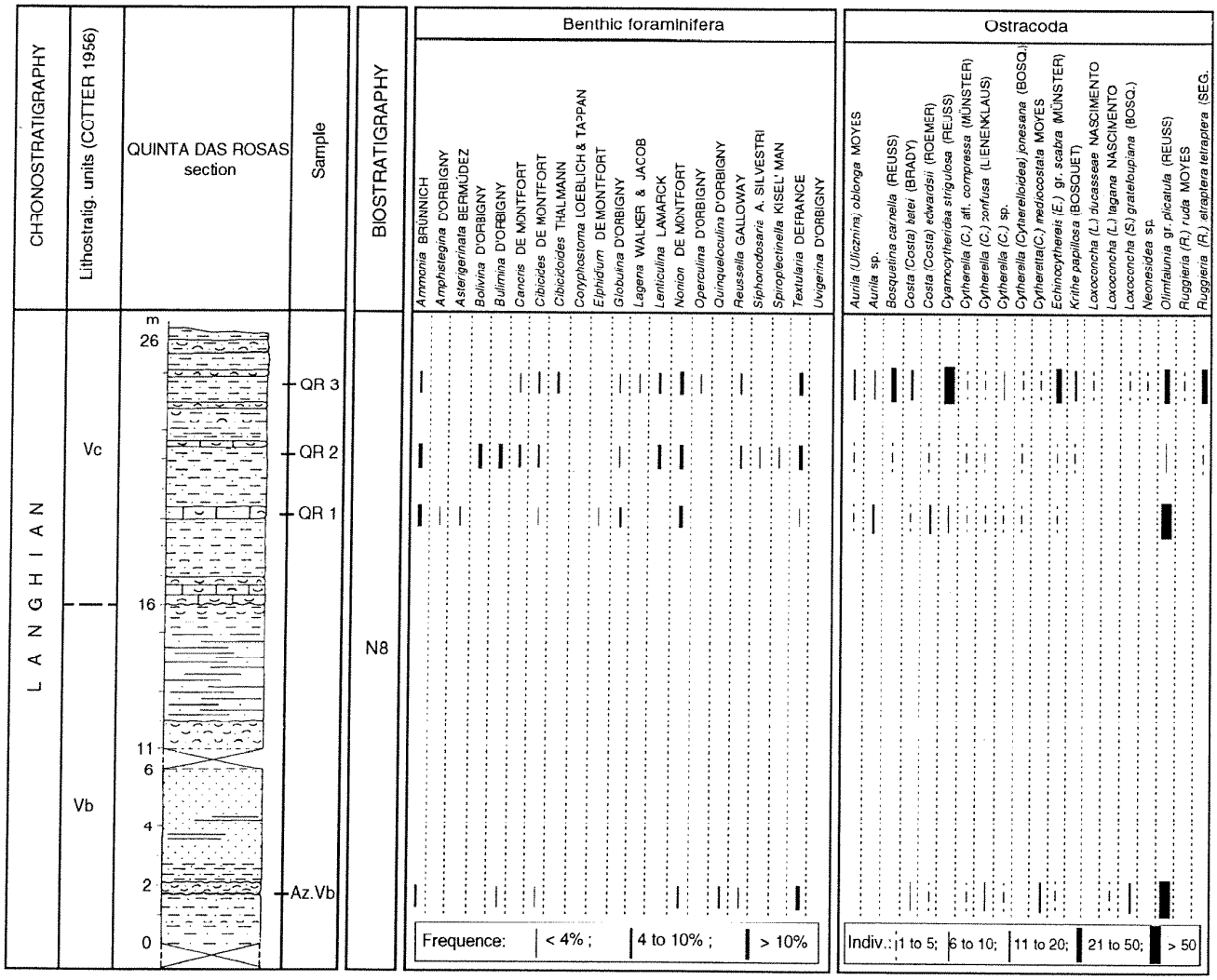

Fig. 5. – Quinta das Rosas section. Benthic foraminifera and ostracoda distribution.

Fig. 5. – Coupe de Quinta das Rosas. Distribution des foraminifères benthiques et des ostracodes.

sample, Cristo Rei section. Depth may have surpassed the infralittoral/circalittoral transition.

Sequencial stratigraphy

Several Miocene sedimentary cycles were recognized in the Lower Tagus basin on evidence of transgression (C) and regression (R) events (Antunes *et al.*, 1973). This model was improved later. Seven transgression events (T0-T6) and alternating six regression ones (R0-R5) were characterized (Antunes and Pais, 1993). Cristo Rei and Quinta das Rosas sections and the regional geologic context allow us to correlate the sections with the cycles: T2/R2, T3/R3, T4/R4 and T5/R5 (beginning). In correspondance with these cycles there are depositional sequences bound by transgressive surfaces. The latter correspond to regional disconformities (Fig. 6).

The T2/R2 cycle comprises the III, IVa and IVb Cotter units and corresponds to the depositional sequence **B1** (Burdigalian 1, ≈19 to ≈17.5 Ma; N5/N6 planktic foram zones; MN4 (lower part) mammal unit and Iberian mammal zone B) which corresponds to the Burdigalian transgression.

The T3/R3 (Va1 and Va2 units) corresponds to the depositional sequence **B2** (Burdigalian 2, ≈17.5 to ≈16.2Ma; N7? to N8 (lower part), MN4 and Iberian zone C).

The T4/R4 (Va3 and Vb units) corresponds to the depositional sequence **L1** (Langhian 1, ≈16.2 to ≈15.1Ma; N8; MN5; Iberian zones D1 and D2).

The T5 (Vc unit) corresponds to the lower part of depositional sequence **S1** (Serravallian 1, base of sequence at ≈15.1 Ma in the Langhian; N8) and represent the earlier stages of the great Serravallian transgression.

Local sea-level changes

Facies analysis and environment characterization through marine (ostracoda, benthic foraminifera) and continental (mammals, flora) organisms allowed us to elaborate a sea level variation local curve (Fig. 6). Four cycles are thus defined.

The oldest cycle is in correspondence with the Burdigalian transgression. Maximum depth was attained (IVa unit). It allowed (in the same area where Cristo Rei and Quinta das Rosas sections are located) the development of infralittoral stage communities. The following sea level decrease may have been the greatest recognized in the basin for the time span considered here. Paleoenvironments are either continental or brackish (progradant unit IVb).

Next cycle (upper Burdigalian) corresponds to shallow water transgressive sediments (Va1) overlain by littoral deposits (Va2). Microfossil assemblage indicate shallow marine and brackish environments. The maximum depth may have been minimal when compared with that attained during other cycles.

Another cycle spans from Late Burdigalian to Langhian. In the left bank of the Tagus, transgressive, Va3 shallow water deposits are overlain by silty marls (Vb). The marl's ostracoda and benthic foraminifera are characteristic of infralittoral-circalittoral transition or nearly so (the maximum for this cycle). Maximum depth seems to exceed the maxima for previous cycles.

The silty marls evolute vertically towards: (a) coarser bioclastic and laminated littoral sands; (b) a conglomerate rich in mollusc casts; (c) whitish marls becoming brownish near the top. This succession probably corresponds to the decrease of the local eustatic level; it seems correlative with the progradant continental sediments well known in Lisbon.

The beginning of a fourth sea level change cycle is marked by the deposition of the Vc unit (upper Langhian). Near the top of the same unit, Ostracoda and foraminifera show a distinct trend towards depth increase; circalittoral stage may have been attained, as well as the so far recognized absolute maximum depth.

Biostratigraphic data allow the dating of the beginning and the end of each sea level local variation cycle. In comparison with the global eustatic curve (Haq *et al.*, 1987), there is a good time correlation between the Lower Tagus basin cycles and the 2.1 to 2.4, 3^{d} order global eustatic cycles (Fig. 6).

