ELSEVIER

Marine Geology 155 (1999) 157–172

MARINE GEOLOGY
INTERNATIONAL JOURNAL OF MARINE GEOLOGY, GEOCHEMISTRY AND GEOPHYSICS

# Late glacial to recent paleoenvironmental changes in the Gulf of Cadiz and formation of sandy contourite layers

F.J. Sierro [a,*], J.A. Flores [a], J. Baraza [b]

[a] Departamento de Geología, Facultad de Ciencias, Universidad de Salamanca, 37008 Salamanca, Spain
[b] Instituto de Ciencias del Mar, CSIC, Passeig Joan de Borbó, 08039 Barcelona, Spain

Received 2 April 1996; revised version received 5 March 1997; accepted 21 September 1998

**Abstract**

Planktonic foraminifera and coccoliths were analyzed from six gravity cores obtained on a deep terrace located on the upper continental slope of the Gulf of Cadiz, between 400 and 700 m water depth. The lithology of these cores consists mainly of muds with some interbedded sandy or silty foraminifer-rich layers that have been reported as contourites originated by the action of the Mediterranean Outflowing Waters (MOW) sweeping the sea-bottom today. After the Last Glacial, characterized by muddy sedimentation, sandy contourites start to deposit in the Gulf of Cadiz during the Bølling–Allerød (14–11 $^{14}$C kyr BP) climatic optimum. This trend was broken during the Younger Dryas (11–10 $^{14}$C kyr BP) and started again after the end of the Younger Dryas. This pattern is recorded in most of the cores by a single sandy contourite layer formed during the first deglaciation stage (Bølling–Allerød time) and a sandy contourite interval that initiates immediately after the end of the Younger Dryas, during the second stage of the deglaciation and continues during the Holocene. The stratigraphy and climatic reconstruction was based on the evolution of the calcareous plankton assemblages during the last climatic transition, from the Last Glacial to the recent Holocene. The sharp reduction of sinistral *N. pachyderma* along with the reduction of *G. quinqueloba* mark the base of Bølling–Allerød time. This is also related to a prominent peak of the subtropical species (*G. sacculifer* and *G. ruber*). The Younger Dryas is identified by a reduction in abundance of the subtropical species, that again increase just after this period. The second step of deglaciation is marked by a sharp decrease in the relative abundance of dextrally coiled *N. pachyderma*. In previous papers the sequence of sandy contourites has been related to sea level rise, greater Gibraltar sill depth and enhanced energy of the MOW. In this work, we suggest that the individual sand layer episodes are condensed layers originating during times of rapid warming and relative sea-level rise within the last deglaciation. During these times the coastline migrated more rapidly landward and the terrigenous input decreased as it began to be trapped on land and on the shelf, resulting in a major drop in sedimentation rate on the upper continental slope. In times of low sedimentation rate the particles would have a longer residence time within the upper mixed layer of the near surface sediment and therefore the energy of currents would act longer, producing a more efficient winnowing of the sediment. At the same time more generations of benthic organisms would rework the mixed layer, favoring this winnowing. 

*Keywords:* Pleistocene; Holocene; contourite; paleoclimatology; Foraminifera; Coccolithophores

* Corresponding author. Tel: +34 923 294497; Fax: +34 923 294514; E-mail: sierro@gugu.usal.es

0025-3227/99/$ – see front matter 
PII: S0025-3227(98)00145-5

## 1. Introduction

The Atlantic South Iberian continental margin, particularly the Gulf of Cadiz region is of great oceanographic and sedimentologic interest. This region is located at the entrance of the Strait of Gibraltar where a large water-exchange takes place between the Atlantic and Mediterranean.

The most prominent feature of the water dynamics in the Gulf of Cadiz is the presence of the highly saline Mediterranean Outflow Waters (MOW) that flows westward and northwestward following the contours of the Spanish and Portuguese continental slope at depths between 400 and 1800 m (Madelain, 1970; Zenk, 1970; Faugeres et al., 1985b, 1986; Nelson et al., 1993). Current speed in the upper continental slope varies from 2.5 m/s, measured near the Gibraltar Strait, and decreases progressively towards the west to 1 m/s and 0.5 m/s (Madelain, 1970; Kenyon and Belderson, 1973). In contrast, surface currents from the North Atlantic flow eastward and southeastward following the Portuguese and Spanish shelf.

Numerous publications have addressed sediment deposition under the action of the MOW on the Portuguese continental slope. Many of these have focused on the Faro Drift sediment (Mougenot and Vanney, 1982; Faugeres et al., 1984, 1985a,b, 1986; Gonthier et al., 1984; Stow et al., 1986, among others) but only a few papers have dealt with sediment deposited on the spanish slope (Díaz et al., 1985; Nelson et al., 1993). The formation of contourites in this region, mainly produced by along-slope depositional processes associated with the flow of the MOW, has been well recognized and described by many of the aforementioned authors. Faugeres et al. (1984, 1985a,b, 1986) recognized three different sandy or silty contourites in the Faro Drift interbedded with muddy sediments and suggested that these sandy contourites formed during episodes of intensification of the MOW during the last deglaciation. The first episode was dated about 15 000–13 000 yr BP, the second at 11 000–9 000 yr BP and the third at 3000–0 yr BP (latest Holocene). They, therefore, concluded that climatic events play an important role in Atlantic–Mediterranean hydrodynamics.

On the Spanish continental slope, Nelson et al. (1993) studied numerous gravity cores and identified several sandy contourite layers. The ages of these layers dated by radiocarbon analyses, are approximately the same as those found by Faugeres and coworkers. Nelson et al. (1993) concluded that the sandy layers originated due to intensification of the MOW during episodes of sea-level rise and therefore designated them as highstand sandy contourites.

In this paper, planktonic foraminifera and coccoliths from six gravity cores were analysed with the aim of reconstructing paleoclimatic evolution and its relationship with the formation of the sandy contourite layers in the upper slope of the Gulf of Cadiz.

## 2. Material and techniques

Six gravity cores from the Gulf of Cadiz continental slope were examined. Most of the cores were taken on wide, gently dipping deep terraces located between 400 and 700 m water depth, just below the upper continental slope (Fig. 1). Cores TG-36, TG-40 and TG-45 were taken in the central part of these terraces, while TG-43 and TG-59 are located just at the base of the steep upper continental slope. In contrast, core TG-55 is very close to a valley that runs SW straight across the continental slope. These cores range from 160 to 200 cm in length and consist of hemipelagic silty clay with interbedded sandy or silty layers. The sand fraction of these sandy layers is dominated by planktonic foraminifera tests.

