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High-resolution correlation of coastal cliff sections in the Lagos- Portimão Formation (Lower – Middle Miocene, central Algarve, Portugal)

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ABSTRACT

Keywords: Bed-by-bed correlation; outcrop gamma ray logging; biofacies analysis; Miocene; Algarve; S-Portugal.

This paper describes a high-resolution stratigraphic correlation scheme for the early to middle Miocene Lagos-Portimão Formation of central Algarve, southern Portugal.

The Lagos Portimão-Formation of central Algarve is a 60 m thick package of horizontally bedded siliciclastics and carbonates. The bryozoan and mollusc dominated biofacies is typical of a shallow marine, warm-temperate climatic environment. We define four stratigraphic marker beds based on biofacies, lithology, and gamma-ray signatures. Marker bed 1 is a reddish shell bed composed predominantly of bivalve shells in various stages of fragmentation. Marker bed 2 is a fossiliferous sandstone / sandy rudstone characterized by bryozoan masses. Marker bed 3 is also a fossiliferous sandstone with abundant larger foraminifers and foliate bryozoans. Marker bed 4 is composed of three distinct layers: two fossiliferous sandstones with an intercalated shell bed. The upper sandstone unit displays thickets of the bryozoan *Celleporaria palmata* associated with the coral *Culizia parasitica*.

This stratigraphic framework allows to correlate isolated outcrops within the stratigraphic context of the Lagos-Portimão Formation and to establish high resolution chronostratigraphic Sr-isotopic dating .

RESUMO

Palavras-chave: correlação camada a camada; perfis "gamma ray"; análise de biofácies; Miocénico; Algarve; Portugal.

Apresenta-se um esquema de correlação de alta resolução para o Miocénico inferior da Formação de Lagos-Portimão (Algarve central). Esta Formação é constituída por 60 metros de carbonatos com alguns siliciclásticos. As biofácies de briozoários e de moluscos dominam; são típicas de ambientes marinhos pouco profundos, e de condições climáticas temperadas quentes.

Definem-se 4 marcadores estratigráficos com base nas biofácies, litologia e registos de raios gama. O marcador 1 é constituído por uma bancada avermelhada, muito rica de fragmentos de conchas de moluscos. O marcador 2 é um arenito rico de briozoários. O marcador 3 é, também, um arenito fossilífero, rico de macroforaminíferos e de briozoários foliados. O marcador 4 é composto por 3 camadas: um arenito fossilífero intercalado em dois arenitos. O arenito superior é rico do briozoário *Celleporaria palmata* associado ao coraliário *Culizia parasitica*.

Este quadro estratigráfico permite correlacionar afloramentos isolados no contexto da Formação de Lagos-Portimão e estabelecer ligações com datações isotópicas de Sr conseguidas em diversos cortes da unidade.

INTRODUCTION

The Neogene of Portugal is dominated by terrestrial and shallow marine siliciclastics with minor additions of calcareous sandstone and limestone. Typical examples exist in the Lower Tagus Basin, the Setúbal Peninsula, and the Serra da Arrábida (Antunes *et al.*, 1995, 1997, 1999, 2000; Antunes & Pais, 1993). In contrast, the lower to middle Miocene Lagos-Portimão Formation of Algarve (southern Portugal) is dominated by shallow marine calcareous sandstones and sandy limestones. Between the towns of Lagos to the west and Albufeira to the east, the Lagos-Portimão Formation forms a narrow band parallel to the present-day shoreline. To the north, the Lagos Portimão Formation abuts the Serra do Caldeirão (Fig.1).

The scenic coastal cliffs exhibit a conspicous horizontal bedding formed by an alternation of siliciclastic and calcareous lithologies. The overall low degree of cementation causes a high degree of instability of the cliffs. Biogenic associations are dominated by various bivalves, bryozoans, larger benthic foraminifers and coralline algae with minor additions of echinoids and balanids, which all in all implies a shallow-water depositional system of a warm-temperate climatic regime. Zooxanthellate colonial corals do occur but never in a rock forming abundance or boundstone texture, which suggests a temperate/tropical transitional situation (Forst *et al.*, 1999, 2000; Betzler *et al.*, 1997; James, 1997).

A Burdigalian to Serravallian age for the Lagos-Portimão Formation is well established through biostratigraphic work on marine vertebrates and foraminifers, and stable Sr-isotopic analyses (Antunes *et al.* 1981, 1997).

This paper describes a high resolution correlation framework for coastal cliff outcrops of the central Algarve. Detailed documentation of biofacies and gamma-ray logging allows the recognition of four marker beds and stratigraphic correlation of coastal cliff exposures inbetween the small towns of Carvoeiro to the west and Albufeira to the east. From a total of 14 measured sections, we document here four outcrops which span from the stratigraphically lowest units, close to the contact of the mesozoic basement, to the top of the observed interval of the calcareous Lagos Portimão-Formation. The correlations are important for providing a framework for detailed chronostratigraphic Strontium isotopic calibrations (Antunes *et al.*, 1981, 1997; 2000) and long-term palaeoclimatic reconstructions (Forst, in prep.).

METHODS

Detailed sections were measured in accessible coastal cliffs of Vale Covo, Algar Seco, Leixão do Ladrão and Praia da Galé. In the field, lithologies were described and classified according to sand content, grain-size, fossil content and depositional texture. Beds and layers were traced along the coast by boat and large photographic mosaics. Continuous gamma-ray logging of outcrops followed the methods described by Heckemann & Krämer (1989) and Aigner *et al.* (1995) using a portable ENVIspec GR 320 spectrometer. Measurements were carried out for the total gamma-ray radiation, at equal distances of 14 cm (diameter of the detector) over the complete section.

MEASURED SECTIONS

Vale Covo

The stratigraphically lowermost section described here is Vale Covo (VDC). It is located below Hotel "Almansor" in the vicinity of the village of Carvoeiro. The lowermost part of the section is accessible during low-tide only (Fig. 1, 2).

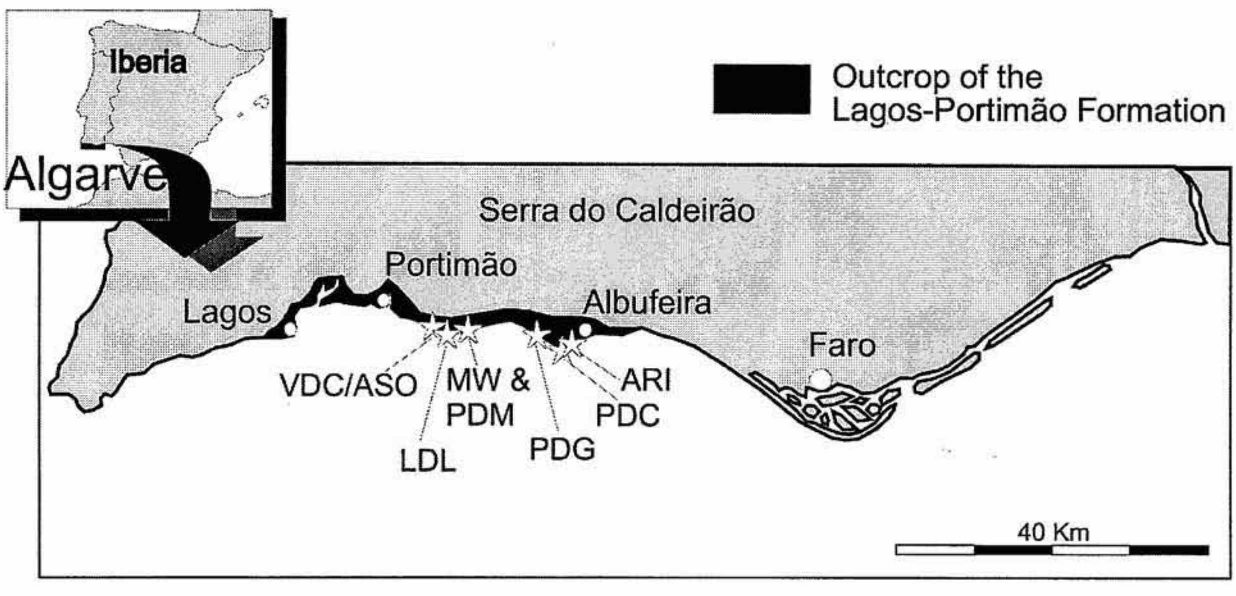

Fig. 1 - Location map of the working area. Outcrops and sections are indicated by stars. VDC: Vale Covo section; ASO: Algar Seco East section; LDL: Leixão do Ladrão section; MW: Praia da Marinha-West; PDM: Praia da Marinha; PDG: Praia da Galé section; PDC: Praia da Coelha; ARI: Praia Arrifes.