Nevertheless there are significant differences about 2.1 and 2.2 cycles. As for the 2.1 cycle, the eustatic sea level decrease that closes it seems to be even more marked in the Lower Tagus basin. As far as the 2.2 is concerned, the eustatic decrease at the close of the cycle is not so evident in the Lower Tagus basin. These differences may be explained by subsidence rate, sediment supply and tectonics.

Particularly relevant are the differences related to the terminal part of the 2.1 cycle (corresponding to the eustatic fall). In the Tagus basin there is an acumulation of prograding, upwards thinning arkosic deposits. Cristo Rei section sediments indicate shallow water sedimentation; near the top there are fine sands with plant macroremains and small mammals. This shallowing seems to be a consequence of continental uplift related to the intra-Burdigalian rupture (Antunes *et al.*, 1987).

In the Betic domain, Soria (1994) recognized a Burdigalian (*G. subquadratus* zone) tectonic phase that he correlates to the well known paroxysmal Burdigalian phase (Hermes, 1985; Martín-Algarra, 1987). These events may be correlated with Lisboa-Almada events.

The eustatic fall at the end of 2.2 cycle in the Lower Tagus basin is not as pronounced as the one shown in the Haq *et al.* (1987) curve. This may be explained by a significant increase of the subsidence rate which balanced the global eustatic fall and the sediment supply.

The sedimentation in the Lisbon area of progradant feldspathic sands (Vb) coming from far away granite outcrops, and the diminishing depth in the Almada region (regression phase of L1 sequence) should be remarked. These events may be correlated to the Betic area intra-Langhian phase (Soria, 1994) and to the intra-Middle Aragonian sedimentary break of the Ebro, Tejo and Douro basins (Calvo *et al.*, 1993).

Climate changes

Climatic changes are related to global changes and to local or regional conditions. In this paper we will not discuss meaningful climate data contributed by several groups (Antunes and Pais, 1984), especially through the occurrences of excellent stenotherm, warm environment indicators:

– crocodilians, and specially *Tomistoma* and *Gavialis* (apogee: Va2);

– Squamata, as *Iberovaranus* and a Boid snake (more conspicuous at Va2); *Ophisaurus* - like lizards are warm region dwellers;

– huge tortoises (*Geochelone* cf. *bolivari*) are common in IVb and Vb, apparently less in Va2; they point out to warm conditions and open spaces (Antunes and Rage, 1974);

– fishes (nurse sharks, *Ginglymostoma* in Va2 and Vb; lemon sharks, *Negaprion* from Va1 to Vc; the shark *Hemipristis* apogee at Va1/Va3; the large-sized tropical barracudas, *Sphyraena olisiponensis*; bivalves as the typically warm sea dweller *Placuna miocenica*; the *Lates* (giant Nile perchs, and allied forms) and catfishes apogee (Va2).

Initial re-warming (Fig. 6) went on during the Middle Burdigalian (IVa). Spores became plentiful. Gymnosperms are not as common as at the beginning of the Burdigalian. On the contrary, Angiosperms are quite abundant. The climate must have been rather warm and humid, probably tropical.

In the Upper Burdigalian (IVb) the vegetation is initially rich in sub-tropical and temperate taxa. Sapotaceæ and Lauraceae are very rare. Mammals include humid area dwellers as *Brachyodus*, and many others that indicate terrestrial, more or less wooded environments. Forest-gallery could be represented near a large river; beyond that there were open, savanna to steppe areas. Not even rodents suggest forest environments: there is a predominance of terrestrial glirids (*Peridyromys, Pseudodryomys*) over rare forest forms (*Ligerimys*).

In the latest Burdigalian (Va2), this flora is replaced by another one corresponding to warmer and more humid conditions as shown by *Engelhardtia* and Sapotaceæ. The Va2 mammalian fauna (i.e. Tragulids) points out again to humid areas with a close by rich plant cover. A plant resources optimum associated to forest development is shown by the common presence of *Prodeinotherium* and of *Amphicyon giganteus* (which would require plenty of suitable game, and therefore a rich plant cover). Terrestrial elements (terrestrial glirids, ground squirrels, probably cricetids too) are nevertheless predominant among the small mammals as are most of the larger forms. There is no evidence of close by steppe environments even if open spaces probably existed too.

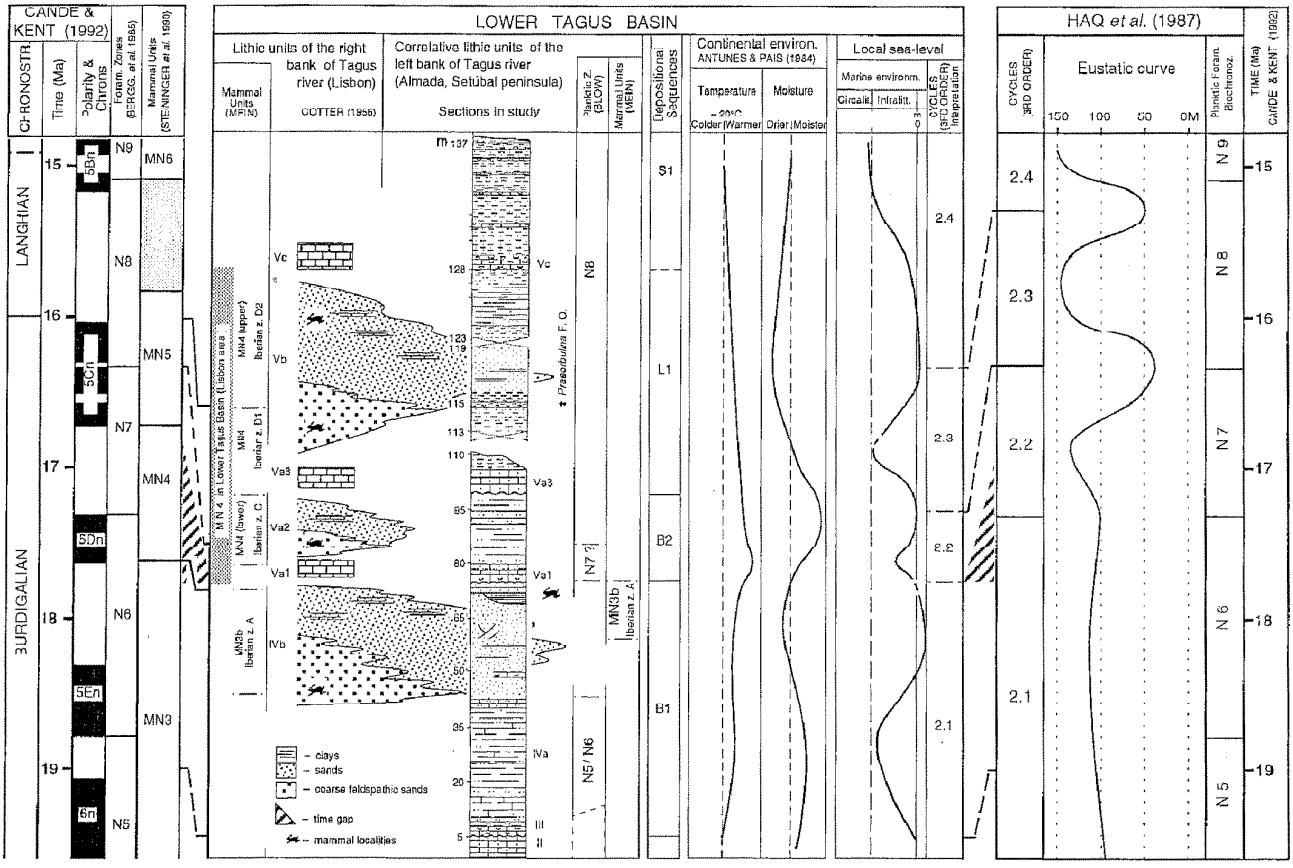

Fig. 6. – Upper Burdigalian and Langhian from the Lower Tagus basin.
Mammal localities: 1 - Quinta do Narigão; 2 - Quinta das Pedreiras, Quinta do Pombeiro; 3 - Quinta da Farinheira; 4 - Chelas 2.

