

BENTHIC FORAMINIFER ASSEMBLAGES IN TEMPERATE *CLADOCORA CAESPITOSA* BEARING DEPOSITS (ALMERÍA-NÍJAR BASIN, LATE PLIOCENE, SE SPAIN)

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ABSTRACT

Benthic foraminifer assemblages of Upper Pliocene Unit II of the Almería-Níjar Basin (SE Spain) have been studied. This unit represents a shallowing-upward sequence consisting of siliciclastic sediments with intercalations of *Cladocora caespitosa* coral banks. They were deposited in a shallow sheltered bay where fan deltas prograded. Benthic foraminifer assemblages record the shallowing-upward trend inferred from facies analysis, especially in distal parts of the basin (Rambla Quebrada section). Here, the lower part of the unit contains relatively deep-water species such as *Cibicides refulgens*, *Cibicidoides pseudoungerianus*, *C. bradyi*, *Asterigerinata* spp, *Lobatula lobatula*, *Rosalina globularis*, *Textularia* sp, *Lenticulina calcar* and keeled elphidiis. The upper part of the unit is dominated by very shallow-water species such as *Ammonia* spp and unkeeled elphidiis. The benthic foraminifer assemblages of the lower part further suggest that fully marine waters well-connected with the open sea prevailed, whereas the *Ammonia*-dominated assemblages of the upper part indicate brackish conditions. The continuous advance of the fan-delta systems in a progressively shallower setting accounts for this change in the major assemblage components. The epiphytic species *Elphidium* spp, *Cibicides refulgens*, *Lobatula lobatula*, *Rosalina globularis* and *Asterigerinata* spp dominated in the lower part of the unit. *Posidonia oceanica* meadows probably provided the vegetated substrate in distal areas (Rambla Quebrada section), whereas small, arborescent and short-lived algae dominated in proximal settings (Rambla de la Sepultura section). The relative abundance of epiphytic species decreases considerably upunit as a

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consequence of fan-delta progradation, which led to an increase in water turbidity and a much greater influence of freshwaters. Muddwellers (*Reussella spinulosa* and *Nonion asterizans*) inhabiting soft bottoms dominate in the mid to upper part of the unit. *Canceris auriculus*, *Nonion asterizans*, and *Cassidulina neocarinata* are also locally abundant in the upper part of the unit. These species are usually abundant with high contents of organic matter, adscribable in this case to the advance of the fan deltas and a subsequent increase in nutrients flowing into the basin. Additionally, species coping well in low-oxygen bottoms occur in varve-like laminated sediments in the upper part of the unit: *Bulimina aculeata* and *Fursenkoina acuta*. Minor components of this low-oxygen assemblage are *Bolivina dilatata*, *Bulimina costata*, *B. marginata*, *Cassidulina laevigata*, *Pleurostomella* sp., and *Rectuvigerina multicostata*. This assemblage suggests poor water circulation, probably due to stratification of the water column related with freshwater outflows that caused water layers with different salt concentrations.

Key words: Benthic foraminifers, *Cladocora caespitosa*, epiphytic foraminifers, Late Pliocene, Almería-Níjar Basin, SE Spain.

INTRODUCTION

Benthic foraminifers are cosmopolitan, substrate-dependent organisms. Their distribution is controlled by a number of physical, chemical and biological factors (i.e. Boltovskoy and Wright, 1976; Murray, 1991; Sen Gupta 1999a; Murray, 2006). Many works have focused on local, regional, or global environmental factors that constrain their distribution in present-day oceans (see a recent summary in Murray, 2006). These studies are cornerstone actualistic approaches to understanding the paleoecological factors controlling the distribution of benthic foraminifers in the past and to reconstructing paleoenvironmental conditions (Sen Gupta, 1999a). There is a large amount of research dedicated to analyzing the recent bathymetric distribution of benthic foraminifer assemblages (e.g. van Morkhoven and others, 1986; Lagoe, 1988; van Marle, 1989; Matoba and Fukasawa, 1992; Hayward and others, 2001, 2003; Hayward, 2004), being most studies concentrated in shallow settings (tropical and temperate carbonate and siliciclastic platforms, estuaries, lagoons and bays). These studies provide the framework for paleoenvironmental interpretations.

In the present-day Mediterranean, shallow-water embayments and platform settings are often occupied by extensive banks and thickets formed by *Cladocora caespitosa*. This is an endemic scleractinian ahermatypic coral species and an important carbonate producer in the present-day

Mediterranean (Zibrowius, 1980; Schiller, 1993a, 1993b; Peirano and others, 1998, 1999, 2004). The Upper Pliocene deposits of the Almería-Níjar Basin (SE Spain) formed in a sheltered shallow bay where *Cladocora caespitosa* developed extensive banks (Aguirre and Jiménez, 1998; Aguirre, 1998). These deposits are very rich in benthic foraminifers. To the knowledge of the authors, no detailed study on the benthic foraminifer assemblages associated with present-day *C. caespitosa* banks useful for comparisons with the fossil record has been carried out. Therefore, the study of the Upper Pliocene benthic foraminifer assemblages in the Almería-Níjar Basin will provide new, precise data on the local paleoenvironmental conditions in which this important species of coral developed. The main objectives of this paper are: 1) to document the benthic foraminifer assemblages associated with the *Cladocora caespitosa* coral banks; 2) to analyse the changes in the assemblages during the deposition of the Upper Pliocene sediments in the Almería-Níjar Basin; 3) to determine the key paleoecological factors controlling the distribution and abundance of benthic foraminifer assemblages; and 4) to propose a detailed paleoenvironmental model for the formation of the Upper Pliocene deposits.

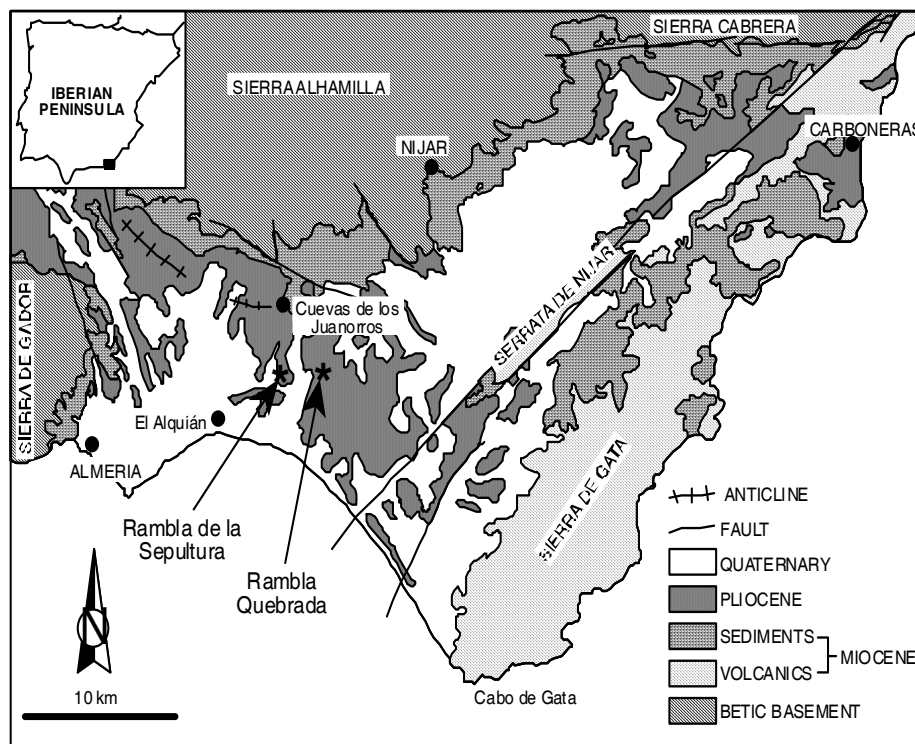


Figure 1. Geological map of the Almería-Níjar Basin showing the location of the two study sections.

GEOGRAPHIC AND GEOLOGICAL SETTING

The study area is located along Rambla de la Sepultura and Rambla Quebrada, two ravines crossing the central part of the Almería-Níjar Basin from the north to the south (Fig. 1). The former

is approximately 3 km NE of El Alquíán, and the latter is near El Acebuche prison.

The Almería-Níjar Basin is a Neogene intermontane basin with a sedimentary record starting with Middle Miocene conglomerates and calcilutites (Serrano, 1990), followed by Upper Miocene and Pliocene marine and continental deposits (Montenat and others, 1990; Aguirre 1998). Beach and alluvial-fan sediments attributed to the Quaternary unconformably overlie the Neogene sediments (Goy and Zazo, 1982).

The Pliocene deposits in the Almería-Níjar Basin can be divided into two unconformable units, Unit I and Unit II from bottom to top (Aguirre, 1998). Unit I, 100-150 m thick, is a shallowing-upward sequence consisting of mixed siliciclastic-carbonate sediments deposited in a delta and a variety of platform settings (Aguirre, 1998). During the deposition of this unit, the Almería-Níjar Basin was a SW-NE elongated gulf opening to the south (Alborán Sea), limited by the Miocene volcanic substrate to the east (Serrata de Níjar-Sierra de Gata system) and by the Betic basement to the north (Sierra Alhamilla and Sierra Cabrera) and to the west (Sierra de Gádor) (Aguirre, 1998; Braga and others, 2003; Martín and others, 2003) (Fig. 2A). The maximum temporal range of this unit is from Early Pliocene at the bottom to Middle Pliocene at the top (Aguirre, 1998).

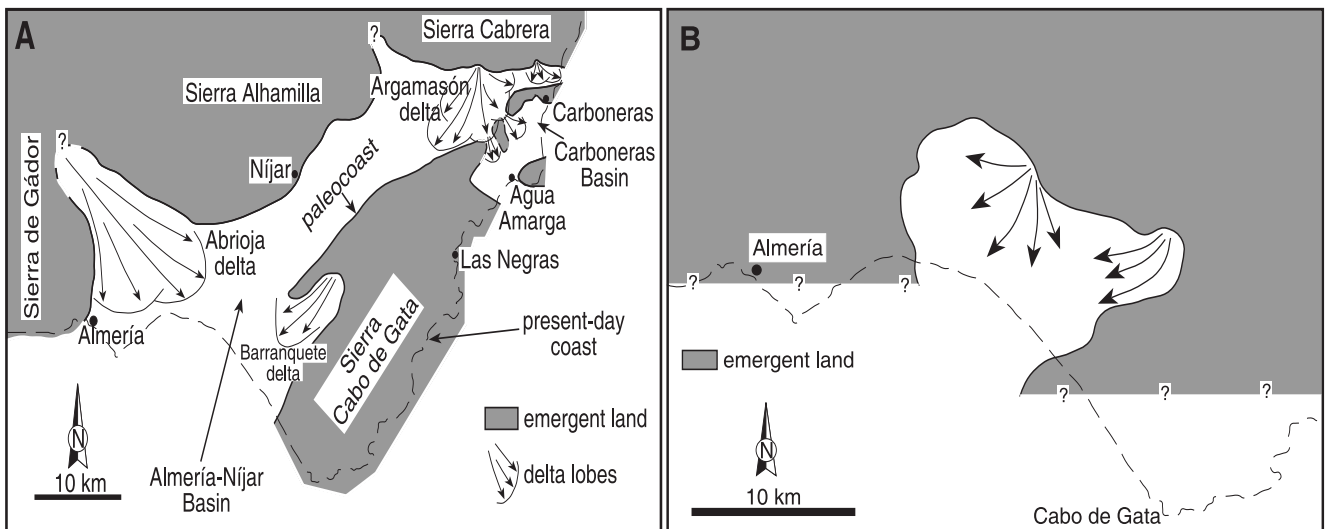


Figure 2. Paleogeographic reconstructions of the Almería-Níjar Basin during the deposition of Unit I (A) and Unit II (B).

Unit II, which is the topic of this study, is Late Pliocene in age (Aguirre, 1998). It unconformably overlies Unit I sediments. Unit II (up to 20 m in thickness) is made up of siliciclastics and *Cladocora caespitosa* coral banks deposited in a sheltered bay open to the south, where fan deltas prograded (Fig. 2B) (Aguirre and Jiménez, 1997, 1998; Aguirre, 1998). Unit II can

be divided into two subunits: a lower subunit made up mainly of siliciclastic deposits (mostly conglomerates and sands) with scattered isolated colonies or small thickets of *Cladocora caespitosa*. The upper subunit consists of an alternation of extensive *C. caespitosa* coral banks and terrigenous sediments (Fig. 3). A detailed description of Unit II has been provided elsewhere (Aguirre and Jiménez, 1997; 1998; Aguirre, 1998) consequently in the section below we describe only the general features of the unit in the two selected outcrops.