Samples for planktonic foraminifera analyses were washed over a 63 μm mesh sieve and dry sieved at 150 μm. The residues were split, when necessary, into suitable aliquots of about 250 specimens which were then counted.

Light-microscope studies were carried out following the preparation procedure proposed by Flores et al. (1995) for calcareous nannofossils. In order to determine the coccolith assemblage and to obtain homogeneous and comparable data among different samples, several counts were made. Around 500 coccoliths were counted per slide in a variable number of fields of view. A second counting of around 300 coccoliths for specimens larger than 3 μm (in general less abundant than the small forms) was made. To improve the counting resolution of several scarce forms, a number of additional visual fields were examined until a minimum of one hundred specimens

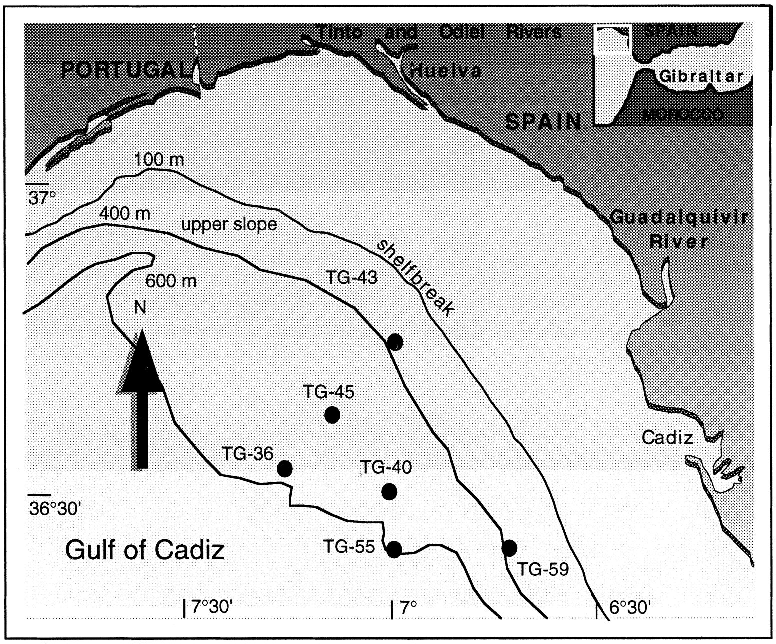



Fig. 1. Map of the Gulf of Cadiz region with the location of the core sites.

were found. The data are presented as coccoliths per visual field (coccoliths per surface) and as relative values among the species of the same genus (i.e. *Gephyrocapsa* spp.) or for the total assemblage (i.e. *Syracosphaera*, *C. leptoporus*).

## 3. Calcareous planktonic assemblages and paleoclimatology

In this section we shall focus on the quantitative evolution of some of the planktonic species, placing special emphasis on those of paleoclimatic or biostratigraphic significance.

### 3.1. Planktonic foraminifera

In a general view of the quantitative analysis shown in Fig. 2, it can be seen that the distribution of some of the most abundant species of planktonic foraminifera follow certain trends that are very similar in most of the cores. Some of these changes in abundance are isochronous based upon the radiocarbon ages available for some cores (Nelson et al., 1993).

*Globigerinoides ruber* (d'Orbigny) along with *Globigerinoides sacculifer* (Brady) are subtropical and tropical species abundant today in surface waters of the Gulf of Cadiz during the summer (e.g. Cifelli, 1974; Duprat, 1983; Devaux, 1985). These species are almost absent in the lowermost part of some of the cores (i.e. TG-59, TG-45, TG-43) and always show an increasing trend from bottom to top in most of the cores analysed.

These species generally reach two maxima during the Pleistocene–Holocene transition in most of the cores, separated by an interval of lower abundances (see Fig. 2). This interval is located between 40 and 80 cm depth in cores TG-55, TG-43, from 30 to 45 cm in core TG-45 and from 90 to 130 in core TG-40. It was not identified in cores TG-36 and TG-59 probably because of the low sampling resolution.

*Neogloboquadrina pachyderma* (Ehrenberg), in contrast, is a characteristic cold water species today (i.e. Ericson, 1959; Cifelli, 1971; Imbrie and Kipp, 1971; Be, 1977). In general, it is abundant in all of the cores, reaching values of over 30 and 40%, until it decreases sharply in the upper part where it usually persists at percentages under 10%. This strong reduction coincides with the increase in subtropical

