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Inner shelf paleoenvironmental evolution as a function of land–ocean interactions in the vicinity of the Guadiana River, SW Iberia

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ABSTRACT

This study investigates the land–ocean interactions along the northern margin of the Gulf of Cadiz in the vicinity of the Guadiana River. Benthic foraminifera and sedimentological characteristics were analysed in a sedimentary sequence spanning ca. 5000 years (core 8, 22 m water depth) retrieved from the inner shelf prodeltaic wedge. The analyses were integrated in a temporal framework based on accelerated mass spectrometry radiocarbon dating. Paleoenvironmental changes and sediment transfer mechanisms from the continent to the shelf were investigated and related to climatic oscillations and anthropogenic impact in the region.

The results allowed the identification of two main periods of deposition. The first period, from ca. 5150 cal. BP (core base) to 1500–1200 cal. BP, is characterised by a mix of fine and coarse sediments, relatively constant percentages of terrigenous and bioclasts, and benthic foraminifera species characteristic of coastal environments. These features indicate an environment strongly influenced by discharge from the Guadiana River. The second period, from ca. 1500–1200 cal. BP to ca. 200 cal. BP (core top), is characterised by silt-clay fraction dominated sediments, an increase in terrigenous sediment towards the top, and benthic foraminifera species characteristic of environments with low levels of energy. An increase in the level of human occupation associated with changes in climate led to widespread erosion and soil loss to the continental shelf during this period, with possible silting up of the Guadiana eastern distributary, allowing the transport of high amounts of sediment to the shelf by the western distributary that led to the enhancement of fine sedimentation and the formation of the prodeltaic wedge in the area of the studied core.

1. Introduction

Continental shelf mud deposits have received greater interest in studies of Holocene paleogeography and paleoclimate, because sedimentary reservoirs with high depositional rates are capable of registering rapid environmental changes and high-frequency events (Lesueur et al., 1996; Bauch et al., 2001; Oldfield et al., 2003). In addition, such depositional environments are characterised by the transfer of energy and sediments between the continent and the ocean. Therefore, variations in sediment supply and patterns of shelf deposition detected in these deposits can be linked to the occurrence of climatic oscillations and/or modifications in anthropogenic impact. It is also well established that floods represent one of the most important transfer mechanisms of sediments to the shelf, and that their frequency and intensity is strongly controlled by climate variations, particularly in semi-arid regions (Dias et al., 2004). Furthermore, the amount of sediment available for export to coastal areas depends on the intensity of the erosion processes along the relevant river basin, which in turn have been significantly affected by the impact of human activities over time (Chester and James, 1999; Boone and Worman, 2007; Gonzalez et al., 2007).

With respect to the paleogeography of Southwestern Iberia, various studies have focused on the transgressive sequences and highstand deposits along the northern margin of the Gulf of Cadiz (e.g. Nelson et al., 1999; Gonzalez et al., 2004; Lobo et al., 2005; Mendes et al., 2006; Rosa et al., 2008), while other studies have investigated the estuarine infilling of the Guadiana River (e.g. Boski et al., 2002, 2008). However, information concerning the recent evolution of transitional sedimentary deposits, such as the Guadiana prodeltaic wedge, is still lacking and is likely to be crucial in understanding the rapid climatic and environmental changes associated with the Holocene. In this context, the main goals of the

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present study are to determine the nature of land–ocean interactions in the Guadiana inner shelf and to investigate the paleoenvironmental changes associated with climatic and anthropogenic impacts in the area. For this purpose, sedimentological examinations and benthic foraminifera analyses were performed on a sedimentary sequence extracted from the Guadiana prodeltaic wedge.

2. Regional setting

The study area is located in the Southwestern Iberian Peninsula, specifically the inner shelf on the northern margin of the Gulf of Cadiz close to the Guadiana River mouth (Fig. 1). The Guadiana estuary is one of the most important fluvio-marine systems of SW Iberia, and its main channel works as a bypass channel through which sediments are supplied from the continent to the adjacent shelf (Lobo et al., 2002; Morales et al., 2006). The Guadiana River is the main regional sediment source to the continental shelf and drains a semi-arid region (Loureiro et al., 1986). The region is influenced by both small-scale climatic variations (such as dry summers alternating with wet winter floods) and large-scale variations such as the North Atlantic Oscillation (NAO). Episodic floods play a major role in the supply of sediment from the river to the continental shelf (Morales, 1997; Portela, 2006). Littoral drift provides the second regional source of sediments to the shelf, mainly sand which is transported eastward along the coastline from the Portuguese coast to the eastern section of the Gulf of Cadiz (e.g. Gonzalez et al., 2001).

At the beginning of the Holocene, around 9800 yr BP, the Guadiana estuary started to be rapidly infilled with clay sediments, and between 7500 and 7000 yr BP the central part of the estuary began to accommodate coarser sediments partly derived from the adjacent shelf, whilst clay continued to deposit in the marginal lagoons (Boski et al., 2002). Since that time, sea level rise decelerated, leading to the enclosure of lagoons behind sand spits, and the deposition of predominantly sandy sediment inside the estuary, until stabilization of sea level at close to the present level took place around 5000 yr BP (Boski et al., 2002).

The patterns of sediment distribution in the northern Gulf of Cadiz shelf indicate that, since the Late Quaternary, depositional dynamics express the interaction of several factors dominated by the eastward transport of sediments under the influence of south-eastward Atlantic inflow currents (Nelson et al., 1999). The morphology