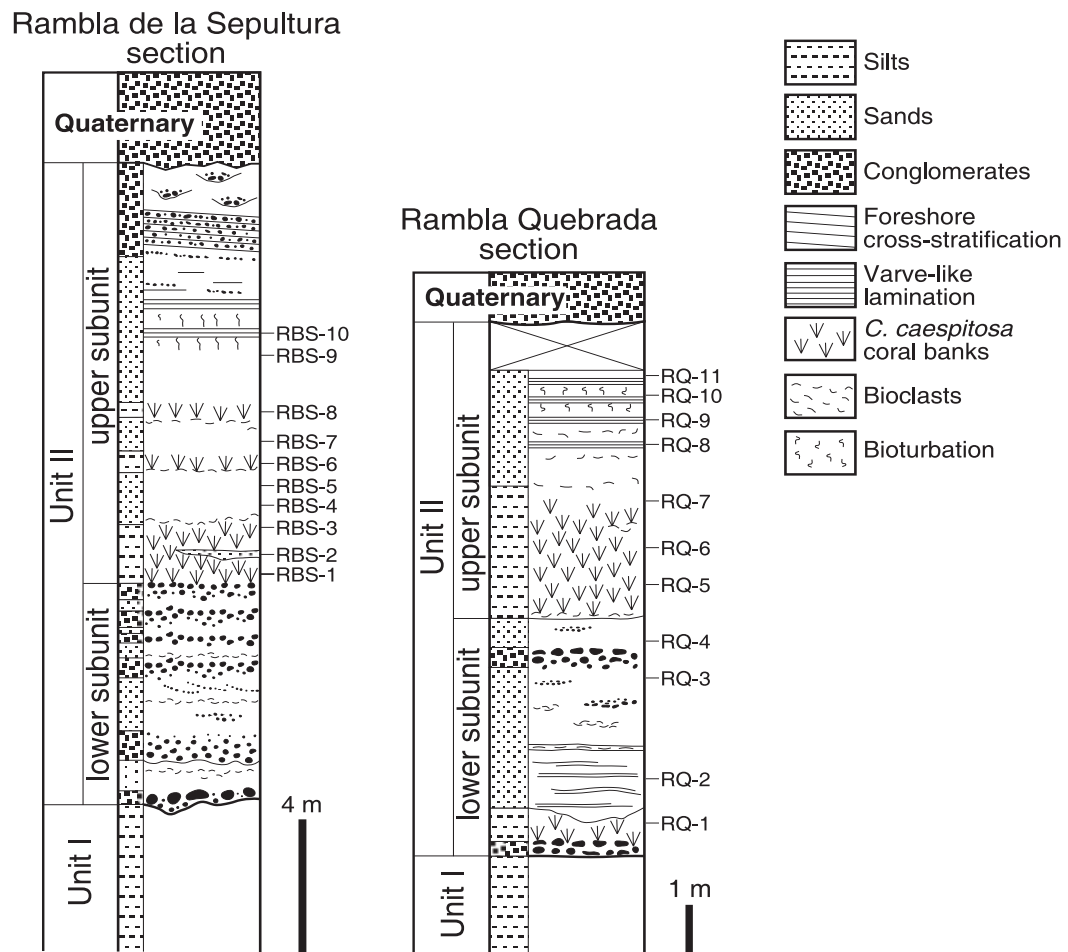


Figure 3. Stratigraphic columns of the two study sections (Rambla de la Sepultura and Rambla Quebrada) indicating the sampling sites

UNIT II STRATIGRAPHY

RAMBLA DE LA SEPULTURA

The lower subunit (up to 7 m in thickness) consists of debris-flow conglomerates alternating

with coarse- to fine-grained sands (Fig. 3). Debris-flow conglomerate beds are amalgamated and show inverse-grading, although some channelised, normal-graded conglomerates are also present. Conglomerates thickness ranges from 0.2 to 1 m with clasts comprising schists, quartzites, dolostones, and limestones from the Betic basement at the north of the basin (Sierra Alhamilla), and sandstone-siltstone blocks from the underlying Unit I. Clasts can reach up to 40 cm across and are embedded in a microconglomerate matrix. Coastal, rocky-shore organisms (mussels, coralline algae, encrusting bryozoans, barnacles, regular sea-urchins, etc.), as well as borings of *Lithophaga*, typical of this setting, are often found in the conglomerates (Aguirre and Jiménez, 1997).

Sand beds are massive and structureless due to intense background bioturbation, which has destroyed the vast majority of the original sedimentary structures (ii4-ii5; ichnofabric indices *sensu* Droser and Bottjer, 1986). However, horizontal-, wavy- and trough cross-lamination are occasionally preserved. The sand beds range from several centimetres to 1.5 m in thickness. Sand grain size ranges from fine to coarse, with some isolated and scattered small pebbles. Lenticular bodies of silty clay and channelised fossiliferous conglomerates intercalate within the sand beds.

The upper subunit (up to 20 m thick) consists of three *Cladocora* banks, which can be continuously traced, interbedded with terrigenous material (Fig. 3). The coral colonies are embedded in fine-grained sands and silts. The lowermost coral bank has an intercalated lenticular shell-lag deposit. Terrigenous beds are massive sands, highly bioturbated fine-grained sands and silts. Very fine-grained sands and silts with conspicuous horizontal thin lamination (varve-like lamination) occur in the upper part of the subunit (Fig. 3). Beds several centimetres thick with perfectly preserved varve-like lamination alternate with beds homogenised by bioturbation. Sand beds coarsen upsequence, changing to conglomerates showing low-angle, unidirectional tabular cross-stratification dipping to the south-southeast. The unit ends with reddish conglomerates and breccias.

RAMBLA QUEBRADA

The lower subunit in this outcrop (up to 4 m thick) has similar features to those described in Rambla de la Sepultura. It is mainly characterised by siliciclastic deposits, conglomerates, and coarse- to medium-grained sands, with isolated coral colonies or small-scale thickets growing on top of the conglomerates (Fig. 3). Conglomerates occur as inverse-graded debris-flow beds or, less frequently, as channelised beds with normal grading. Sand beds are massive and mostly structureless due to background bioturbation. Occasional wavy and ripple lamination can be observed. The lower subunit ends with a massive, coarse- to medium-grained sand bed (2 m thick)

with some dispersed channelised inverse-graded conglomerates and shell lags.

The upper subunit (up to 10 m thick) starts with a well-developed and well-preserved *Cladocora caespitosa* bank growing directly on top of blocks and boulders of the underlying conglomerates. Several episodes of coral development alternate with channelised conglomerate and massive sand beds (Fig. 3). These siliciclastic deposits truncated and destroyed the initial stages of the coral bioconstructions. Some oyster concentrations, most fossilized in life position, also intercalate with the coral banks.

Laterally, to the south, coral banks disappear and fine- to medium-grained sands and silts with numerous scattered bivalve shells are found. As in the Rambla de la Sepultura, horizontal thin lamination (varve-like lamination) is well developed close to the top of the subunit in distal sections.

SAMPLING AND METHODS

Up to 21 samples of about 500 g each were collected in the two sections (Fig. 3). Sampling efforts were concentrated on the sandy and silty beds in attempts to sample the different facies.

Samples were sieved through 1 mm, 0.125 mm and 63 μm meshes. The residue was dried in an oven at approximately 40°C. Only residue above the 0.125 mm fraction was considered for the analyses.

All benthic foraminifer specimens were identified to the species level. The diversity of each sample was calculated using several metrics: 1) total number of species (species richness; S); 2) Shannon-Weaver diversity index (H); and 3) evenness *sensu* Hayek and Buzas (1997) ($E=e^H/S$). We also calculated the generic and specific dominances (percentage of the most abundant genus and species, respectively).

Fossil assemblages were characterised using two quantitative analyses: 1) the relative abundance of benthic foraminifer species, represented in percentages, and 2) multivariate statistical grouping techniques. The multivariate techniques used are the R-mode cluster analyses, using the Ward method and Pearson's correlation coefficient distances, as well as the principal component analyses (PCA) using the Canoco programme. The PCA analyses group samples or species with similar significance in biplots (Shi, 1993).

The quantitative analyses are based on 300 individuals randomly counted in each sample and taking into consideration those species comprising 3% or more of the total assemblage (Buzas, 1990; Serandrei-Barbero and others, 1997). Both the relative abundance and the multivariate

statistical techniques offer complementary information useful for inferring palaeoenvironmental conditions (Mello and Buzas, 1968; Kafescioglu, 1975; Zellers, 1990; Van der Zwaan, 1983; Parker and Arnold, 1999; among others).

The assemblages are thought to be autochthonous-parautochthonous because no differences in preservation of foraminifer tests are observed. Further, the benthic foraminifer species in each sample are ecologically consistent, suggesting the absence of reworking or other significant taphonomic bias.

BENTHIC FORAMINIFER ASSEMBLAGES

RAMBLA DE LA SEPULTURA SECTION

A total of 104 species of benthic foraminifers have been identified in the entire section. Results of the diversity calculated with the different metrics are shown in Figure 4. The number of species is higher than 20 throughout the section except in sample RBS-7, where a minimum in species richness is observed. The number of species reaches several maxima in samples RBS-5, RBS-8, and RBS-9. The curves representing the *H* and *E* indices show parallel trends with a broad increase upsection. There is a minimum in sample RBS-7 and another low value in sample RBS-3. Both parameters peak in samples RBS-2 and RBS-8. Finally, the curves of genus and species dominances are characterised by a zigzag trend, with an alternation of high and low values along the section. This trend is opposite to the one observed in the evenness curve.

Benthic foraminifer assemblages have been defined considering those species representing 3% or more of the total assemblage, amounting to 21 species in the Rambla de la Sepultura section. This section can be divided into two parts (Fig. 5). In the lower part, from RBS-1 to RBS-3, fossil assemblages are clearly dominated by several species of the genus *Elphidium* (*E. traslucens*, *E. granosum*, *E. crispum*, and *E. advenum*). Minor representatives are *Haynesina depressula*, *Criboelphidium* sp 1 and *Criboelphidium* sp 2.

The upper part of the section, from sample RBS-4 up to the top, is characterised by a striking change in the most abundant species. *Elphidium* species dominating the lower part almost disappear and the benthic foraminifer assemblages are mostly dominated by *Ammonia* spp (*A. beccarii*, *A. tepida*, *A. inflata*, and *Ammonia* sp 2), followed by *Reussella spinulosa*, *Criboelphidium vadescens* and, in lesser abundance, by *Elphidium poeyanum* (Fig. 5). *Ammonia* species, although present throughout the section (except *Ammonia* sp 2), underwent a significant increase in this upper part of

the section. The species *R. spinulosa* shows an outstanding increase in sample RBS-4, where it represents more than 40% of the total species. *Nonion asterizans* is a subordinate species in samples RBS-5 and RBS-8. In the sample RBS-9, the species *Bulimina aculeata*, *Hanzawaia boueana*, and *Cibicides refulgens* occur in significant amounts.

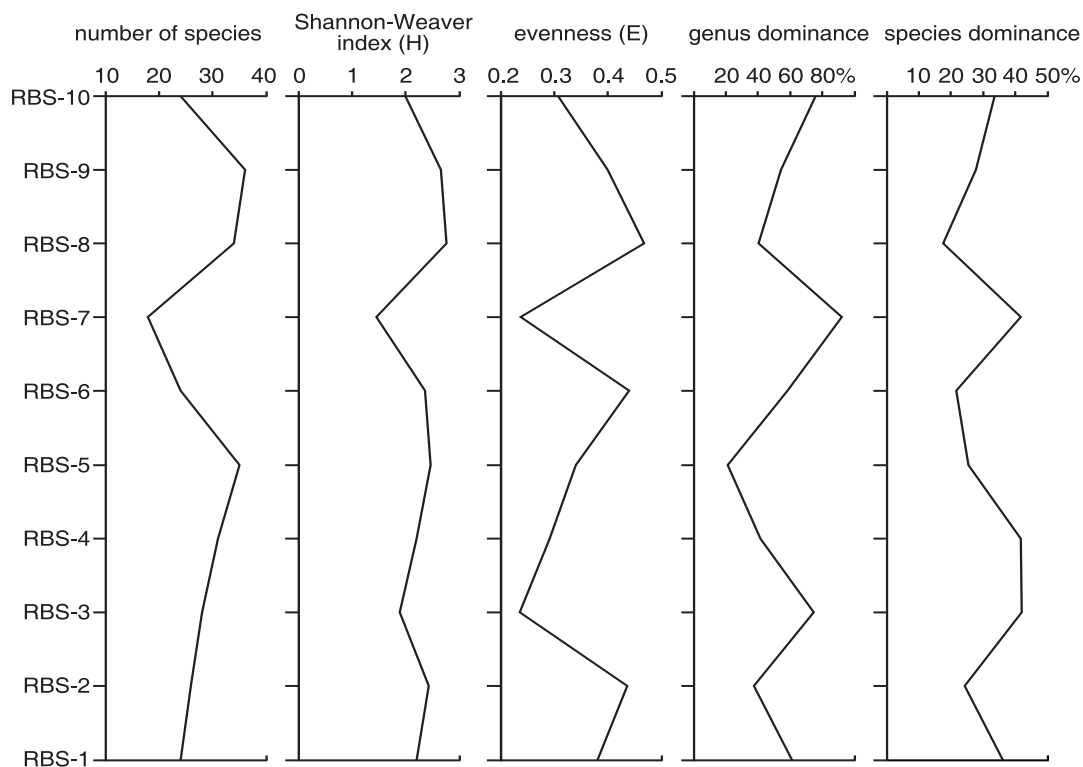


Figure 4. Diversity data in Rambla de la Sepultura section calculated with different metrics used: total number of species (species richness), Shannon-Weaver index (H), evenness (E), and genus and species dominances.