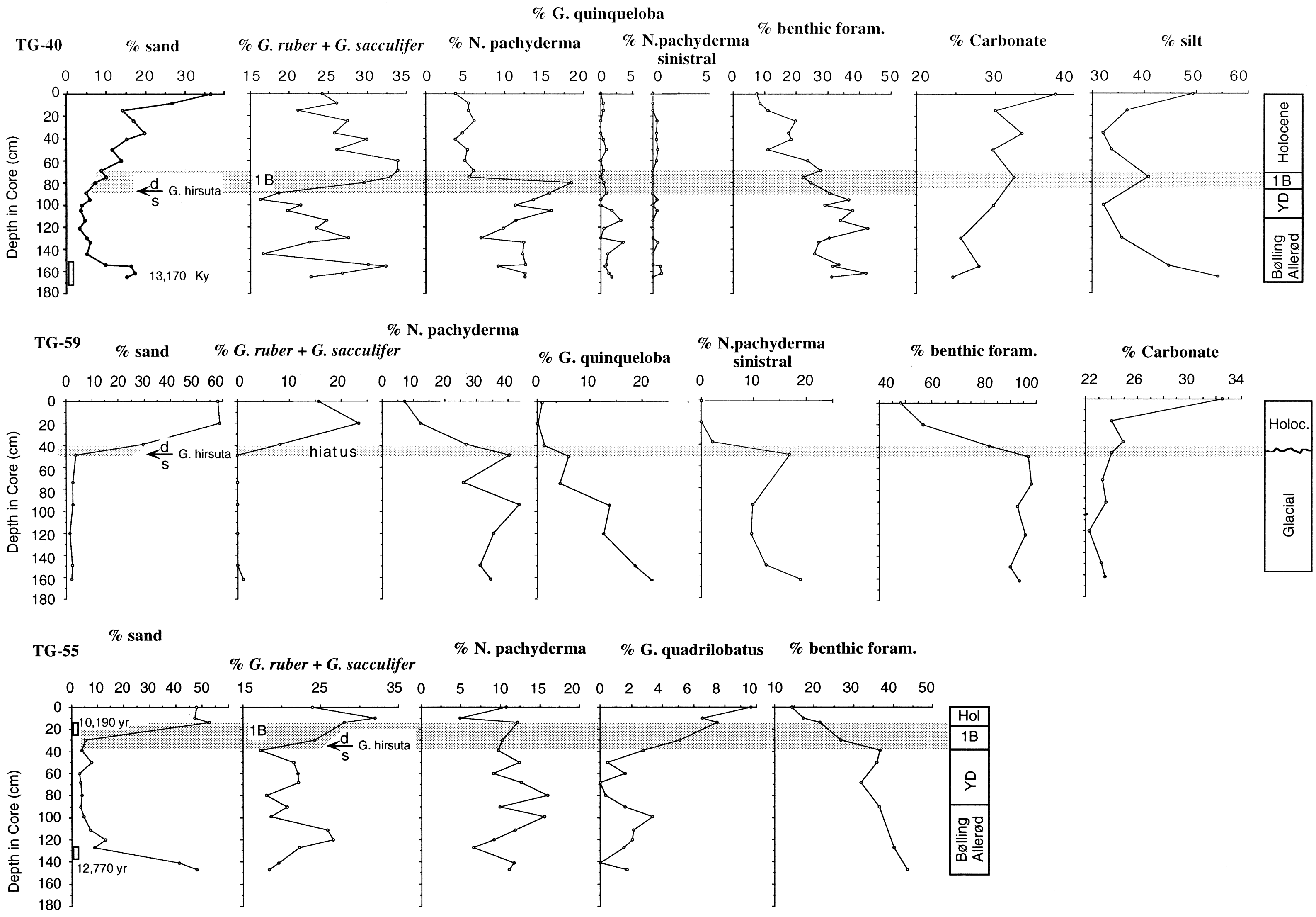



Fig. 2. Frequency distribution of some selected species of planktonic foraminifera correlated with the percentage of sand, carbonate and benthic foraminifera. Dotted intervals illustrate Terminations 1A and 1B. Radiocarbon ages from Nelson et al. (1993) are shown (rectangle is location of the radiocarbon samples). Horizontal arrows indicate the level at which the dextral specimens of *G. hirsuta* start to be common although the population is still preferentially sinistral. *s*: population of *G. hirsuta* entirely sinistral; *d*: dextral specimens of *G. hirsuta* frequent, but the species is still preferentially sinistral; *Holoc.*: Holocene; *Bøll.-All.*: Bølling-Allerød. *Y.D.*: Younger Dryas.

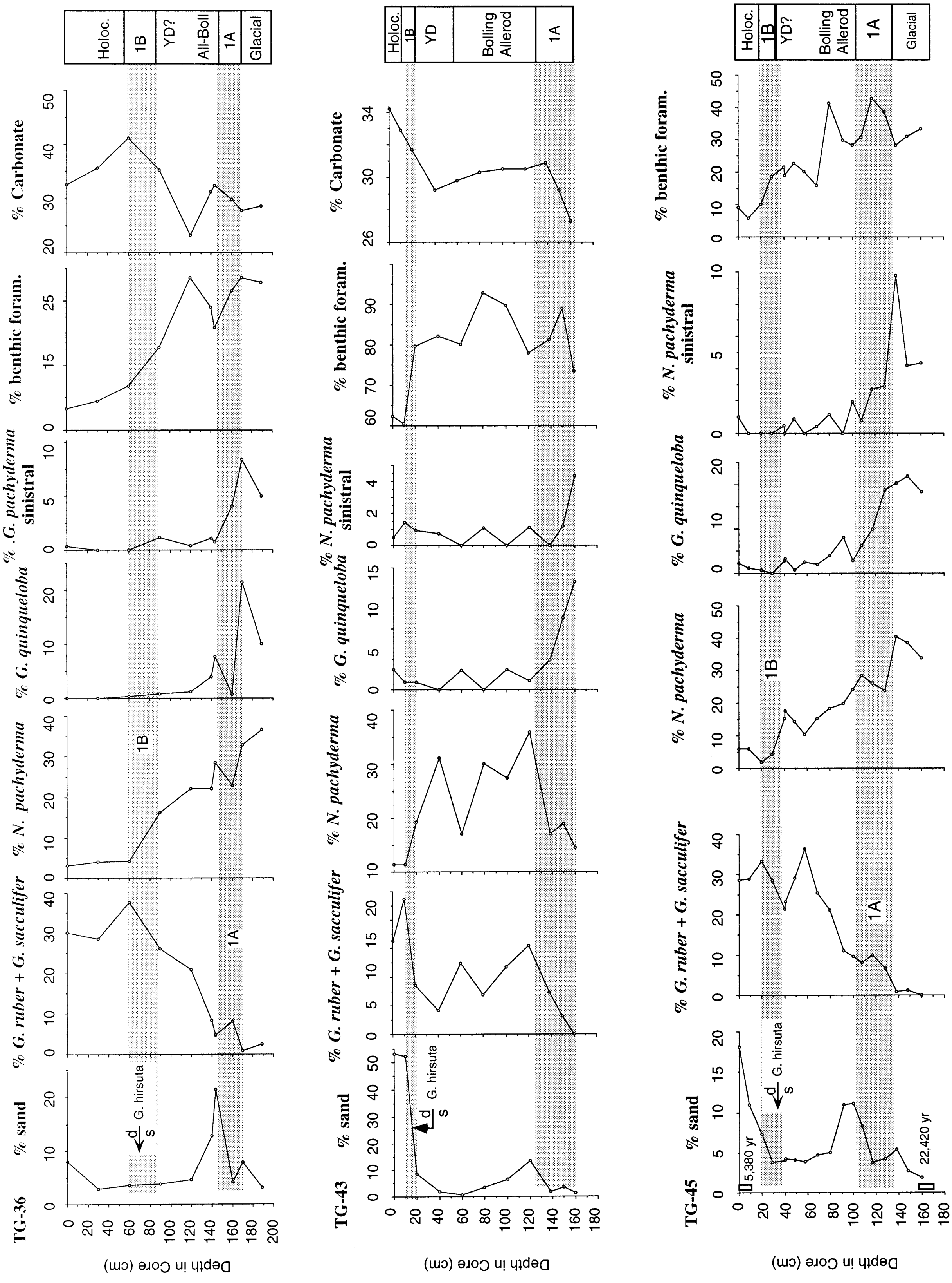
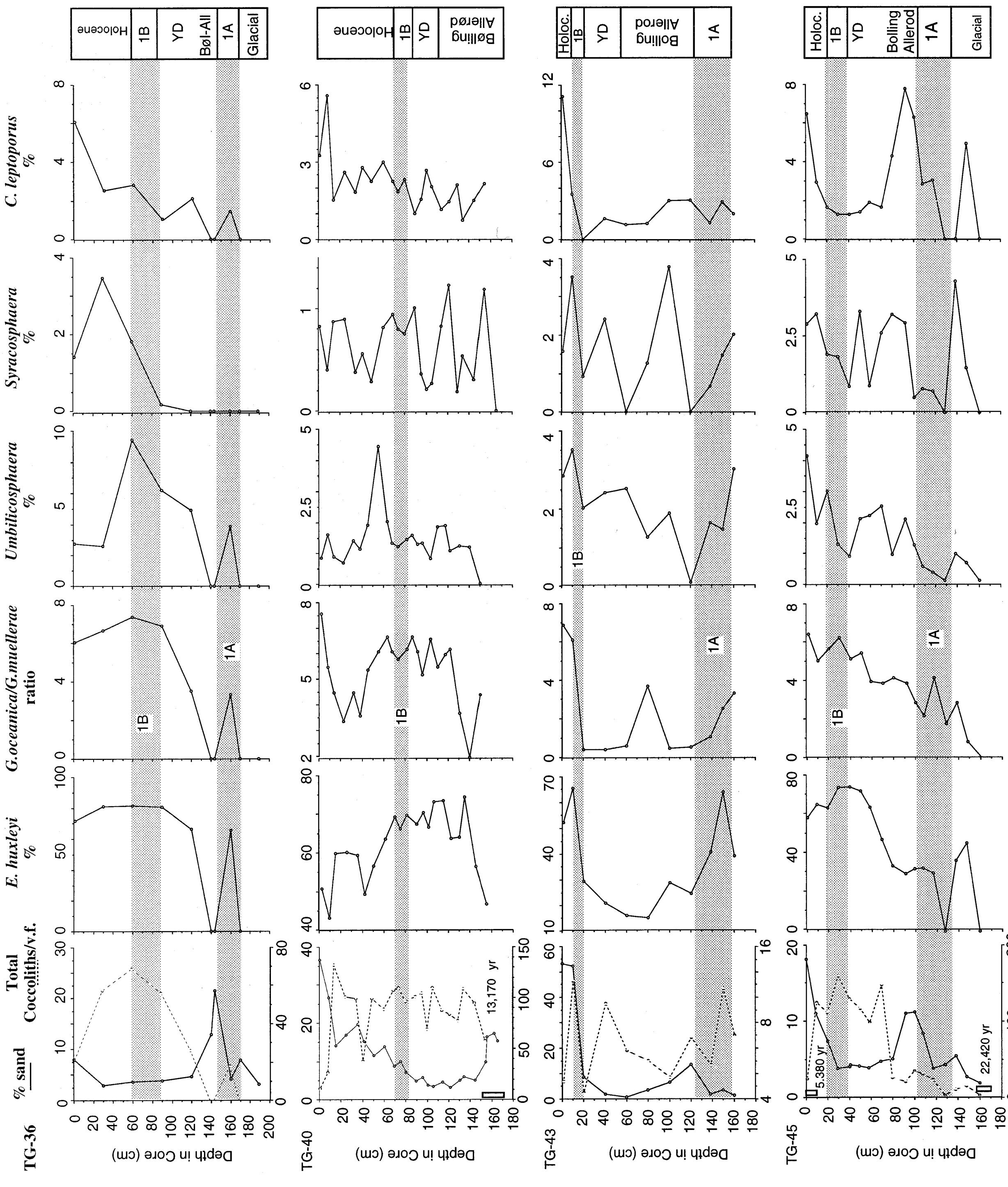