Fig. 6. – Burdigalien supérieur et Langhien dans le Bassin du Bas Tage.
Gisements à Mammifères : 1 - Quinta do Narigão ; 2 - Quinta das Pedreiras, Quinta do Pombeiro ; 3 - Quinta da Farinheira; 4 - Chelas 2.

In the Langhian (Vb) the vegetation is dominated by sub-tropical and temperate forms. *Magnolia* occurs for the last time. *Terminalia* suggests the existence of gallery-forests. Frequent *Rutoxylon* woods with traumatic structures point to a quick change of environmental conditions. These woods (together with *Tamaricoxylon* and the foliar physiognomy) are indicative of a rather warm and dry climate (Pais, 1986). The mammalian fauna from the lower part of the Vb unit is marked by a distinct rarefaction or demise of forest humid area elements. There is otherwise a spectacular predominance of forms adapted to terrestrial, rather dry soil environments as the cursorial rhinoceros *Hispanotherium* (Antunes, 1979). Savannas or/and steppe probably attained their maximal development. Among the small mammals, the newly acquired Cricetid predominance seems compatible with this situation. Data are scarce about the upper part of Vb unit, which indeed is related to the early stages of the next transgression (Serravallian). The presence of a few small mammals (*Microdyromys*, ? *Ligerimys)* may suggest some recovery of moisture.

The climatic conditions changed again. In the Serravallian (VIa unit) humid tropical plants are common (*Toddalia, Spirematospermum*, Sapotaceae). They are associated to aquatic plants or plants that grew in close-by streams (*Taxodium, Nuphar, Sparganium, Stratiotes, Alnus, Myrica*). The climate became less warm and far more humid than before.

Conclusions

1. The biostratigraphic knowledge of III to Vc units (Lower to Middle Miocene, Lower Tagus basin) has been improved;

2. The depositional sequences organization, corresponding to lithostratigraphic units III to Vc, were characterized; the depositional sequences are bound by regional disconformities that are related to transgressive surfaces. Four sequences are defined:

– **B1** (Burdigalian 1, ≈19 to 17.5 Ma; N5/N6 planktic foram zones; MN4 mammal unit and Iberian zone B mammal zone);

– **B2** (Burdigalian 2, ≈17.5 to 16.2Ma; N6 to N8 (lower part), MN4 and Iberian zone C);

– **L1** (Langhian 1, ≈16,2 to 15.1Ma; N8; MN5; Iberian zones D1 and D2);

– **S1** (Serravallian 1, base of sequence at ≈15.1Ma; N8 (top still under study).

3. Characterization of paleoenvironments, both marine (ostracods and benthic foraminifera) and continental (plant macro remains, pollen and spores, mammals) led us to recognize four sea level local variation cycles. These cycles can be correlated to 3^{d} order eustatic cycles 2.1 to 2.4 (Haq *et al.*, 1987).

4. There are however some differences as far as the regression events of the 2.1 and 2.2 eustatic cycles are concerned. These differences may be explained in the Almada area through basinal tectonics: continental uplift (2.1 cycle); eustatic fall and the sedimentary supply balanced by subsidence (2.2 cycle).

References

ANTUNES M.T. (1979) – "*Hispanotherium fauna*" in Iberian Middle Miocene, its importance and paleogeographical meaning. *Ann. Géol. Pays Helléniques*, Athens, t. hors sér. (I), pp. 19-26.

ANTUNES M.T. (1984). – Essai de synthèse sur les mammifères du Miocène du Portugal. Vol. d'hommage au géologue G. Zbyszewski, *Ed. Recherche sur les Civilisations*, Paris, pp. 301-323.

ANTUNES M.T. (1990). – The proboscidean data, age and paleogeography: evidence from the Miocene of Lisbon. *European Neogene Mammal Chronology*, Edt. E.H. Lindsay *et al.*, Plenum Press, New York, pp. 253-262.

ANTUNES M.T. (1993-1995). – Lower Miocene continental-marine correlation in the Tagus basin, Portugal. Mammals, planktonic foraminifera and other evidence. *Ann. Géol. Pays Helléniques*, Athens, prem. sér., 36, pp. 531-538.

ANTUNES, M.T., CALVO J.P., HOYOS M., MORALES J., ORDOÑEZ S., PAIS J., SESE C. (1987). – Ensayo de correlacion entre el Neogeno de las areas de Madrid y Lisboa (Cuencas Alta y Baja del rio Tajo). *Com. Serv. Geol. Portugal, Lisboa*, 73 (1/2), pp. 85-102.

ANTUNES M.T., CHEVALIER J.P. (1971). – Notes sur la Géologie et la Paléontologie du Miocène de Lisbonne. VII - Observations complémentaires sur les madréporaires et les faciès récifaux. *Rev. Fac. Ciênc. Lisboa*, 2ª sér., C, **16**, n° 2, pp. 291-306.

ANTUNES M.T., GINSBURG L. (1983). – Les rhinocérotidés du Miocène de Lisbonne. Systématique, écologie, paléobiogéographie, valeur stratigraphique. *Ciências da Terra (UNL), Lisboa*, 7, pp. 17-98.

ANTUNES M.T., GINSBURG L., TORQUATO J.R., UBALDO M. (1973). – Age des couches à mammifères de la basse vallée du Tage (Portugal) et de la Loire moyenne (France). *C.R. Acad. Sci. Paris Fr.*, **277**, (D), pp. 2313-2316.

ANTUNES M.T., MEIN P. (1981). – Vertébrés du Miocène moyen de ammor (Leiria)/Importance stratigraphique. *Ciências da Terra (UNL)*, Lisboa, 6, pp. 169-188.

ANTUNES M.T., MEIN P. (1986). – Petits mammifères du Burdigalien inférieur (Universidade Católica, Avenida do Uruguay). *Ciências da Terra (UNL)*, Lisboa, 8, pp. 123-138.

ANTUNES M.T., MEIN P. (1992). – Les plus anciens mammifères terrestres du Miocène marin de Lisbonne - le gisement du km10. *Ciências da Terra (UNL)*, Lisboa, 11, pp. 127-140.

ANTUNES M.T., PAIS J. (1984). – Climate during Miocene in Portugal and its evolution. *Paléobiologie Continentale*, Montpellier, XIV(2), pp. 75-89.

ANTUNES M.T., PAIS J. (1993). – The Neogene of Portugal. *Ciências da Terra (UNL)*, Lisboa, 12, pp. 7-22.

ANTUNES M.T., RAGE J.C. (1974). – Notes sur la Géologie et la Paléontologie du Miocène de Lisbonne.XIV - Quelques Squamata (Reptilia). *Bol. Soc. Geol. Portugal*, Lisboa, XIX, pp. 47-60.

BERGGREN W.A., KENT D. V., COUVERING J. A. van (1985). - The Neogene, 2. Geochronology and chronostratigraphy. *In:* N. J. Snelling (ed.). *The chronology of the stratigraphic record.* Geol. Soc. London Mem., 10, pp. 211-250.

BLOW W.H. (1969). – Late Middle Eocene to recent planktonic foraminiferal biostratigraphy. *Proc. First Intern. Confer. on Planktonic microfossils. Geneva 1967*, **1**, pp. 199-442.