The lower part of the section (6 m) consists of fossiliferous carbonate sandstones. Characteristic biota include burrowing bivalves (steinkerns), various echinoids, scattered pectinids and coralline red algae. Larger benthic foraminifers of the *Heterostegina* type occur. This sandstone unit is followed by the most obvious bed of the VDC section, a reddish shell bed of 2 m thickness (marker bed 1). The contact to the underlying units is gradual and rich in rhodolites and pectinid shells. The middle part is dominated by densely packed pectinid shells in various stages of fragmentation. The upper part shows large pectinids and oysters incrusted by balanids. Further faunal elements are gastropod moulds, branched bryozoans and clypeasteroid echinoids. Bioturbation is present throughout the shell bed and thick (5 cm), compartimentalized tubes exist throughout the bed. The top of the shell bed is an erosional surface. Depressions and pockets of the erosional relief are filled with sediment of the overlying unit, a fossiliferous carbonate sandstone. Above this layer a sandy rudstone rich in burrowing bivalves and shell fragments occurs, which is grading into a succesion of fossiliferous sandstone and carbonate sandstone. After a total thickness of 12 m the section ends at the garden fence of the Hotel.

Algar Seco East

The Algar Seco East-section (ASO) is located 100 m to the west of VDC and 250 m to the east of the touristic point Algar Seco, a group of karstholes close to the village of Carvoeiro (Fig. 1, 2).

The base of the ASO section is the upper part of the reddish shell bed in VDC (marker bed 1). It is followed by a succession (20 m) of alternating beds of fossiliferous sandstones and sandy rudstones rich in turritellid gastropods, burrowing bivalves and broken valves of pectinids. The gastropods and burrowing bivalves exist as moulds infilled with orange-red coloured micrite. Several layers contain celleporiform bryozoans and clypeasteroid echinoids. Larger foraminifers ("*Heterostegina*") are common but never abundant. Bioturbation as discrete traces and mottling occurs throughout. A four meter thick shell bed of reddish colour formed by disarticulated and broken pectinid shells, oysters, burrowing bivalves and some celleporiform bryozoans is intercalated with the fossiliferous sandstones below and above. Towards the upper half of the shell bed rhodolites occur. The following unit (2 m in thickness) is represented by fossiliferous sandstone. Most conspicuous is a dense packing of branching to nodular bryozoan colonies (*Calpensia* and celleporids) at the top. The large bryozoan colonies (< 8 cm) are well preserved and typically exhibit a central void interpreted to derive from incrustation of an uncalcified substrate. This unit is prominent in all sections measured to the east of Algar Seco. The unit forms a clearly visible notch in the cliffs which can easily be walked out and traced laterally for 18 km. It represents therefore one of the best marker beds (marker bed 2) of the study area. The bryozoans are dominant in all localities, however, variations in abundance exist. A spectacularly dense packing of bryozoans may be observed at Praia da Marinha (next to the beach restaurant) and Praia de Benagil.

Upsection, very fossiliferous sandstones with intervening beds of sandy lime-rudstone grade into massive limestone composed of various shell materials, rhodolites, bryozoans and clypeasteroids (7 m). Larger benthic foraminifers ("*Heterostegina*"), gastropod molds and balanids are common but never abundant. Marker bed 3 is a fossiliferous sandstone (2.4 m) again forming a distinct notch in the coastal cliff (ASO 27-28). In the ASO section fossil density of marker bed 3 is increasing upward and dominated by abundant blades of foliate bryozoans (5 cm) with minor additions of0 "*Heterostegina*".

The final 5 m of section are heavily encrusted by calcrete but can be indentified as a rather coarse grained carbonate. Apparently at the base it is particulary rich in gastropods and dominated by shells towards the top.

Leixão do Ladrão

The section of Leixão do Ladrão (LDL) is located 400 m to the east of Cabo Carvoeiro lighthouse and next to the hotel complex of Clube Atlântico. The LDL locality is influenced by heavy karstification. Several karst holes and collapsed natural bridges form a narrow embayment, where access to the section is possible (Fig. 1, 2).

The section starts close to sea level with 5 m of fossiliferous sandstone and an intervening bed (45 cm) of rhodolite rudstone at 3 m. Upward the sandstone grades into a calcareous sandstone and sandy limestone with a massive shell bed on top. The latter is composed of pectinids oysters and within the topmost part rhodolites. According to its fossil content, depositional texture, and reddish colour it was identified as the shell bed below marker 2 of ASO section (Fig. 2). Above follows a fossiliferous sandstone (LDL 9) rich in branching bryozoans (*Calpensia* and celleporids). This unit (2 m) forms marker bed 2. As compared to ASO section, bryozoans are more abundant, however, less abundant than in the easternmost sections. Further skeletal elements are broken pectinid and oyster shells, other bryozoans with various growth forms (fenestrate, thick foliate and nodular), and clypeasteroid echinoids. The following 6 m of section are characterized by alternating beds of coarse grained skeletal carbonate (rudstone) and intercalated fossiliferous sandstone. Skeletal particles include bivalve shells and bryozoans. Rhodolites are gradually more common upsection. On top of this stratigraphic interval is a fossiliferous sandstone (2.9 m) with a strong yellow colour and composed of three layers (LDL 16, 17, 18). It has been classified as marker bed 3 of ASO-section. The base shows heavy bioturbation in the form of discrete burrows (essentially *Thallassinoides*). Larger foraminifers ("*Heterostegina*") are very abundant. Foliate bryozoans are gradually more abundant towards the top of the unit and clearly dominate within the uppermost bed. Other common bryozoan growth forms include, massive branching and nodular colonies. Another typical element