The R-mode cluster analysis differentiates five groups of species (Fig. 6). Cluster 1 groups *A. beccarii*, *A. inflata*, *A. tepida*, *Elphidium poeyanum*, and *Anomalinoidea* sp 1, some of the most abundant species in the upper part of the section. Cluster 2 includes *R. spinulosa* and *C. vadescens*, both species peaking in samples RBS-4 and RBS-8. Cluster 3 is represented by the species occurring in sample RBS-9: *Bulimina aculeata*, *Hanzawaia boueana*, *Cibicides refulgens*, and *Ammonia* sp 2. Cluster 4 comprises a group of species irregularly distributed throughout the section but abundant in sample RBS-2, such as *Ammonia papillosa*, *Nonion asterizans*, *Elphidium advenum*, *E. granosum* and *Haynesina depressula*. Finally, Cluster 5 groups the most abundant species in the lower part of the section: *Criboelphidium* sp 1, *Criboelphidium* sp 2, *E. crispum*, *E. traslucens*, and *Lobatula lobatula* (Fig. 6).

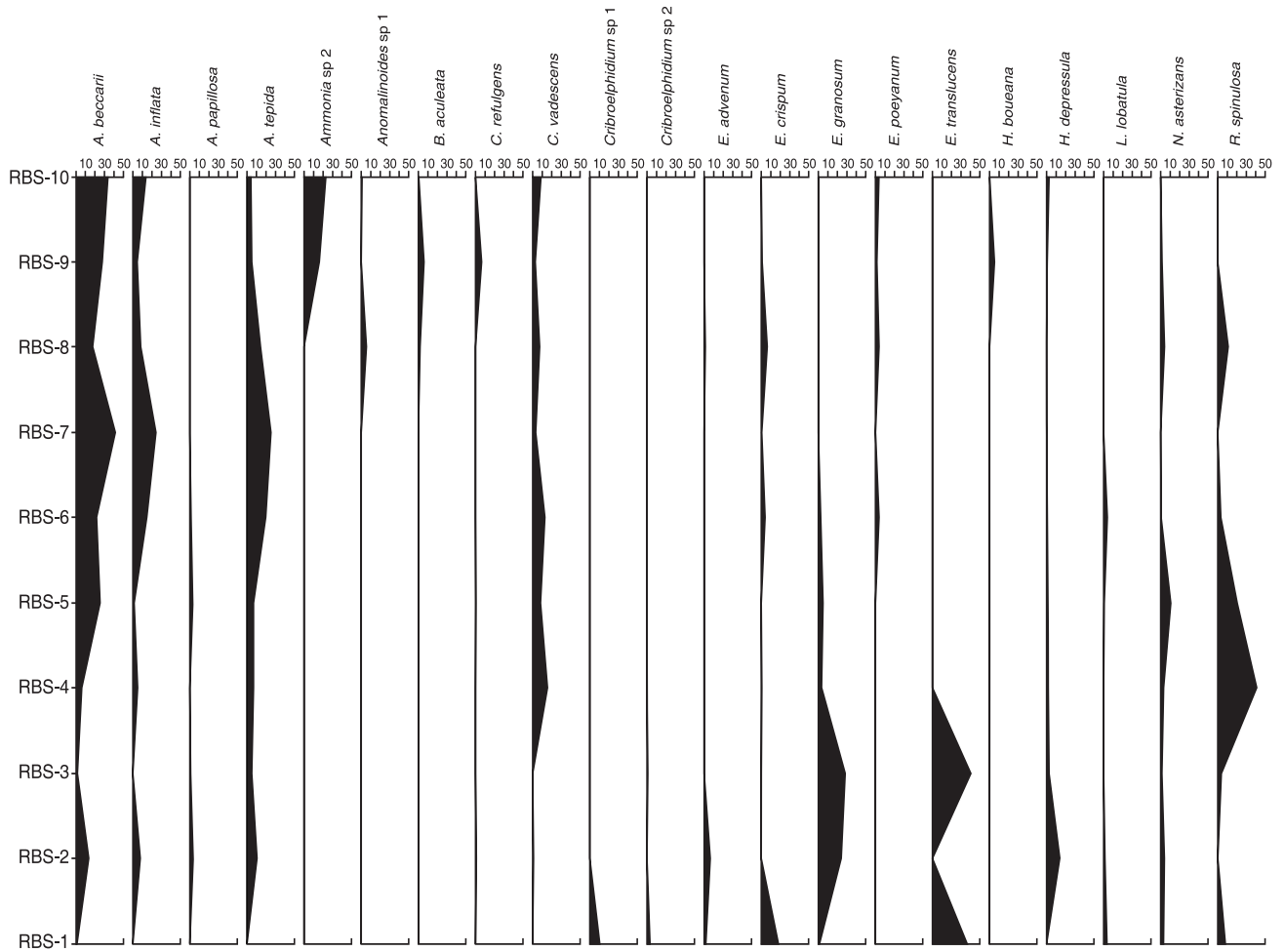


Figure 5. Abundance of benthic foraminifer species (in percentages) in Rambla de la Sepultura section. Species involved in the analysis comprise 3% or more of the total assemblage.

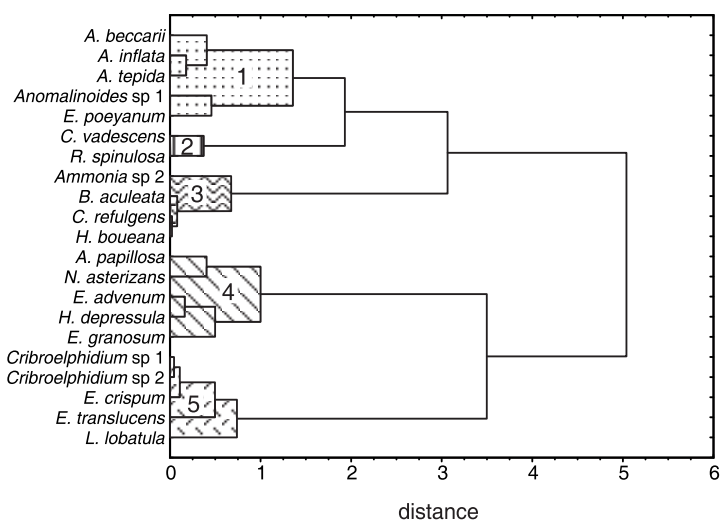


Figure 6. R-mode cluster analysis of benthic foraminifer species of Rambla de la Sepultura section.

Three groups, including species and samples, can be recognised in the PCA biplot (Fig. 7). Group I is characterised by positive values along the two axes and consists of the same species included in the Cluster 5 of the R-mode cluster analysis. These species are dominant in samples RBS-1 and RBS-3. Group II of the PCA is represented by the species of the Cluster 4 of the R-mode cluster analysis plus *Reussella spinulosa*. These species dominate in the samples RBS-2, RBS-4, and RBS-5, typified by positive values of the X axis and negative values of the Y axis in the biplot. Group III of the PCA shows negative values with respect to the horizontal axis of the biplot. It includes the species dominating Clusters 1 and 3 of the R-mode cluster, plus *Criboelphidium vadescens*. These species dominate from sample RBS-6 up to the top of the section.

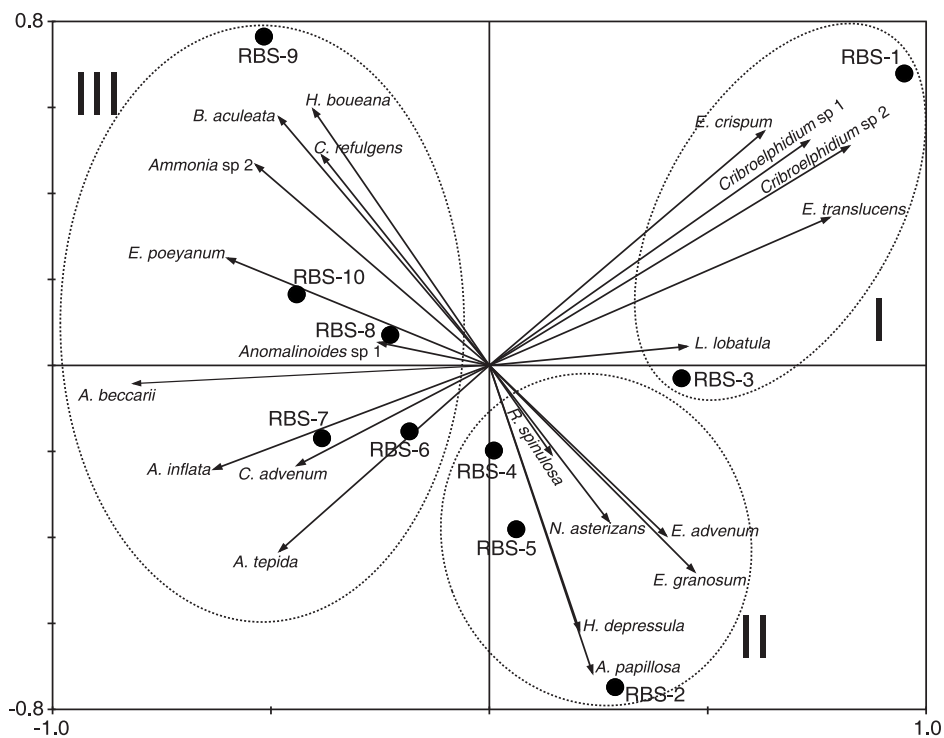


Figure 7. Principal components analysis (PCA) of benthic foraminifer species of Rambla de la Sepultura section.

RAMBLA QUEBRADA SECTION

Up to 79 species of benthic foraminifers have been identified in the Rambla Quebrada section. The number of species is relatively high throughout the section, except in samples RQ-6, RQ-7, and RQ-8, where the assemblages contain less than 20 species (Fig. 8). The curve of species richness decreases from the base to a minimum in the middle part of the section (sample RQ-6) then it progressively recovers up to the top of the section (Fig. 8). This trend is also observed in the curve

of the Shannon-Weaver index (Fig. 8). Evenness fluctuates in the lower part of the section up to sample RQ-6, and then is stable up to the top of the section. Genus and species dominances show opposite trends in relation with evenness (Fig. 8).

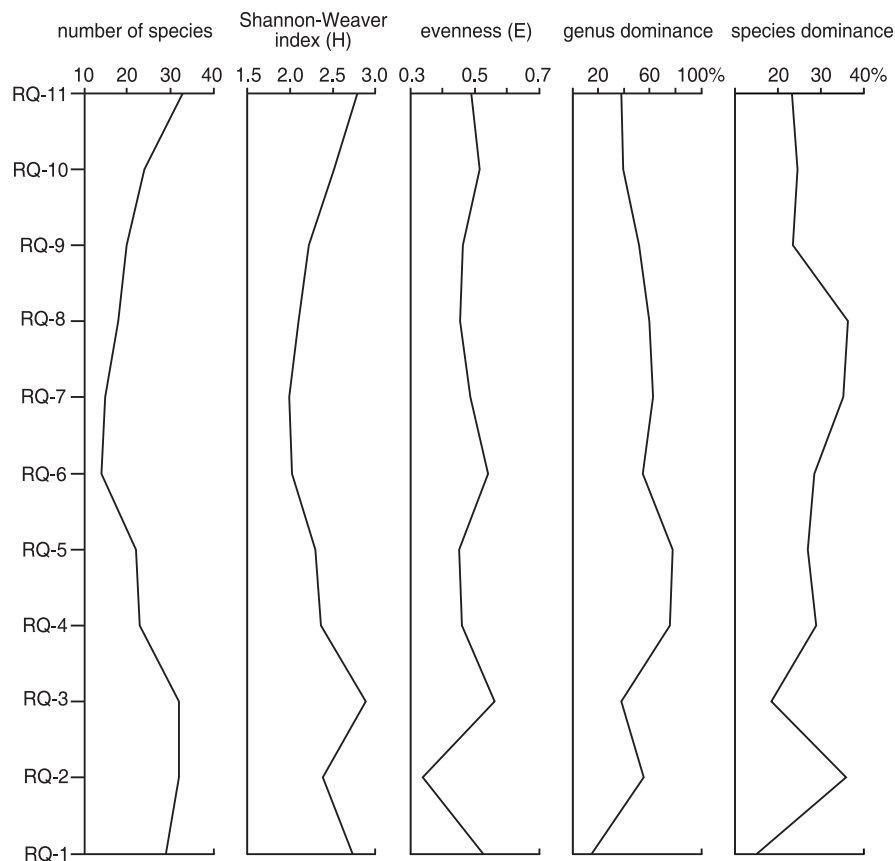


Figure 8. Diversity data in Rambla Quebrada section calculated with the different metrics used: total number of species (species richness), Shannon-Weaver index (H), evenness (E), and genus and species dominances.