Fig. 2 (continued).


TG-36
TG-40
TG-43
TG-45
Depth in Core (cm)
% sand
Total Coccoliths/v.f.
E. huxleyi %
G.oceanica/G.muellerae ratio
Umbilicosphaera %
Syracosphaera %
C. leptoporus %
Holocene
1B
YD
Bøl-All
1A
Glacial
Bølling Allerød
Holoc.
Bolling Allerod
13,170 yr
5,380 yr
22,420 yr

forms previously described. The predominance of sinistral forms of this species is associated with polar waters in the North Atlantic (Ericson, 1959; Cifelli, 1971; Imbrie and Kipp, 1971). Absent today in the Gulf of Cadiz, they were abundant during the Last Glacial on the Iberian margin and Gulf of Biscaye (Pujol, 1980; Duprat, 1983; Devaux, 1985; Weaver and Pujol, 1988) and during the Younger Dryas in the northern part of this region. In the cores analysed in this study, the sinistral forms are relatively frequent only in the basal levels of cores TG-36, TG-43 and TG-45, decreasing towards the top from more than 5% to less than 1%. They are almost absent in cores TG-40 and TG-55, and very abundant, reaching values close to 20% in some levels, in core TG-59 from the bottom to 40 cm depth.

Other species such as *Globigerina quinqueloba* (Natland) not as evidently related to water temperature as the previous species but usually linked to cold waters, follow a very similar trend to that of *N. pachyderma* (sinistral) (Fig. 2).

*Globorotalia hirsuta* (d'Orbigny) is more stratigraphically interesting than paleoclimatically significant. We investigated both the analysis of relative abundance in the assemblage of planktonic foraminifera and coiling direction fluctuations of this species. *Globorotalia hirsuta* is very scarce in the sediments and it is therefore sometimes quite difficult to obtain enough specimens to monitor coiling. In general, this species is rare in the lower part of most of the cores becoming relatively frequent in the uppermost centimeters. In these upper levels, the specimens are nearly 100% dextrally coiled, while in the lower part they are sinistrally coiled. In the middle part there is an interval where both dextral and sinistral forms coexist, although the sinistral forms are always dominant. *G. hirsuta* gradually passes from nearly 100% sinistral to nearly 100% dextral. Although it is sometimes very doubtful, the location of this coiling change from nearly 100% sinistral to preferentially sinistral may be seen in Fig. 2. This change is very difficult to identify, however, because when the species become preferentially sinistral, its abundance becomes extremely low, in some cases leading to a complete disappearance.

### 3.2. Coccolithophores

Coccolithophores are an important component of the sediments in the cores studied. Their abundance is variable, as shown by the total number of coccoliths per visual field (Figs. 3 and 4). In cores TG-36, TG-45 and TG-40, the average value is over 40 coccoliths per visual field (cc/v.f.) with only a few exceptions in samples where coccoliths are almost absent. Core TG-43 shows very low coccolith concentrations, with average values around 5 cc/v.f. In core TG-59, the mean concentration is below 1 cc/v.f.