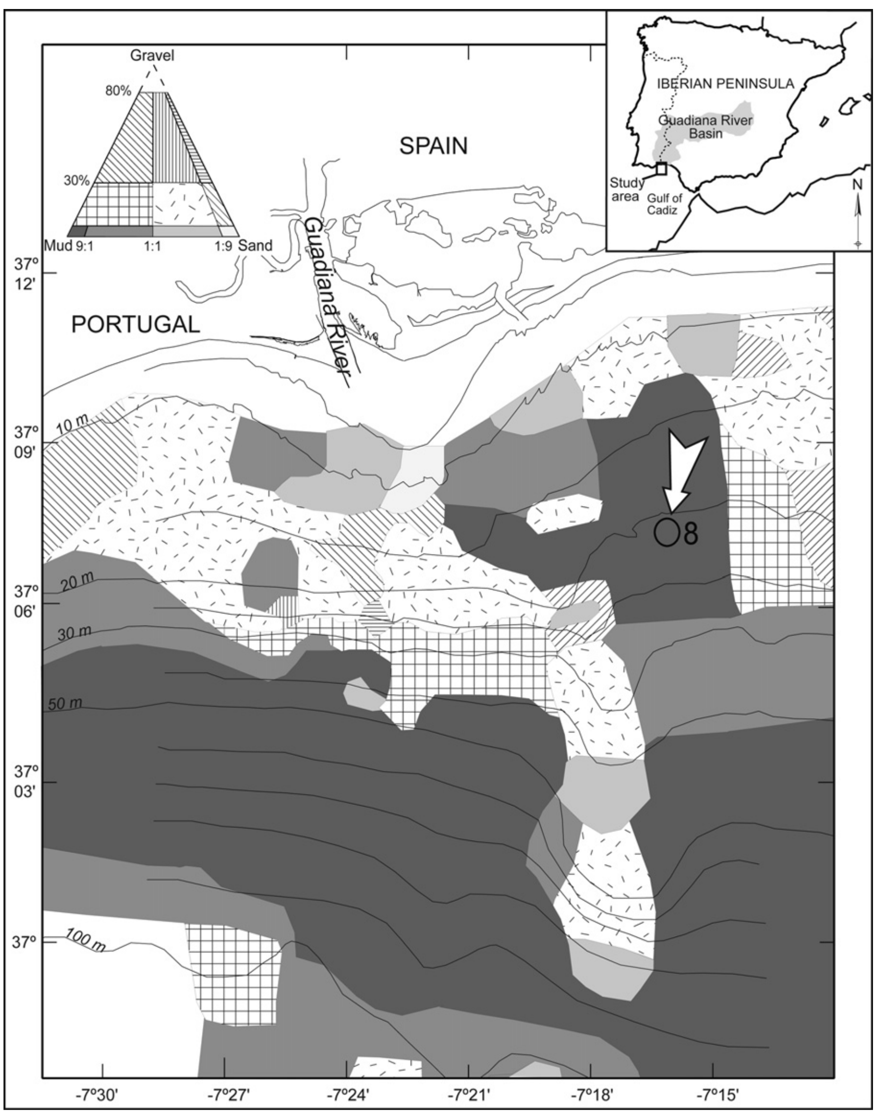

Fig. 1. Location of core 8 and the distribution of surface sediments on the continental shelf off the Guadiana River. Adapted from Gonzalez et al. (2004).

of the Guadiana shelf is complex and has an important influence on both sedimentary processes and the distribution of sediment. Modern sediment distribution patterns show an important depth control and indicate the strong influence of river discharge in the depositional system (e.g. Gonzalez et al., 2004). Sediments of the inner shelf close to the Guadiana river mouth, in water depths shallower than about 10 m, correspond essentially to fine sands, which become finer both westward and eastward and are dominated by terrigenous particles, mainly quartz (Gonzalez et al., 2004). Other terrigenous sediments are found in large quantities in this area close to the river mouth, including fragments of Paleozoic metaschists and greywackes that are abundant along the river basin. Increasing water depth is accompanied by coarser deposition, in the form of several coarse-sand patches distributed between the 10 and 30 m bathymetric contours (Fig. 1), where quartz remains the most abundant component (Gonzalez et al., 2004). To the east of the Guadiana River mouth, the sandy deltaic bulge gives place to a highstand deposit of silt-clay material (Fig. 1), identified as the Guadiana prodeltaic wedge (Fernández-Salas et al., 1999; Gonzalez et al., 2004). Fine sedimentation of the prodeltaic wedge occurs together with an increasing quartz component in all fractions (Gonzalez et al., 2004). The middle shelf is characterised by an extensive mud belt, which to the east of the Guadiana River is cut from north to south by a transgressive wedge composed of muddy gravelly sands and muddy sands (Fig. 1). The sand fraction in the Guadiana Mud Patch presents very low percentages and corresponds essentially to grains of bioclastic origin, mainly foraminiferal tests (Gonzalez et al., 2004).

3. Materials and methods

3.1. Core collection and sampling

Core 8 was extracted from the Guadiana prodeltaic wedge (Fig. 1) by vibrocoring. This core of 376 cm length was collected in July 2002 during the campaign CRIDA 0702, on board the vessel *Aguayo*, at latitude 37°7′6″N, longitude 7°16′6″W, and a water depth of 22 m. In the laboratory the core was vertically sectioned in two parts, with one part being frozen for archiving and the other part immediately sampled at intervals of 1 cm from the top until 50 cm and at intervals of 2 cm from there to the base of the core. Each level was sampled for geochemistry (not used in this study), grain size, and benthic foraminifera.

3.2. AMS radiocarbon dating

Four accelerated mass spectrometry (AMS) radiocarbon datings were performed (Beta Analytic, USA) using a mixture of benthic foraminifera, between 20 and 40 mg for each sample. The calibration of radiocarbon ages to solar calendar was made with the program Calib 5.1 (Stuiver et al., 2005), using the MARINE 04 curve with a global ocean reservoir correction of about 400 years (Stuiver and Reimer, 1993). The local reservoir (delta R) effect was applied according to Soares and Dias (2006) and Soares (2008), in this case 0 ± 100 for dates older than 2000 radiocarbon years and -135 ± 20 for dates younger than 2000 radiocarbon years.

3.3. Grain size

Grain size analyses were performed sequentially along the core. When insufficient material was available, two or more adjacent levels were combined. Samples were washed with hydrogen peroxide to remove organic matter. Fine (silt and clay) and coarse (sand and gravel) fractions were wet separated using a 63 μm (4 phi) sieve. The fine fraction was analysed using the pipette method and the coarse fraction was separated by dry sieving using a sieve rack. Both fractions were separated in phi intervals. Textural classification followed Folk (1954).

3.4. Components of the sand fraction

Components of the sand fraction were analysed in 38 samples, collected at the top of the core (1 cm slice) and at every 10 cm (2 cm slices). For each phi class of the sand fraction, 100 grains were counted and identified under a binocular microscope to determine the main components (terrigenous and biogenic) of the sediment. Grains were classified visually as quartz, mica, schists and greywackes, other terrigenous, glauconitic, foraminifera, molluscs, and other bioclasts. For each sample, the weighted mean was calculated as the total sum of grains in each phi class multiplied by their weight, and divided by the total weight of the sand fraction.

