

The Neogene of Algarve (Portugal)

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ABSTRACT

Key-words: Neogene; Stratigraphy; Algarve; Portugal.

A synthesis about the Neogene and Quaternary of Algarve (Southern Portugal) is presented. New isotopic $^{87}\text{Sr}/^{86}\text{Sr}$ ages as well as biostratigraphic data about the Miocene deposits allow to present a new stratigraphic frame for the previously characterized units. The Lagos-Portimão Formation corresponds to deposits of "temperate carbonate platform" sedimentological type, developed during a long time span (Lower Burdigalian to Upper Serravallian). A major change in sedimentation conditions (carbonate to siliciclastic environments) occurred in the Lower Tortonian with the deposition of yellowish sands.

Spongoliths rich in microfossils are represented in Algarve inland. Their age is not well established; calcareous nannofossils indicate the CN5a zone (Upper Serravallian) while foraminifera point out at least N16 zone (Lower Tortonian).

In the Upper Tortonian, the sedimentation is widespread in Eastern Algarve, related with the Guadalquivir Basin infill. The deposits begin with detrital limestones, locally very rich in *Heterostegina*, passing to fossiliferous conglomerates and siltstones (Cacela Formation).

Coarse-grained conglomerates at Galvana (Faro) pose some age problems. K/Ar age on glauconite indicates 6.72 ± 0.17 Ma. However, glauconites may be reworked from older deposits (Cacela Formation). The Galvana Conglomerate could be related to Pliocene deposits are not well characterized. Olhos de Água sands, with a thin marine intercalation rich in marine vertebrates (fishes, a crocodile, cetaceans, sirenians), may be Upper Pliocene; however, the vertebrates point out to a Serravallian to Tortonian age. $^{87}\text{Sr}/^{86}\text{Sr}$ ages on oysters from above the level with vertebrates point out to $3.0(+2.5-1.0)$ Ma. Similar sand deposits occur at Morgadinho (Luz de Tavira). These sands are overlain by marls, lignite clays, lacustrine limestones and a silty calcareous crust. A small mammals association indicate an age span between Upper Pliocene and Lower Middle Pleistocene (MN17-MN20). A Biharian mammal fauna (Lower Pleistocene) was collected at Algoz in similar deposits. In the present state of knowledge, Morgadinho and Algoz deposits may be correlative.

RESUMO

Palavras-chave: Neogénico; Estratigrafia; Algarve; Portugal.

Apresenta-se uma síntese sobre o Neogénico do Algarve. Datações de $^{87}\text{Sr}/^{86}\text{Sr}$, bem como dados biostratigráficos de unidades miocénicas, permitiram o estabelecimento de um novo quadro estratigráfico para as unidades líticas algarvias. A Formação de Lagos-Portimão corresponde a depósitos sedimentares de tipo "plataforma carbonatada temperada" que se desenvolveu durante um longo intervalo de tempo (Burdigaliano inferior a Serravaliano superior). Uma mudança maior na sedimentação (ambientes siliciclásticos) deu-se no Tortoniano inferior com a deposição de areias finas amareladas.

No interior do Algarve ocorrem espongolitos ricos de microfósseis. A idade não está perfeitamente definida. Foraminíferos indicam a zona N16 (Tortoniano inferior) e os Nanofósseis calcários a zona CN5a (Serravaliano superior).

No Tortoniano superior a sedimentação foi mais significativa no Algarve Oriental, em relação com o enchimento da bacia do Guadalquivir. Os depósitos iniciam-se por calcários detriticos, localmente muito ricos de *Heterostegina*, que passam a conglomerados e siltitos muito fossilíferos (Formação de Cacela).

O conglomerado grosseiro de Galvana (Faro) põe alguns problemas. Datações K/Ar de glauconite indicam 6.72 ± 0.17 Ma. Todavia, a glauconite pode ter sido remobilizada a partir de níveis mais antigos (Formação de Cacula). Parecem estar relacionados com momento de forte instabilidade tectónica como o da instalação do olistostroma do Guadalquivir.

O Pliocénico não está bem caracterizado. As areias de Olhos de Água com uma intercalação marinha pouco espessa, rica de vertebrados marinhos (peixes, um crocodilo, cetáceos, sirenídeos) possivelmente redepositados, pode corresponder ao início do Pliocénico superior; contudo, os peixes, mamíferos marinhos e o crocodilo apontam para o Serravaliano a Tortoniano inferior. Datações $^{87}\text{Sr}/^{86}\text{Sr}$ efectuadas em ostras e em dentes de peixe forneceram valores de $3.0(+2.5-1.0)$ Ma. Areias do mesmo tipo ocorrem em Morgadinho (Luz de Tavira). São sobrepostas por margas, argilitos lignitosos, calcários lacustres e uma crosta carbonatada. Os argilitos lignitosos forneceram fauna de pequenos mamíferos correspondente ao intervalo Pliocénico superior a parte inferior do Plistocénico médio (MN17-MN20). Em Algoz foi recolhida uma fauna datada do Plistocénico inferior (Bihariano) em depósitos semelhantes. É possível que as jazidas de Morgadinho e de Algoz sejam correlativas.

FOREWORD

The first studies about the Cenozoic of Algarve dealt only with some fossil localities and deposits (Pereira da Costa, 1866; Dollfus *et al.*, 1903-1904; Bourcart & Zbyszewski, 1940; Chavan, 1940; Zbyszewski, 1948; 1950).

In 1979, M.T. Antunes and J. Pais, carried out stratigraphic studies on the Neogene of Algarve (Research line nº 1 of the former "Centro de Estratigrafia e Paleobiologia da Universidade Nova de Lisboa"). Some synthetic interpretations have been published (Antunes *et al.*, 1981; Antunes *et al.*, 1990; Antunes *et al.*, 1992). New developments have been achieved concerning mainly $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic dating at the Department of Earth Sciences of Cambridge University (Table 1, Fig. 1). A revision is under way taking into account all the available data, and specially isotopic ages, micropaleontology and sequence stratigraphy analysis.

At the present status of knowledge, the Neogene units characterized so far are mainly of Miocene age and mostly marine. They range from Lower to Uppermost Miocene. However, there are lithological differences. Olhos de Água sands could be ascribed to the Pliocene based on $^{87}\text{Sr}/^{86}\text{Sr}$ dating, but this needs to be confirmed. Those of Morgadinho (Antunes *et al.*, 1986c) may (at least in part) be Pliocene in age.

The Neogene units so far recognized in Algarve are shown in the Fig. 7, and will be discussed by chronological order.