BULOT C., GINSBURG L. (1993). – Gisements à mammifères miocènes du Haut-Armagnac et âge des plus anciens proboscidiens d'Europe occidentale. *C.R. Acad. Sci. Paris, Fr.*, **316**, (II), pp. 1011-1016.

CALVO J.P., DAAMS R., MORALES J., LOPEZ-MARTINEZ N., AGUSTI J., ANADON P., ARMENTEROS I., CABRERA L., CIVIS J., CORROCHANO A., DIAZ-MOLINA M., ELIZAGA E., HOYOS M., MARTIN-SUAREZ E., MARTINEZ J., MOISSENET E., MUÑOZ A., PEREZ-GARCIA A., PEREZ-GONZALEZ A., PORTERO J.M., ROBLES, F., SANTISTEBAN C., TORRES T., Van der MEULEN A.J., VERA J.A., MEIN P. (1993). – Up-to-date Spanish continental Neogene synthesis and paleoclimatic interpretation. *Rev. Soc. Geol. España*, 6 (3-4), pp. 29-40.

CANDE S.C., KENT D.V. (1992). – A new geomagnetic polarity time scale for the Late Cretaceous and Cenozoic. *Journal of Geophysical Research*, **97**, n. B10, pp. 13917-13951.

CHEVALIER J.P., NASCIMENTO A. (1975). – Notes sur la Géologie et la Paléontologie du Miocène de Lisbonne. XVI - Contribution à la connaissance des madréporaires et des faciès récifaux du Miocène inférieur. *Bol. Soc. Geol. Portugal*, Lisboa, **19**, n° 3, pp. 247-281.

COTTER J.C.B. (1956). – O Miocénico marinho de Lisboa. *Com. Serv. Geol. Portugal*, Lisboa, XXXVI, suplemento, 170 p.

DE BRUIJN H., DAAMS R., DAXNER-HÖCK G., FAHLBUSCH V., GINSBURG L., MEIN P., MORALES, J. with the contribution of HEINZMANN E., MAYHEW D.F., Van der MEULEN A.J., SCHMIDT-KITTLER N., ANTUNES M.T. (1992). – Report of the RCMNS working group on fossil mammals, Reisensburg 1990. *Newsl. Strat.*, 26(2/3), pp. 65-118.

HAQ B.U., HARDENBOL J., VAIL P.R. (1987). – Chronology of fluctuating sea levels since the Triassic. *Science*, 235, pp. 1156-1166.

HERMES J.J. (1985). – Algunos aspectos de la estructura de la Zona Subbética (Cordilleras Béticas, España meridional). *Est. Geol.*, **41**, pp. 157-176.

MARTIN-ALGARRA A. (1987). – Evolución geológica alpina del contacto entre las Zonas Internas e las Zonas Externas de la Cordillera Bética. *Tésis Univ. Granada*, 1171 p.

NASCIMENTO A. (1978). – Notes sur la Géologie et la Paléontologie du Miocène de Lisbonne. XXII - Une espèce nouvelle, *Pokornyella lusitanica* (Ostracoda), dans le Miocène inferieur du bassin du Tage. *Ciências da Terra (UNL)*, Lisboa, n° 4, pp. 47-58.

NASCIMENTO A. (1983). – The ostracoda fauna of the portuguese Neogene and its relationship to those from the Atlantic and Mediterranean Basins, in Applications of Ostracoda. *Proceedings Eighth Intern. Symposium on Ostracoda, R. F. Maddocks, edit.*, Houston, pp. 429-436.

NASCIMENTO A. (1988). – *Ostracodos do Miocénico da bacia do Tejo: sistemática, biostratigrafia, paleoecologia, paleogeografia e relações Mediterrâneo-Atlântico*. Dissertação de Doutoramento, Universidade Nova de Lisboa, 305 p.

NASCIMENTO A. (1989). – Nouvelles espèces d'ostracodes du Miocène du Bassin du Tage (Portugal). *Ciências da Terra (UNL)*, Lisboa, 10, pp. 107-126.

NASCIMENTO A. (1990). – Tentative ostracode biozonation of the Portuguese Neogene. *Cour. Forsch.- Inst. Senckenberg*, Frankfurt am Main, 123, pp. 181-190.

NASCIMENTO A. (1993). – Application of abundances of Cyprideis group taxa and marine species to the reconstitution of Aquitanian paleoenvironments in Tagus Basin (Portugal). *In: Ostracoda in the Earth and life sciencies, A. A. Balkema*, Rotterdam, pp. 229-239.

PAIS J. (1981). – *Contribuição para o conhecimento da vegetação miocénica da parte ocidental da bacia do Tejo*. Dissertação de Doutoramento, Universidade Nova de Lisboa, 328 p.

PAIS J. (1986). – Évolution de la végétation et du climat pendant le Miocène au Portugal. *Ciências da Terra (UNL)*, Lisboa, 8, pp. 179-191.

PAIS J. (1989). – Macrorrestes de végétaux du Burdigalien supérieur de Cristo Rei (Almada, Portugal). *II European Paleobotanical Conference*, Madrid.

ROMAN F. (1907). – Le Neogène continental dans la basse vallée du Tage (rive droite). 1re partie Paléontologie. *Mem. Serv. Geol. Portugal*, Lisboa, pp. 1-78.

SEN S., ANTUNES M.T., PAIS J., LEGOINHA P. (1992). – Bio and magnetostratigraphy of two Lower Miocene sections, Tagus basin (Portugal). *Ciências da Terra (UNL)*, Lisboa, 11, pp. 173-184.

SORIA J.M. (1994). – Sedimentación y tectónica durante el Mioceno en la region de Sierra Arana-Mencal y su relación com la evolución geodinámica de la Cordillera Bética. *Rev. Soc. Geol. España*, Madrid, 7(3-4), pp. 199-213.

STEININGER F.F., BERNOR R.L., FAHLBULSCH V. (1990). – European Neogene marine/continental chronologic correlations. In E.H.Lindsay, V.Fahlbusch and P.Mein (eds.): European Neogene Mammal Chronology. *Plenum Press*, New York, NATO ASI Series, A, 180, pp. 15-46.

VAN der MADE J. (1994). – Suoidea from the Lower Miocene of Cetina de Aragón (Spain). *Rev. Española de Paleontología*, Madrid, 9(1), pp.1-23.

VAN der MEULEN A.J., DAAMS R. (1992). – Evolution of Early -Middle Miocene rodent faunas in relation to long-term palaeoenvironmental changes. *Palaeo., Palaeo., Palaeo.*, Amsterdam, 93, pp. 227-253.

VERGNAUD-GRAZZINI C., RABUSSIER-LOINTIER D. (1980). – Essai de corrélation stratigraphique par le moyen des isotopes de l'oxygène et du carbone. *Bull. Soc. géol. Fr.*, **22**, (5), pp. 719-730.

ZBYSZEWSKI G. (1954). – L'Aquitanien supérieur de Lisbonne et du Ribatejo. *Com. Serv. Geol. Portugal*, Lisboa, **35**, pp. 99-154.

ZBYSZEWSKI G. (1962). – Considérations sur la position stratigraphique de l'Aquitanien portugais. *Com. Serv. Geol. Portugal*, Lisboa, **46**, pp. 297-316.

Addendum

Mammals from Lower to Middle Miocene of the Lower Tagus basin

(by M. T. Antunes)

Previous remarks and concerned methods

As an important methodological point, we must previously recall that **in this paper we deal primarily and essentially with facts (and not just interpretations) upon which our work is based**. Of course, we also deal with comparative interpretations.