3.5. Benthic foraminifera

Analyses of benthic foraminifera were performed on 38 samples collected from the core at 10 cm intervals, using 1 cm sediment slices from the top to 50 cm depth and 2 cm slices from this depth to the core base. Each sample was washed with running water for 10–15 min through 63 and 2000 μm sieves. The respective fractions 63–2000 μm and >2000 μm were dried in an oven at 50 °C and weighed. The 63–2000 μm fraction was separated in aliquots using a micro-splitter placed in a picking tray and afterwards analysed using a binocular microscope. Whenever possible, at least 300 well preserved benthic foraminifera tests were collected from each sample and mounted on lightly glued cardboard slides, identified, and counted. Benthic foraminifera were identified according to Jones (1994), Ellis and Messina (1942), Levy et al. (1995), and Martins and Gomes (2004). The relative abundance and the number of benthic foraminifera per gram of dry sediment, excluding the gravel fraction, were calculated.

The Shannon index (H), a measure of diversity, was computed taking into account the number of individuals (n) and the number of species, using the formulation $H = -\Sigma\ ni/n \ln ni/n$ (Murray, 2006). The index varies from 0 in single species assemblages to high values when all species in the sample are equally abundant. Cluster analyses were performed using the PAST program (Hammer et al., 2008). A matrix of data was constructed using species with abundance >5% in at least one analysed sample. R-mode cluster analyses were used to group species using the correlation method, and clusters were joined using the unweighted pair-group average (UPGMA). In this method, clusters are joined based on the average distance between all members in the two groups. Q-mode cluster analysis was performed using Ward's method, whereby clusters are joined in such a way that the increase in within-group variance is minimized.

4. Results

4.1. Grain size and chronology

Grain size analyses allow the identification of two distinct units in core 8 (Fig. 2). The lower unit (376–157 cm) generally presents similar percentages of fine (clay-silt) and coarse (sand-gravel) fractions, with a mean grain size around 4–5 phi. The exception is the clayey silt unit between 318 and 290 cm, which has a mean grain size of 6–7 phi. The upper unit, between 157 and 4 cm, is characterised by a higher percentage of silt-clay, with the exception of sporadic levels of coarser material. The fine fraction reaches >90% of total sediment, with mean grain size values ranging from 7 to 8 phi. The top 4 cm of the core are characterised by a large increase in the gravel fraction, with mean grain size values reaching −2.72 phi at the top of the core (Fig. 2).

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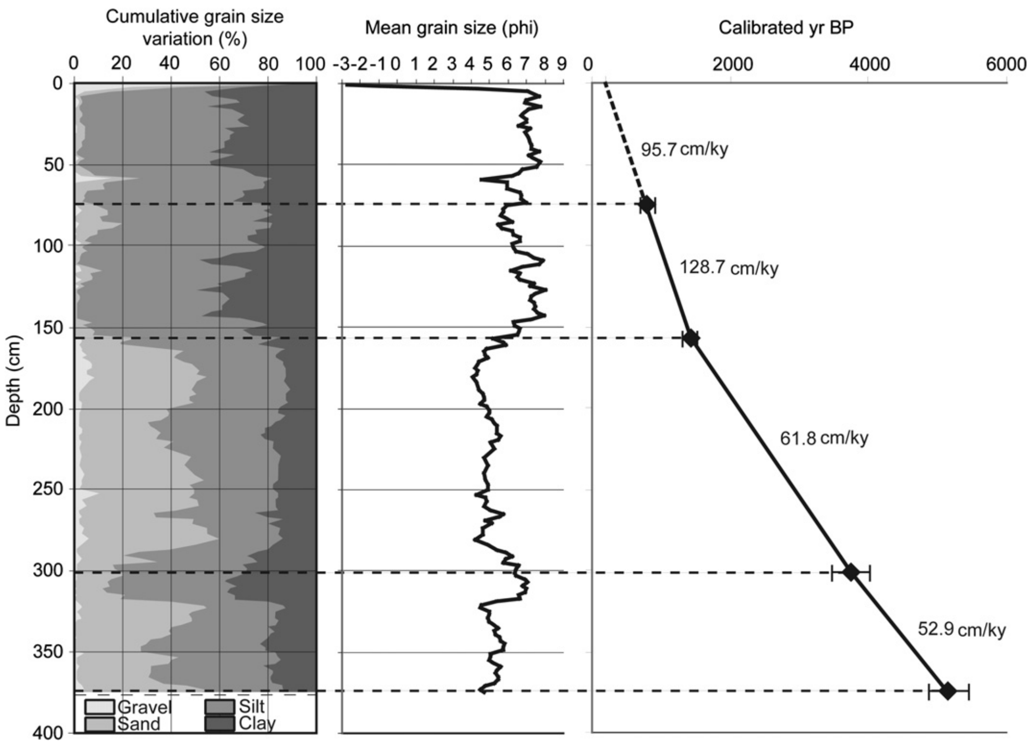

Fig. 2. Variation in cumulative grain size, mean grain size, age, and sedimentation rate with depth (cm) in core 8.

The chronology of core 8 is based on four AMS ^{14}C calibrated ages, corrected for the local reservoir effect (Table 1). The ^{14}C date obtained at the base of the core (374–376 cm) indicates that the sediments in the core record the history of deposition since ca. 5150 cal. BP. Calculated mean sedimentation rates (Fig. 2) assume a stable accumulation rate between the dated levels and are not corrected for compaction. The zero validation for the age model gives an age of ca. 200 years for the top of the core. The lowest sedimentation rate (ca. 53 cm/ky) was observed between 375 and 301 cm core depth, and the highest (ca. 129 cm/ky) between 157 and 77 cm.