Pereira de Sousa (1917; 1918; 1922) admitted the presence of Miocene igneous rocks in Algarve although these were not found later. In 1971, a small basanite outcrop enclosed by Miocene biocalcarenes was detected, showing clear evidence of low grade thermal effects on the sedimentary rocks along the contact with the igneous dike. This rock represents the latest volcanic activity in Portugal (Pinto Coelho & Bravo, 1983). However, Cenozoic volcanic activity is well known in Southern Spain, since Langhian-Serravalian till the Quaternary.

Tectonic structures concerning the Mesozoic and Cenozoic deposits of the Algarve basin allow to recognize the following alpine orogenic events: Jurassic (Upper Triassic at least) - Lower Cretaceous N-S distension; E-W distension during Lower to Upper Cretaceous; N-S compression during the setting-up of the Monchique syenite dome at the uppermost Cretaceous; Paleogene

compression (only locally ? - at the Albufeira salt dome); Lower and Middle Miocene N-S and E-W distension; Tortonian N-S compression; post-Messinian E-W compression; N-S compression during the Quaternary.

Table 1 - $^{87}\text{Sr}/^{86}\text{Sr}$ results.

Localit. n°	Localities	Samp.	Ma	$^{87}\text{Sr}/^{86}\text{Sr}$	$\pm 2\sigma$
1	Aljezur	3	9.8(± 1.5)	0.708903	0.000024
		2	12.6(+0.9-0.8)	0.708850	0.000020
	Furna Amarela	1	11.9(± 0.8)	0.708867	0.000018
2	Alj./Igreja Nova		16.9(± 0.3)	0.708701	0.000018
3	Aljezur	2	18.5(± 0.3)	0.708605	0.000017
		/Gimnodesportivo	1	19.5(+0.3-0.2)	0.708537
4	Sagres		12.0(+1.3-1.3)	0.708886	0.000021
			12.5(+0.8-0.7)	0.708850	0.000047
5	Zavial		16.2(+0.5-0.5)	0.708734	0.000021
6	Praia do Canavial	1	17.5(+0.7-0.7)	0.708653	0.000026
		3	16.3(+0.5-0.3)	0.708737	0.000020
		4	14.3(+0.5-0.5)	0.708804	0.000017
		5	15.3(+0.5-0.5)	0.708771	0.000018
7	Albardeira		5.5(+4.1-0.7)	0.708959	0.000018
8	Praia da Rocha	2	12.2(+1.2-1.3)	0.708860	0.000018
		3	11.5(+0.8-0.5)	0.708875	0.000026
		II	10.7(+0.8-1.2)	0.708886	0.000018
9	Albandeira	W7	15.5(± 0.4)	0.708763	0.000017
		W6	16.3(+0.4-0.5)	0.708799	0.000017
10	Galé		11.3(+0.9-1.3)	0.708880	0.000024
11	Praia do Castelo		15.5(+0.8-0.3)	0.708759	0.000017
12	Arrifão	1	19.5(+0.2-0.3)	0.708515	0.000017
		2	19.2(+0.2-0.4)	0.708553	0.000018
		3	14.2(+0.6-0.4)	0.708807	0.000020
		4	8.3(+2.2-3.3)	0.708922	0.000021
13	Santa Eulália	3	14.4(+0.5-0.6)	0.708804	0.000017
		2	14.6(+0.5-0.6)	0.708799	0.000017
		1	15.5(± 0.4)	0.708763	0.000017
14	Hotel Auramar	2	9.5(+1.0-0.5)	0.708907	0.000016
15	Olhos de Água		14.6(-0.4+1.4)	0.708797	0.000020
16	Areias/Olhos de Água		3.0(+2.5-1.0)	0.709044	0.000048
17	Quelfes	4	5.2(+4.4-0.6)	0.708961	0.000014
		3	5.2(+4.4-1.1)	0.708971	0.000018
		1	5.3(+4.3-0.7)	0.708952	0.000018
18	Cacula	1	5.7(+3.9-1.1)	0.708950	0.000014
		4	8.3(+2.2-3.3)	0.708922	0.000021
19	Mem Moniz	Forams	12.5(-1.7+0.7)	0.708857	0.000016

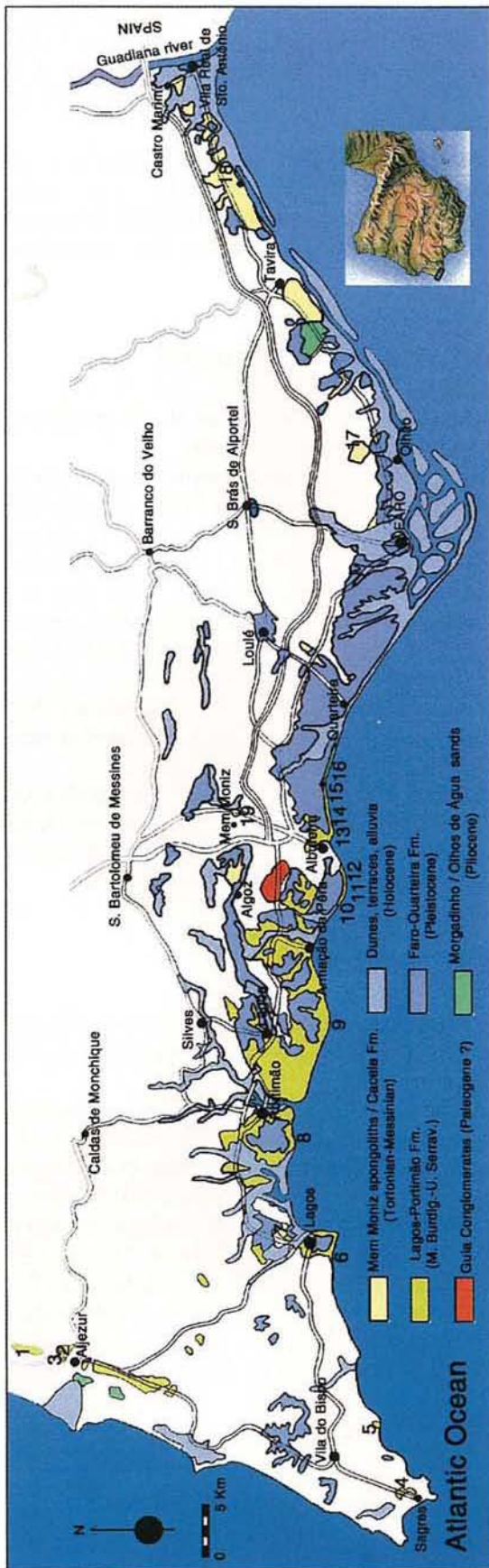


Fig 1 - Geological schematic map of Algarve. Numbers - Sr isotopes sampling localities.