Out of the 79 species identified in the Rambla Quebrada section, 29 species represent 3% or more of the total assemblages. As in the Rambla de la Sepultura section, the Rambla Quebrada section can be divided into two parts based on the relative abundance of these species: a lower part from RQ-1 to RQ-5 and an upper one from RQ-6 upwards. The boundary between the two parts is marked by a significant change in faunal composition (Fig. 9). The lower part of the section is dominated by different species of the genus *Elphidium* (except for *E. granosum* and *E. traslucens*). Other abundant species are *Lobatula lobatula*, *Rosalina globularis*, *Asterigerinata planorbis*, and *Cibicides refulgens*. Minor components, showing only local abundances, are *Criboelphidium vadescens*, *Cibicoides bradyi*, *C. pseudoungerianus*, *Asterigerinata mamilla*, *Lenticulina calcar*, and *Textularia* sp (Fig. 9).

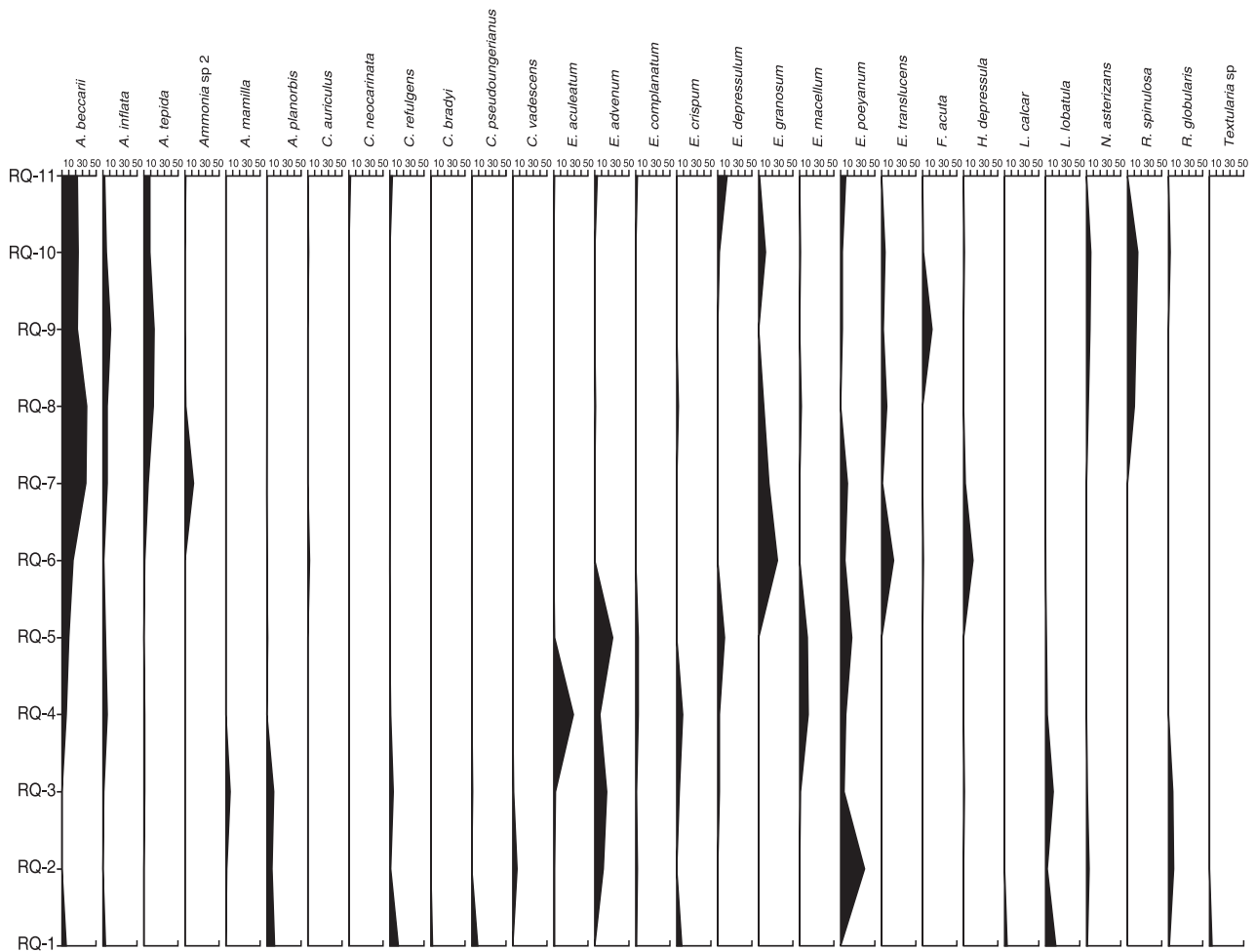


Figure 9. Abundance of benthic foraminifer species (in percentages) in Rambla Quebrada section. Species involved in the analysis represent 3% or more of the total assemblage.

The upper part of the section is characterised by a progressive increase in *Ammonia* spp (*A. beccarii*, *A. tepida*, and *A. inflata*) (Fig. 9). In this part of the section, the unkeeled species *Elphidium granosum* and *E. translucens* are dominant, whereas *E. macellum* and *E. poeyanum* decrease significantly. Other elphidiis are anecdotal (Fig. 9). Together with *Ammonia* spp, *Reusella spinulosa*, and *Nonion asterizans* are dominant. *Cancris auriculus* is a minor component in this upper part. *Haynesina depressula* and *Fursenkoina acuta* peak in samples RQ-6 and RQ-9, respectively (Fig. 9). Finally, it is worth noting the assemblage found in the uppermost RQ-11 sample, which consists of minor peaks of the species found in the lower part of the section together with *Cassidulina neocarinata* (Fig. 9).

The R-mode cluster analysis shows three groups of benthic foraminifer species (Fig. 10). Cluster 1 includes the most abundant species in the upper part of the section and can be divided into two subgroups: a) Subgroup 1A, dominated by the most abundant species (*A. beccarii*, *A. tepida*, *A.*

inflata, *Fursenkoina acuta*, *Reusella spinulosa*, and *Nonion asterizans*), and b) Subgroup 1B, constituted by those species that are more abundant in the middle part of the section (*E. granosum*, *E. translucens*, *H. depressula*, and *C. auriculus*). Cluster 2 consists of those species in the lower part of the section and can also be divided into two subgroups: a) Subgroup 2A grouping *A. mamilla*, *A. planorbis*, *L. lobatula*, *C. vadescens*, *R. globularis*, and *E. poeyanum*, and b) Subgroup 2B including the remaining elphidiid species together with *C. neocarinata*. Cluster 3 is composed of those species in the lowermost sample, RQ-1 (*C. refulges*, *C. bradyi*, *C. pseudoungerianus*, *L. calcar*, and *Textularia* sp) (Fig. 10).

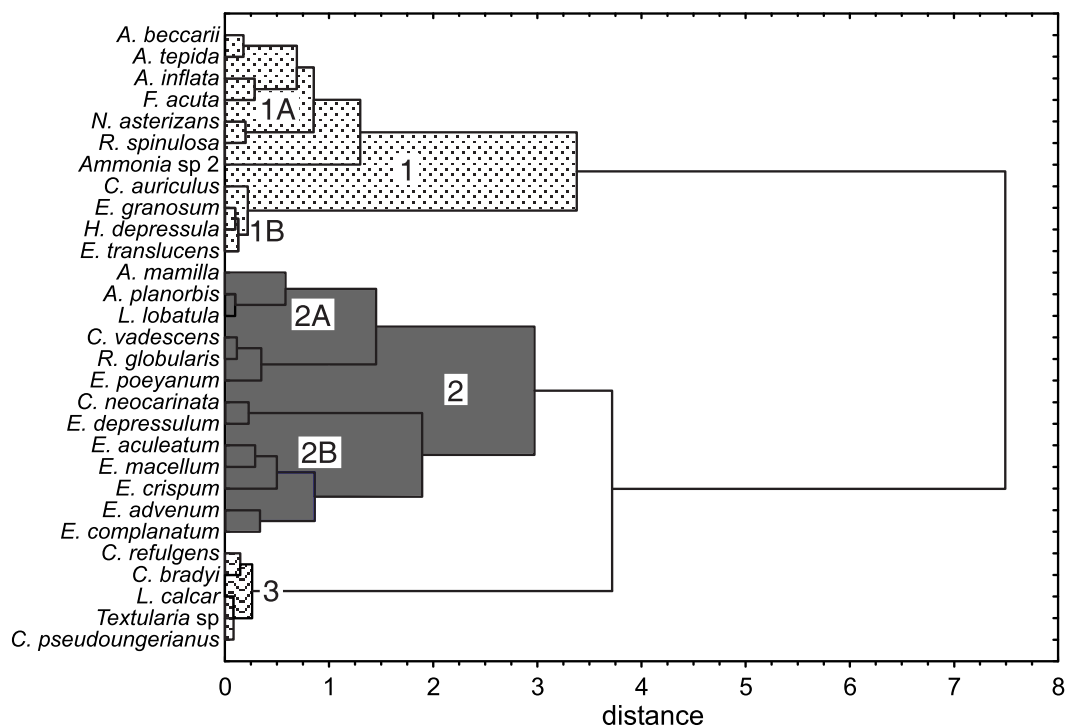


Figure 10. R-mode cluster analysis of benthic foraminifer species of Rambla Quebrada section.

The PCA biplot shows four distinct groups of species characterising different samples from the section (Fig. 11). Groups I and II are differentiated in the positive part of the X-axis of the biplot and include species dominating the lower part of the section (samples RQ-1 to RQ-5). Nonetheless, Group I is in the NE sector of the biplot, in the positive part of the two axes, and Group II is in the negative part of the Y-axis. Group IV comprises the species in the upper part of the section (from RQ-6 to RQ-11) and is in the NW quarter of the biplot. Group III, isolated in the negative part of the two axes of the biplot, is only represented by the species *C. neocarinata* and includes sample RQ-11.