Generally, coccolith concentrations are inversely proportional to the sand content (Figs. 3 and 4). On the other hand, preservation is also related to sediment grain-size; intervals with low sand content show better preservation than sandy intervals. These data point to a certain disturbance in the assemblages, and should therefore be considered with caution. Dissolution is specially significant in the small and very small taxa, as well as in the peripheral and central elements of placoliths, cribiliths, helicoliths and caneoliths. In several cases, the dissolution effect precludes the identification of several taxa.

The most abundant species in the cores studied are *Emiliania huxleyi*, *Gephyrocapsa oceanica*, *Gephyrocapsa muellerae* and small Gephyrocapsa (*Gephyrocapsa ericsonii* and *Gephyrocapsa aperta*). These species represent about 90% of the assemblage (Fig. 3). Other significant taxa include *Calcidiscus leptoporus*, *Helicosphaera carteri*, *Braarudosphaera bigelowi*, *Coccolithus pelagicus*, *Florisphaera profunda*, *Umbilicosphaera sibogae*, *Syracosphaera* spp., *Pontosphaera discophora*, *Rhabdosphaera claviger*, *Umbellosphaera irregularis* and *Umbellosphaera tenuis*.

The commonly abundant *E. huxleyi* shows maximum frequencies towards the top of the cores, with the exception of levels in which the sand compo-

Fig. 3. Frequency distribution of selected species of Coccolithophorids, the *G. oceanica*/*G. muellerae* ratio, concentration of coccoliths in the sediment and the sand content. Dotted intervals illustrate Terminations 1A and 1B. Radiocarbon ages from Nelson et al. (1993) are shown (rectangle = location of the radiocarbon samples) *Holoc.*: Holocene. *Bøll.-Aller.*: Bølling-Allerød. *Y.D.*: Younger Dryas.

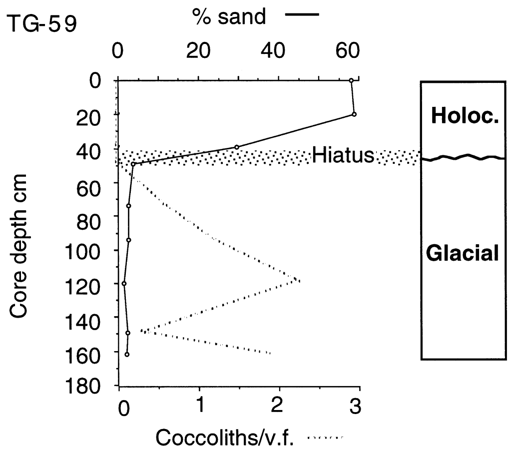



Fig. 4. Distribution of sand content versus coccolith concentration with depth in core TG-59. Dotted interval illustrates the location of a hiatus. *Holoc.*: Holocene.

nent is high (Fig. 3). The variations in abundance of some of the Coccolithophorids can also be linked to climatic parameters. Weaver and Pujol (1988) observed an increase in *E. huxleyi* above Termination 1B (10 kyr), and following Thierstein et al. (1977) they relate this fact to the expansion of *E. huxleyi* at the expense of *G. muellerae*. *G. oceanica* is a warm water species (Geitzenauer et al., 1976) that in colder waters is replaced by *G. muellerae* (Weaver and Pujol, 1988; Jordan et al., 1996). As a result, the *G. oceanica*/*G. muellerae* ratio (*G. oceanica*/*G. oceanica* + *G. muellerae* = Go/Gm ratio) can be considered as a temperature indicator of surface water (Fig. 3).

In general, a progressive increase is observed from bottom to top, with some intervals in which the ratio is reduced. A similar trend is observed in the warm water species *U. sibogae* although this species seems to reduce its abundance in the uppermost centimeters of cores TG-36 and TG-45. This taxon has been reported in subtropical to transitional waters during interglacial periods. During glacial intervals when there was a southward displacement of the Subtropical Gyre, *U. sibogae* was restricted to south of about 30ºN near the African coast (McIntyre, 1967).

Other possible thermally sensitive taxa, such as *C. pelagicus* and *H. carteri*, do not show any particular trend in these cores, while *C. leptoporus* has in general a parallel distribution with the warm water indicators. Other interesting taxa are the representatives of the genus *Syracosphaera*. This genus has no clear ecological significance (Bukry, 1974; Weaver and Pujol, 1988). In general, however, it is more abundant in warm water masses and occurred in peak abundances after deglaciation events in the Catalonian and Balearic seas (Flores et al., 1997). This trend was seen here in core 36 and core 45 with maxima at the base of the Holocene (Fig. 3).

## 4. Taphonomy

The concentration of coccoliths in the sediments is inversely proportional to the distribution of sand, which is mainly controlled by the foraminiferal content especially in residues larger than 125 μm (Figs. 3 and 4). At the same time, the abundance of coccoliths is parallel to the calcium carbonate curve, with the exception of the sandy intervals. These data suggest that Cadiz slope sediments could have been deposited under the action of intense bottom currents, causing a selective winnowing of fines and concentration of larger particles in the residual sediment. Since the clay and coccoliths were probably washed out, the foraminiferal tests and silty or sandy terrigenous particles increased in abundance proportionally. Regardless of winnowing processes, dilution effects should produce a parallel distribution of foraminifera and coccoliths, depending on the fluctuations of terrigenous input over time. Thus, the parallelism between the abundance of coccoliths and the calcium carbonate curve may initially be due to dilution, although the winnowing processes produced by bottom currents would modify the sediments, washing out fine carbonate particles and thereby reducing the final carbonate content. The winnowing enrichment of calcareous foraminifera, however, might also counterbalance carbonate losses and explain why some of the sandy layers are carbonate-rich and yet the abundance of coccoliths is extremely low or completely absent. The carbonate and coccolith trends suggest efficient winnowing by the MOW when sand layers were deposited.

In contrast, the low coccolith concentrations in the clay intervals of cores such as TG-59 and TG-43 appear to be explained by terrigenous dilution, rather than winnowing.

## 5. Paleoclimatic interpretation and stratigraphy

The distribution of calcareous planktonic taxa is controlled primarily by thermal variations. The general increasing trend from bottom to top of *G. ruber* and other subtropical forms in all cores, together with the decreasing pattern of *N. pachyderma*, a characteristic cold water species, clearly indicates a progressive warming of surface waters from the Gulf of Cadiz. These planktonic foraminifera data are in agreement with the general progressive increase observed in the Go/Gm ratio and percentages of *Umbilicosphaera*. The paleoclimatic interpretation becomes more complicated, however, when attempts are made to follow the climatic changes in greater detail.