4.2. Components of the sand fraction

Analysis of the sand fraction components shows that terrigenous grains are always more abundant than bioclasts. Quartz (ranging from 46 to 75%) dominates through the entire core, but other terrigenous minerals and mica also have significant percentages (Fig. 3). Important fluctuations in the relative abundance of terrigenous and biogenic components occur through the sedimentary record, on the basis of which two distinct units can be identified. The lower unit (376–157 cm), representing the period ca. 5150 to 1500–1400 cal. BP, presents relatively constant percentages of all sand fraction components, with terrigenous varying from 63 to 83% and biogenic components from 17% to 37%. The higher abundances of biogenic components, namely molluscs, correspond to two peaks in the sand fraction (~35%) at approximately 3400 and 1800 cal. BP (Fig. 3). The upper unit (157–4 cm) shows an increase in the terrigenous components from ca. 1650–1400 cal. BP to maximum abundance values (95%) attained in the core top at ca. 200 cal. BP. The biogenic components, namely the foraminifera and molluscs, show a consequent decreasing trend from 30 to 5% through the unit. The transition between the units occurs at ca. 1500 and 1400 cal. BP, when the silt-clay fraction increases substantially (Fig. 3).

Table 1
AMS radiocarbon age data from core 8.

Depth (cm)	Lab no.	Conventional radiocarbon age (BP)	Local reservoir effect	2 Sigma calibrated results (cal. BP)
76–78	Beta-204308	1120 ± 40	−135 ± 20	698–902
156–158	Beta-204309	1750 ± 40	−135 ± 20	1319–1533
300–302	Beta-204310	3800 ± 40	0 ± 100	3468–4041
374–376	Beta-194506	4870 ± 40	0 ± 100	4870–5437

4.3. Benthic foraminifera

The number of benthic foraminifera tests per gram of dry sediment in core 8 varies between 17 (ca. 600 cal. BP) and 3090 (ca. 5000 cal. BP) (Fig. 4a). Based on benthic foraminiferal assemblages, two units can be discriminated through the sedimentary record. The lower unit extends from the core base (ca. 5150 cal. BP) until approximately 1400–1200 cal. BP, and is characterised by a higher number of benthic foraminifera (mean value of 1500 tests/g). The upper unit, extending from 1400 to 1200 cal. BP to the top (ca. 200 cal. BP), is characterised by a lower and relatively constant number of tests/g (mean value of 600 tests/g) (Fig. 4a). The maximum number of species (115) was observed at ca. 1400 cal. BP and the minimum (30) at ca. 600 cal. BP (Fig. 4b). The maximum value coincides with the transition between the two units as described, and the minimum number of species with the middle of the upper unit. The Shannon index of diversity ranges from 3.11 to 4.05 and shows small variations through the core with the most abrupt change occurring in the transitional portion (Fig. 4c).

Twelve benthic foraminifera species showed relative abundance values >5% in at least one analysed sample. A first group of species includes *Asterigerinata mamilla* (Williamson) with abundances from 0 to 12%, *Planorbulina mediterranensis* (d'Orbigny) from 0 to 23%,

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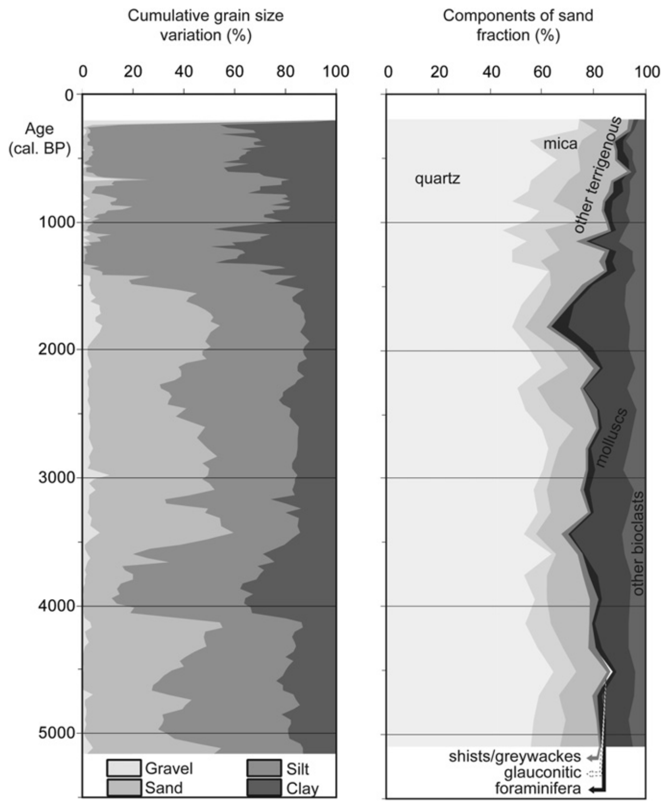

Fig. 3. Variation in cumulative grain size and components of the sand fraction with age (cal. BP) in core 8.

Quinqueloculina stelligera (Schlumberger) from 0 to 6%, *Cribroelphidium gerthi* (Von Voorthuysen) from 1 to 10%, and *Nonionella stella* (Cushman and Moyer) from 0 to 6%. These species present relatively constant abundances from the core base until ca. 1400–1200 cal. BP (lower unit) (Fig. 5). From this level to the core top the abundance values decrease for all mentioned species, with the exception of *N. stella* which shows two peaks of abundance during this period (ca. 1100 and 900 cal. BP) (Fig. 5). Most of the species of this first group present lower values between 1400 and 1200 cal. BP and 200 cal. BP (upper unit).

A second group of species with relative abundance values >5% in at least one sample includes *Bolivina ordinaria* (Phleger and Parker) with abundances from 5 to 29%, *Bulimina marginata* (d'Orbigny) from 0 to 6%, *Hopkinsina atlantica* (Cushman) from 0 to 27%, *Bulimina aculeata* (d'Orbigny) from 0 to 9%, *Eggerelloides scaber* (Williamson) from 0 to 14%, *Cribroelphidium excavatum* (Terquem) from 0 to 6%, and *Ammonia beccarii* (Linné) from 2 to 10%. These species exhibit contrasting behaviour to those of the first group, by presenting their lowest abundances from the core base to 1400 cal. BP (lower unit) and increasing in abundance from ca. 1400–1200 cal. BP to the core top (upper unit) (Fig. 6). *E. scaber* and *A. beccarii* present their peaks of abundance (14 and 10%, respectively) at ca. 600 cal. BP. *A. beccarii* is the only species of this group that presents a peak of abundance in the lower unit of the core, at ca. 2000 cal. BP. All the species from both groups are present in more than 50% of the samples, with the exception of *B. marginata*, *H. atlantica*, and *E. scaber*, which appear in 30–50% of the samples, with the lower frequencies being observed in the lower unit of the core.