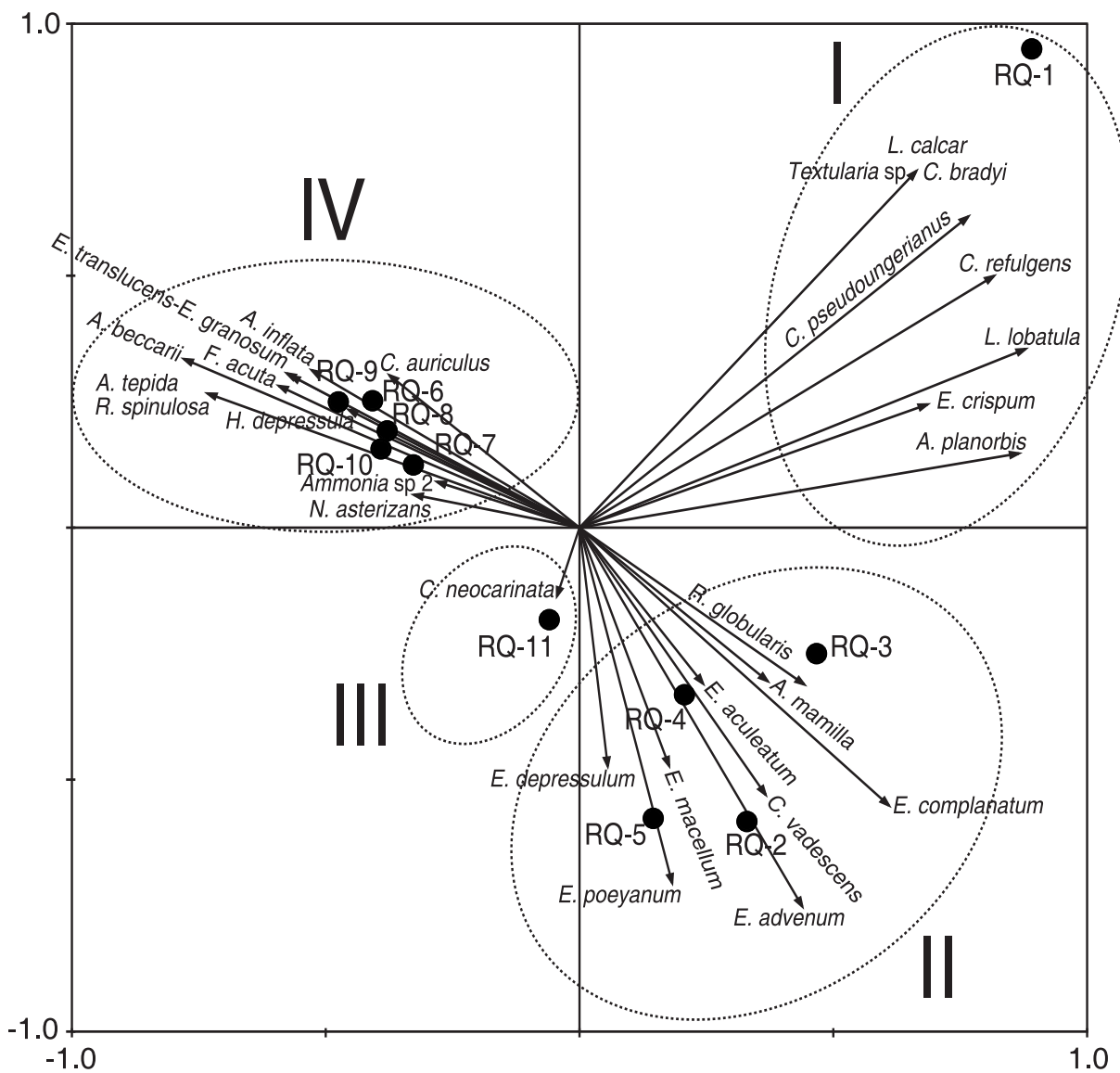


Figure 11. Principal components analysis (PCA) of benthic foraminifer species of Rambla Quebrada section.

DISCUSSION

PALEOENVIRONMENTAL INTERPRETATION

The benthic foraminifer assemblages in the two sections are mostly dominated by *Ammonia* spp and *Elphidium* spp. Abundance of these species suggests very shallow conditions, most likely no deeper than 50 m (Murray, 1991, 2006). This water-depth estimate coincides with the depth distribution of *Cladocora caespitosa* in the present-day Mediterranean (Schiller, 1993a; Peirano

and others, 1998).

Although the benthic foraminifers indicate shallow-water conditions during the deposition of Unit II, a vertical relay of the main components of the assemblages consistent with a change in water depth is inferred. The foraminifer relay is strikingly evidenced in the Rambla Quebrada section. Here, *Cibicides refulgens*, *Lenticulina calcar*, *Lobatula lobatula*, *Cibicidoides* spp, *Textularia* sp, *Rosalina globularis*, *Asterigerinata* spp, and keeled elphidiids are the most abundant species in the lower part of the unit. These species can be found in present-day mid to outer platforms (Murray, 1991; Reid, 1998; Holbourn and Henderson, 2002; van Hinsbergen and others, 2005; Murray, 2006). On the other hand, the overabundance of *Ammonia* spp in the upper part of the unit, together with *Haynesina depressula* and unkeeled elphidiids (*E. granosum* and *E. traslucens*), suggests very shallow conditions such as marginal lagoons or estuaries. These species characterise, for instance, the present-day estuaries of the Tinto, Odiel, Piedras and Guadiana rivers (Huelva, SW Spain) (Ruiz and others, 2004, 2005), the Holocene Bilbao estuary (N Spain) (Leorri and Cearreta, 2004; Cearreta, 2006), and the Venice lagoon since the 5th Century (Serrandrei-Barbero and others, 1997). These are all opportunistic species that are able to cope in fluctuating and stressful environmental conditions (Sen Gupta 1999b; Drinia and others, 2008).

In the Rambla de la Sepultura section, there is no clear vertical change in the main components of the foraminifer assemblages, making it more difficult to interpret the shallowing-upward trend based on benthic foraminifers. It is remarkable to note the dominance of *Ammonia* spp, followed by unkeeled elphidiids, and *Criboelphidium vadescens* throughout the unit, suggesting general shallow-water conditions. In addition, facies analysis in Rambla de la Sepultura supports the shallowing-upward trend since the unit ends with beach deposits and reddish breccias and conglomerates of the alluvial fans that fed the fan deltas (Aguirre, 1998). The Rambla de la Sepultura section was located in a more proximal position than the Rambla Quebrada section within the basin, accounting for the lack of a clear vertical trend in the benthic foraminifers. The fact that fine-grained sediments are volumetrically more abundant in the Rambla Quebrada section than in the Rambla de la Sepultura section is also indicative of distality in the case of the former (Aguirre and Jiménez, 1998).

The vertical change in benthic foraminifer assemblages also suggests variations in salinity. This change is more evident in the Rambla Quebrada section than in the Rambla de la Sepultura section. The species in the lower part of Unit II, for instance, are stenohalines that prefer fully marine habitats (Leorri and Cearreta, 2004; Ruiz and others, 2005; Curzi and others, 2006). However, the assemblages in the upper part of the unit consist mostly of euryhaline species that could withstand

wide fluctuations in salinity. The association of *Ammonia* spp, unkeeled elphidiids (such as *Elphidium poeyanum*, and *E. granosum*), *Haynesina depressula*, and *Nonion asterizans* strongly suggests brackish waters. *Ammonia* spp and *Elphidium poeyanum*, for example, can survive in freshwater (2‰) up to hypersaline waters (50‰, and sometimes even more) (Murray, 1991, 2006; Sen Gupta, 1999b; Vaiani, 2000; Curzi and others, 2006). Similarly, the unkeeled elphidiid *E. granosum*, is very abundant in the upper part of the Rambla Quebrada section (Fig 9), withstands brackish conditions in lagoons and sheltered infralittoral settings with fluvial influence (Vaiani, 2000; Amorosi and others, 2004; Bernasconi and others, 2006; Curzi and others, 2006). This indicates that the influence of freshwater outflows was progressively more pronounced towards the top of Unit II. This is, in turn, consistent with the progradation of fan deltas in a protected bay, favouring the development of the euryhaline species. These brackish species are abundant from the base of the unit to the top in Rambla de la Sepultura, which is consistent with the proximal position of this section.

These two salinity-controlled assemblages can be recognised both in the cluster analyses and in the PCA biplots obtained in the two sections. Thus, the stenohaline assemblage corresponds with Cluster 5 in Rambla de la Sepultura and Clusters 2 and 3 in Rambla Quebrada (except for *C. vadescens* and *E. poeyanum*) (Figs. 6, 10). In the PCA biplots, this assemblage is within Group I in Rambla de la Sepultura and Groups I and II in Rambla Quebrada (Figs. 7, 11). The euryhaline assemblage is represented in Clusters 1, 2, and 4 in Rambla de la Sepultura (except *E. advenum*) and Cluster 1 in Rambla Quebrada (Figs. 6, 10). In the PCA biplots, the euryhaline assemblage is clearly represented in the Group IV in Rambla Quebrada (Fig. 11) but it is vague in Rambla de la Sepultura.

The general paleoenvironmental scenario proposed above is consistent with previous interpretations. Data based on facies analysis, macroinvertebrate assemblages, and taphonomy of marine organisms together show that Unit II was deposited in a shallow sheltered bay with a high sedimentation rate due to the progradation of fan deltas to the centre of the basin (Aguirre and Jiménez, 1997, 1998; Aguirre, 1998). The continuous terrigenous supply together with generalised shallowing during the Late Pliocene led to the progressive closure and, consequently, filling up of the basin.

PALEONVIRONMENTAL FACTORS CONTROLLING THE BENTHIC FORAMINIFER ASSEMBLAGES

In addition to water depth and salinity, other factors directly related with the general

paleoenvironmental setting also controlled the benthic foraminifer assemblages: 1) substrate and habitat preferences, 2) water turbidity, 3) oxygen content, and 4) organic matter content.

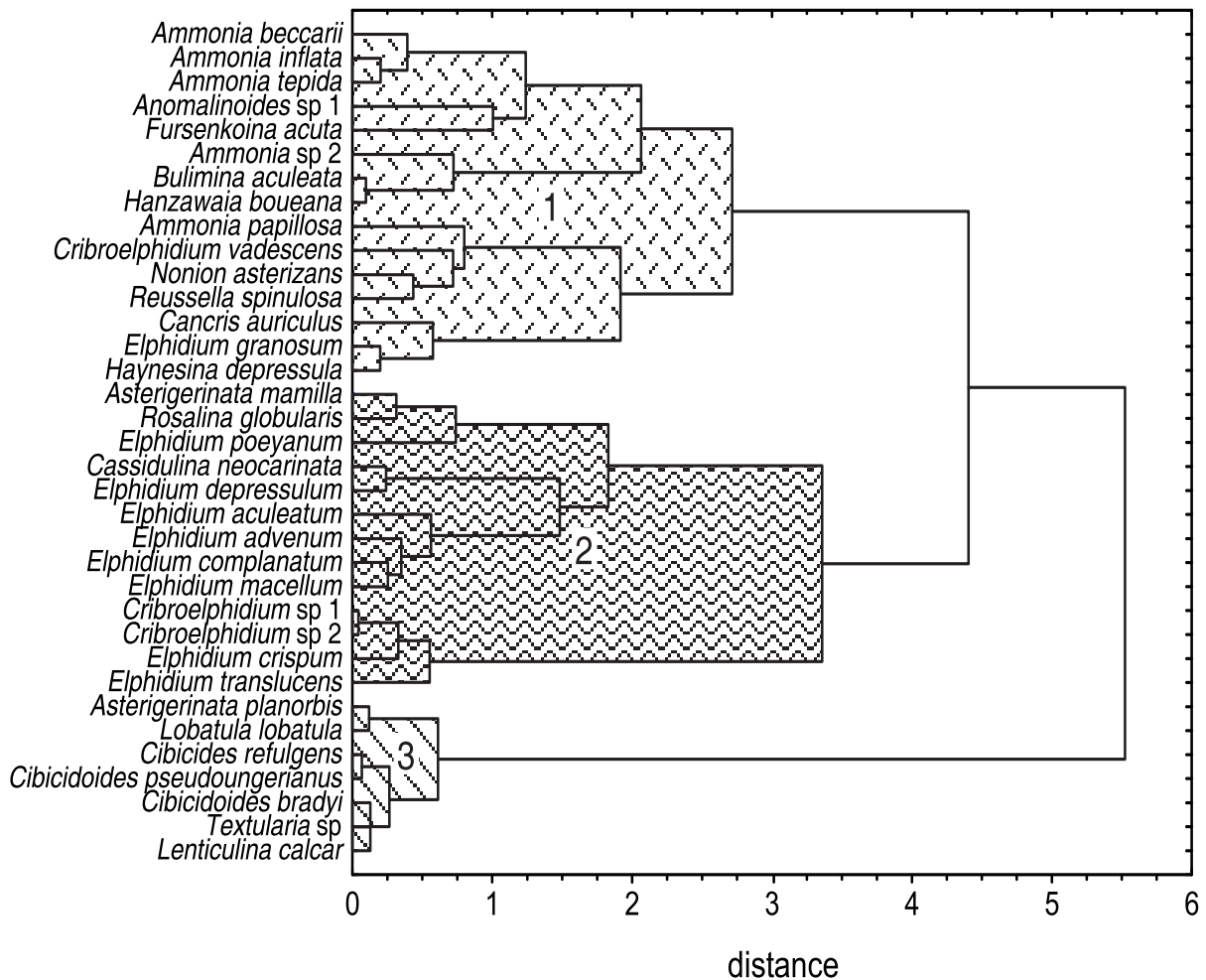


Figure 12. R-mode cluster analysis of benthic foraminifer species including all species found in the two sections.