The absence of subtropical forms in the basal levels of some cores together with the relative frequency of sinistral *N. pachyderma* and *G. quinqueloba* suggest that these sediments could be related to full glacial conditions in the region. From these levels upwards, two significant paleoclimatic and hence stratigraphic events have been identified in all cores correlated with Termination 1A (14–12 $^{14}$C kyr) and Termination 1B (10–9 $^{14}$C kyr), first and second stages of the deglaciation, interrupted by the Younger Dryas glacial event (11–10 $^{14}$C kyr).

The first increase in the abundance of *G. ruber*, coinciding with the strong reduction of *N. pachyderma* (sinistral) and *G. quinqueloba*, and the relatively high values in the Go/Gm ratio and *Umbilicosphaera* must be related to the beginning of postglacial conditions in the region and have therefore been correlated with Termination 1A. These changes were already observed by Devaux (1985) in the Gulf of Cadiz coinciding with Termination 1A. Jorissen et al. (1993) illustrated a similar reduction of *G. quinqueloba* in the Tyrrhenian Sea parallel to an increase of *G. ruber* and coinciding with the limit between their zones III and II with a radiocarbon age of 12.7 $^{14}$C kyr BP. In the Strait of Sicily, Vergnaud-Grazzini et al. (1988) found a similar reduction in *G. quinqueloba* within Termination 1A. However, this species increased again during the Younger Dryas. Similar events occurred in the Alboran Sea (Pujol and Vergnaud-Grazzini, 1989), while Weaver and Pujol (1988) reported small positive peaks in the Go/Gm ratio coinciding with Termination 1A in the North Atlantic and Alboran Sea.

The second event located in the upper part of the cores (Figs. 2 and 3) was correlated with Termination 1B, the second stage of the deglaciation. This event is defined by the sharp drop in abundance of *N. pachyderma* to percentages below 10% and paralleled by a rapid increase in *G. ruber*. This event has always been related to the last deglaciation (Duprat, 1983; Devaux, 1985; Vergnaud-Grazzini et al., 1988; Keigwin and Jones, 1989; Pujol and Vergnaud-Grazzini, 1989; Jorissen et al., 1993; Rohling et al., 1993). However, the reduction in *N. pachyderma* seems to occur a bit later in the Alboran Sea than in the Gulf of Cadiz (see Devaux, 1985; Pujol and Vergnaud-Grazzini, 1989). Jorissen et al. (1993) used this event to identify the boundary between zone I and II dated 9 600 yr BP, coinciding with Termination 1B and correlated with the base of the Holocene. We therefore consider this event to be a good indicator for locating the Pleistocene–Holocene boundary in the region. In this study, an important increase in surface warm water indicators in the coccolith assemblages is recorded at this time.

Between these two events, another two intervals characterized by relatively high and cool water temperatures, respectively, can be observed. The increase in subtropical forms such as *G. ruber* and *Umbilicosphaera* above Termination 1A is interpreted as corresponding to the Bølling–Allerød time that reached its optimum at around 12 $^{14}$C kyr BP (Duplessy et al., 1981; Bard et al., 1989), while the reduction in these warm and transitional forms, along with the high percentages of *N. pachyderma*, is correlated with the Younger Dryas at around 11–10 $^{14}$C kyr (see cores 36, 43, 40 and 55 in Figs. 2 and 3). This interval concludes with the sharp increase in *G. ruber* which characterizes the second stage of the last deglaciation (Termination 1B, 10–9 $^{14}$C kyr BP) (Figs. 2 and 3). These faunal trends are very similar to those found by Devaux (1985) in the Portuguese region. In cores TG-36 and TG-45 the Younger Dryas cannot be identified, at least following the patterns of variation of *G. ruber* and *N. pachyderma*. However, the strong reduction of *N. pachyderma* together with the other coccolith indicators mentioned have also been used in these cores to locate the Pleistocene–Holocene transition.

The changes in coiling pattern of some Globorotaliids have been used in the NE Atlantic as good stratigraphic indicators. According to Pujol and Caralp (1974), Duprat (1983), Pujol (1980), Faugeres et al. (1984) and Devaux (1985), *G. hirsuta* is sinistrally coiled during the Pleistocene and passed from preferentially sinistral to preferentially dextral during the Holocene. The level at which this species pass from completely sinistral to preferentially sinistral was illustrated in Fig. 2. As reported for the North Atlantic, it coincides approximately with the Pleistocene–Holocene boundary.

Several authors (Pujol and Caralp, 1974; Pujol, 1980; Duprat, 1983; Devaux, 1985, among others) have reported changes in the coiling pattern of *G. truncatulinoides* throughout the late Pleistocene and Holocene in the Iberian margin. However, Duprat (1983) questioned the validity of these changes as useful stratigraphic markers because today *G. truncatulinoides* shows different coiling patterns depending on the oceanographic region (Ericson et al., 1954). For this reason we did not use these changes biostratigraphically, although the interval with scarce and preferentially sinistral *G. truncatulinoides* could be synchronous. This interval has usually been identified between the first and second stages of the deglaciation, approximately coeval with the Younger Dryas.

As may be seen in Figs. 2 and 3, the main paleoclimatic stages have been identified in most cores, although some doubt exists with respect to core TG-45. On one hand, the main increase in *G. ruber* is recorded at 80 and 60 cm depth, but *N. pachyderma* still persists at higher percentages than usual for the Holocene, although its abundance reduces at this level. This species definitely reduces in abundance between 40 and 30 cm depth and, hence, we place the Pleistocene–Holocene boundary at this level. Unfortunately, the trend in coiling pattern of *G. hirsuta* and *G. truncatulinoides* is not very clear.

## 6. Benthic foraminifera

The relative abundance of planktonic and benthic foraminifera in the sediments was analysed in all cores (Fig. 2). The proportion of benthic foraminifera usually shows a progressively decreasing trend from bottom to top. However, a prominent drop in this ratio occurs in the upper part of the cores, coinciding exactly with the upper increase in the sutropical forms and the reduction in *N. pachyderma*. In cores for which there are carbonate analyses, even though the resolution is very low it is possible to see that the main variations in the planktonic/benthic ratio are opposite to those recorded in carbonate and sand contents. The reduction in benthic foraminifera in the sandy and sometimes carbonate-rich intervals may be explained by the fact that these layers have been intensively winnowed by bottom currents. Hence, the fine grained organic detritus and other possible adequate food for benthic foraminifera would have been washed away, thus preventing the small benthic organisms, especially infaunal elements, from thriving under these conditions. However this kind of habitat can be very favorable to other groups of the macro- and meio-infauna, especially the surface deposit and suspension feeders that take advantage of the food supplied by the strong bottom currents (Yingst and Aller, 1982).