First of all, we are showing the reality provided by the Lower Tagus basin. The concerned Miocene record is that of a succession of lithostratigraphic units that represent a wide variety of marine to continental environments with many intermediate situations between. The marine units yielded planktic foraminifera that allow correlations with N Blow's zones. These zones are well calibrated to the absolute age scale. This, along with K-Ar dating, a set of magnetostratigraphic evidence, and Sr ages are essential and allow us to establish an accurate frame (see Table). Other data from ostracods, calcareous nannoplancton, pollen and spores, and other fossils give complementary, compatible evidence. All that has been carried on during the last 35 years in cooperation with many Colleagues that are among the best placed to do these particular jobs. As far as mammals are concerned, the contributions from L. Ginsburg (Paris) and P. Mein (Lyon) are most important.

Intercalated in the series there are several continental, paralic or shallow, littoral marine sediments with land mammals. Problems arise when comparisons are established. Biostratigraphic units based on mammals are interpretations that often enforce limits where Nature perhaps did not (as would be any important datum - i.e. significant extinctions and new appearances).

How to correlate the Lower Tagus basin Miocene land-mammal assemblages, dated not on mammalian evidence itself but according to their stratigraphic situation in an accurate frame, to other mammalian assemblages elsewhere in purely continental contexts?

In order to approach the fundamental aim of correlating continental mammal assemblages, a system of mammal-units (MN) was deviced by P. Mein and later improved. It was an accomplishment to convert it to a time scale in Ma (Steininger *et al.*, 1990). Hence we must take it into account.

Later on, the MN system was revised but only in continental, relative (and not absolute) terms (de Bruijn *et al.*, 1992). In this revised scale, the MN units' boundaries often differ from those of Steininger *et al.* (1990) and of van der Meulen and Daams (1992). Furthermore, the corresponding tables do not always depict the real situation as far as localities are concerned. For instance, in the table 2, p. 73 (de Bruijn *et al.*, 1992) some localities appear on a vertical succession for MN5 and MN4; the situation in Lisbon area is as follows:

MN5 (Pontlevoy):

– Chelas 2 [quoted only as «Chelas»] + Quintanelas + Amor (the three apparently are synchronous);

– Quinta da Farinheira + Charneca do Lumiar (synchronous among themselves and a little older than Chelas 2).

[These two sets of localities correspond to the time span of *Hispanotherium* known occurrences in Portugal].

MN4 (La Romieu):

– Quinta do Pombeiro + Quinta das Pedreiras (with a mammalian assemblage nearly identical to that from La Romieu);

– Quinta do Narigão (and other non referred sites), whose mammalian assemblage is distinctly earlier than that from Quinta do Pombeiro and closely matches that from Artenay.

The MN mammal-units are open to discussion, even more if some seem much too broad in time and corresponding to really distinct assemblages. Should it be appropriate to blur the better resolution as afforded by mammals itselves? Should we otherwise prefer to subdivise the MN units? And, if yes, how to do it (there have been different attempts)?

Another basic reference for our land-mammal comparison work is the great contribution by van der Meulen and Daams (1992). Let us antecipate that our results are generally in fairly good agreement with the latter. However, it must be remarked that for van der Meulen and Daams (1992) the Chelas and Quinta da Farinheira assemblages are ascribed to MN4 (Iberian zones D2 and D1 respectively), while the same are reported to MN5 by De Bruijn *et al.* (1992). The Quinta do Narigão and Cristo Rei assemblages are ascribed to MN 4 by De Bruijn *et al.* (1992) and van der Meulen and Daams (Iberian zone B). However, the lower boundary of this zone is placed at *ca* 17.5 Ma by Steininger et al. (1990) and at *ca* 18.5 Ma by van der Meulen and Daams (1992) (see Fig. 6).

All in all, in our synthesis fig. 6 we choose the best possible solution in the present status of knowledge to match data with corresponding units as presented by both Steininger *et al.* (1990), De Bruijn *et al.* (1992) and van der Meulen and Daams (1992). A fundamental revision based on the mammal assemblages is a huge work that must be accomplished with the help of other specialists. Let us simply stress that we present the main facts as they are observed in the Lower Tagus basin.

Units I and **II** (Divisions —lithostratigraphic units— of the Lisbon Miocene according to J. B. Cotter)

This unit corresponds to the earliest neogene marine transgression in the Lower Tagus Basin. Most of the unit I beds have been deposited in shallow warm waters including a well developped fringe reef barrier (limestones with *Venus Ribeiroi*). This beds are Aquitanian in age.

Conglomerates outcroping at Km 10 (eastern embankment of Lisbon-Oporto A1 highway) yielded a small mammal assemblage:

Cainotherium sp.
Andegameryx andegaviensis
Lagopsis spiracensis
Melissiodon dominans
Ligerimys antiquus
Glirudinus modestus
Pseudodryomys ibericus
Pseudodryomys simplicidens
Peridyromys murinus
Blackia miocaenica
Palaeosciurus fissurae
Heteroxerus rubricati (archaic)
Sciuridae
Galerix sp.
Soricinae

This assemblage comprises earlier forms that are replaced by other ones in Universidade Católica and Avenida do Uruguay (for dis-

cussion see Antunes and Mein, 1992). Hence we ascribed Km 10 mammals to MN2 (upper part).

Later, swamps or marshes allowed the sedimentation of clays. The old site of Horta das Tripas (top of the unit) yielded a few large mammals:

Pseudaelurus transitorius
Protaceratherium minutum
Diaceratherium aurelianensis
Brachyodus intermedius (formerly classified as *Br. onoideus*)
Aureliachoerus aurelianensis

The last form has lately been ascribed with doubt to the common aquitanian species *Hyotherium meisneri* by van der Made (1994). The doubt may perhaps be related to the belief (Roman, 1907, followed by other authors) in a Burdigalian age, too late for *H. meisneri*. One may think instead that Horta das Tripas suid and the remaining, all rather archaic, forms suggest an age maybe early Burdigalian (earliest MN3); anyway it is very close to the end of the Aquitanian.

Stratigraphic evidences points out to a somewhat later age for two localities in Lisbon with identical small mammal assemblages (Universidade Católica and Avenida do Uruguay) ascribed to Unit II:

Cainotherium sp.
Lagopsis cadeoti
Eucricetodon infralactorensis
Melissiodon dominans
Ligerimys antiquus
Glirudinus modestus
Glirinae
Pseudodryomys ibericus
Pseudodryomys simplicidens
Armantomys sp.
Peridyromys murinus
Microdyromys legidensis
Heteroxerus vireti
Heteroxerus rubricati

This association can be ascribed to MN3 (lower part), Lower Burdigalian.

Unit IVb

Mammals (from sites (a) Lower part of the unit, in Lisbon - Quinta Noiva, Quinta do Narigão, Quinta da Carrapata, Pote de Água; (b) close to the top of the unit, at Cristo Rei section, left bank of the Tagus (*). The stratigraphic position of Cristo Rei higher than all other localities is well established.

There is the last appearance of *Brachyodus* as far as we can ascertain. > - first occurrences of forms either previously unknown from the Lower Tagus basin and supposedly immigrants, or maybe present there before but whose remnants are unknown in these (older) levels. Gomphotheres are recorded in the Lower Tagus Basin for the first time, but they could have reached the region some time before [their arrival in Europe happened still during MN3 (Bulot and Ginsburg, 1993)]. Both large and small mammals point out to MN4, Iberian zone B:

> *Amphicyon olisiponensis*
> *Hemicyon* cf. *stehlini*
> *Plithocyon antunesi*
Pseudaelurus turnauensis
Brachyodus onoideus
Cainotherium miocaenicum (*)
> *Amphitragulus aurelianensis*
Procervulus dichotomus
Lagomeryx minimus
Palaeomerycidae undet.
> *Eotragus artenensis*
Anchitherium aurelianense
> *Plesiaceratherium platyodon*
Diaceratherium aurelianensis
> *Prosantorhinus cf. germanicus*
> *Gomphotherium angustidens*
Cf. *Metaxytherium medium*
Lagopsis peñai (*)
Ligerimys sp. (*)
Peridyromys occitanus (*)
Miodyromys sp. (*)
Pseudodryomys simplicidens (*)
Pseudodryomys robustus (*)

Unit Va2

Mammals are known from sites in Lisbon at Quinta do Pombeiro, Quinta das Pedreiras and Quinta da Conceição; no localities are known in the left bank of the Tagus.