Cluster analyses were performed using the 12 species with >5% abundance in at least one analysed sample. These species comprise between 44 and 63% of all species found in each of the 38 analysed samples, with an average value of 52%. R-mode cluster analyses, using a correlation similarity measure, a paired group algorithm, and a cophenetic correlation value of 0.9128, produced a dendogram which distinguishes two assemblages or clusters (Fig. 7a). These clusters are closely linked with the groups formed by the individual distribution of the most abundant species. Cluster I, with *A. mamilla*, *P. mediterranensis*, *Q. stelligera*, *Cribroelphidium gerthi*, and *N. stella*, corresponds to an assemblage of species with relatively constant abundances from the base to ca. 1400–1200 cal. BP (lower unit), and a decreasing abundance trend from this level to the core top (upper unit) (Fig. 5). Cluster II, with *B. ordinaria*, *B. marginata*, *H. atlantica*, *B. aculeata*, *E. scaber*, *C. excavatum*, and *A. beccarii*, includes species that present the lowest abundances from the core base to 1400 cal. BP (lower unit) and an increase in abundance from ca. 1400–1200 cal. BP to the core top (upper unit) (Fig. 6).

Q-mode cluster analyses, with a cophenetic correlation value of 0.7483, also produced two distinct clusters. Cluster A, with 23 samples, groups all the samples from the core base to ca. 1300 cal. BP (lower unit). Cluster B, with 15 samples, groups all samples that correspond to the period extending from ca. 1300 cal. BP to ca. 200 cal. BP (upper unit) (Fig. 7b).

5. Discussion

Core 8 reflects the environmental changes that occurred on the inner shelf offshore of the Guadiana River during the last ca. 5000 cal. BP, a time frame that corresponds to the attainment of present mean sea level in this region (Boski et al., 2002). This time scale is supported by the temporal framework (age model) established for the core, in which approximately constant sedimentation rates were observed through time (Fig. 2). In all samples taken from the core, quartz is the most abundant component in the sand fraction, which with the significant amount of mica and other terrigenous throughout the core points to a dominant fluvial origin of the sand fraction. The Shannon index diversity is relatively constant through the core, indicating a normal marine shelf environment (Murray, 2006). However, on the basis of vertical variations in grain size distribution, in the mineralogical components of the sand fraction, and in the distribution of individual benthic foraminifera in the assemblages, supported by R-Q-mode cluster analyses, two different periods of deposition can be identified in the core. The first period extended from ca. 5150 cal. BP (core base) to 1500–1200 cal. BP (lower unit), and the second from 1500 to 1200 cal. BP to ca. 200 cal. BP (core top) (upper unit), as detailed below.

5.1. Lower unit: ca. 5150 to 1500–1200 cal. BP

During this period the similar percentages of the fine and coarse fractions, together with the relatively constant percentages of all components of the sand fraction and of individual abundances of benthic foraminifera through the core, indicate relatively stable climatic and environmental conditions at the location of the core. R-mode cluster analysis confirms the individual abundances of benthic foraminifera, supported by Q-mode cluster analysis which distinguishes all samples from this period.

According to Mendes et al. (2004), the distributions of recent benthic foraminifera species such as *A. mamilla* and *P. mediterranensis* on the Guadiana shelf show that they are more abundant in shallow waters (up to 12 m), whereas *Cribroelphidium gerthi* (identified by Mendes et al. as *Cribrononion gerthi*) is more abundant at water depths of 12–40 m. The abundance of these species in sediments with high sand content has been identified previously, including *A. mamilla* (Pujos, 1976), *P. mediterranensis* (Villanueva and Cervera, 1999; Mendes et al., 2004), and *Cribroelphidium gerthi* (Mendes et al., 2004). *N. stella* is usually well represented in