The percentages of benthic foraminifera in sand and mud differ considerably depending on the area. In cores located near the base of the upper slope (TG-43 and TG-59), and therefore closer to the shore, the abundance of benthic foraminifera is higher in relation to the plankton (from 60 to 90%), while in cores located within the terrace (TG-36, TG-40, TG-45 and TG-55) the percentages of benthic foraminifera are lower (10–40%). The energy of the currents is higher on the upper slope than on the terraces, because the bottom is steeper in these regions and hence one would expect a greater winnowing efficiency and therefore fewer benthic foraminifera. In addition, towards the land, especially towards the mouth of the Guadalquivir river, nutrients and organic detritus provided by the river show an increase. Such detritus would have accumulated over the bottom, at least over a certain time, until they had been completely washed away by the current. This would favor the growth of microbenthic organisms during certain seasons of the year. Furthermore, the organic detritus coming from the land and surface productivity (Abrantes, 1990) decrease seaward, resulting in less favorable conditions for the benthos in these more distal regions.

## 7. Sandy contourites

After the Last Glacial maximum, characterized by muddy sedimentation, the sand content tends to increase in all the cores analyzed in the Gulf of Cadiz. This trend was broken after the Bølling climatic optimum and started again after the end of the Younger Dryas. This pattern is recorded in most of the cores by a single sandy contourite layer formed during the first deglaciation stage, during Bølling time, and a sandy contourite interval that initiates immediately after the end of the Younger Dryas, during the second stage of the deglaciation and continues during the Holocene.

As shown in Figs. 2–4, a deep sandy layer is present in all cores analysed, except core TG-59, in which there is a hiatus at that time. In each core the peak of maximum sand content is recorded after the sharp reduction in the abundance of *N. pachyderma* (sinistral forms) and *G. quinqueloba*. At the same time, this layer always coincides with the first significant increase in *G. ruber* and peaks in the warm water indicators of the coccolith assemblage, such as the Go/Gm ratio and *Umbilicosphaera*.

Although there are no isotopic data, the biostratigraphic markers already discussed support the idea that the first sandy contourite would be coeval with the end of Termination 1A (14–12 $^{14}$C kyr BP) around the climatic optimum of Bølling–Allerød time, and therefore with the first deglaciation. This is also supported by the radiocarbon ages of Nelson et al. (1993) ($13\,170 \pm 180$ and $12\,770 \pm 180$ in cores TG-40 and TG-55, respectively).

After this maximum at the base of the Bølling–Allerød time the grain-size in the sediments of the region began to decrease, reaching minimum values in the Younger Dryas that usually coincide with minima in carbonate and hence maximum terrigenous proportions. This interval is also characterized by a reduction in the abundance of the subtropical forms *G. ruber*, *G. sacculifer*, *G. oceanica* and *Umbilicosphaera* spp.

Immediately after the Younger Dryas, a significant grain-size increase in the sediments is observed in most of the cores, pointing to extremely high percentages of foraminiferal sand during the Holocene, especially towards the top of the cores. In some cores the entire Holocene is recorded by a layer of about 20–30 cm thickness (i.e. TG-43, TG-45 and TG-55). Here, the Holocene is characterized either by a very low sedimentation rate or no sedimentation at all during certain periods. So far, we have no conclusive data to determine whether the entire Holocene is recorded in this layer. However, at least the late Holocene does seem to be registered, as may be deduced by the relative abundance of *G. hirsuta*, preferentially dextral in the first centimeter. As we have seen in earlier discussion, according to Duprat (1983) and Devaux (1985) this species is preferentially dextral until 5 kyr.

Only in core TG-40, two different contourite layers were identified during the Holocene: the older one, identified by a higher silt content, is located between 70 and 90 cm depth, and coincides with Termination 1B (10–9 $^{14}$C kyr BP), whereas the younger one is recorded within the late Holocene. These two Holocene contourites were also found by Faugeres et al. (1984, 1985a,b, 1986) in the Faro Drift.

In conclusion, on the upper continental slope of the Gulf of Cadiz there are two prominent sandy contourites, one originated during Termination 1A and the base of the Bølling–Allerød time and the other beginning after the Younger Dryas and reaching maximum grain-size values towards the late Holocene.

## 8. Origin of the sandy contourite layers

According to the above data and other publications (Faugeres et al., 1984, 1985a,b, 1986; Nelson et al., 1993), it seems evident that the origin of the sandy contourite layers is certainly related to the main deglaciation pulses, following the last glaciation. Faugeres et al. (1986) and Nelson et al. (1993) concluded that these layers were formed by the increase in intensity of the MOW during the stages of global sea level rise, causing stronger currents reworking the bottom sediment of the upper continental slope of the Gulf of Cadiz. This conclusion led Nelson and coworkers to cite these layers as highstand sandy contourites developed when the greater depth resulted in increased development of MOW circulation through the Strait of Gibraltar. Without rejecting this hypothesis, we propose other possible mechanisms that could have plaid a significant role enhancing the effects of current winnowing of the sediment. Briefly, we suggest that these sandy layers may in fact be condensed layers originated during stages of relative sea level rise.

During the stages of low sea level, as for example during the Last Glacial, the mouth of the Guadalquivir river probably was very close to the present shelf break and hence the terrigenous supply was probably very high, resulting in a very high sedimentation rate in the region. However, during the first, and especially during the second deglaciation the shore was rapidly displaced landward, causing a major drop in terrigenous supply to the continental slope and consequently a strong reduction in the sedimentation rate in the region. Evidently, the sedimentation rate not only depends on terrigenous supplies but also on biogenic production and the along-slope sediment transport in the region. However, the overall carbonate content (mainly the biogenic fraction) in the cores analysed ranges between 20 and 35%, so that fluctuations in terrigenous input are more significant regarding the sedimentation rate control.

Bottom currents of the MOW have been washing the upper slope sediments of the Gulf of Cadiz throughout the Quaternary (Mougenot and Vanney, 1982; Gonthier et al., 1984). Accordingly the final sediment facies in the Cadiz margin can be considered to be the result of a very delicate balance between the sediment input and loss rates. The sediment input is mainly controlled by the relative sea level changes that shift depocenters landward or seaward, while the loss rate is rather linked to the intensity of the MOW at each particular site or to the activity of the benthic communities reworking the surface sediments. Fig. 5 shows an idealized model explaining the processes controlling the sedimentation rate in the region.