Main arrivals: *Bunolistriodon, Dorcatherium, Gaindatherium, Prodeinotherium* (common), Cricetidae; absence of *Brachyodus* (last appearance, IVb); curiously, no Eomyidae were found. Cricetidae indicate zone MN4 (De Bruijn *et al.*, 1992), Iberian zone C (van der Meulen and Daams, 1992):

> *Amphicyon giganteus*
Amphicyon sp.
Hemicyon stehlini
Ischyrictis cf. *bezianensis*
Martes cf. *munki*
Mustelidae und.
Viverra (Viverrictis) modica aff. *vetusta*
Pseudaelurus lorteti
Pseudaelurus turnauensis
> *Bunolistriodon lockarti*
Albanohyus pygmaeus
Cainotherium miocaenicum
> *Dorcatherium crassum*
Amphitragulus aurelianensis
Palaeomerycidae undet.
Plesiaceratherium lumiarense
Prosantorhinus douvillei
> *Gaindatherium (Iberotherium) rexmanuelli*
Gomphoterium angustidens
> *Prodeinotherium bavaricum* (common)
Metaxytherium medium
Lagopsis peñai
Heteroxerus rubricati
Heteroxerus cf. *grivensis*
Pseudodryomys ibericus
Praearmantomys ginsburgi
> *Megacricetodon primitivus*
> *Democricetodon hispanicus*
Galerix symeonidisi

Unit Vb (lower part - fluviatile sands)

Mammals from sites in Lisbon at Quinta da Silvéria, Olival da Susana, Quinta Grande, Casal das Chitas, Quinta das Flamengas, Quinta da Farinheira, etc.

No Eomyidae; Cricetids became predominant among rodents and inversely for glirids. *Hispanotherium* is the more conspicuous element, hence the name "*Hispanotherium* fauna" characterized by it. > immigrants; (-) rare; (LA) last appearance. MN 5 (De Bruijn *et al.*, 1992) (with *M. primitivus*), Iberian zone D1 (van der Meulen and Daams, 1992):

Amphicyon giganteus
Amphicyon sp.
Hemicyon sansaniensis parvus
Plithocyon antunesi
Ischyrictis cf. *bezianensis*
Viverra (Viverrictis) modica aff. *vetusta*
Pseudaelurus romieviensis
Pseudaelurus lorteti
Pseudaelurus turnauensis
Hyotherium soemmeringi
Bunolistriodon lockarti
Taucanamo cf. *sansaniense*
Cainotherium miocaenicum
Dorcatherium crassum
Procervulus dichotomus
Lagomeryx minimus
Palaeomerycidae undet.

Anchitherium aurelianense

> *Moropus* sp.

Aceratherium lumiarense

Prosanthorhinus douvillei

> *Diceratorhinus (Lartetotherium) sansaniensis*

> *Hispanotherium matritensis*

Gaindatherium (Iberotherium) rexmanueli zbyszewskii

> *Chilotherium ibericus* (-)

Gomphotherium angustidens

Prodeinotherium bavaricum (extremely rare)

Metaxytherium medium

Lagopsis peñai

Heteroxerus rubricati

Microdyromys sp.

Armantomys sp.

Megacricetodon primitivus (LA)

Democricetodon cf. *hispanicus*

Galerix sp.

Unit Vb (upper part - coarse sands and conglomerate with *Gryphaea*)

Mammals from the sole site of Chelas 2.

Pseudofahlbuschia is a good D2 Iberian zone indicator; *Melissiodon* and *Ligerimys* are but survivors from earlier times - MN5 (De Bruijn *et al.*, 1992), Iberian zone D2 (van der Meulen and Daams, 1992); the predominance of Cricetids goes on - Cricetids are by far more important than previously, before Vb unit prevailing Glirids; squirrels are very scarce, even land ones as *Heteroxerus*. The whole list is as follows:

Cainotherium miocaenicum

Procervulus dichotomus

Lagopsis peñai

? Ligerimys sp.

Heteroxerus rubricati

Microdyromys koenigswaldi

Pseudodryomys simplicidens

Megacricetodon collongensis

> *Pseudofahlbuschia jordensi*

Melissiodon cf. *dehmi*

Galerix sp.

Two additional localities outside the Lower Tagus basin are more or less the same age as Chelas 2: Quintanelas and Amor (near Leiria). At Quintanelas, a mammalian assemblage with *Hispanotherium* and *Prodeinotherium* (among other forms) occurs just under deposits that corresponds to the earlier stades of the great Middle Miocene (Upper Langhian and Serravalian) transgression. This situation is nearly identical to that of Chelas 2; hence correlation with the Lower Tagus basin is easy.

Amor (see Antunes and Mein, 1981) yielded a good small mammal assemblage and *Hispanotherium* (M. T. Antunes, unpublished data). It may compare with Quintanelas as far as age is concerned. It appears therefore that the span of the *Hispanotherium* faunas is since about 16.3Ma (Quinta da Farinheira) to ca 15.5Ma (Chelas 2 and correlative sites).

PLATE I

Ostracoda

Fig. 1. – *Cytherella (Cytherelloidea) jonesiana* (Bosquet, 1852), right valve outside lateral view (× 80). Burdigalian, Cristo Rei, Va2 unit.

Fig. 2. – *Cytherella (Cytherella) confusa* (Lienenklaus, 1900), carapace, lateral view of the left valve (× 100). Burdigalian, Cristo Rei, IVa unit.

Fig. 3. – *Miocyprideis fortisensis* (Key, 1955), left valve seen from the outside (× 80). Burdigalian, Cristo Rei, IVa unit.

Fig. 4. – *Ruggieria (Ruggieria) nuda* (Moyes, 1965), right valve seen from the outside (× 80). Langhian, Quinta das Rosas, Vc unit.

Fig. 5. – *Cytherella (Cytherella) antunesi* (Nascimento, 1989), carapace, lateral view of the left valve (× 80). Burdigalian, Cristo Rei, IVa unit.

Fig. 6. – *Costa (Costa) batei* (Brady, 1866), left valve seen from the outside (× 80). Langhian, Quinta das Rosas, Vb unit.

Fig. 7. – *Cyamocytheridea strigulosa* (Reuss, 1850), left valve seen from the outside (× 80). Langhian, Quinta das Rosas, Vc unit.

Fig. 8. – *Loxoconcha (Loxoconcha) tagana* (Nascimento, 1981), left valve seen from the outside (× 150). Burdigalian, Cristo Rei, IVa unit.

Fig. 9. – *Cytherella (Cytherella)* aff. *compressa* (G. W. Münster, 1830), right valve seen from the outside (× 80). Burdigalian, Cristo Rei, IVa unit.

Fig. 10. – *Xestoleberis (Xestoleberis) glabrescens* (Reuss, 1850), left valve seen from the outside (× 150). Transition zone Burdigalian/Langhian, Cristo Rei, Vb unit.

Fig. 11. – *Pterygocytheris (Pterygocytheris) siveteri* Athersuch, 1978, left valve seen from the outside (× 80). Transition zone Burdigalian/Langhian, Cristo Rei, Vb unit.