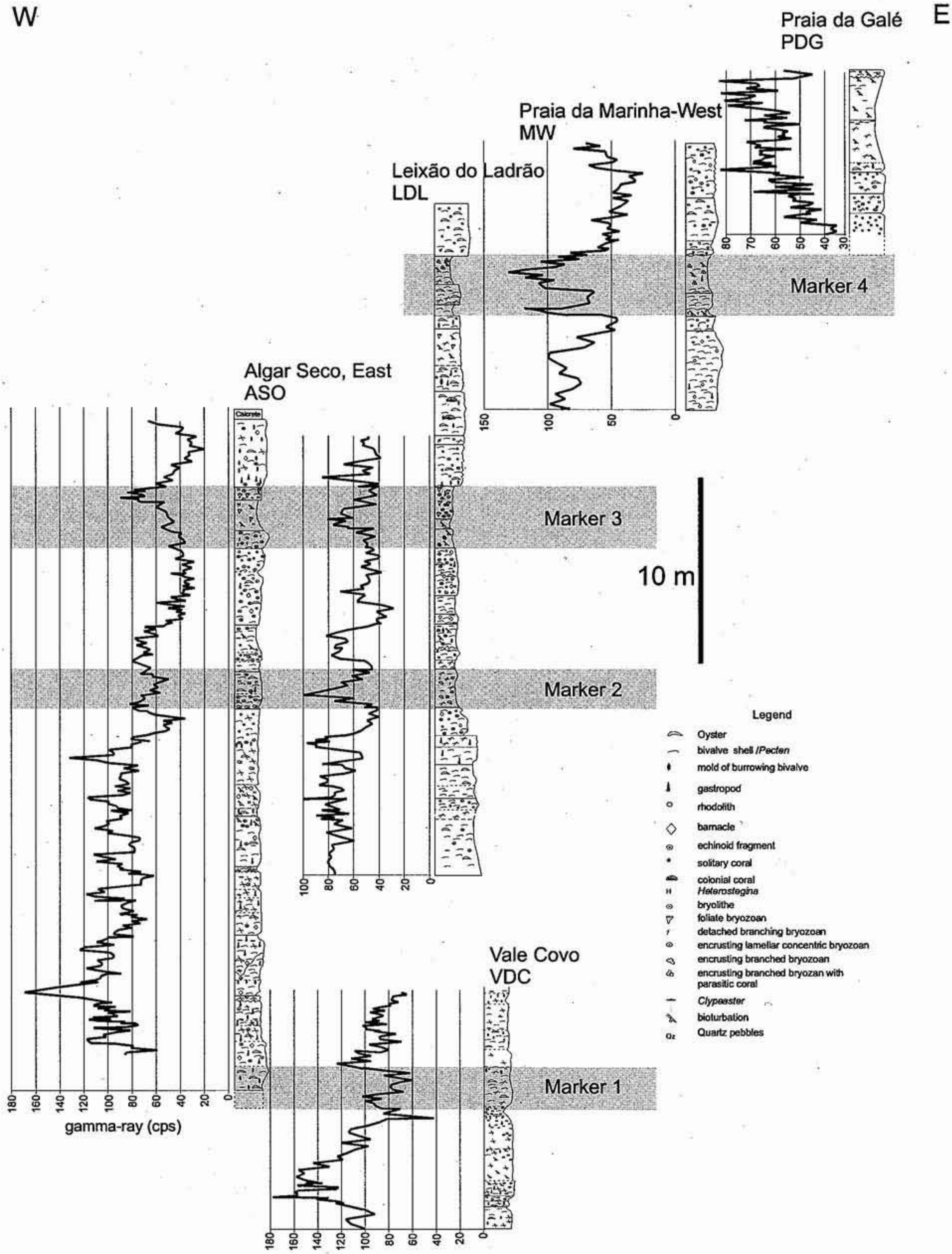

Fig. 2 - Stratigraphic correlation of four sections within the Lagos-Portimão Formation by defined marker beds 1 – 4. Definition of marker beds is based on biofacies and lithology. Gamma-ray logs display total counts per second (cps). MW section (Forst, in prep.) was selected as substitute for the gamma-ray log of the not accessible upper part of LDL section. Scale bar equals 10 m.

for marker bed 3 is the common occurrence of small (< 2cm) irregular echinoids. On top of marker 3 there is a seven meter thick succession of more or less coarse grained carbonates. Bivalve shells and moulds are dominant. Not abundant but common compositional elements are rhodolites, bryozoans, balanids, gastropods and rare solitary corals. Remarkable is the occurence of isolated specimens of the zooxanthellate coral *Tarbellastrea* in bed LDL 21. This coral is known in the Algarve from this particular bed only, which displays zooxanthellate corals best at Praia de Albandeira. In the Neogene of Algarve well preserved specimens of zooxanthellate corals occur as isolated incrustations on mobile oyster shells which represented secondary hardgrounds, but never occur in a reef-building abundance nor in a boundstone texture. This part of the section ends below a doublet of two sandstone beds with an intervening shell bed. The lower bed is a thin bed (50 cm) of fossiliferous sandstone which is grading into a shell bed composed of disarticulated pectinid and oyster shells. In LDL section, the thickness of the shell bed is 90 cm. The shells are of large size and reach diameters over 10 cm. Balanids are common encrusting faunal elements in this bed. The second sandstone bed has a thickness of 1.35 m in LDL. A unique feature of this sandstone bed is the presence of *Celleporaria palmata* thickets (decimetre to metre size). The well preserved bryozoan colonies (size < 10 cm) exhibit a branching growth form and small holes (1.5 mm) which we interpret as traces of the intergrown coral *Culizia parasitica* (cf. Pouyet, 1973; Spjeldnaes & Moisette, 1997). We have never found this particular biozoenosis in any other bed of the Lagos-Portimão Formation. Within the upper part of the sandstone bed there is an increasing number of thallassinoid burrows which are filled with small clasts of rhodolites derived from the overlying unit. Other burrows exhibit the typical meniscus backfill patterns of echinoid trackways. Infaunal irregular echinids and small pectinid shells are common within this layer. The sandstone doublet forms a characteristic sequence of two stacked notches within the coastal cliffs and is the most homogenous marker bed of the Lagos-Portimão Formation (marker bed 4). It is easy to identify by its lithology and skeletal composition. The top of LDL section is a 2 m coarse grained limestone composed mainly of rhodolites and bivalve shells. In thin section some of the rhodolith nuclei display poorly preserved fragments of the coral *Porites*.

Praia da Galé

Praia da Galé-section (PDG) is located at the beach of the village Praia da Galé situated 4.5 km to the east of Armação de Pera and 4.5 km to the west of Albufeira (Fig.1, 2). PDG-section is 8 m thick and can be stratigraphically connected to the top of the LDL section.

A 3.4 m thick limestone package dominated by rhodolites forms the base of the section. Towards the top of the package, there is an increase of sand contents and bivalve shells (pectinids, *Spondylus*). Further skeletal elements of the limestones are nodular celleporiform bryozoans, larger foraminifers ("*Heterostegina*") and Clypeasteroids. The sandy rudstone grades into a fossiliferous sandstone of 4 m thickness. In the lower part, the sandstone is strongly bioturbated, has broken bivalve shells, rare nodular celleporiform bryozoans and gastropod moulds. Within the middle of the unit, at 2 m, there is a concentration of flat domed clypeasteroids (thickness 40 cm). The sandstones within the upper part of the unit contains few small pectinid shells, local clusters of balanids and fragments of the epifaunal bivalve *Pinna*. An irregular erosion surface forms the base of a grayish sandy rudstone (40 cm) on the top of the section. It contains pectinids, oysters, large balanids, burrowing bivalve molds and clypeaster tests. Quartz pebbles (2 cm) are common.

Tracing the lowermost unit of the section PDG into the outcrops of Praia do Castelo allows connection to the rhodolite-rich units on top of marker bed 4.

DISCUSSION

Biofacies

The skeletal associations of the Lagos-Portimão Formation are of the bryomol – foramol – rhodalgal type, which are generally considered to be typical of cool-water carbonates (James 1997). The almost omnipresent occurrence of larger foraminifers (essentially *Heterostegina*), however, implies warm-temperate temperatures. According to Brachert *et al.* (1996) and Betzler *et al.* (1997) the lower threshold temperature for *Heterostegina* in the present-day Mediterranean is 17°C. Zooxanthellate corals (*Porites*, *Tarbellastrea*) are uncommon and have only been documented within two beds (LDL 21 and 31). These corals occur as isolated incrustations on secondary hardgrounds (oyster shells) only, but never occur in a reef-building abundance or in boundstone textures. Thus, temperatures may have remained below the threshold value for reef growth, which is 20°C for modern oceans (Schlager, 1992, Brachert *et al.*, 1996). Condensed Miocene vertebrate faunas, derived from screen washing of karst sediments, indicate shallow waters of a warm-temperate, but not strictly tropical, milieu, too (Antunes *et al.*, 1981).