The R-mode cluster analysis including all species found in the two sections (Fig. 12) distinguishes three groups, two of which are dominated by epiphytic benthic foraminifer species: 1) Cluster 2, including *Elphidium crispum*, *E. depressulum*, *E. translucens*, *E. aculeatum*, *E. advenum*, *E. complanatum*, *E. macellum*, *Criboelphidium* sp 1, *Criboelphidium* sp 2, *Asterigerinata mamilla*, and *Rosalina globularis*; and 2) Cluster 3, including *Asterigerinata planorbis*, *Lobatula lobatula*, and *Cibicides refulgens* (Lee and others, 1969; Jorissen, 1987; Kitazato, 1988; Langer, 1988, 1993; Semeniuk, 2001; Diz and others, 2004; Drinia and others, 2005; Murray, 2006). These species are very abundant in the lower half of the two sections (Fig. 13) and occur in the *Cladocora caespitosa* coral banks and in fine-grained sand and silt beds. That is, vegetated hard- and soft-

bottoms can be inferred. In the Rambla de la Sepultura section, the epiphytic species associated with the coral banks are *Elphidium traslucens*, *E. crispum*, *Lobatula lobatula*, *Criboelphidium* sp 1 and *Criboelphidium* sp 2 (Cluster 5 and PCA group I in Figs. 6, 7), whereas epiphytic species of the soft substrates are *Elphidium advenum* and *Cibicides refulgens*. In the Rambla Quebrada section, the separation of epiphytic species associated to either hard or soft bottoms is not as clear; most of the epiphytes are included in Cluster 2 and in the PCA Groups I and II (Figs. 10, 11).

In the present-day Mediterranean, Langer (1988, 1993) has described four morphotypes, (A to D) of benthic foraminifers associated with different vegetated substrates. Among the epiphytic species found herein are representatives of morphotypes B and C: 1) *C. refulgens*, *L. lobatula*, *Rosalina globularis*, and *Asterigerinata* spp are included in the morphotype B, and 2) *Elphidium* spp represent morphotype C (Langer, 1993). Miliolids belonging to the morphotype D (e.g. *Quinqueloculina*, *Triloculina*, *Massilina*, *Cycloforina*, *Adelosina*, *Pseudotriloculina*, and *Lachlanella*) have been found, although they are represented by less than 3% of the total assemblages and have therefore not been included in the statistical analyses. In addition, *Planorbulina*, a genus belonging to morphotype A, is found in the Rambla Quebrada section, but also represents less than 3% of the total assemblages.

Taking into consideration exclusively the epiphytic forms, the lower part of the Rambla de la Sepultura is dominated by representatives of morphotype C, with minor abundance of morphotypes B and D (Table 1, Fig. 13). In the upper part of the section, morphotypes B and C coexist in similar proportions. According to Langer's (1993) study, overabundance of morphotype C indicates a vegetated substrate provided by small, arborescent, short-span algae such as *Ectocarpus*, *Dictyopteris*, *Cutleria*, *Dasycladus*, and *Fucus*. Species of the morphotype B do not prefer any specific plant substrate (Langer, 1993). Thus, the results suggest the development of small, arborescent short-live algae (high frequency of morphotype C). High abundance in some samples of *Rosalina*, *Lobatula*, and *Cibicides*, benthic foraminifers of morphotype B that inhabit blades and rhizomes of *Posidonia* (Langer, 1993), indicates the occasional presence of large, long-lived plants, such as *Posidonia oceanica*. Finally, samples RBS-5 and RBS-8 show substantial increases in miliolids of morphotype D (Table 1 and Fig. 13) that could be due to the spread of the small brown algae *Padina* and *Halopteris* (Langer, 1993).

In Rambla Quebrada, the lower part is dominated by specimens of morphotype B, whilst the upper part is clearly dominated by benthic foraminifer species of morphotype C (Table 1, Fig. 13). Although very rare, morphotype A is present in the lower part of the section in samples RQ-1, RQ-2, and RQ-4 (Table 1). Several pieces of evidence strongly suggest that *Posidonia* meadows might

have developed in this lower part. 1) As commented above, there are high proportions of *Rosalina*, *Lobatula*, and *Cibicides* (morphotype B) living on the blades and rhizomes of *Posidonia* (Langer, 1993). 2) *Elphidium crispum* (morphotype C) is very abundant in this part of the section (Fig. 9); this species preferentially inhabits *Posidonia* rhizomes. 3) Langer (1993) found that the maximum diversity of epiphytic foraminifers is associated with the large, long-lived *Posidonia* seagrass. In Rambla Quebrada, the highest abundance of epiphytic foraminifer species is in the lower part of Unit II (Fig. 13), coinciding with the highest species richness (Fig. 8). 4) Morphotype A occurs in all vegetated substrates, but is most important in *Posidonia* (Langer, 1993). In Rambla Quebrada, this morphotype is present anecdotally and therefore, no characteristic vegetated substrate type can be ruled out. However, it is worth mentioning that it is only present in this part of the section, where other data point to the presence of *Posidonia*.

Rambla de la Sepultura	Morphotype A	Morphotype B	Morphotype C	Morphotype D
RBS-10	0,0	37,5	50,0	12,5
RBS-9	0,0	66,7	33,3	0,0
RBS-8	0,0	24,2	40,3	35,5
RBS-7	0,0	39,8	60,2	0,0
RBS-6	0,0	60,6	39,4	0,0
RBS-5	0,0	30,0	9,9	60,1
RBS-4	0,0	42,8	42,8	14,4
RBS-3	0,0	3,5	93,8	2,8
RBS-2	0,0	22,6	74,3	3,2
RBS-1	0,0	9,8	88,2	2,0
Rambla Quebrada				
RQ-11	0,0	24,0	76,0	0,0
RQ-10	0,0	31,9	68,1	0,0
RQ-9	0,0	18,8	56,3	25,0
RQ-8	0,0	4,0	96,0	0,0
RQ-7	0,0	0,0	100,0	0,0
RQ-6	0,0	5,0	95,0	0,0
RQ-5	0,0	5,0	95,0	0,0
RQ-4	0,5	6,9	92,2	0,5
RQ-3	0,0	55,3	43,0	1,8
RQ-2	0,8	55,8	43,4	0,0
RQ-1	0,6	74,4	23,8	1,2

Table 1. Percentage of the four epiphytic morphotypes in the two sections (following the classification scheme of Langer 1988, 1993).

Posidonia is a very shallow (up to 45 m depth), stenohaline seagrass that grows in clear waters in the present-day Mediterranean (Bethoux and Copin-Montegut, 1986). As interpreted above, benthic foraminifer assemblages suggest that the Rambla Quebrada section was located in a more distal position than the Rambla de la Sepultura section. Therefore, salinity variations due to freshwater outflows and turbid conditions due to sediment discharges could have prevented the widespread colonisation of *Posidonia* in Rambla de la Sepultura but not in Rambla Quebrada.

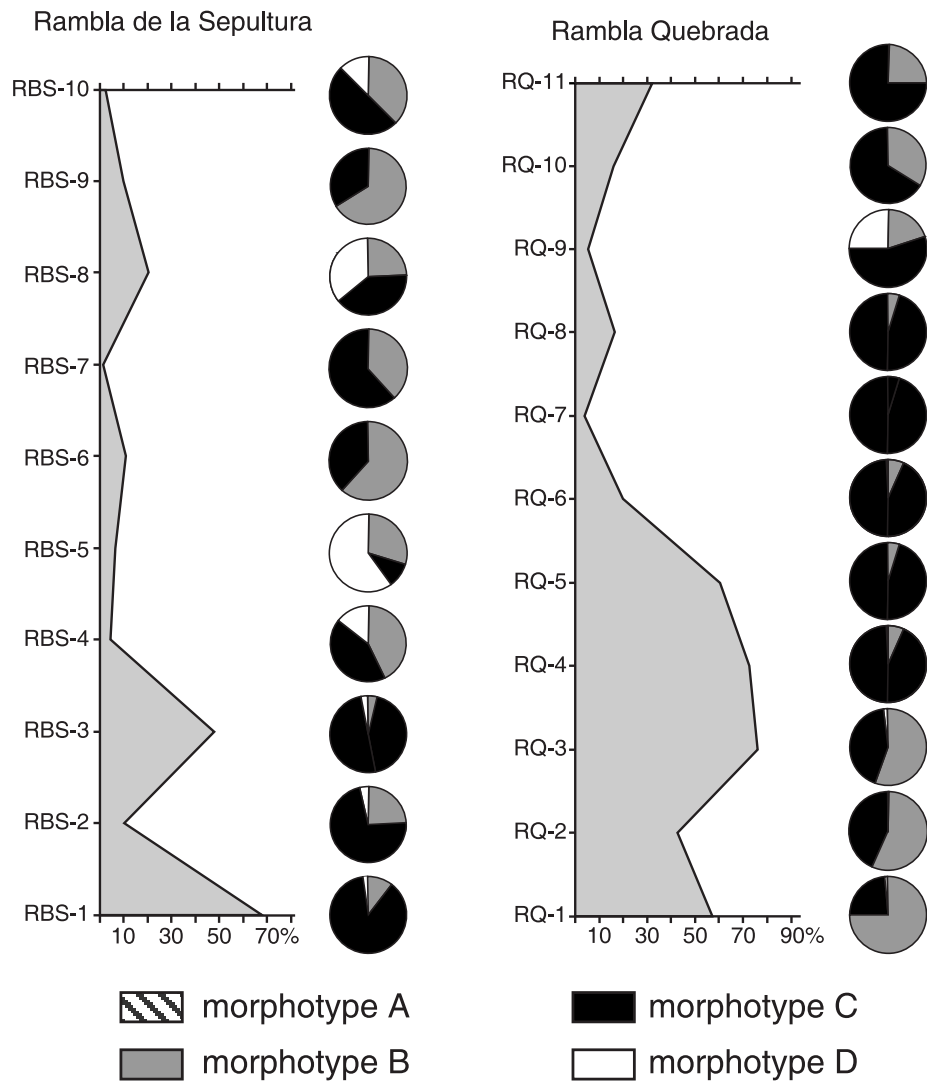


Figure 13. Relative abundance of epiphytic foraminifer species and pie diagrams representing the percentage of the four epiphytic morphotypes in both sections (following the classification of Langer 1988, 1993). Note the significant reduction in epiphytic species in upper half of unit in both sections.

The substantial reduction in epiphytic species upunit in both sections (Fig. 13) can be explained by the shallowing-upward trend and the progradation of the fan deltas. Both factors led to an

increase in water turbidity due to continuous terrigenous discharges in a progressively shallower and more sheltered bay negatively effecting plants.

In contrast with these groups of species associated with vegetated substrates, Cluster 1 of the R-mode cluster analysis including all the species (Fig. 12) groups inhabitants of soft substrates. *Reussella spinulosa* and *Nonion asterizans*, for instance, are mudwellers inhabiting fine-grained sediments (Jorissen, 1987; Murray, 1991, 2006). In the present-day inner-shelf off Valencia and Alicante (E Spain), *R. spinulosa* inhabits silt-clay substrates (Usera and Blázquez, 1997). In the study case, both *R. spinulosa* and *N. asterizans* dominate in the mid-upper half of Unit II, which formed during high terrigenous inputs due to the progradation of the fan deltas. Under these conditions, vegetated substrates diminished and medium- to fine-grained soft substrates formed in the mid fan-delta settings.

Benthic foraminifer assemblages also suggest a restriction of the basin due to a progressive disconnection with the open marine waters. In the lower part of the Unit II, for instance, deep-waters species, occurring in areas well connected with open marine seawaters, are found: *Cibicides refulges*, *Cibicidoides pseudoungerianus*, *C. bradyi*, *Lenticulina calcar*, *Elphidium crispum*, *Lobatula lobatula*, *Asterigerinata* spp, *Rosalina globularis*, and *Textularia* sp (Cluster 3 in Fig. 12) (Murray, 1991, 2006; Leorri and Cearreta, 2004; Ruiz and others, 2005; Curzi and others, 2006). Accompanying open marine species is *Massilina* cf. *M. gualtieriana* (Leorri and Cearreta, 2004). However, the upper part of the unit is largely dominated by the brackish species *Ammonia* spp and unkeeled elphidiis thriving in sheltered brackish lagoons (Murray, 1991, 2006; Sen Gupta, 1999b).

As a consequence of the isolation of the basin from open seawaters, low oxygen conditions prevailed in the bottom of the bay. The varve-like laminated silts and fine-grained sands of the upper part of Unit II contain benthic foraminifer species such as the infaunal *Bulimina aculeata* and *Fursenkoina acuta*. Additional species (although represented by less than 3% of the total assemblages) found in these finely laminated deposits are *Bolivina dilatata*, *Bulimina costata*, *B. marginata*, *Cassidulina laevigata*, *Nonionella turgida*, *Pleurostomella* sp., and *Rectuvigerina multicostata*. These species prefer low-oxygen conditions (Sen Gupta and Machain-Castillo, 1993; Kaiho and Hasegawa, 1994; Kaiho, 1994, 1999; Moodley and others, 1998; Bernhard and Sen Gupta, 1999; Diz and others, 2000; Fontanier and others, 2002; Pezelj and others, 2007; Kirci-Elmas and others, 2008). The presence of these assemblages indicates a certain restriction of the basin with low water circulation that favoured water stratification and, consequently, the establishment of dysoxic bottoms. The stratification of the water column can be related to freshwater outflows as a consequence of the fan-delta progradation that formed water layers with

different densities due to salt concentrations (Aguirre and Jiménez, 1998; Aguirre, 1998).