Fig. 12. – *Cytheretta (Cytheretta) mediocostata* Moyes, 1965, carapace, lateral view of the left valve (× 80). Transition zone Burdigalian/Langhian, Cristo Rei, Vb unit.

Fig. 13. – *Costa (Costa) edwardsii* (Roemer, 1838), right valve seen from the outside (× 80). Transition zone Burdigalian/Langhian, Cristo Rei, Vb unit.

Fig. 14. – *Olimfalunia* gr. *plicatula* (Reuss, 1850), left valve seen from the outside (× 80). Transition zone Burdigalian/Langhian, Cristo Rei, Vb unit.

Fig. 15. – *Loxoconcha (Sagmatocythere) grateloupiana* (Bosquet, 1852), left valve seen from the outside (× 80). Langhian, Quinta das Rosas, Vb unit.

Fig. 16. – *Aurila (Ulicznina) oblonga* Moyes, 1965, left valve seen from the outside (× 80). Langhian, Quinta das Rosas, Vc unit.

Fig. 17. – *Cytheretta (Cytheretta) rhenana rhenana* Triebel, 1952, right valve seen from the outside (× 100). Burdigalian, Cristo Rei, IVa unit.

Fig. 18. – *Paracypris polita* Sars, 1866, right valve seen from the outside (× 80). Burdigalian, Cristo Rei, IVa unit.

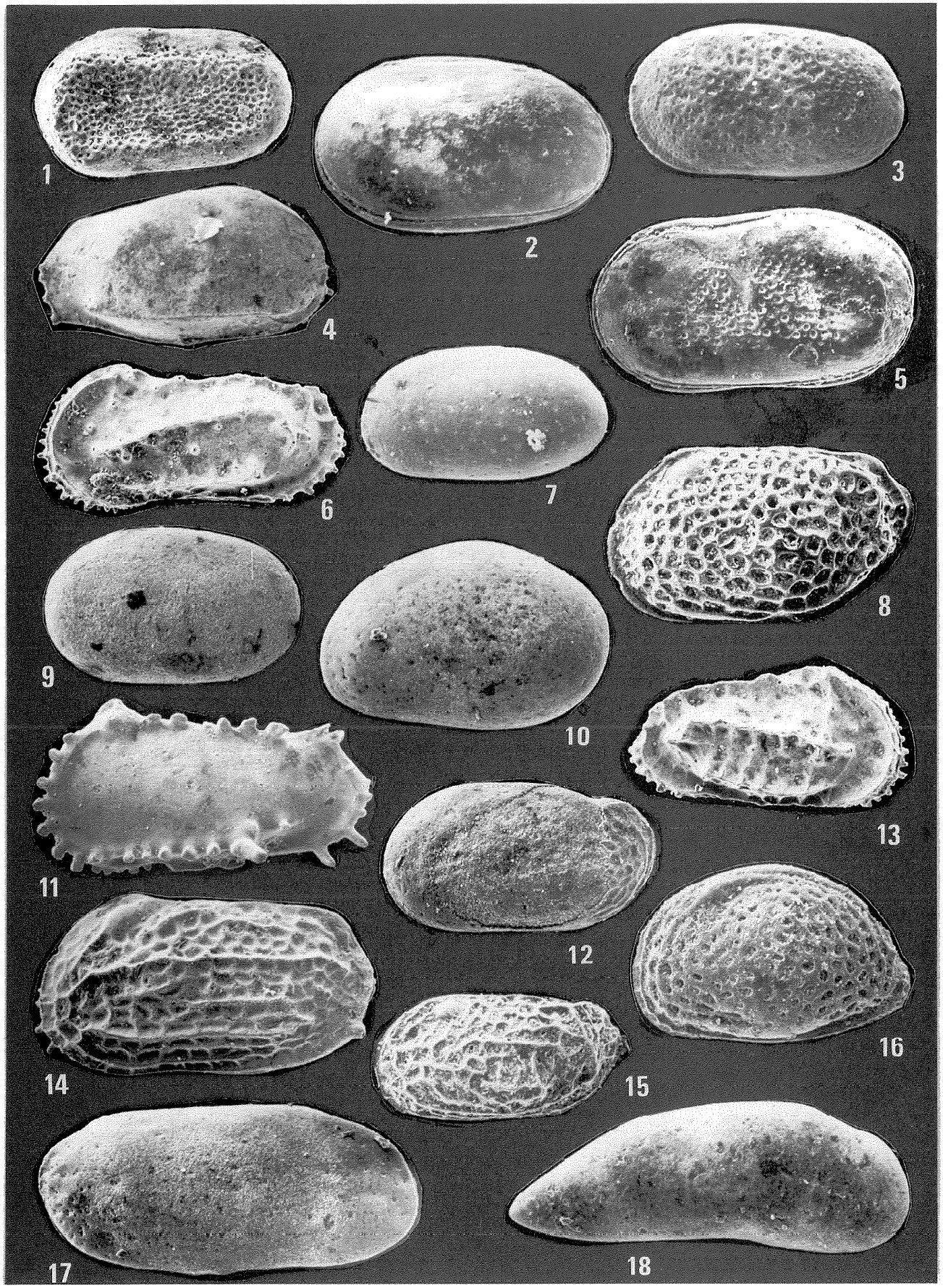
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PLATE II

Ostracoda

Fig. 1. – *Echinocythereis* gr. *scabra* (Münster, 1830), right valve seen from the outside (× 80). Transition zone Burdigalian/Langhian, Cristo Rei, Vb unit.

Fig. 2. – *Ruggieria (Ruggieria) tetraptera tetraptera* (Seguenza, 1880), right valve seen from the outside (× 80). Langhian, Quinta das Rosas, Vc unit.

Fig. 3. – *Incongruellina (Lixouria) marginata* (Terquem, 1878), right valve seen from the outside (× 100). Burdigalian, Cristo Rei, IVa unit.

Fig. 4. – *Loxoconcha (Loxoconcha) ducasseae* (Nascimento, 1989), carapace, lateral view of the right valve (× 150). Langhian, Quinta das Rosas, Vc unit.

Fig. 5. – *Ruggieria (Ruggieria) micheliniana* (Bosquet, 1852), right valve seen from the outside (× 80). Burdigalian, Cristo Rei, IVa unit.

Fig. 6. – *Cytheridea (Cytheridea)* sp., left valve seen from the outside (× 80). Burdigalian/Langhian transition zone, Cristo Rei Vb unit.

Fig. 7. – *Bythocypris arcuata* (Münster, 1830), left valve seen from the outside (× 80). Burdigalian, Cristo Rei, IVa unit.

Fig. 8. – *Bosquetina carinella* (Reuss, 1850), right valve seen from the outside (× 100). Burdigalian, Cristo Rei, IVa unit.

Planktic Foraminifera

Fig. 9. – *Catapsydrax unicavus* (Bolli, Loeblich and Tappan) (× 240). Burdigalian, Cristo Rei, IVa unit.

Fig. 10. – *Globigerinoides altiaperturus* (Bolli) (× 100). Burdigalian, Cristo Rei, IVa unit.

Fig. 11. – *Globorotalia mayeri* (Cushman and Ellisor) (× 155). Burdigalian, Cristo Rei, IVa unit.