Factors other than temperature, controlling growth of corals and bryozoans, can be excluded. Beside rather warm temperatures, biota like zooxanthelate corals and larger benthic foraminiferes need light and well ventilated ocean waters. Fine sediments in suspension reduce penetration of light, therefore coralline red algae and larger benthic foraminiferes would be uncommon in the Lagos-Portimão also. Larger benthic foraminifers use similar light limited symbionts as colonial corals. Furthermore we assume a high energy depositional environment in the temperate to tropic transition zone for the Lagos-Portimão Formation (Forst *et al.*, 1999, 2000; Forst, in prep.), comparable to the West Australian shelf. This implies a well ventilated water column and seafloor, rich in benthic and infaunal biota.

CORRELATIONS

Correlation of coastal cliff sections within the Lagos-Portimão Formation along the Algarve coast between Carvoeiro and Praia da Galé relies on the documentation of four marker beds. These are reddish shell concentrations and certain notches within the cliffs derived from the weathering of the sandstone beds. Tracing of marker beds is possible by walking out the coast and by boat trips.

Marker bed 1 (Fig. 2) is a coarse rudstone of reddish colour mainly consisting of bivalve shells (pectinids and oysters) in various stages of fragmentation. Because of it's low stratigraphic position it rarely crops out above the present day's sea level. Actually it is restricted on the Carvoeiro area between the ASO- and VDC-sections to the beach of Vale de Centianes.

Marker bed 2 (Fig. 2, Tab.1 A) is a fossiliferous sandstone – sandy rudstone of yellowish to brownish colour, particulary rich in branching colonies of the bryozoa *Calpensia* and branching celleporids. They occur in dense masses and make this bed unique in its lithology. The density varies laterally and increases eastwards from the ASO section (20 – 30%) to a maximum density at Praia do Marinha (PDM section; 70%) and slightly decreases to lower concentrations (40 – 50%) at the eastern outcrops (e.g. Praia de Arrifes). The thickness of this unit is rather constant (2 m). This bed can be traced from the ASO section to the easternmost section at Praia de Arrifes. It is apparently not present in the overall sandy sections to the west of Portimão (Antunes *et al.*,1997). These sandy sections may represent the upper half of the Lagos-Portimão Formation, which is in general of a more siliciclastic character. Sr- isotopic dates indicate a similar age of Praia da Rocha and Praia da Galé (Antunes *et al.*, 1997). The sandy western sections might be connected to the sandy top of the PDG section.

Marker bed 3 (Fig. 2, Tab. 1 B) is a fossiliferous sandstone bed of yellow colour. It exhibits lateral variations in facies and thickness. The base of the sandstone exhibits strong bioturbation in most outcrops. Upsection of the bioturbated interval, mass occurrences of larger foraminifers ("*Heterostegina*") occur, some of which reach diameters of 2 – 3 cm. The topmost interval of marker 3 is characterized by the predominance of bryozoans, dominated by foliate growth forms (ASO-section) with minor additions of celleporiform and fenestrate colonies (LDL-section). The bed can be clearly traced from the Carvoeiro region to the east to Praia da Coelha, where a lateral lithologic change takes place. The thickness of this unit reaches it's maximum in the LDL section (2.9 m). Whereas in the ASO section a thickness of 2.4 m is recorded. East of LDL section a continuous decrease of thickness is recorded until the unit wedges out east of the outcrop of Praia da Coelha. As for marker bed 1 the western sandy sections are in a too high stratigraphic position for marker bed 3. Variations in the fossil density, especially the mass occurences of heterosteginids, are very inhomogenous. LDL section shows a very high density of heterosteginids (> 50%), whereas ASO section definitely is below 50%. At other localities density varies also, but no continuous decreasing pattern can be observed. Similar observations can be made for the bryozoans.

Marker bed 4 (Fig. 2, Tab. 1 C) is composed as a triplet of two sandstone layers and a intercalated limestone bed. The double notch appearance and the faunal composition of the upper sandstone bed makes this bed easy to identify. Thallassinoid burrows filled with sediment particles from the overlying unit (rhodolite fragments) and the presence of the branching celleporiform bryozoan *Celleporaria palmata* which is associated with the parasitic coral *Culizia parasitica* make this bed unique within the Lagos-Portimão Formation. Thickness of the upper sandstone unit with the *Celleporaria* thickets increases continuously from 1.4 m at LDL section to 2.7 m at the easternmost outcrop of marker bed 4 in Praia de São Rafael. Simultaneously the intercalated shell bed decreases from 0.9 m at LDL section to 0.4 m at Praia de São Rafael. The lower sandstone unit does not show a continuous trend in thickness and varies between 0.4 m to 1.0 m at the various outcrops. Due to the stratigraphically high position of marker bed 4 within the Lagos-Portimão Formation, it has been erosionally removed during younger events of peneplanation over wide areas of the Algarve coast.

Continuous gamma-ray logging of outcrops provides an additional information for the correlation of stratigraphic sections. Fig. 2 shows the results for total counts per second (cps) measured at equal distances of 14 cm (diametre of the detector). In ASO- and LDL-sections the patterns of change are very similar, although local variations exist. For the reason of difficult access with the spectrometer equipment, we could not produce gamma-ray curves for the lowest part of ASO-section and the upper part of LDL-section respectively. Fig. 2 therefore shows the gamma-ray log of MW-section (Praia da Marinha-West; Forst, in prep.) for marker bed 4. Praia da Marinha-West section (MW) correlates with the upper part of the LDL section, whereas the Praia da Marinha section (PDM) correlates with the lower part of LDL.

Praia da Galé-section (PDG) is a rather isolated outcrop in eastern part of the study area. According to the system of marker beds presented here, however, it is possible to demonstrate that it is indeed located within the uppermost Lagos-Portimão Formation of eastern Algarve (Fig. 2). Sr-isotopic ages of 11,3 (+0.9-1.3) Ma for Praia da Galé presented by Antunes *et al.* (1997) therefore give a minimum age for the Lagos-Portimão Formation.