In the uppermost part of Unit II, where the varve-like deposits are recorded, *Nonion asterizans*, *Cancris auriculus*, and *Cassidulina neocarinata* are locally abundant (Figs. 5, 9). These species are tolerant to high contents of organic matter due to high productivity (Altenbach and others, 1999). Organic matter supply from the fan deltas might account for mesotrophic bottoms, which is consistent with the paleoenvironmental scenario inferred for the upper part of Unit II.

CONCLUSIONS

1. Upper Pliocene deposits of the Almería-Níjar Basin (SE Spain), termed Unit II, record a shallowing-upward sequence deposited in a sheltered bay where fan deltas prograded to the centre of the basin. Benthic foraminifer assemblages track this trend, especially in distal positions, in the Rambla Quebrada section, where the lower part of the unit contains species living in the mid to outer shelf (*Cibicides refulgens*, *Cibicidoides pseudoungerianus*, *C. bradyi*, *Lobatula lobatula*, *Asterigerinata* spp, *Rosalina globularis*, *Textularia* sp, *Lenticulina calcar*, and keeled elphiids). The mid to upper half of the unit is dominated by very shallow species (*Ammonia* spp, *Haynesina depressula*, and unkeeled elphiids).

2. The benthic foraminifer assemblages found in the mid to upper part of the unit also suggest brackish conditions. Continuous progradation of the fan deltas led to a progressively increase in freshwater influx.

3. Benthic foraminifer assemblages were dominated by epiphytic species during the deposition of the lower half of the unit: *Elphidium* spp, *Cibicides refulgens*, *Lobatula lobatula*, *Rosalina globularis*, and *Asterigerinata* spp. The most likely vegetated substrate that developed in the lower part of the Rambla Quebrada section (in a distal position) was the seagrass *Posidonia*. A progressive increase in the influence of freshwater and sediment supply upunit precluded the development of this plant and the vegetated substrate comprised small, arborescent, short-lived algae.

4. The muddwellers *Reussella spinulosa* and *Nonion asterizans* proliferated in the mid to upper part of Unit II, associated with fine-grained sediment from the middle fan-delta settings.

5. The progradation of the fan deltas led to the progressive closure of the Almería-Níjar Basin during the deposition of the upper part of the Unit II, producing a gradual disconnection between the basin and the Mediterranean Sea. As a consequence, the Almería-Níjar Basin developed low-oxygen bottoms due to water stratification. The reduction in water circulation is most likely related

to the freshwater outflows that produced water layers with different densities due to varying salt concentrations.

6. Local abundance of *Cancris auriculus*, *Nonion asterizans* and *Cassidulina neocarinata* in sediments closely related with the low-oxygen varve-like laminated deposits suggests a high influx of organic matter most likely provided by the fan deltas.

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REFERENCES

- AGUIRRE, J., 1998, El Plioceno del SE de la Península Ibérica (Provincia de Almería). Síntesis estratigráfica, sedimentaria, bioestratigráfica y paleogeográfica: *Revista de la Sociedad Geológica de España*, v. 11, p. 297-315.
- , and JIMÉNEZ, A. P., 1997, Census assemblages in hard-bottom coastal communities: A case study from the Plio-Pleistocene Mediterranean: *Palaios*, v. 12, p. 598-608.
- , and JIMÉNEZ, 1998, Fossil analogues of present-day *Cladocora caespitosa* coral banks: Sedimentary setting, dwelling community, and taphonomy (Late Pliocene, W Mediterranean): *Coral Reefs*, v. 17, p. 203-213.
- ALTENBACH, A. V., PFLAUMANN, U., SCHIEBEL, R., THIES, A., TIMM, S., and TRAUTH, M., 1999, Scaling percentages and distributional patterns of benthic foraminifera with flux rates of organic carbon: *Journal of Foraminiferal Research*, v. 29, p. 173–185.
- AMOROSI, A., RICCI LUCCHI, M., SARTI, G., VAIANI, S. C., PRADIN, S., and MUTI, A., 2004, Late Quaternary sedimentary evolution of the Piombino alluvial plain (western Tuscany) as revealed by subsurface data: *GeoActa*, v. 3, p. 97-106.
- BERNASCONI, M. P., MELIS, R., and STANLEY, J., -D., 2006, Benthic biofacies to interpret Holocene environmental changes and human impact in Alexandria's Eastern Harbour, Egypt. *The Holocene*, v. 16, p. 1163-1176.

- BERNHARD, J. M., and SEN GUPTA, B. K., 1999, Foraminifera of oxygen-depleted environments, *in* Sen Gupta, B. K. (ed.), *Modern Foraminifera*: Kluwer Academic Publishers, Dordrecht, p. 201-216.
- BETHOUX, J.P., and COPIN-MONTEGUT, G., 1986, Biological fixation of atmospheric nitrogen in the Mediterranean Sea: *Limnology and Oceanography*, v. 31, p. 1353-1358.
- BOLTOVSKOY, E., and WRIGHT, R., 1976, *Recent foraminifera*: W. Junk, The Hague, 515 p.
- BRAGA, J. C, MARTÍN, J. M. and QUESADA, C., 2003, Patterns and average rates of late Neogene–Recent uplift of the Betic Cordillera, SE Spain: *Geomorphology*, v. 50, p. 3–26.
- BUZAS, M. A., 1990, Another look at confidence limits for species proportions. *Journal of Paleontology*, v. 64, p. 842-843.
- CEARRETA, A., LEORRI, E., and SANTOS, L., 2006, The stratigraphic significance of reworked Quaternary microfossils in the Holocene of the Bilbao estuary (northern Spain). *Revista Española de Micropaleontología*, v. 38, p. 207-217.
- CURZI, P. V., DINELLI, E., RICCI LUCCHI, M., and VAIANI, S. C., 2006, Palaeoenvironmental control on sediment composition and provenance in the late Quaternary deltaic successions: a case study from the Po delta area (Northern Italy): *Geological Journal*, v. 41, p. 591-612.
- DIZ, P., FRANCÉS, G., and VILAS, F., 2000, Microhábitats de foraminíferos bentónicos en la ría de Vigo y su aplicación a la interpretación paleoecológica: *Journal of Iberian Geology*, v. 26, p. 99-119.
- , FRANCÉS, G., COSTAS, S., SOUTO, C., and ALEJO, I., 2004, Distribution of benthic foraminifera in coarse sediments, Ría de Vigo, NW Iberian margin: *Journal of Foraminiferal Research*, v. 34, p. 258–278.
- DRINIA, H., KOSKERIDOU, E., and ANTONARAKOU, A., 2005, Late Pliocene benthic foraminifera and mollusks from the Atsipades Section, central Crete; Palaeoecological distribution and use in palaeoenvironmental assessment: *Geobios*, v. 38, p. 315-324.
- , ANTONARAKOU, A., and KONTAKIOTIS, G., 2008, On the occurrence of Early Pliocene marine deposits in the Ierapetra Basin, Eastern Crete, Greece: *Bulletin of Geosciences*, v. 83, p. 63-78.
- DROSER, M. L., and BOTTJER, D. J., 1986, A semiquantitative field classification of ichnofabric: *Journal of Sedimentary Research*, v. 56, p. 558-559.
- FONTANIER, C., JORISSEN, F. J., LICARI, L., ALEXANDRE, A., ANSCHUTZ, P., and CARBONEL, P., 2002, Live benthic foraminiferal faunas from the Bay of Biscay: faunal density, composition, and microhabitats: *Deep-Sea Research I*, v. 49, p. 751–785.
- GOY, J. L., and ZAZO, C., 1982, Niveles marinos cuaternarios y su relación con la neotectónica en el litoral de Almería (España): *Boletín de la Real Sociedad Española de Historia Natural (Geología)*, v. 80, p. 171-184.

- HAYEK, L. A. C. and BUZAS, M. A., 1997, *Surveying Natural Populations*: Columbia University Press, New York, 563 p.
- HAYWARD, B. W., 2004, Foraminifera-based estimates of paleobathymetry using Modern Analogue Technique, and the subsidence history of the early Miocene Waitemata Basin: *New Zealand Journal of Geology & Geophysics*, v. 47, p. 749–767.
- , CARTER, R., GRENFELL, H. R., and HAYWARD, J. J., 2001, Depth distribution of Recent deep-sea benthic foraminifera east of New Zealand, and their potential for improving paleobathymetric assessments of Neogene microfaunas. *New Zealand Journal of Geology & Geophysics*, v. 44, p. 555-587.
- , GRENFELL, H. R., SABAA, A., and HAYWARD, J. J., 2003, Recent benthic foraminifera from offshore Taranaki, New Zealand: *New Zealand Journal of Geology & Geophysics*, v. 46, p. 489–518.
- HOLBOURN, A. E., and HENDERSON, A. S., 2002, Re-illustration and revised taxonomy for selected deepsea benthic foraminifers: *Palaeontologia Electronica*, v. 4, p. 1-36.
- JORISSEN, F. J., 1987, The distribution of benthic foraminifera in the Adriatic Sea: *Marine Micropaleontology*, v. 12, p. 21-48.
- KAFESCIOGLU, I. A., 1975, Quantitative distribution of foraminifera on the continental shelf and uppermost slope off Massachusetts: *Micropaleontology*, v. 21, p. 261-305.
- KAIHO, K., 1994, Benthic foraminiferal dissolved-oxygen index and dissolved-oxygen levels in the modern ocean: *Geology*, v. 22, p. 719-722.
- , 1999, Effect of organic carbon flux and dissolved oxygen on the benthic foraminiferal oxygen index (BFOI): *Marine Micropaleontology*, v. 37, p. 67-76.
- , and HASEGAWA, T., 1994, End-Cenomanian benthic foraminiferal extinctions and oceanic dysoxic events in the northwestern Pacific Ocean: *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 111, p. 29-43.
- KIRCI-ELMAS, E., ALGAN, O., ÖZKAR-ÖNGEN, I., STRUCK, U., ALTENBACH, A. V., SAGULAR, E. K., and NAZIK, A., 2008, Palaeoenvironmental Investigation of Sapropelic Sediments from the Marmara Sea: A Biostratigraphic Approach to Palaeoceanographic History During the Glacial–Holocene: *Turkish Journal of Earth Sciences*, v. 17, p. 129–168.
- KITAZATO, H., 1988, Ecology of benthic foraminifera in the tidal zone of a rocky shore: *Revue de Paléobiologie*, v. 2, p. 815-825.

- LAGOE, M. B., 1988, An evaluation of Paleogene paleobathymetric models: benthic foraminiferal distributions in the Metrella Member of the Tejon Formation, central California: *Palaios*, v. 3, p. 523-536.
- LANGER, M. R., 1988, Recent epiphytic foraminifera from Vulcano (Mediterranean Sea): *Revue de Paléobiologie*, v. 2, p. 827-832.
- , 1993, Epiphytic foraminifera: *Marine Micropaleontology*, v. 20, p. 235-265.
- LEE, J. J., MULLER, W. A., STONE, R. J., MCENERY, M. E., and ZUCKER, W., 1969, Standing crop of foraminifera in sublittoral epiphytic communities of a Long Island salt marsh: *Marine Biology*, v. 4, p. 44-61.
- LEORRI, E., and CEARRETA, A., 2004, Holocene environmental development of the Bilbao estuary, northern Spain: sequence stratigraphy and foraminiferal interpretation: *Marine Micropaleontology*, v. 51, p. 75-94.
- MARTÍN, J. M., BRAGA, J. C., and BETZLER, C., 2003, Late Neogene–Recent uplift of the Cabo de Gata volcanic province, Almería, SE Spain: *Geomorphology*, v. 50, p. 27–42.
- MATOBA, Y., and FUKASAWA, K., 1992, Depth distribution of recent benthic foraminifera on the continental shelf and uppermost slope off southern Akita Prefecture, northeast Japan (the eastern Japan Sea): Centenary of Japanese Micropaleontology, Ishizaki, K. and, Kaito, T (eds.), p 207-226.
- MELLO, J. F., and BUZAS, M. A., 1968, An application of cluster analysis as a method of determining biofacies: *Journal of Paleontology*, v. 42, p. 747-758.
- MONTENAT, C., OTT D'ESTEVOU, P., and LA CHAPELLE, G., 1990, La bassin de Nijar-Carboneras et le couloir du bas-Andarax, *in* Les bassins Néogènes du domaine Bétique oriental (Espagne): tectonique et sédimentation dans un couloir de décrochement: Première partie: étude régionale. Documents et Travaux, Institut Géologique Albert-de-Lapparent, 12-13, p 129-164.
- MOODLEY, L., VAN DER ZWAAN, G. J., RUTTEN, G. M. W., BOOM, R. C. E., and KEMPERS, A. J., 1998, Subsurface activity of benthic foraminifera in relation to porewater oxygen content: laboratory experiments: *Marine Micropaleontology*, v. 34, p. 91–106.
- MURRAY, J. W., 1991, Ecology and Palaeoecology of Benthic Foraminifera: Longman Scientific & Technical, UK, 397 p.
- , 2006, Ecology and Applications of Benthic Foraminifera: Cambridge University Press, Cambridge, 438 p.
- PARKER, W. C., AND ARNOLD, A. J., 1999, Quantitative methods of data analysis in foraminiferal ecology, *in* Sen Gupta, B. K. (ed.), *Modern Foraminifera*: Kluwer Academic Publishers, Dordrecht, p. 71-89.