The NE-SW fractures affecting the Paleozoic basement are related to the first distension phases. The mesozoic N-S distension is the main cause of the two E-W flexures so far recognized. The tectonic inversion occurred after the setting up of the Monchique syenite. If the Lower Cretaceous-Lower Miocene Albufeira's unconformity is a local effect of halokinesis, then the true tectonic inversion of the Algarve basin only took place in the Lower to Middle Tortonian.

These events correlate well with those known in southern Spain and Morocco (Kullberg *et al.*, 1992).

LAGOS - PORTIMÃO FORMATION

This Formation, first described by Antunes *et al.* (1981), is the most evident Miocene unit in western Algarve. It makes up a sizable portion of the costal sea cliffs, and is of considerable scenic interest. It overlies Carboniferous, Jurassic, Cretaceous and possibly Paleogene units. In some places a very clear angular unconformity can be observed, whereas stratigraphical hiatuses or paraconformities may be recognized elsewhere.

The whole succession has been much affected by karst phenomena.

The Lagos-Portimão Formation comprises yellow or pink massive and very fossiliferous biocalcarenes of "warm temperate" platform type. The unit ends by an erosion surface, and is overlain by laminated sandstones, poor in fossils.

At Olhos de Água-Praia de Santa Eulália, a lenticular body of sandstones with sand waves outcrop. ⁸⁷Sr/⁸⁶Sr isotopic ages give 15.5(±0.4) Ma taken for biocalcarenes under the sandstones (Santa Eulália beach), 14.6(+0.5-0.6) Ma for the sandstones and, above it, 14.4(+0.5-0.6) Ma.

In the lower part, well exposed at Praia do Canavial (Fig. 3), molluscs are plentiful. As for the upper part, there are many sea-urchins, Bryozoa, pectinids and fishes. The locality of Cerro das Mós (Lagos), from where a large crocodylian (*Tomistoma*) tooth was collected long ago (Antunes, 1961; Antunes *et al.*, 1981), has also produced some Odontoceti teeth. These may be dated from the Serravallian, which, constitute the oldest marine mammal occurrence in Algarve (Estevens, 2000).

Planktic Foraminifera from the upper levels include *Globigerinoides trilobus*, *G. subquadratus*, *G. bisphericus*, *Globoquadrina baroemoenensis* and cf. *Praeorbulina transitoria*, which point out to N7-N8(?) (Upper Burdigalian to Langhian) (Antunes *et al.*, 1981). The presence of *Orbulina* in biocalcarenes at the Faro borehole indicate that the Serravallian is also represented there (Antunes *et al.*, 1984; Antunes & Pais, 1992).

A ⁸⁷Sr/⁸⁶Sr isotopic age indicate 19.5(+0.2-0.3) Ma (Lower Burdigalian) at Arrifão (lower deposits, overlying the Cretaceous) and 11.3(+0.9-1.3) Ma (Upper Serravallian) at Praia da Galé (upper part) (Fig. 2). At Praia do Canavial (Fig. 3), ⁸⁷Sr/⁸⁶Sr from oyster and/or pectinid shells indicates ages of 17.5(±0.7) Ma, 16.3(+0.5-0.3) Ma

and 14.3(±0.5) Ma (Burdigalian to Lower Serravallian). The upper beds at Praia da Rocha (Fig. 4) gave a $^{87}\text{Sr}/^{86}\text{Sr}$ age of 12.2(+1.2-1.3) Ma and 11.5(+0.8-0.5) Ma (Upper Serravallian). At Aljezur, the lower levels (sands with oysters, outcropping at the "Pavilhão Gimnodesportivo") indicate 19.5(+0.3-0.2) and 18.5(±0.3) Ma, thus corresponding to the Lower Burdigalian. At Igreja Nova, marls with biocalcarenes gave 16.9(±0.3) Ma and upper levels, silstones and marls at Furna Amarela, gave values between 12.6 and 9.8 Ma (Table 1). They may correspond to the great Serravallian transgression.

Nannoplankton (*Reticulofenestra pseudoumbilicus* and *Calcidiscus premacintyreii*) from the upper part of the unit (Albardeira, Lagos), also points out to a Serravallian age (NN6 or CN5a) (Cachão, 1995).

On the other hand, this unit is older than the K-Ar dated glauconite fine sands from Praia da Galé (10.1±0.25 Ma), as well as the sandstones from Praia da Rocha [$^{87}\text{Sr}/^{86}\text{Sr}$: 10.7(+0.8-1.2) Ma].

MEM MONIZ SPONGOLITHS

Overlying the Cretaceous in the inner Algarve there is an outcrop of white spongoliths virtually devoid of macrofossils but containing microfauna. These deposits were originally described by Romariz *et al.* (1979-1980b). They are unknown elsewhere in Portugal, but closely similar ones are widespread around the Mediterranean. They seem to have accumulated in upwelling conditions in a trough related to tectonic events.

The rock is composed essentially of skeletal elements of sponges. They also yielded some fish remnants along with large numbers of microfossils, including diatoms, calcareous nannofossils (among others, *Helicosphera carteri*, *Reticulofenestra pseudoumbilicus*, *Coccolithus pelagicus*, *Cyclococcolithus macintyreii*, *Sphenolithus abies*, *Discolithina multipora*) (Antunes *et al.*, 1981; Cachão, 1995) benthic (*Nonion boueanum*, *Ammonia*, *Buliminids*, *Bolivinids*, *Uvigerinids*) and planktic Foraminifera, and Ostracoda (*Aurila zbyzewska*, *Nonurocythereis seminulum*, *Carinocythereis galilea*) (Antunes *et al.*, 1981; 1990; 1992).

Planktic foraminifera (*Globigerina bulloides*, *G. quinqueloba*, *G. druryi*, *G. glutinata*, *Neoglobobadrina acostaensis*, *Globigerinoides bulloideus*) date these beds at least from N 16 (Lower Tortonian) (Antunes *et al.*, 1981; 1990; 1992). Calcareous nannoplankton indicate zone

CN5a of Bukry (upper Serravallian) (Cachão, 1995). $^{87}\text{Sr}/^{86}\text{Sr}$ age on planktic foraminifera is 12.5(+0.7-1.7) Ma (Upper Serravallian). Hence, the accurate age of these deposits is still open to discussion, albeit between rather narrow limits.