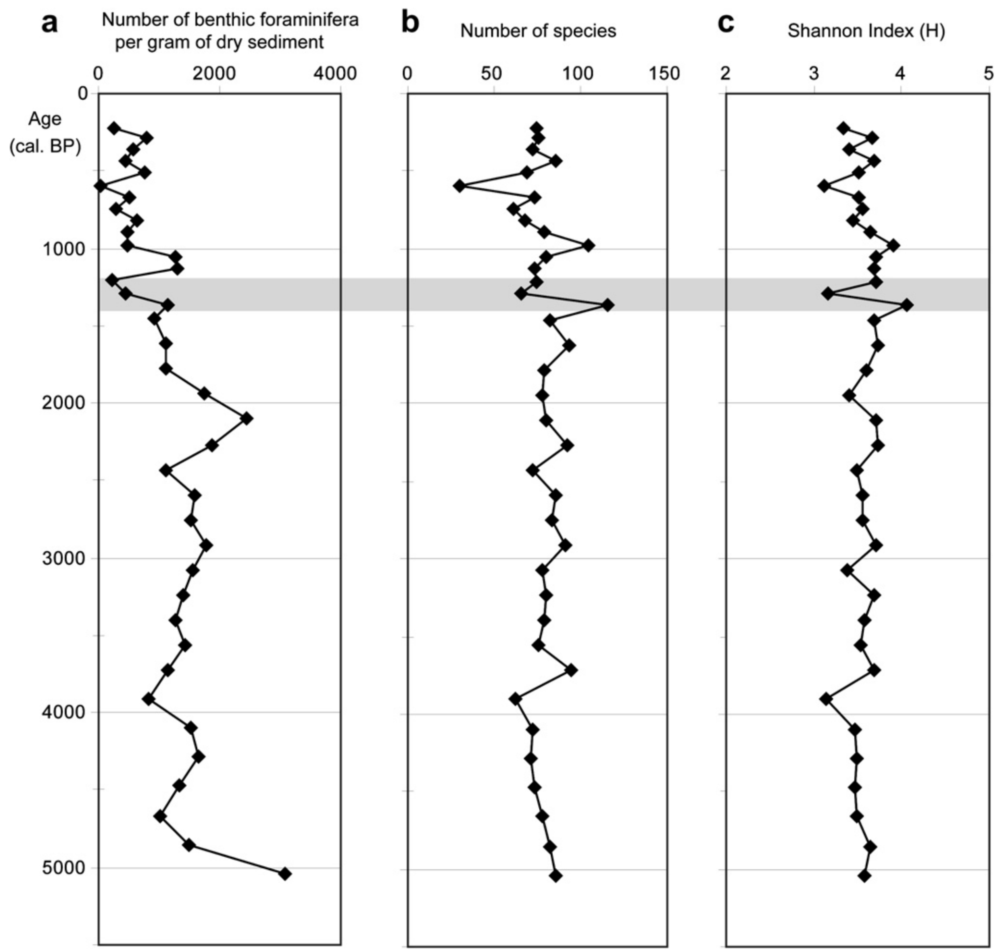

Fig. 4. Variation with age (cal. BP) in core 8 in: a) number of benthic foraminifera per gram of dry sediment; b) number of species; and c) Shannon index of diversity. The grey band denotes the transitional stage between the two identified depositional units.

environments with low oxygen conditions (Bernhard and Sen Gupta, 1999), and its presence in this section of the sedimentary record seems to indicate that dysoxia or short periods of anoxia might have occurred. This is evident at ca. 3700 cal. BP, around which time increases in both the percentage of fine fraction and the abundance of *N. stella* were observed, and within the upper unit, after the establishment of the fine fraction dominance, at ca. 1100 and 900 cal. BP respectively (Figs. 3 and 5). The relatively constant and higher abundances of these species in the oldest sediments of the core can be interpreted as representative of a depositional unit formed under the direct influence of the Guadiana River. The description by Strabo (Geographica, III, 1, 9) of the southern Iberian Peninsula reports the existence of two mouths of the Guadiana Delta around 2000 cal. BP. This description, together with geomorphologic evidence, indicates that the easternmost distributary of the Guadiana estuary could have been active for a time, and may have been responsible for direct river discharge into the location of the present-day prodeltaic wedge.

5.2. Upper unit: 1500–1200 to ca. 200 cal. BP

The period between 1500 and 1200 cal. BP is interpreted as a transitional stage, characterised by a rapid increase in the percentage of the fine fraction and a smooth increase in the terrigenous grain component, as well as by important shifts in individual benthic foraminifera abundances. The maximum number of benthic foraminifera species occurs during this time (Fig. 4b), a clear indication of a transitional stage in which species from the lower and upper units coexist for some duration until the stabilization of the new environmental conditions. The higher abundances shown during this stage by species associated normally with high amounts of organic carbon, such as *B. ordinaria* (Martins et al., 2006) and *B. marginata* (Donnici and Barbero, 2002), also point to environmental changes. Palynological evidence in the lower Guadiana valley (Fletcher et al., 2007) indicates human influence on the landscape after ca. 4000 cal. BP, with intensification of human impact on woodland resources and a considerable anthropogenic influence on the landscape during the protohistoric periods (Iron age, Roman). During the Roman occupation in the Iberian Peninsula, between 218 BC and 411 AD (ca. 2168–1539 cal. BP) (Alarcão, 1988), the Guadiana River drained agricultural products such as wine (Alarcão, 1988) and copper from the exploration of São Domingos mines (Fabião, 1992). Between 1500 and 1000 cal. BP, climatic deterioration occurred in northern Europe characterised by a rapid cooling (Lamb, 1977). The increase in fine sediment proportions and shifts in the benthic foraminiferal assemblages observed for the inner shelf between 1500 and 1200 cal. BP could be related to possible change in climate characterised by enhanced humid conditions in southern Europe that allowed the transportation of large volumes of sediment to the continental shelf.

After 1200 cal. BP and extending up to the core top, the relatively constant abundance values of the fine fraction and the smooth increase in terrigenous components, as well as the variations in abundance of individual benthic foraminifera species and the lower

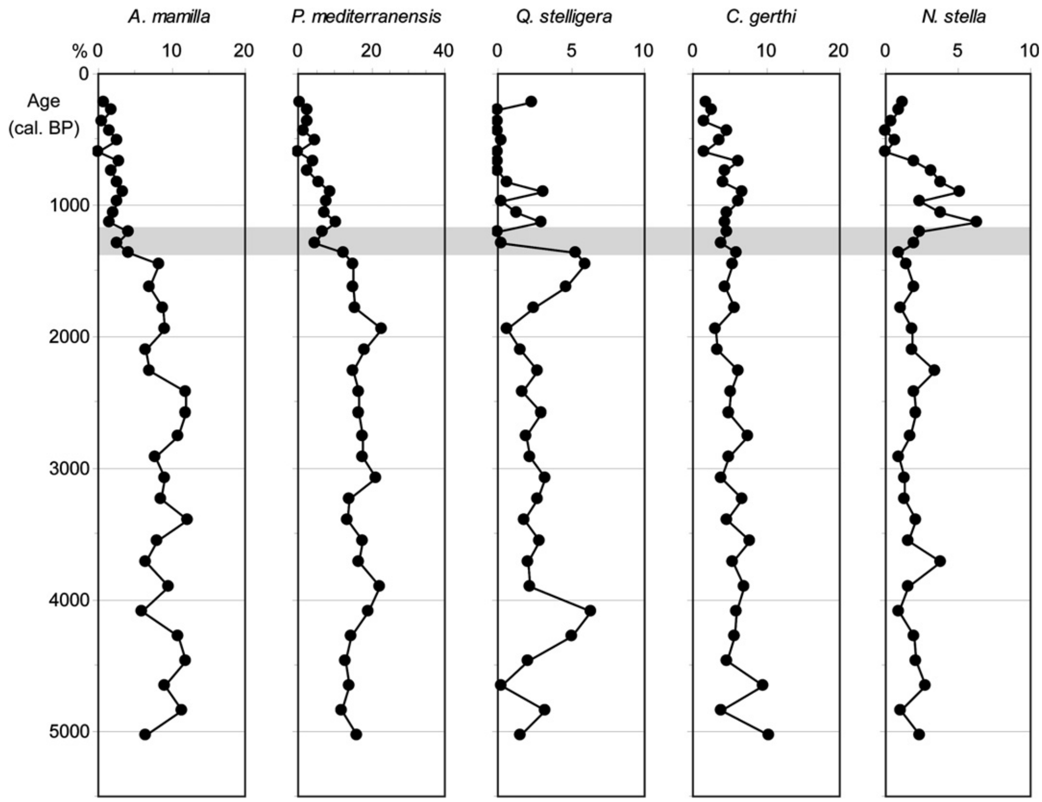

Fig. 5. Variation in the main species relative abundance (%) in the lower unit with age (cal. BP) in core 8. The grey band denotes the transitional stage between the two identified depositional units.