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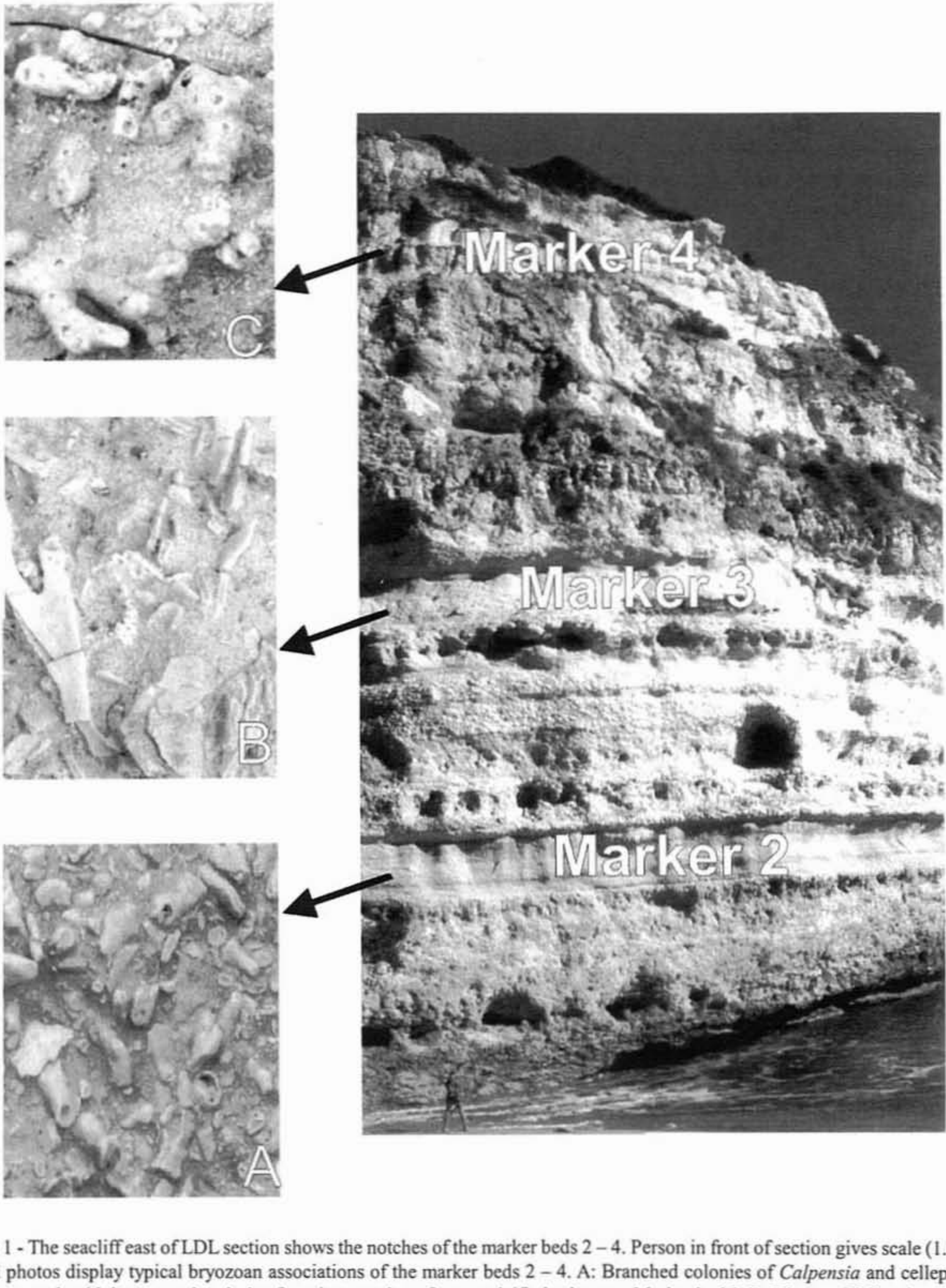

Table 1 - The seacliff east of LDL section shows the notches of the marker beds 2 – 4. Person in front of section gives scale (1.8 m). Small photos display typical bryozoan associations of the marker beds 2 – 4. A: Branched colonies of *Calpensia* and celleporids with a central void, interpreted to derive from incrustation of an uncalcified substrate; Marker bed 2. B: Blades of foliate bryozoans from the top of marker bed 3. C: Detail from thicket of branched *Celleporaria palmata* colonies. Arrow indicates small holes, interpreted to derive from the coral *Culizia parasitica*; upper unit of marker bed 4.

REFERENCES

Aigner, T., Schauer, M., Junghans, W.-D. & Reinhard, L. (1995) - Outcrop gamma-ray logging and its applications: Examples from the German Triassic. *Sedimentary Geology*, 100: 47-61.

Antunes, M.T., Bizon, G., Nascimento, A. & Pais, J. (1981) - Nouvelles données sur la datation des dépots miocènes de l'Algarve (Portugal), et l'évolution géologique regionale. *Ciências da Terra (UNL)*, Lisboa, 6: 153 – 168.

Antunes, M.T., Jonet, S. & Nascimento, A. (1981) - Vertébrés (crocodiliens, poissons) du Miocène marin de l'Algarve occidentale. *Ciências da Terra (UNL)*, Lisboa, 6: 9 – 38.

Antunes, M.T. & Pais, J. (1993) - The Neogene of Portugal. *Ciências da Terra (UNL)*, Lisboa, 12: 7 – 22.

Antunes, M.T., Elderfield, H., Legoinha, P. & Pais, J. (1995) - Datações isotópicas com Sr do Miocénico do flanco sul da Serra da Arrábida. *Comun. Inst. Geol. e Mineiro*, Lisboa, 81: 73 – 78.

Antunes, M.T., Elderfield, H., Legoinha, P. & Pais, J. (1997) - The Neogene of Algarve. *In* González Delgado, J.A. *et al.* (1997): Field Trip Guide, The Guadalquivir Basin and Algarve (Spain, Portugal). Second Congress R.C.A.N.S., Salamanca, pp.37 – 55.

Antunes, M.T., Elderfield, H., Legoinha, P., Nascimento, A. & Pais, J. (1999) - A stratigraphic framework for the Miocene from the lower Tagus Basin (Lisbon, Setúbal Peninsula, Portugal) Depositional sequences, biostratigraphy and isotopic ages.- *Rev.Soc.Geol.España*, Madrid, 12(1): 3 – 15.

Antunes, M.T., Azevedo, M.T., Estevens, M., González-Delgado, J.A., Legoinha, P., Pais, J., Pimentel, N. & Sousa, L. (2000) - *Field Trip Guide, Cenozoic of Setúbal Peninsula.* 1° Congresso sobre o Cenozóico de Portugal, Monte de Caparica, 57 pp.

Antunes, M.T.; Pais, J.; Legoinha, P.; Elderfield, H.; Sousa, L. & Estevens, M. (2000) - The Neogene of Algarve (Portugal). *1° Congresso sobre o Cenozóico de Portugal*, Monte de Caparica, pp. 235-246, 7 figs.

Betzler, C., Brachert, T.C., Braga, J.-C. & Martin, J.M. (1997) - Nearshore, temperate, carbonate depositional systems (lower Tortonian, Agua Amarga Basin, southern Spain): implications for carbonate sequence stratigraphy. *Sedimentary Geology*, 113: 27 – 53.

Brachert, T.C., Betzler, C., Braga, J.C. & Martin, J.M. (1996) - Record of climatic change in neritic carbonates: turnover in biogenic associations and depositional modes (Late Miocene, southern Spain). *Geologische Rundschau*, 85: 327 – 337.

Forst, M.H. & Brachert, T.C. (1999) - Sedimentologie und Paläoökologie einer nichttropischen Hochenergieküste: Geologische Signatur von Klima- und Meeresspiegelschwankungen (Unter- bis Mittelmiozän, Portugal). *Terra Nostra*, 99 (4): 61 – 62.

Forst, M.H., Brachert, T.C., Pais, J. & Legoinha, P. (2000) - Sedimentology and paleoecology of a temperate high-energy shelf, Signatures of climate and sea level (Early and Middle Miocene, Algarve, Portugal). 1° Congresso sobre o Cenozóico de Portugal, Monte de Caparica, Abstracts, p.247.

Forst, M.H. (in prep.) - *Sequenzstratigraphische Architektur, Biofazies und klimatische Signaturen eines unter - mittelmiozänen Hochenergie-Schelfs (Algarve, S-Portugal).* Unpublished Dissertation Thesis, University of Mainz.

Heckemann, W. & Krämer, F. (1989) - Radiometrie und Sedimentationscharakteristik der Trifels-Schichten (sT) im Raum Wilgartswiesen (Pfälzer-Wald). *Oberrheinische Geol. Abh.*, 35: 245 – 257.

James, N.P. (1997) - The cool-water carbonate depositional realm. *In*: James, N.P. & Clarke, J.A.D (eds.) - Cool water carbonates.- *SEPM Special Publication*, 56: 1 – 23.

Pouyet, S. (1973) - Révision systématique des Cellépores (Bryozoa, Cheilostomata) et des espèces fossiles européenes. Analyse de quelques populations à Cellépores dans le néogène du Bassin Rhodanien. *Docum. Lab. Géol. Fac. Sci. Lyon*, 55, 263 pp.

Schlager, W. (1992) - *Sedimentology and sequence stratigraphy of reefs and carbonate platforms.* AAPG, Continuing Education Course Notes Series, 34, 71 pp.