Benthic Foraminifera point out to shallow environments, rich in organic matter, and to low oxygen contents.

Such facies are quite alike some Upper Miocene ones in Southern Spain that overlie the Guadalquivir olistostrome.

FINE SANDS AND SANDSTONES

This unit is separated from the Lagos-Portimão Formation through a disconformity.

It marks a major change from carbonated to siliciclastic sedimentation. Taking into account the isotopic ages from the lower levels, this change can be correlated with the beginning of the eustatic 2nd order cycle TB3 (Haq *et al.*, 1987).

The lowermost level at Praia da Rocha (Fig. 4) is a conglomerate with phosphatic clasts and glauconite. *Ostrea* shells gave a $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic age of 10.7(+0.8-1.2) Ma (Lower Tortonian).

Fine sands at the Hotel Auramar beach [$^{87}\text{Sr}/^{86}\text{Sr}$ isotopic age 9.5(+1.0-0.5) Ma] are considered correlative of the unit Fine sands and sandstones.

At Praia da Galé, glauconite-rich fine sands allowed K-Ar dating (10.1±0.25 Ma, Lower Tortonian) (Antunes *et al.*, 1984). Boski *et al.* (1995) obtained K-Ar ages from the same region 8,15±0,29 and 7,54±0,27 Ma.

CACELA FORMATION

The uppermost Miocene deposits are well represented in eastern Algarve, but they also outcrop near Lagos (western Algarve).

At Campina de Faro and Quelfes there are fossiliferous carbonate rocks rich in detrital quartz; in some places these deposits grade into microconglomerates (Faro limestones with quartz pebbles and conglomerates). At the upper part of the Auramar Hotel beach there is a lower level of conglomerates with oysters that give a $^{87}\text{Sr}/^{86}\text{Sr}$ age of 8.3(+2.2-3.3) Ma. This is in agreement with the biostratigraphic datation of the lower levels of Cacela river (N16-N17) which begin by a conglomerate directly overlying the Triassic (Fig. 5). The Auramar conglomerate

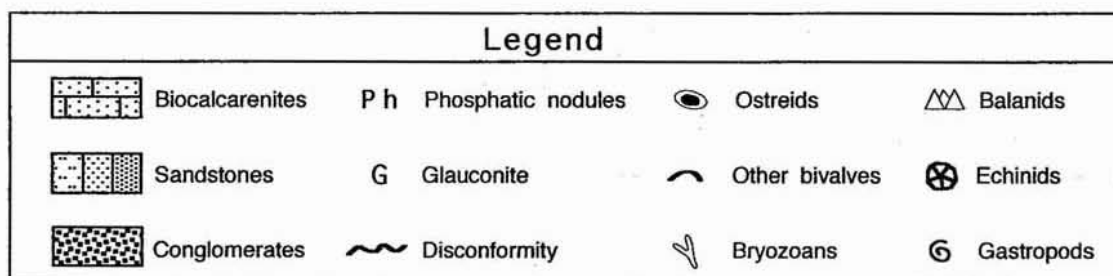


Fig. 2 - Legend of the sections.

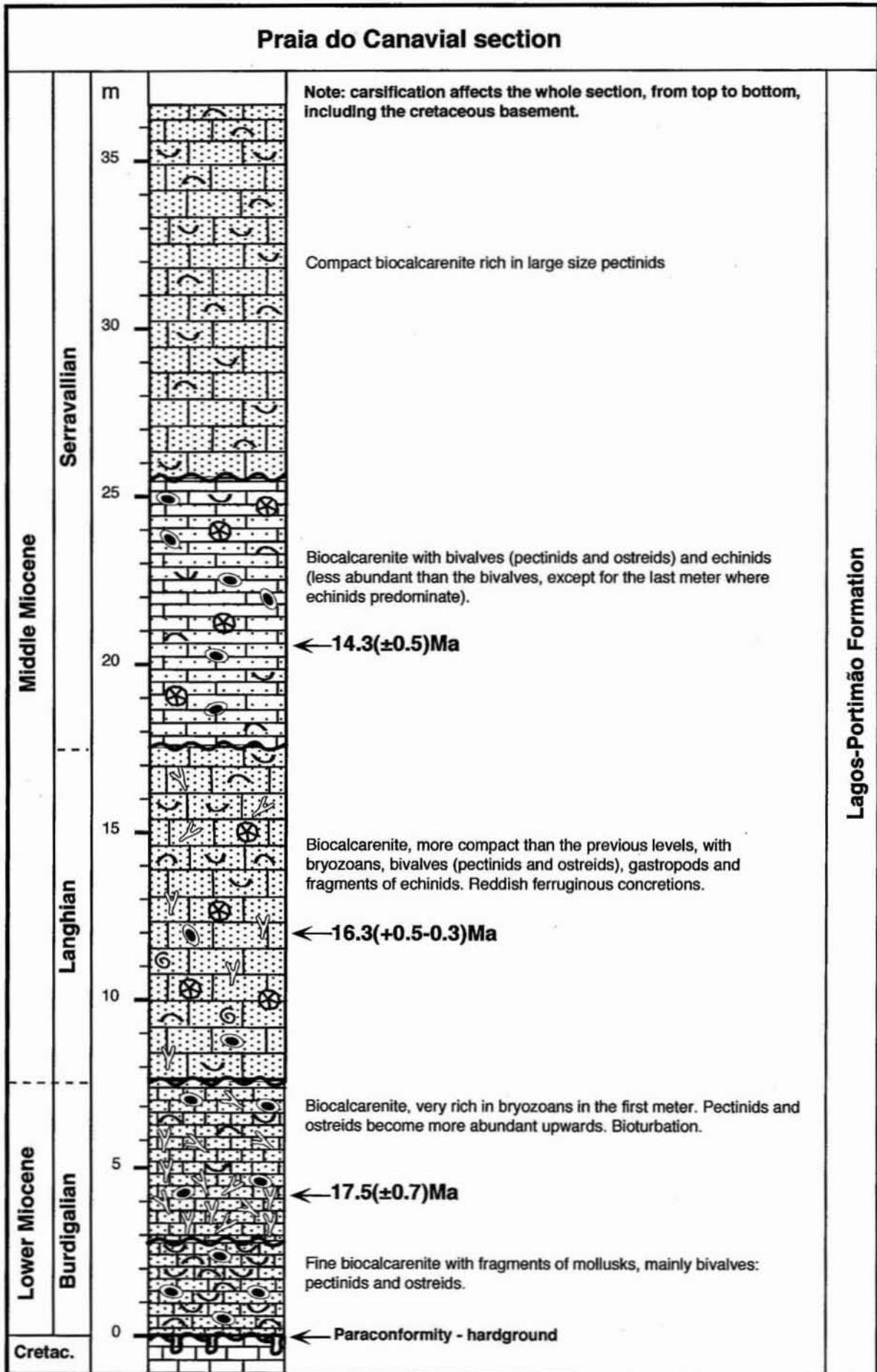


Fig. 3 - Praia do Canavial section (Antunes *et al.*, 1997).