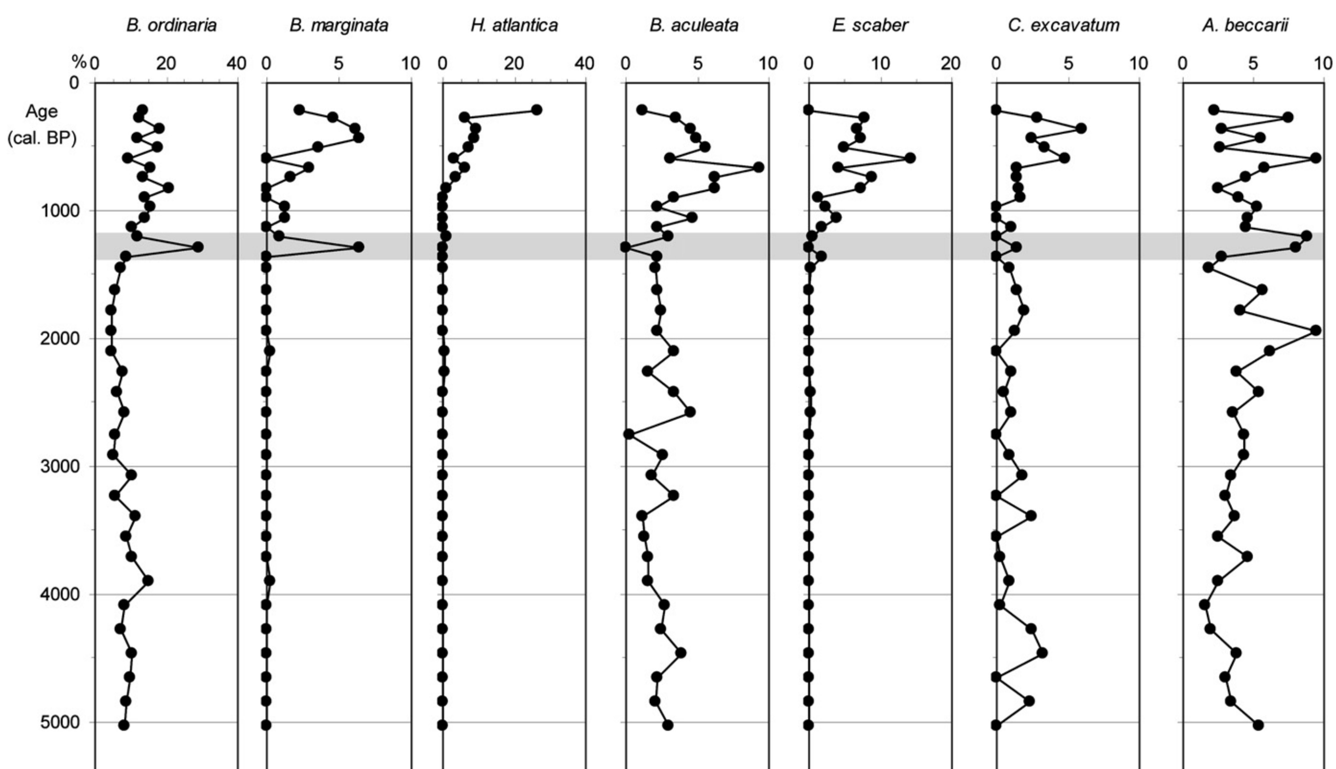

Fig. 6. Variation in the main species relative abundance (%) in the upper unit with age (cal. BP) in core 8. The grey band denotes the transitional stage between the two identified depositional units.