Spjeldnaes, N. & Moisette, P. (1997) - Celleporid (bryozoan) thickets from the upper Pliocene of the island of Rhodes, Greece. *In*: James, N.P. & Clarke, J.A.D (eds.) - Cool water carbonates. *SEPM Special Publication*, 56: 263 – 270.

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Ciclicidad estacional en perfiles de isótopos de C y O de *Megacardita jouanneti* del Tortoniense superior de Cacela (Algarve, Portugal) y Arroyo Trujillo (Sevilla, España)

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ABSTRACT

Keywords: C and O isotopes; *Megacardita jouanneti* profiles; Tortonian; Guadalquivir Basin.

Two C and O isotopic profiles of the bivalve *Megacardita jouanneti* from the Upper Tortonian of Cacela (Portugal) and Arroyo Trujillo (Spain) (Guadalquivir Basin) are studied. They include 57 samples drilled from the umbonal to ventral margin. The cyclic organisation is best in the O profile of the Arroyo Trujillo shell. Isotopic values are similar in both profiles, with the same mean values (0,6-0,5), althought oxygen values range is higher (2,15δ) in the Cacela bivalve than in that of the Arroyo Trujillo one (1,17δ). This could be related with a higher anual range of temperatures in Cacela than in Arroyo Trujillo.

RESUMEN

Palavras-chave: Isótopos de C y O; *Megacardita jouanneti* profiles; Tortoniense; Cuenca del Guadalquivir.

Se estudian dos perfiles isotópicos de C y O realizados en el bivalvo *Megacardita jouanneti* del Tortoniense superior de Cacela (Portugal) y Arroyo Trujillo (Sevilla), ambos de la Cuenca del Guadalquivir. Se han tomado 57 muestras en sentido umbo-paleal. La ciclicidad observada es mejor en el perfil del Oxígeno de Arroyo Trujillo. Los resultados isotópicos del O son similares en ambos bivalvos, con la misma media (0,6-0,5), aunque el rango es mayor en Cacela (2,15δ) que en Arroyo Trujillo (1,17δ), lo que puede relacionarse con un rango de temperaturas anual mayor en Cacela.

INTRODUCCIÓN

Los estudios de perfiles de isótopos estables de C y O realizados en conchas moluscos marinos del Terciario y Cuaternario han sido ampliamente utilizados en paleontología para interpretación de paleoambientes (Rye & Sommer, 1980; Krantz *et al.*, 1987; Andreasson & Schmitz, 1996), ya que permiten interpretar cambios intra-anuales producidos durante la vida del molusco y registrados en su concha. En España estos estudios han sido realizados en niveles cuaternarios de Baleares y Canarias (Cornu *et al.*, 1993; González Delgado *et al.*, 1998), y en gasterópodos prehistóricos de Cantabria (Bailey *et al.*, 1983). Los resultados que aquí se presentan son los primeros realizados en el Neógeno de la Península Ibérica, y se han obtenido a partir de dos ejemplares del bivalvo *Megacardita jouanneti* procedentes de dos yacimientos de la misma edad (Tortoniense superior), clásicos en la bibliografía malacológica por su abundancia en Moluscos: Cacela (Algarve, Portugal), coordenadas N 37° 9' 48" / W 7° 32' 50", y Arroyo Trujillo (Sevilla, España), coordenadas N 37° 37' 54" / W 5° 47' 34" (Fig. 1).

Los yacimientos de los que procede el material estudiado son muy ricos en malacofauna [González Delgado *et al.*, (1995) citan 154 especies de moluscos en Cacela, y 92 en Arroyo Trujillo]. Se encuentran encuadrados en el borde occidental de la Cuenca del Guadalquivir, y corresponden a facies detríticas del cortejo sedimentario transgresivo (Transgressive systems tract) basal de la secuencia deposicional "B" definida por Sierro *et al.* (1996) para la Cuenca del Guadalquivir,

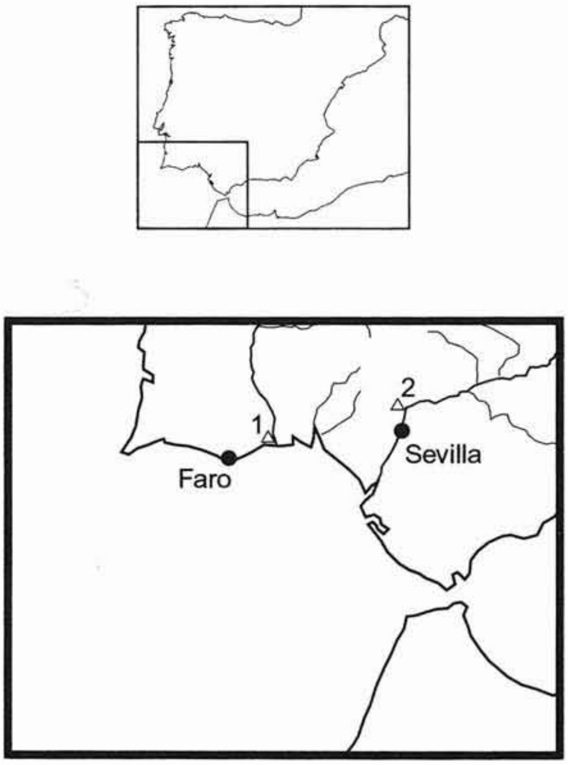

Fig. 1 - Situación de los yacimientos de procedencia de *Megacardita jouanetti*. 1: Cacela, 2: Arroyo Trujillo.

correlacionada con el ciclo eustático 3.2 de Haq *et al.*, (1987) (González Delgado *et al.*, 1995).

Las características tafonómicas y paleoecológicas de los Moluscos reflejan un ambiente sedimentario correspondiente a un medio marino de plataforma siliciclástica interna, somera, sometido a la acción del oleaje de tormentas (González Delgado *et al.*, 1995).

MATERIAL Y MÉTODOS

Se han escogido para los análisis isotópicos dos ejemplares del bivalvo *Megacardita jouanneti* (Fig. 2), cuya concha es de composición aragonítica. La preservación es excelente, ya que la observación de las valvas al binocular permite apreciar que conservan en el ectostraco la microestructura original: lamelar cruzada simple, con disposición radial de láminas primarias (Taylor *et al.*, 1973). Las especies de este género no tienen representantes actuales en los que se hayan podido realizar estudios isotópicos. No obstante, una especie viviente de un género muy próximo, *Venericardia purpurata*, perteneciente a la misma subfamilia Venericardiinae, infaunal somera, ha sido ya objeto de estudios isotópicos, si bien limitados al conjunto de la concha (Stevens & Vella, 1981). Andreasson & Schmitz (1996) utilizan perfiles isotópicos de*Venericardia imbricata* en su estudio paleoclimático del Eoceno de la Cuenca de Paris. De todas formas, los perfiles isotópicos obtenidos (Figs. 3, 4) son la mejor evidencia de conchas inalteradas por fosildiagénesis.

Las muestras fueron tomadas realizando una incisión en el ectostraco paralela a las líneas de crecimiento, siguiendo el diámetro umbo-paleal (Fig. 2). Se ha utilizado un microtorno dental, con una broca de 1 mm. El carbonato así obtenido se calentó a 400° C en vacío durante 2 horas, para eliminar la posible materia orgánica, y después fue analizado en un espectrómetro modelo Sira II (VG), del

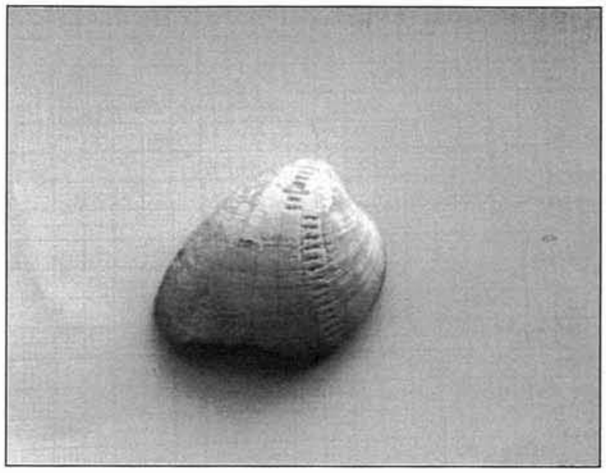

Fig. 2 - Muestreo a lo largo del diámetro umbo-paleal en la concha de *Megacardita jouanetti* de Arroyo Trujillo.