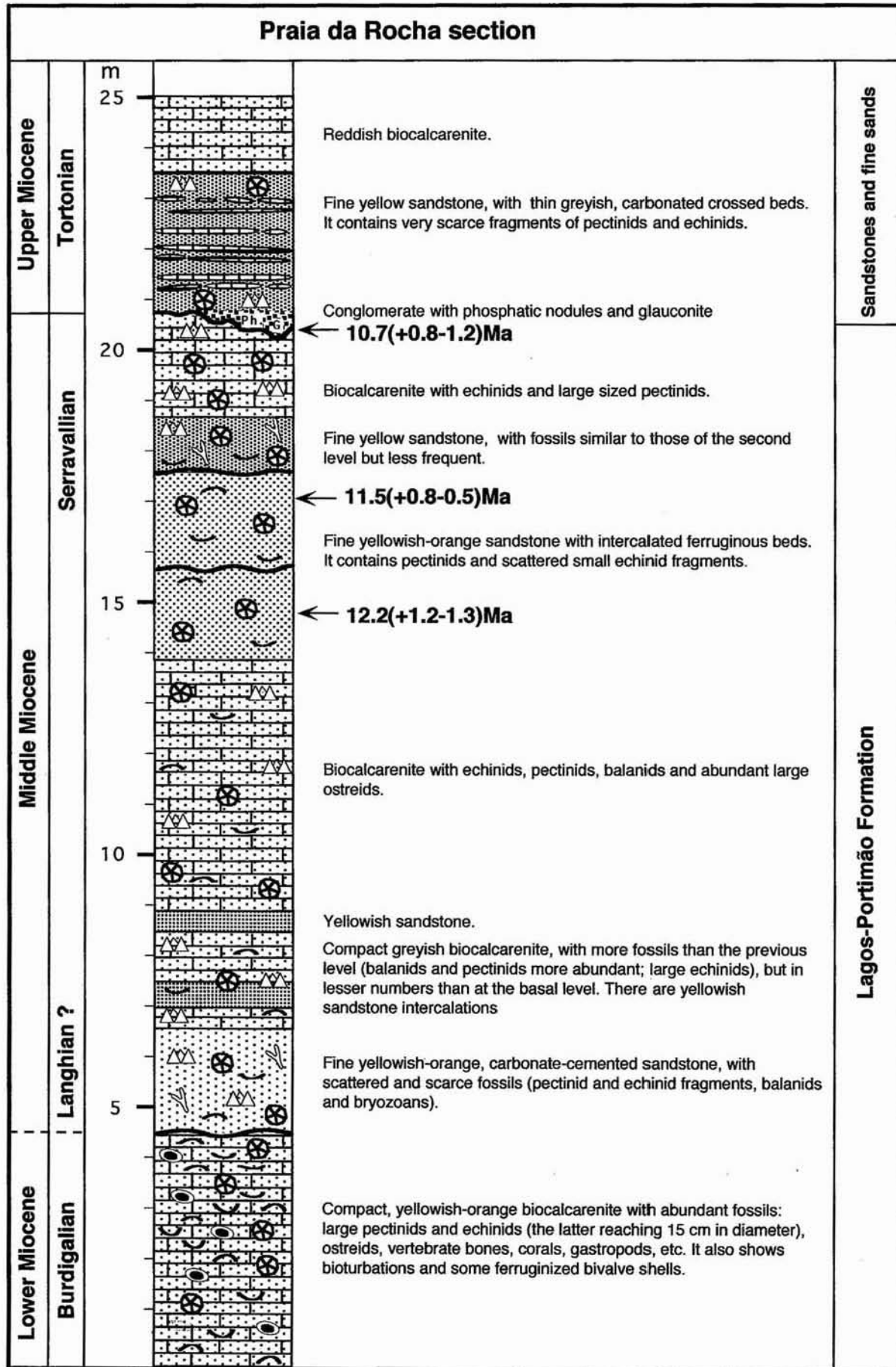


Fig. 4 - Praia da Rocha section (Antunes *et al.*, 1997).

is interpreted here as correlative of the lowermost deposits of Cacela Formation, which comprise mainly yellow, orange, or green glauconite silts.

The lower conglomerates at Cacela (Fig. 5) and the directly overlying silts yielded the richest and best preserved Miocene mollusk fauna in Portugal. This fauna was described by Pereira da Costa (1866, 1867) and Dollfus *et al.* (1903, 1904), and revised by Chavan (1940) and Bourcart & Zbyszewski (1940). *Glycymeris*, *Cardium*, *Megacardita*, *Panopea*, *Pelecypora*, *Callista*, Turritellids, Naticids, and *Conus* are common. There are also some Vertebrata. Among the selacians, *Carcharocles megalodon* has been recorded but no *Carcharodon carcharias* (both species coexist in Pliocene when the latter appears for the first time, this association being known in Southern Spain — Elche, etc.) (inform. of M. T. Antunes). Also, a few previously unreported cetacean remains have been collected long ago at Cacela supposedly from the yellowish silt levels. These consist of vertebrae, rostrum and mandible fragments of large-sized Mysticeti, which are deposited at the Geological and Mining Institute.

Olhos de Água and Cerro das Mós occurrences (referred to elsewhere), are the only localities in Algarve that yielded fossils of marine mammals. Moreover, Cacela is one of the youngest records of marine mammals in Portugal; it is only a little older than the late Messinian remains from the Esbarrondadoiro Formation in Alvalade Basin, Alentejo (Antunes *et al.*, 1986).

As no accurately dated post-lower Tortonian miocene deposits are known in the Lower Tagus Basin (where the remainder of the series is very well represented), the importance of the Cacela record becomes obvious. Foraminifera and Ostracoda [*Aurila* (*Cymbaurila*) *diecci*, *A. gr. semilunata*, *Carinocythereis galilea* and *Nonurocythereis seminulum*] are plentiful.