- PEIRANO, A., MORRI, C., and BIANCHI, N., 1999, Skeleton growth and density pattern of the temperate, zooxanthellate scleractinian *Cladocora caespitosa* from the Ligurian Sea (NW Mediterranean): Marine Ecology Progress Series, v. 185, p.195-201.
- , MORRI, C., MASTRONUZZI, G., and BIANCHI, N., 1998, The coral *Cladocora caespitosa* (Anthozoa, Scleractinia) as a bioherm builder in the Mediterranean Sea: Memorie descrittive della Carta geologica d'Italia, v. 52(1994), p. 59-74.
- , MORRI, C., BIANCHI, C. N., AGUIRRE, J., ANTONIOLI, F., CALZETTA., G., CAROBENE, L., MASTRONUZZI, G., and ORRÙ, P., 2004, The Mediterranean coral *Cladocora caespitosa*: a proxy for past climate fluctuations?: Global and Planetary Change, v. 40, p. 195–200.
- PEZELJ, D., SREMAC, J., and SOKAČ, A., 2007, Palaeoecology of the Late Badenian foraminifera and ostracoda from the SW Central Paratethys (Medvednica Mt., Croatia): Geologia Croatica, v. 60, p. 139-150.
- REID, C. M., 1998, Stratigraphy, paleontology, and tectonics of lower Miocene rocks in the Waipatiki/Mangatuna area, southern Hawke's Bay, New Zealand: New Zealand Journal of Geology and Geophysics, v. 41, p. 115-131.
- RUIZ, F., GONZÁLEZ-REGALADO, M. L., BORREGO, J., ABAD, M, and PENDÓN, J. G., 2004, Ostracoda and foraminifera as short-term tracers of environmental changes in very polluted areas: the Odiel Estuary (SW Spain): Environmental Pollution, v. 129, p. 49-61.
- , GONZÁLEZ-REGALADO, M. L., PENDÓN, J. G., ABAD, M., OLÍAS, M., and MUÑOZ, J. M., 2005, Correlation between foraminifera and sedimentary environments in recent estuaries of Southwestern Spain: Applications to Holocene reconstructions: Quaternary International, v. 140-141, p 21-36.
- SCHILLER, C., 1993a, Ecology of the symbiotic coral *Cladocora caespitosa* (L.) (Faviidae, Scleractinia) in the Bay of Piran (Adriatic Sea): I Distribution and biometry: Marine Ecology, v.14, p. 205-219.
- , 1993b, Ecology of the symbiotic coral *Cladocora caespitosa* (L.) (Faviidae, Scleractinia) in the Bay of Piran (Adriatic Sea): II Energy budget: Marine Ecology, v. 14, p. 221-238.
- SEMENIUK, T. A., 2001, Epiphytic foraminifera along a climatic gradient, Western Australia: Journal of Foraminiferal Research, v. 31, p. 191–200.
- SEN GUPTA, B. K., 1999a, Introduction to modern Foraminifera, in Sen Gupta, B. K. (ed.), Modern Foraminifera: Kluwer Academic Publishers, Dordrecht, p. 3-6.
- , 1999b, Foraminifera in marginal marine environments, in Sen Gupta, B. K. (ed.), Modern Foraminifera: Kluwer Academic Publishers, Dordrecht, p 141-159.
- , and MACHAIN-CASTILLO, M. L., 1993, Benthic foraminifera in oxygen-poor habits: Marine Micropaleontology, v. 20, p. 183-201.

- SERANDREI-BARBERO, R., ALBANI, A. D., and ZECCHETTO, S., 1997, Palaeoenvironmental significance of a benthic foraminiferal fauna from an archaeological excavation in the Lagoon of Venice, Italy: *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 136, p. 41-52.
- SERRANO, F., 1990, El Mioceno medio en el área de Níjar (Almería, España): *Revista de la Sociedad Geológica de España*, v. 3, p. 65-77.
- SHI, G. R., 1993, Multivariate data analysis in palaeoecology and palaeobiogeography-a review: *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 105, p. 199-234.
- USERA, J., and BLÁZQUEZ, A. M., 1997, Influencia del sustrato en la distribución de los foraminíferos bentónicos de la plataforma continental interna entre Valencia y Alicante (España): *Revista Española de Micropaleontología*, v. 29, p. 85-104.
- VAIANI, S. C., 2000, Testing the Applicability of Strontium Isotope Stratigraphy in Marine to Deltaic Pleistocene Deposits: An Example from the Lamone River Valley (Northern Italy): *The Journal of Geology*, v. 108, p. 585-599.
- VAN DER ZWAAN, G. J., 1983, Quantitative analysis and the reconstruction of benthic foraminiferal communities: *Utrecht Micropaleontological Bulletin*, v. 30, p. 49-69.
- VAN HINSBERGEN, D. J. J., KOUWENHOVEN, T. J., and VAN DER ZWAAN, G. J., 2005, Paleobathymetry in the backstripping procedure: Correction for oxygenation effects on depth estimates: *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 221, p. 245-265.
- VAN MARLE, L. J., 1989, Recent and fossil benthic foraminifera and late Cenozoic palaeobathymetry of Seram, eastern Indonesia: *Netherlands Journal of Sea Research*, v. 24, p. 445-457.
- VAN MORKHOVEN, F. P. C. M., BERGGREN, W. A., and EDWARDS, A. S., 1986, Cenozoic cosmopolitan deep-water benthic foraminifera: *Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine, Mem. 11, Pau*, 421 p.
- ZELLERS, S. D., 1990, Foraminiferal biofacies analysis of the Yakataga Formation, Icy Bay, Alaska: insights into Pliocene glaciomarine paleoenvironments of the Gulf of Alaska: *Palaios*, v. 5, p. 273-296.
- ZIBROWIUS, H., 1980, Les Scléactiniaux de la Méditerranée et de l'Atlantique nord-oriental: *Mémoires de l'Institut Océanographique*, v.11, p. 1-227.

**ASOCIACIONES DE FORAMINÍFEROS BENTÓNICOS ASOCIADAS A DEPÓSITOS
CON *CLADOCORA CAESPITOSA* (CUENCA DE ALMERÍA-NÍJAR, PLIOCENO
SUPERIOR, SE ESPAÑA)**

RESUMEN

Se han estudiado las asociaciones de foraminíferos bentónicos de la Unidad II del Plioceno Superior de la Cuenca de Almería-Níjar (SE España). Esta unidad representa una secuencia somerizante constituida por sedimentos siliciclásticos con intercalaciones de bancos de coral de *Cladocora caespitosa*. Estos se depositaron en una bahía somera protegida en la cual había abanicos deltaicos que progradaban. Las asociaciones de foraminíferos bentónicos registran la tendencia somerizante hacia techo inferida a partir del análisis de facies, especialmente en las partes distales de la cuenca (sección de Rambla Quebrada). Aquí, la parte inferior de la unidad contiene especies relativamente profundas como *Cibicides refulgens*, *Cibicidoides pseudoungerianus*, *C. bradyi*, *Asterigerinata* spp, *Lobatula lobatula*, *Rosalina globularis*, *Textularia* sp, *Lenticulina calcar* y elphídidos carenados. La parte superior de la unidad está dominada por especies de aguas muy someras como *Ammonia* spp y elphídidos sin carena. Las asociaciones de foraminíferos bentónicos de la parte inferior de la unidad además sugieren la existencia de aguas con salinidades típicas de mar abierto, mientras que las asociaciones de la parte superior dominadas por el género *Ammonia* indican aguas salobres. El continuo avance de los sistemas de abanicos deltaicos en un ambiente progresivamente más somero explica este cambio en los principales componentes de las asociaciones. La especies epifíticas *Elphidium* spp, *Cibicides refulgens*, *Lobatula lobatula*, *Rosalina globularis* y *Asterigerinata* spp dominan en la parte inferior de la unidad. Praderas de *Posidonia oceanica* probablemente proporcionaron un substrato vegetado en las áreas distales (sección de Rambla Quebrada), mientras que algas pequeñas, arborescentes y poco longevas dominaron en los ambientes proximales (sección de Rambla de la Sepultura). La abundancia relativa de especies epifíticas se reduce considerablemente hacia la parte superior de la unidad como consecuencia de la progradación de abanicos deltaicos que provocaron un incremento de la turbidez del agua y una mayor influencia de aguas dulces. Los foraminíferos que habitan en sedimentos finos (*Reussella spinulosa* y *Nonion asterizans*) dominan en la parte media-alta de la unidad. *Cancris auriculus*, *Nonion asterizans* y *Cassidulina neocarinata* son también localmente abundantes en la parte alta de la unidad. Estas especies normalmente abundan en presencia de alto contenido en materia orgánica. El avance de los abanicos deltaicos produjo un aumento del

contenido en nutrientes. Además, especies que toleran aguas pobres en oxígeno aparecen en los sedimentos con laminación de tipo varva de la parte superior de la unidad: *Bulimina aculeata* y *Fursenkoina acuta*. Los componentes minoritarios de esta asociación de especies que sobreviven en ambientes pobres en oxígeno son *Bolivina dilatata*, *Bulimina costata*, *B. marginata*, *Cassidulina laevigata*, *Pleurostomella* sp. y *Rectuvigerina multicosata*. La aparición de esta asociación se debe a una escasa circulación del agua probablemente debida a una estratificación de la columna de agua relacionada con las descargas de agua dulce que originan capas de agua con concentraciones de sal diferentes.

CONCLUSIONES

1. Los depósitos del Plioceno Superior de la Cuenca de Almería-Níjar (SE España), llamados Unidad II, registran una secuencia de somerización depositada en una bahía protegida en la cual abanicos deltaicos progradaban hacia el centro de la cuenca. Las asociaciones de foraminíferos bentónicos reflejan esta tendencia, especialmente en posiciones distales (Sección de Rambla Quebrada) donde la parte inferior de la unidad contiene especies que viven en la plataforma media-externa (*Cibicides refulgens*, *Cibicidoides pseudoungerianus*, *C. bradyi*, *Lobatula lobatula*, *Asterigerinata* spp, *Rosalina globularis*, *Textularia* sp, *Lenticulina calcar* y elphídidos con carena) y la parte media-superior está dominada por especies muy someras (*Ammonia* spp, *Haynesina depressula*, y elphídidos sin carena).

2. Las asociaciones de foraminíferos bentónicos encontradas en la parte media-alta de la unidad además indican condiciones salobres. La continua progradación de los abanicos deltaicos provocó un incremento progresivo de la descarga de agua dulce hacia la parte superior de la unidad.

3. Las asociaciones de foraminíferos bentónicos dominadas por especies epifíticas dominan la parte baja de la unidad: *Elphidium* spp, *Cibicides refulgens*, *Lobatula lobatula*, *Rosalina globularis* y *Asterigerinata* spp. En la parte inferior de la sección de Rambla Quebrada (zona distal de la cuenca) el substrato vegetado que más probablemente se desarrolló es *Posidonia*. El progresivo aumento de las descargas de agua dulce y de sedimento hacia la parte superior de la unidad impidió el desarrollo de este tipo de vegetación favoreciendo el desarrollo de algas pequeñas, arborescentes y poco longevas.

4. Los foraminíferos que viven en sedimento fino como *Reussella spinulosa* y *Nonion asterizans* proliferaron en la parte media-alta de la Unidad II, asociados con sedimento fino de los ambientes de abanico deltaico medio.

5. La progradación de los abanicos deltaicos dio lugar a un cierre progresivo de la Cuenca del

Almería-Níjar durante el depósito de la parte superior de la Unidad II, produciendo una desconexión gradual entre la cuenca y el Mar Mediterráneo. Como consecuencia de esto, se establecieron fondos con aguas pobres en oxígeno. La reducción de la circulación de agua puede estar relacionada con las descargas de agua dulce que produjeron capas de agua con diferente salinidad.

6. La abundancia local de *Cancris auriculus*, *Nonion asterizans* y *Cassidulina neocarinata* en sedimentos muy relacionados con los depósitos con laminación de tipo varva sugiere un alto flujo de materia orgánica proporcionado por los abanicos deltaicos.