Servicio de Isótopos estables de la Universidad de Salamanca. Todos los datos se refieren a la desviación por mil con respecto al standard PDB. El error cometido es de ±0,056δ para el $\delta^{13}C$, y ±0,101δ para el $\delta^{18}O$.

RESULTADOS Y DISCUSIÓN

Se han analizado 27 muestras en el ejemplar procedente de Cacela, y 30 en el de Arroyo Trujillo. Los resultados isotópicos están indicados en la Tabla 1, y su distribución gráfica se aprecia en las figs. 3 y 4.

Se observa una ciclicidad bien marcada en la curva isotópica del Oxígeno del ejemplar de Arroyo Trujillo (Fig. 4), y menos clara en el de Cacela (Fig. 3). En ambos casos se aprecian variaciones en la señal isotópica, que interpretamos como variaciones estacionales. Las dos curvas isotópicas presentan pequeñas variaciones, reflejadas más en el rango que en los valores medios. La media aritmética de $\delta^{18}O$ para el bivalvo de Cacela es de 0,6δ, y la del de Arroyo Trujillo de 0,5δ. El rango es mayor en Cacela, donde la señal oscila entre 1,31 y -0,84δ (rango 2,15δ), que con respecto a Arroyo Trujillo, en el que la señal varía entre 0,99 y -0,17δ (rango de 1,17δ).

La señal isotópica del Oxígeno, al considerar dos individuos de la misma especie, edad y ambiente sedimentario cabe esperar que esté influenciada fundamentalmente por la temperatura. La salinidad, que en ambientes marinos de transición influye también sobre el resultado isotópico, parece que fue en ambos

Tabla I - Valores isotópicos de C y O en los bivalvos de Cacela (CA) y Arroyo Trujillo (AT).

Muestra	$\delta^{13}C(PDB)$	$\delta^{18}O(PDB)$	distancia (mm) al borde paleal
AT-1-MJ	1,269	0,36	1
AT-2-MJ	1,048	0,785	3
AT-3-MJ	1,476	0,854	5
AT-4-MJ	1,786	0,726	7
AT-5-MJ	1,624	0,776	10
AT-6-MJ	2,16	0,734	13
AT-7-MJ	1,771	0,719	16
AT-8-MJ	1,911	0,084	18
AT-9-MJ	1,939	0,947	20
AT-10-MJ	1,664	0,63	22
AT-11-MJ	2,22	0,751	24
AT-12-MJ	1,671	0,335	27
AT-13-MJ	1,47	0,469	30
AT-14-MJ	1,82	0,637	33
AT-15-MJ	1,843	0,094	36
AT-16-MJ	1,6	0,746	39
AT-17-MJ	1,586	0,997	42
AT-18-MJ	1,706	0,504	45
AT-19-MJ	1,741	0,145	48
AT-20-MJ	1,473	-0,018	50
AT-21-MJ	1,372	0,492	52
AT-22-MJ	1,409	0,69	55
AT-23-MJ	1,699	0,774	58
AT-24-MJ	1,798	0,098	60
AT-25-MJ	1,58	0,288	62
AT-26-MJ	1,405	0,664	65
AT-27-MJ	1,357	0,379	68
AT-28-MJ	1,49	0,24	71
AT-29-MJ	1,49	-0,17	76
AT-30-MJ	1,331	0,147	82

CA-1-MJ	1,535	1,240	1
CA-2-MJ	1,913	1,312	3
CA-3-MJ	1,559	1,147	6
CA-4-MJ	1,681	1,247	8
CA-5-MJ	1,439	0,935	10
CA-6-MJ	1,602	0,94	12
CA-7-MJ	1,625	0,829	15
CA-8-MJ	1,432	0,811	17
CA-9-MJ	1,324	0,675	20
CA-10-MJ	1,104	1,001	22
CA-11-MJ	1,24	0,658	26
CA-12-MJ	1,128	-0,836	29
CA-13-MJ	1,306	0,558	32
CA-14-MJ	1,264	0,516	34
CA-15-MJ	1,242	0,23	48
CA-16-MJ	1,297	0,787	51
CA-17-MJ	1,327	0,973	54
CA-18-MJ	1,21	0,629	57
CA-19-MJ	0,97	0,319	60
CA-20-MJ	0,668	0,718	63
CA-21-MJ	1,119	0,653	66
CA-22-MJ	1,384	0,46	69
CA-23-MJ	0,982	0,279	72
CA-24-MJ	0,839	0,095	76
CA-25-MJ	0,888	0,812	80
CA-26-MJ	0,737	-0,31	83
CA-27-MJ	0,566	-0,546	88

yacimientos muy similar, y muy cercana a la de un ambiente marino normal, ya que la alta diversidad de Moluscos sugiere una salinidad normal, y además están presentes en ambos yacimientos bivalvos y gasterópodos estenohalinos (como *Nuculana fragilis, Acanthocardia paucicostata, Plagiocardium papillosum,* Terébridos, Olívidos) que no toleran bajas salinidades ni ambientes hipersalinos. De todas formas, no puede descartarse alguna influencia de la salinidad en la señal isotópica, como se discute más adelante. En ambos bivalvos, la media aritmética de $\delta^{18}O$ es muy semejante, lo que sugiere que la temperatura media anual del agua sería en ambos yacimientos muy parecida.

Sí han quedado registradas variaciones intra-anuales de la temperatura (diferencias entre verano-invierno) del agua marina en la que vivieron los ejemplares estudiados. Estas diferencias serían mayores (del orden de 9° C) en Cacela, que en Arroyo Trujillo (del orden de 5°C), y podrían interpretarse como debidas a que el yacimiento de Arroyo Trujillo estaba situado en una zona más protegida que el de Cacela, con lo que se explicaría su menor rango en el ciclo anual de temperatura. Sin embargo, las diferencias de la señal isotópica del Oxígeno se refieren sobre todo a que el bivalvo de Cacela alcanza valores isotópicos más ligeros (hasta -0,84 $\delta^{18}O$) que el de Arroyo Trujillo (el valor más ligero es -0,17 $\delta^{18}O$), es decir, veranos más cálidos en Cacela (mar abierto) que en Arroyo Trujillo (ambiente más protegido). Una explicación alternativa puede referirse a una leve (ya que la asociación malacológica no detecta salinidades anormales) influencia de la salinidad. En el bivalvo de Arroyo Trujillo, situado en ambiente más protegido, durante los meses más cálidos, la evaporación sería mayor, y esto haría incrementar el isótopo pesado en el agua, que compensaría en parte la señal más ligera debido a una temperatura mayor. Otra explicación puede deberse a una mayor influencia de aportes continentales en Cacela, que bajaría algo la salinidad y proporcionaría una señal isotópica del Oxígeno más ligera.