Planktic foraminifers are suitable for dating: *Globigerina bulloides*, *Globorotalia scitula*, *G. pseudomiocenica*, *G. menardii*, *G. humerosa*, *G. altispira* and *Neogloboquadrina acostaensis* indicate N16-17 zones of Blow (Upper Tortonian-Lower Messinian). The presence of *Spiroplectamina carinata* (a benthic foraminifer) excludes a Messinian age for the lower levels of the Cacela Formation (Antunes *et al.*, 1981; 1990; 1992).

Calcareous nannoplankton from the lower beds include *Discoaster berggrenii*, *Helicosphaera stalis*, *Minylitha convalis* and *Triquetrorhabdulus rugosus* (?) that also point to the same Upper Tortonian age (CN9a zone of Bukry) (Cachão, 1995).

Somewhat higher levels (at Fábrica) yielded calcareous nannoplankton (*Coccolithus pelagicus*, *Reticulofenestra pseudoumbilica*, *R. minuta*, *R. minutula*, *R. haqii*, *Dictyococcites antarcticus*, *Sphenolithus abies*, *S. moriformis*, *Helicosphaera carteri*, *Eudiscoaster surculus*, *E. icarus*, *E. intercalaris*, *E. pseudovariabilis*, *Triquetrorhabdulus rugosus*) and planktic Foraminifera [*Globigerina bulloideus*, *G. apertura*, *G. druryi*, *G. quinqueloba*, *Globigerinoides extremus*, *G. seigliei*, *G. quadrilobatus*, *Globigerinita glutinata*, *Orbulina universa*, *O. suturalis*, *Globoquadrina globosa*, *Globorotalia* (*Hirsutella*) *scitula*, *Neogloboquadrina acostaensis* sin.]

that may be ascribed to Late Tortonian-Messinian (Antunes *et al.*, 1990). Benthic Foraminifera (Bolivinids, Buliminids) indicate oxygen-poor environments (Antunes *et al.*, 1990).

These beds are overlain by silty or fine sand beds in stratigraphical continuity with scarce, poorly preserved fossils including some plant remnants. Upper beds may be Messinian in age.

The middle, also silty, levels of Cacela Formation are rich in glauconite that gave ages of 6.90±0.18 Ma (Galvana), 6.88±0.5 (Quelfes) and 7.03±0.4 Ma (near Luz de Tavira), uppermost Tortonian (Antunes *et al.*, 1984, 1986d; 1990; 1992). ⁸⁷Sr/⁸⁶Sr ages from the Quelfes silts are 5.3(+4.3-0.7); 5.2(+4.4-1.1) and 5.2(+4.4-0.6) Ma (Fig. 7). At Quelfes, above the glauconite level, the occurrence of *Globorotalia menardii* (100% dext.) and *Globorotalia miotumida* (100% sinist.) allow correlation with the event 3 from the Guadalquivir basin (Sierro *et al.*, 1985, 1993, 1996). This event has been correlated with the Tortonian/Messinian boundary. *Globorotalia conomiozea* (FAD7.12 Ma, Messinian) was found at the uppermost levels from Quelfes region.

The upper deposits of the Cacela Formation overlies ferruginous hardground. They correspond to confined marine environments, fossils being scarce and poorly preserved. The age may be Messinian to Lower Pliocene.

‡ GALVANA CONGLOMERATE

The stratigraphic position of the spectacular Galvana conglomerate, with striate blocks exceeding one meter, and interbedded glauconiferous silts (Antunes *et al.*, 1984), is not clear. Glauconiferous silts indicate a K-Ar age of 6.72±0.17 Ma; however, the glauconite may have been reworked from the Campina de Faro silts (Antunes *et al.*, 1984; 1990; 1992).

Conglomerates are related to strong tectonic instability and were probably formed in the sub-marine slopes associated to the Algarve southern flexure. The K-Ar age is compatible with that of the Guadalquivir basin olistostrome, although this is far away and corresponds to South-North sediment mass movements (the Galvana conglomerate has been generated by North-South sediment movements).

Conglomerates overlying glauconitic silts in a borehole at Campina de Faro, may correspond to the Galvana conglomerate. If so, this is younger than the silts and its age could be Messinian or Pliocene.

OLHOS DE ÁGUA SANDS

A thick sand series outcrops near Olhos de Água between the Sandstones with sand waves and the Faro-Quarteira Formation.

The Olhos de Água section originally described by Romariz *et al.* (1979-1980a), was recently revised (Fig. 6). The succession starts by alternating sandy and pelitic layers (flaser facies) overlain by cross-bedded brownish sands and followed by feldspathic, fluviatile white sands. Locally, the brownish sands outcrop in water-eroded