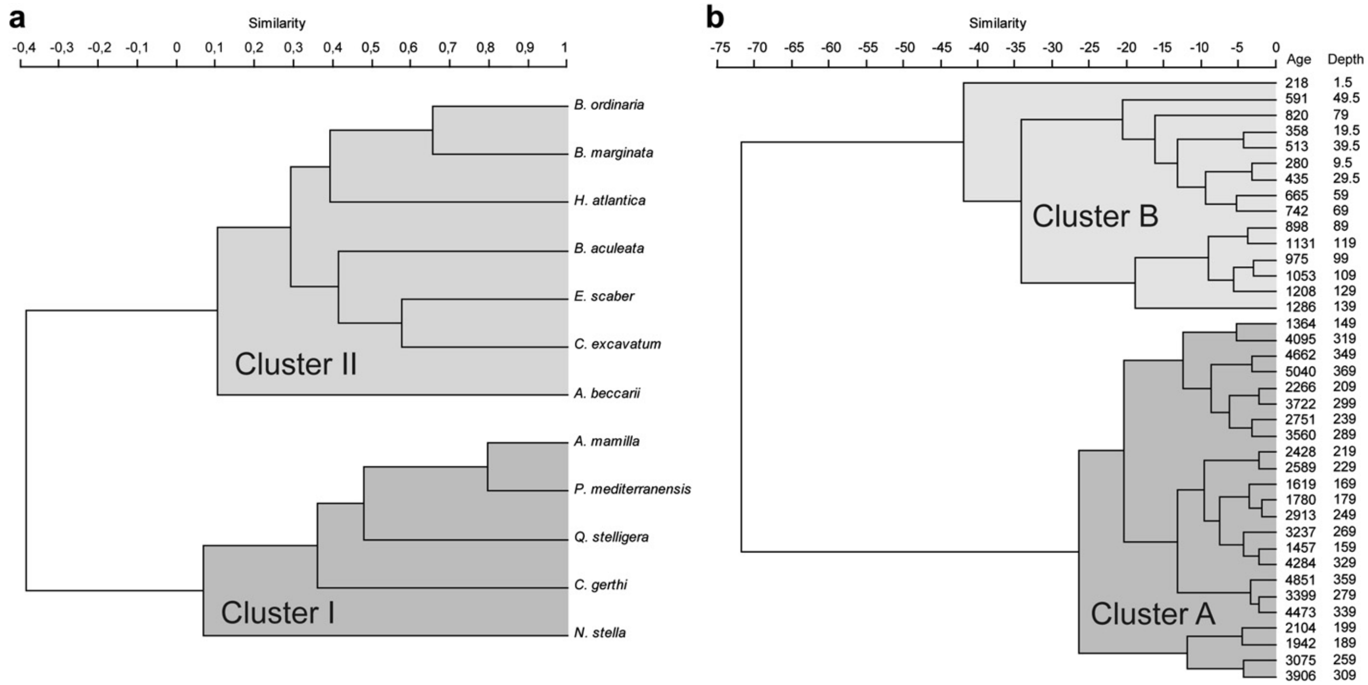

Fig. 7. Dendrogram classification resulting from cluster analyses based on the 12 species with relative abundances higher than 5% in at least one sample: a) Foraminiferal assemblages produced by R-mode analysis (correlation method joined by UPGMA); b) Sample associations produced by Q-mode analysis (Ward's method).

number of benthic foraminifera per gram of dry sediment (Fig. 4a), together indicate the establishment of new climatic and environmental conditions in this area. Within this period, an obvious change seems to occur at ca. 600 cal. BP, when the number of benthic foraminifera reaches a minimum and some species such as *A. beccarii* and *E. scaber* present their peaks of abundance. *A. beccarii* is a typical estuarine form from the Guadiana estuary (Ruiz et al., 2005) and *E. scaber* occurs with higher abundances near the Guadiana River mouth (Mendes et al., 2004). Their highest abundances, associated with a smooth peak of gravel and sand (ca. 650 cal. BP), could be related to a wetter phase such as that identified by Abrantes et al. (2005) in the Tagus prodelta (western Iberian margin) and interpreted as the beginning of the Little Ice Age. According to Dias et al. (2004), discharges from the Guadiana River in the last 50 years show a strong link with the NAO index, with negative values usually resulting in more rainfall and subsequent flooding in the river basin during winter months. The reconstruction of the NAO Index for the last 500 years (Luterbacher et al., 2002) also indicates negative NAO values between 1550 and 1700 AD (400–250 cal. BP). Deterioration of climate and intensification of rains would generate transportation of both coarser sediments and related foraminifera species which are more abundant near the river mouth, to more distal areas of the inner shelf, where core 8 is located. These results are in agreement with those obtained by Bartels-Jónsdóttir et al. (2006) in the Tagus prodelta, where shifts in the benthic foraminifera assemblages around 550 cal. BP were associated with increased river discharges.

The core top, with an estimated age of ca. 200 cal. BP, is characterised by a high abundance of gravel material resulting from the lack of deposition of fine sediments. The presence of this material in an area of generally fine particle deposition is not fully understood but it considered as a lag deposit. Species such as *B. ordinaria*, *H. atlantica* and *B. aculeata* on the Guadiana shelf have been described by Mendes et al. (2004) as being associated with low levels of water energy and fine-grained sediments at water depths of 40–95 m, and the species *B. marginata* at water depths greater than 95 m. *Hopkinsina atlantica* is described as a low opportunistic taxon (Ernst et al., 2002, as *H. pacifica*) with a preference for fresh food (e.g. Ernst et al., 2005 as *H. pacifica*; Diz and Francés, 2008), so its higher abundances at the top of the core could be related to a more stable environment, with enhanced fine deposition in the area accompanied by the settling of light organic matter particles. *C. excavatum* is described by Alve and Murray (1999) in the area of the Skagerrak–Kattegat coast, eastern North Sea, as living abundantly in a wide range of sediment types with variable total organic carbon content.

The time interval between 1400 and 800 cal. BP, following the stabilization of the fine fraction in the core, shows the highest sedimentation rate. According to Boone and Worman (2007), after the dissolution of the Roman control of Iberia in the 5th century A.D. (ca. 1500 cal. BP) and over the next 500 years, particularly after the Muslim invasion of A.D. 711 (ca. 1200 cal. BP), settlement density increased sixfold relative to the number of inhabitants during the Roman period. Geoarchaeological evidence in the region of Mértola (a village near the upper Guadiana estuary, approximately 70 km from the mouth) points to widespread erosion and soil loss after the later Medieval Islamic period (800–900 cal. BP), caused by the overuse of land (Boone and Worman, 2007). This probably led to the exportation of large quantities of sediment to the continental shelf and to the possible silting up of the Guadiana eastern distributary. The reinforcement of the western distributary, with the transportation of greater amounts of sediments to the shelf, led to the formation of the present prodeltaic wedge.

6. Conclusion

This study of core 8 from the inner shelf on the northern margin of the Gulf of Cadiz has revealed a depositional environment influenced by the Guadiana River during the last ca. 5000 years. Variations observed in the sedimentological and benthic foraminifera record have allowed the identification of two main depositional periods in the Guadiana inner shelf, associated with important environmental changes.

The oldest part of the sedimentary sequence corresponds to an environment under the direct influence of the eastern distributary

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of the Guadiana River. From ca. 5150 cal. BP (core base) to 1500–1200 cal. BP, the benthic foraminifera faunas observed are typical of shallower environments, and significant amounts of sand reached this part of the inner shelf. Mica and other terrigenous are significant in these sandy sediments, indicating a significant fluvial supply. The existence of a secondary estuarine channel, located to the east of the present main channel, could explain the discharge of fluvial sediments near the area where core 8 was collected, being responsible for the establishment of this environment on the inner shelf during this period.

Since a rapid transition in the sedimentary record between ca. 1500 and 1200 cal. BP, the sedimentary environment has been dominated by fine particle deposition and an increase in benthic foraminifera species associated with low energy water levels. The intensification of the human impact on woodland resources, landscape exploitation, and the use of the Guadiana River to drain agricultural and mining products, associated with a possible more humid climate, almost certainly led to the exportation of high quantities of sediment to the continental shelf and possibly to the silting up of the eastern distributary of the Guadiana River. Enhanced fine sedimentation initiated the formation of the prodeltaic wedge in the inner shelf, which reflects the modern depositional system.

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