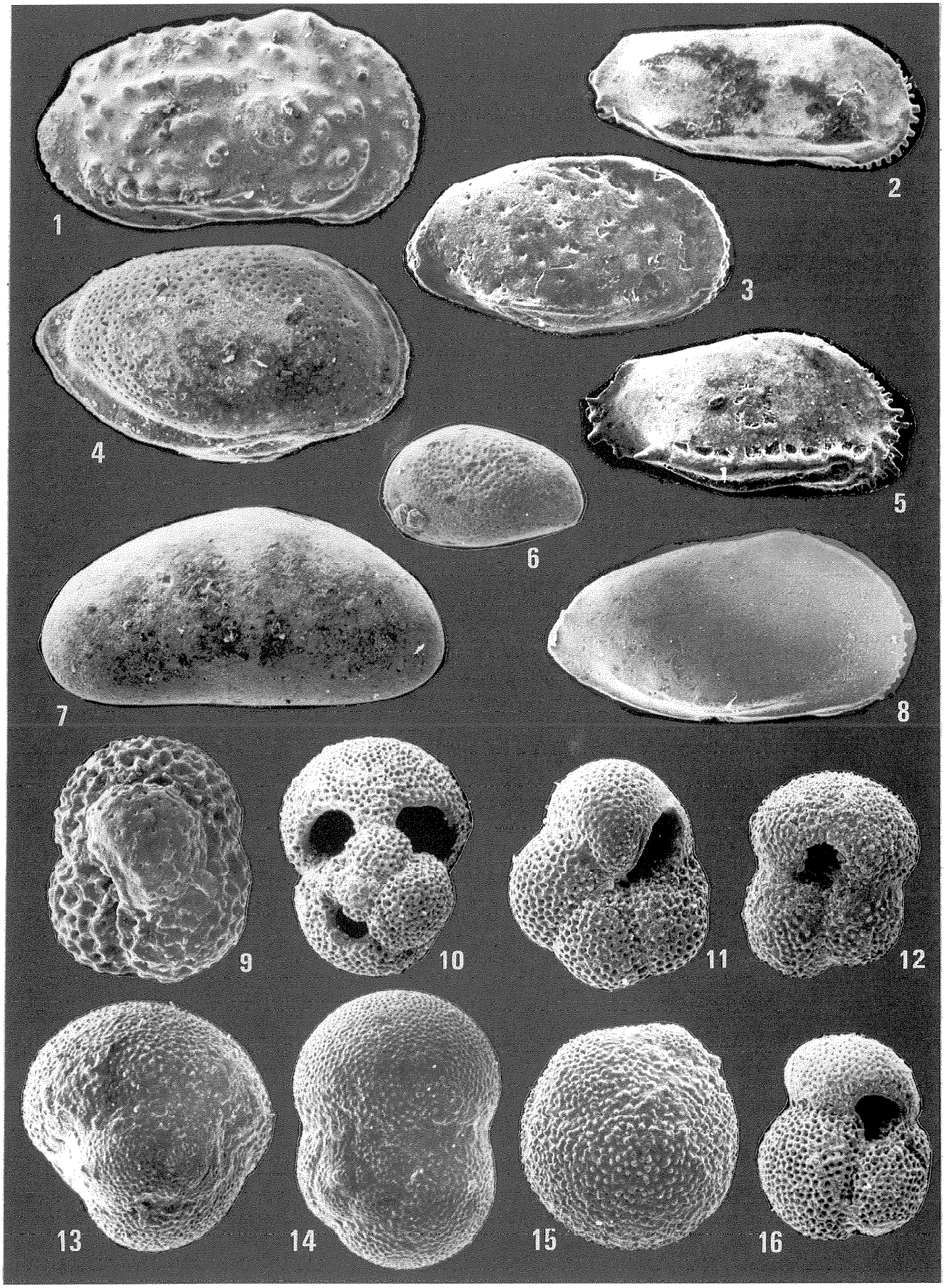
Fig. 12. – *Globigerinoides subquadratus* (Brönimann) (× 150). Burdigalian, Cristo Rei, Vb unit.

Fig. 13. – *Globigerinoides sicanus* (de Stefani) (× 100). Burdigalian, Cristo Rei, Vb unit.

Fig. 14. *Praeorbulina transitoria* (Blow) (× 100). Burdigalian, Cristo Rei, Vb unit.

Fig. 15. – *Praeorbulina glomerosa curva* (Blow) (× 120). Langhian, Quinta das Rosas, Vb unit.

Fig. 16. – *Globigerinoides sacculifer* (Brady) (× 100). Burdigalian, Cristo Rei, IVa unit.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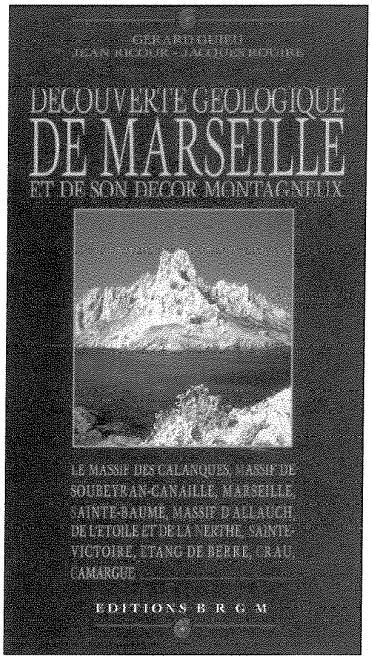

Découverte géologique de Marseille et de son décor montagneux

le massif des calanques, massif de Soubeyran-Canaille, Marseille, Sainte-Baume, massif d'Allauch, de l'Etoile et de la Nerthe, Sainte-Victoire, étang de Berre, Crau, Camargue...

par Gérard Guieu, Jean Ricour, Jacques Rouire

Véritable initiation à la géologie, ce guide — illustré de 120 photographies en couleurs et d'une cinquantaine de croquis didactiques — a un double objectif. Au travers d'une promenade dans les décors somptueux de la région marseillaise, les trois auteurs aident le lecteur à analyser les paysages qui l'entourent et à les interpréter avec l'œil du géologue. En second lieu, ils s'attachent à montrer ce que les sciences de la Terre ont apporté au développement économique de la région, grâce à la mise en valeur des produits du sous-sol : ciment, pierre de taille, sables et graviers, argile, bauxite, charbon, hydroélectricité.... Ils indiquent aussi leur importance pour la défense de l'environnement (ressources en eau potable et industrielle, élimination des déchets), et pour l'aménagement du territoire : routes, voies ferrées, ports, aménagement urbain (métro, tunnels). Il s'agit, en définitive, de démontrer que chacun de nous bénéficie quotidiennement des recherches et des activités des géologues.

Marseillais de souche, Gérard GUIEU, docteur ès sciences et professeur de Géologie appliquée à l'Université de Provence, a consacré toute sa carrière à la Provence. En préparant sa thèse "Etude tectonique de la région de Marseille", il a parcouru, décrit et analysé tous les sites évoqués dans l'ouvrage. Il a, à cette occasion, mis en évidence des phénomènes tectoniques insoupçonnés du grand public. Il est l'auteur d'une centaine de publications scientifiques parues tant en France qu'à l'étranger.

Originaire des Flandres françaises, Jean RICOUR a opté pour la Provence. Après des débuts à l'Institut de Paléontologie humaine et au CNRS, il a poursuivi sa carrière au Bureau de recherches géologiques et minières où il fut l'initiateur de l'hydrogéologie et le créateur des services géologiques régionaux. Docteur ès sciences, il est l'auteur de plus de cent communications scientifiques et dirige, au sein des éditions du BRGM, une série intitulée "Découverte géologique..." des régions de France. Il a été président de la Société géologique de France.

Originaire de l'Aveyron, Jacques ROUIRE a rapidement pris contact avec la Provence puisque, Saint-Cyrien, il fit partie de la promotion "Croix de Provence". Attiré par les sciences naturelles, il abandonna rapidement l'Armée pour soutenir une licence ès sciences et se consacrer à la géologie. Il est l'auteur de 28 cartes géologiques de Provence à des échelles diverses, et a été président de la section des Causses du Club Alpin et secrétaire général de la Société spéléologique de France.

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