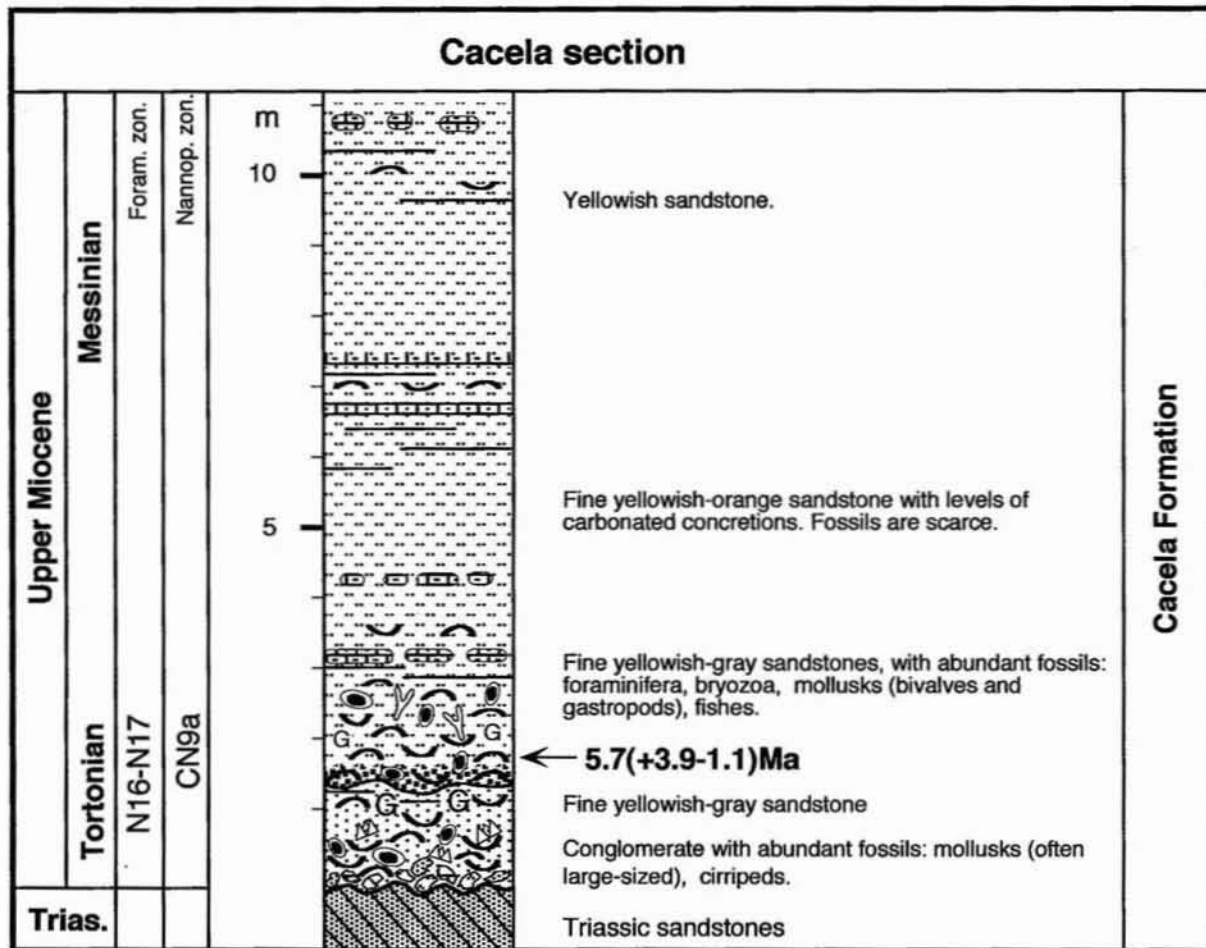


Fig. 5 - Cacela section (Antunes *et al.*, 1997).

gullies and are covered by red pelites. The latter are overlain either by white sands or by the Faro-Quarteira Formation (Quaternary). Over these white fluvial sands there are beach sands and conglomerates with abraded remnants of aquatic Vertebrata (fish vertebrae and teeth, cetacean bones, Sirenian teeth and bones). The majority of the fishes are marine, often very large in size (*Carcharocles megalodon*, *Isurus hastalis*, *Odontaspis cf. taurus*, *Hemipristis serra*, *Carcharhinus* sp.). The degree of abrasion of the vertebrate remnants suggests that they were rolled by waves in shallow, sandy bottoms at a beach. The Sirenians (*Metaxytherium medium*) point out to warm shallow seashore environments, rich in aquatic vegetation (algae, vascular plants). The presence of fish like *Lates*, also frequent in fresh water facies suggests (as well as the feldspathic sands) the existence of a large river whose mouth was quite close by. The presence of large crocodylians as *Tomistoma cf. lusitanica* corroborates these views and indicates tropical to sub-tropical conditions (Antunes, 1979; Antunes *et al.*, 1981; 1990, 1992).

Above these levels there are sands rich in oysters and scarce pectinids — including the rare *Paliolum (Lissochlamys) excisum*. Molluscs indicate estuarine, even brackish environments.

Vertebrata are compatible with a post-Langhian age; they are certainly pre-Pliocene and they may correspond

to the Serravallian or to the Tortonian. The mollusks are not chronologically characteristic. However, *Paliolum (Lissochlamys) excisum* is known both in Upper Miocene and Pliocene (Demarcq, 1979) (it is common in Upper Pliocene in western Portugal). ⁸⁷Sr/⁸⁶Sr age obtained from oysters gave 3.0(+2.5-1.0)Ma. However this value has to be taken cautiously since it corresponds to a brackish environment, with broad errors.

MORGADINHO AND ALGOZ DEPOSITS

This unit comprises thick sandy deposits in association (towards the top) with marls, lignite clays, lacustrine limestone and a silty calcareous crust. This unit is poorly exposed in outcrop, for which most observations have been carried out during the excavation of water wells.

At Morgadinho and Luz de Tavira these sands overly the Cacela Formation and are overlain by the Faro-Quarteira sands, as at Algoz (where the basement is not known).

At Morgadinho, the lignite clays yielded a few small mammals (*Galemys kormosi*, *Prolagus cf. calpensis*, *Mimomys* sp. and Muridae undetermined), freshwater small cyprinid fishes, gastropods, Ostracoda, pollens and spores (including *Anthoceros*, *Ketellaria*, *Pinus*, Cupressaceae and Ericaceae) (Antunes *et al.*, 1986c). The