Los dos yacimientos se originaron en el Tortoniense superior, formando parte del cortejo transgresivo de una

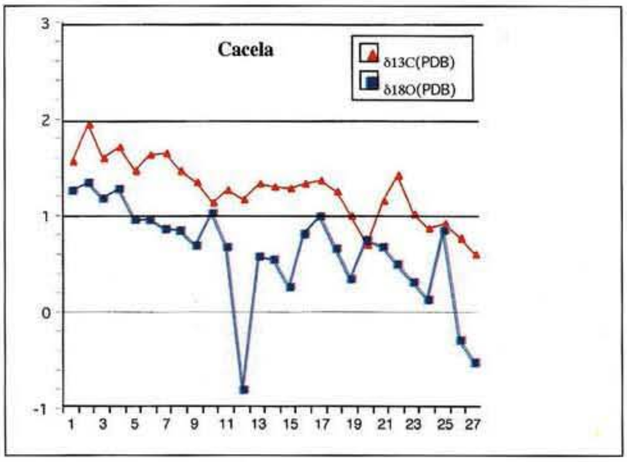

Fig. 3 - Perfiles isotópicos de *Megacardita jouanetti* del yacimiento de Cacela.

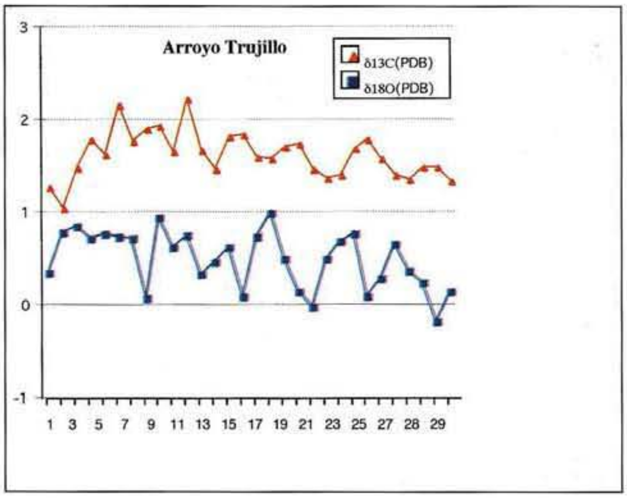

Fig. 4 - Perfiles isotópicos de *Megacardita jouanetti* del yacimiento de Arroyo Trujillo.

subida relativa del nivel del mar (ciclo 3.2) registrada en el Neógeno de la Cuenca del Guadalquivir, con lo que cabe suponer que el clima era cálido. Además ambos yacimientos contienen numerosos moluscos estenotermos cálidos (*Callista italica,* Terébridos, Olívidos). En un contexto de clima cálido, el rango anual de temperatura suele ser pequeño, lo cual corroboraría nuestros datos (aunque para el Luteciense cálido de la Cuenca de París, Andreasson & Schmitz (1996) registran con perfiles isotópicos de *Turritella* y *Venericardia* rangos anuales de 13-14ºC).

En relación a los isótopos del Carbono, los dos perfiles obtenidos (Figs. 3, 4) reflejan poca ciclicidad intra-anual. Los valores isotópicos son en general algo más pesados en el ejemplar de Arroyo Trujillo que en el de Cacela: la media aritmética es de 1,62 y 1,24 respectivamente. El rango de valores del Carbono es similar en ambos bivalvos, si bien algo mayor en Cacela (1,35) que en Arroyo Trujillo (1,17).

Existe una moderada correlación entre la señal isotópica del Carbono y Oxígeno en el bivalvo de Cacela (coeficiente de correlación lineal r de Pearson de 0,68), y muy baja en el de Arroyo Trujillo: r = 0,13

La interpretación de los resultados isotópicos del Carbono es problemática dado que existen muchos factores que influyen en la señal isotópica , unos compensando las diferencias de otros (Wefer & Berger, 1991; Andreasson & Schmitz, 1996). Los valores algo más ligeros registrados en el ejemplar de Cacela quizás pueden estar relacionados con una mayor influencia de aportes continentales que en Arroyo Trujillo. El yacimiento de Cacela comienza litológicamente con conglomerados basales discordantes sobre el Trías, ricos en Moluscos, lo que sugiere también una cierta proximalidad al continente, mientras que el del Arroyo Trujillo está situado en una posición algo más offshore.

CONCLUSION

Los 57 análisis de isótopos estables de C y O realizados sobre 2 ejemplares del bivalvo *Megacardita jouannetti* del Tortoniense superior de los yacimientos de Arroyo Trujillo y Cacela reflejan variaciones estacionales de la señal isotópica, sobre todo la correspondiente al Oxígeno del ejemplar de Arroyo Trujillo. En un paleoambiente de temperatura cálida, se concluye que la media anual de la temperatura de las aguas en las que vivieron ambos bivalvos era similar en ambos yacimientos, y las variaciones de temperatura estacionales fueron pequeñas. Estas variaciones estacionales de temperatura probablemente fueron mayores en Cacela (2,15δ, equivalente a unos 9ºC), que en Arroyo Trujillo (1,17δ, equivalentes a unos 5ºC), o existieron pequeñas diferencias en la salinidad de ambos yacimientos (salinidad algo inferior en Cacela) que produjeron las diferencias en la señal isotópica.

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BIBLIOGRAFÍA

Andreasson, F.P. & Schmitz, B. (1996) - Winter and summer temperatures of the early middle Eocene of France from Turritella $\delta^{18}O$ profiles. *Geology*, 24: 1067-1070.

Bailey, G.N.; Deith, M.R. & Shackleton, N.J. (1983) - Oxygen isotope analysis and seasonality determinations: limits and potential of a new technique. *Amer. Antiquity,* 48: 390-398.

Cornu, S.; Pätzold, J.; Bard, E.; Meco, J. & Cuerda, J. (1993) - Paleotemperature of the last interglacial period based on $\delta^{18}O$ of *Strombus bubonius* from the western Mediterranean Sea. *Palaeogeogr., Palaeoclim., Palaeoecol.,* 103: 1-20.

González Delgado, J.A.; Andrés, I. & Sierro, F.J. (1995) - Late Neogene Molluscan faunas from the NE Atlantic (Portugal, Spain, Morocco). *Geobios* 28: 459-471.

González Delgado, J.A.; Zazo, C.; Goy, J.L.; Hoyos, M.; Civis, J. & Dabrio, C.J. (1998) - Variaciones estacionales en *Strombus bubonius* cuaternarios de Fuerteventura (Islas Canarias) a partir de perfiles de isótopos estables de C y O. *Res. Com. XIV Jorn. Paleontología,* La Laguna: 89-92.

Haq, B.U.; Hardenbol, J. & Vail, P.R. (1987) - Chronology of fluctuating sea levels since the Triassic. *Science*, 235: 1156-1167.

Krantz, D.E.; Williams, D.F. & Jones, D.S. (1987) - Ecological and paleoenvironmental information using stable isotope profiles from living and fossil molluscs. *Palaeogeogr, Palaeoclim. Palaeoecol.* 58: 249-266.

Rye, D.M. & Sommer, M.A. (1980) - Reconstructing paleotemperature and paleosalinity regimes with oxygen isotopes. *In* Rhoads & Lutz (eds.) - Skel. growth aquat. org. Plenum Press: 295-322.

Sierro, F.J.; González Delgado, J.A.; Dabrio, C.J.; Flores, J.A. & Civis, J. (1996) - Late Neogene depositional sequences in the foreland basin of Guadalquivir (SW Spain). *In* P.F.Friend & C.J.Dabrio (eds.) - *Tertiary basins of Spain*. Cambridge Univ. Press: 339-345.

Stevens, K.F. & Vella, P. (1981) - Palaeoclimatic interpretation of stable isotope ratios in Molluscan fossils from Middle Pleistocene marine strata, Wanganui, New Zealand. *Palaeogeogr., Palaeoclim., Palaeoecol.,* 34: 257-265.

Taylor, J.D., Kennedy, W.J. & Hall, A. (1973) - The shell structure and mineralogy of the Bivalvia II. *Bull. British Mus.Nat.Hist* 22: 255-294.

Wefer, G., & Berger, W.H. (1991) - Isotope paleontology: growth and composition of extant calcareous species. *Mar. Geology,* 100: 207-248.