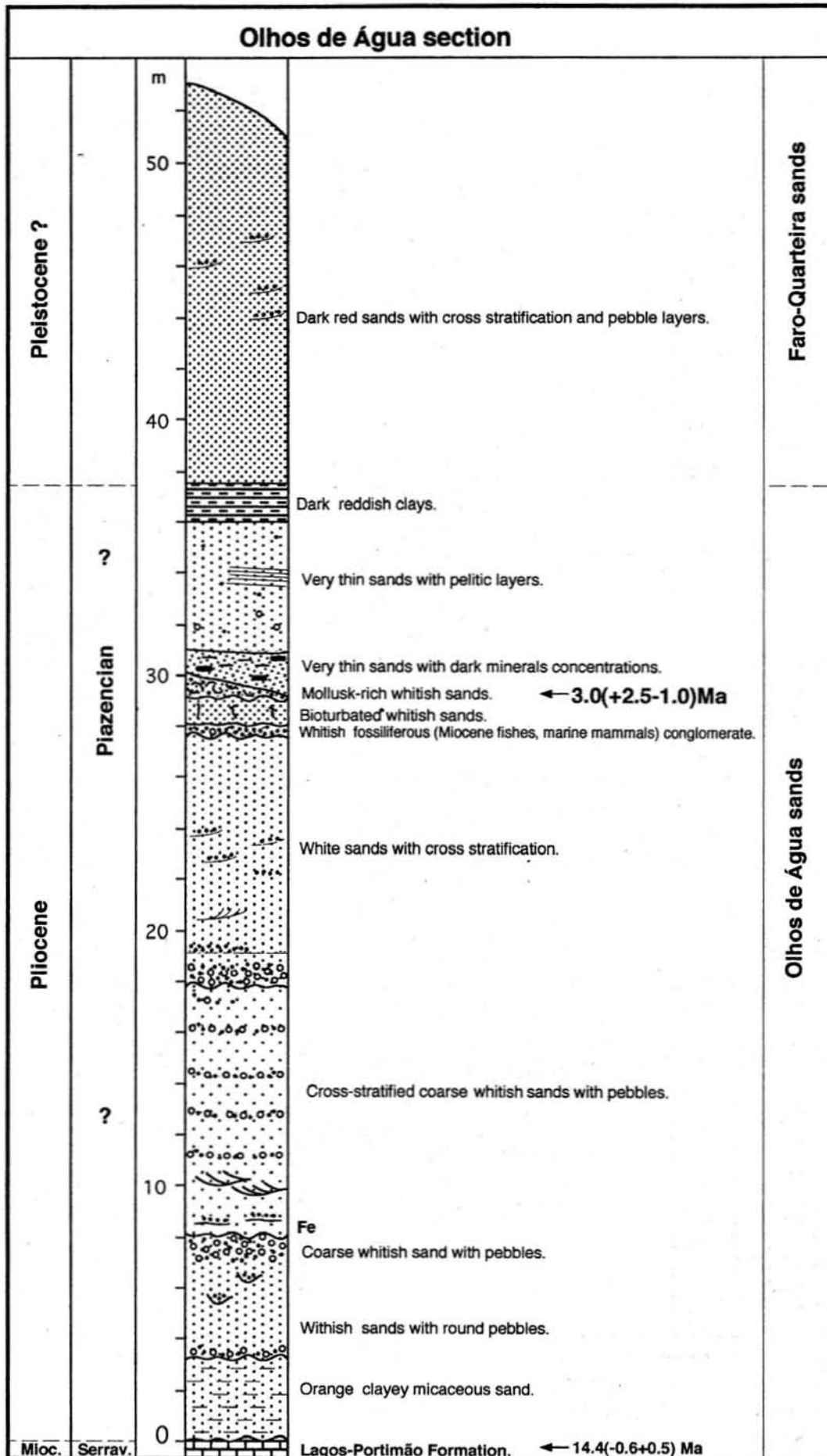


Fig. 6 - Olhos de Água section.

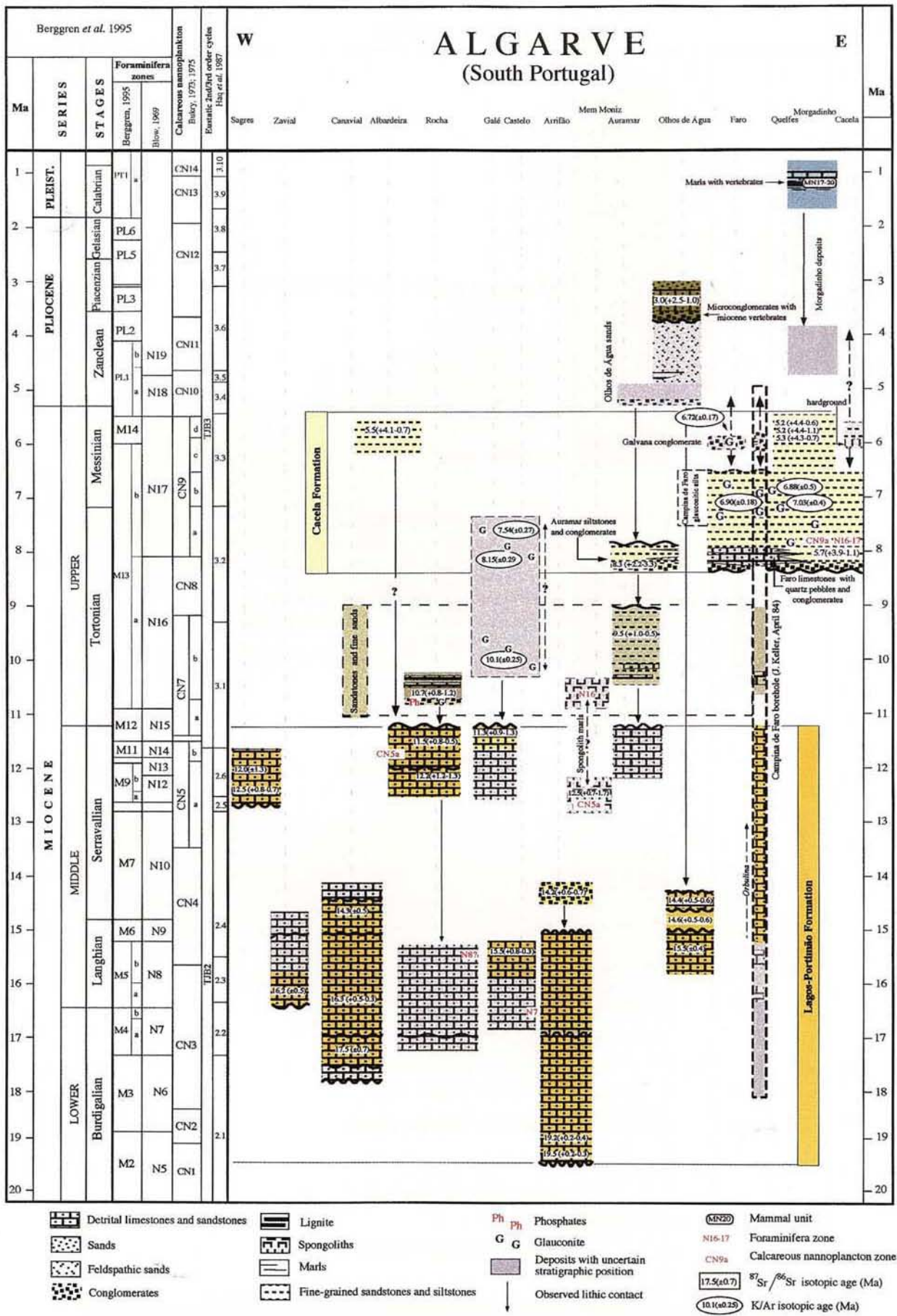


Fig. 7 - Stratigraphic frame of the Algarve Cenozoic .

mammalian fauna indicates an age span between the Upper Pliocene and the lower Middle Pleistocene (MN 17 to MN 20 mammal units).

In the present state of knowledge, Morgadinho and Algoz deposits seem to be correlative. The Algoz mam-

malian fauna [including *Eucladoceros* sp. (*dicranios* or cf. *dicranios*), *Cervus* sp. (? *rhenanus-peyrollensis*), *Hippopotamus antiquus* and *Oryctolagus lacosti*] is rather accurately dated from about 1 Ma, Biharian (Lower Pleistocene) (Antunes *et al.*, 1986a).

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