This balance between the sediment input and loss rate controls the sedimentation rate at each time and therefore the sediment facies. During periods of low sea level, the balance usually moves in a trend that

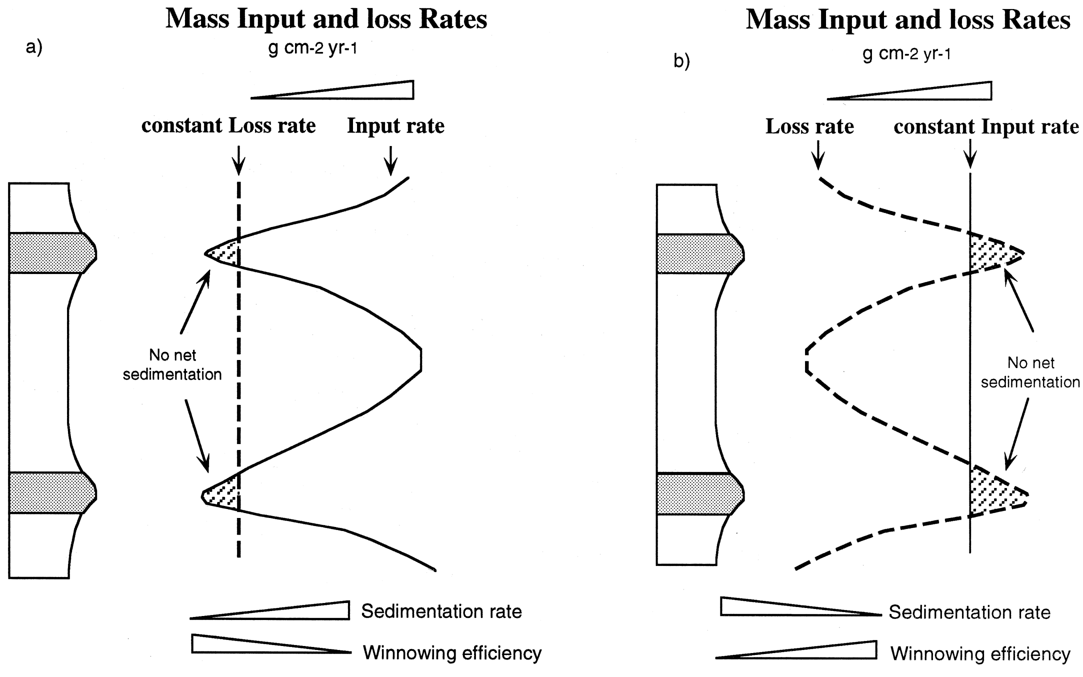



Fig. 5. Proposed schematic model explaining processes controlling the sedimentation rate on the Gulf of Cadiz continental slope. The degree of condensation depends on the energy of the current and on sediment input. The two extreme cases are illustrated: (a) high fluctuations in the sediment input with a constant loss due to the action of stable energy. The intensity of the Mediterranean undercurrent is assumed to be static in this case. (b) High fluctuations in rate of sediment loss due to changes in the energy of the bottom currents with no change in the sediment input rate.

enhances the sedimentation rate unless a significant increase in the intensity of the MOW occurs at the same time. By contrast, during periods of high rates of relative sea level rise, the terrigenous supply starts to be trapped at the shelf (Posamentier and Vail, 1988; Loutit et al., 1988) and therefore the balance moves in the opposite direction, producing significatively low sedimentation rates.

During intervals of low sedimentation rates, the surface sediments are winnowed by the bottom currents over longer times and more generations of benthic organisms are able to rework the sediment (Yingst and Aller, 1982). Conversely, with high sedimentation rates, the particles are buried very fast, spending very little time within the mixed layer where they can be affected by the current and the benthic organisms. Rapid burial may also be responsible for the better preservation of the coccolith assemblages in the fine grain-size intervals, by reducing the time the coccoliths are in contact with pore waters in the mixed layer.

According to the data analysed in previous sections, the two sandy contourite units, specially the upper one, could also be condensed deposits formed during times of eustatic rises. The first started to form during Termination 1A and reached its maximum at the end of the first step of deglaciation during melt-water pulse-IA (ca. 12 000 yr BP) (Fairbanks, 1989). At this time, transgressive sands deposited on the shelf (Nelson and Baraza, 1998) mark the beginning of a landward migration of the depositional system. However, since sea level was still low (see Nelson and Baraza, 1998), terrigenous sediment input could have been high enough to maintain relatively high sedimentation rates and therefore an increase in sediment loss rates due to a higher intensity of the MOW would be needed to form a sandy contourite layer. After this event the sedimentation rate started to increase becoming higher during the Younger Dryas (e.g. TG-55) probably due to the relatively higher terrigenous supply from the Guadalquivir river due to the relative sea level drop at that time. These high sedimentation rates sharply reduce at about 10 $^{14}C$ kyr BP when the rate of sea level rise increased very rapidly during melt-water pulse IB (Fairbanks, 1989). During the Holocene, sedimentation rate remains low. This is probably due to a major decrease in the terrigenous supply as indicated by the higher carbonate values during this stage. The broad marshes of the Guadalquivir Valley or those of the Tinto and Odiel rivers and the Cadiz shelf have been trapping a large part of the terrigenous sediments transported by these rivers throughout the Holocene, preventing these sediments from being supplied to the upper slope (Goy et al., 1996; Nelson and Baraza, 1998). A similar scenario can be suggested for the Bølling–Allerød stage, while local factors such as the growth or destruction of littoral spit bars, which can partially close or open the mouth of the Guadalquivir river, could play a secondary role in the control of the terrigenous supply to the Cadiz margin.

One of the consequences of the model is the lower the sedimentation rate, the higher the sand content in the sediments. Along this line of reasoning, during the Holocene, especially the late part, the proportion of sand is high, reaching values over 50%. It is still difficult to know whether there is continuous condensed sedimentation throughout the Holocene, or whether there are discontinuities or no sedimentation at all during certain intervals. In any case, if we take into account core TG-45 where the uppermost sediments were dated at 5380 yr BP, it can be suggested that the latest Holocene was extremely condensed. This greater condensation within the late Holocene may be inferred from the increase in grain-size towards the top of the section in core TG-40 and many other cores (see Nelson et al., 1993). According to our model, this means that, currently terrigenous material continues to be trapped in the mid-shelf mud layer (Nelson and Baraza, 1998) and within the broad marshes and tidal flats that spread several km inland in the Guadalquivir and other rivers of the region (Zazo et al., 1992; Goy et al., 1996).

In conclusion, as in many other geological studies, time and energy are two parameters that are very difficult to distinguish. A high energy of bottom currents is totally necessary to explain sediment winnowing and to produce current driven bedforms as those observed on the Cadiz slope off Spain as well as the current grading of grain size from proximal regions (Gibraltar) to distal regions (Faro Drift) (see Nelson et al., 1993). As far as we know, this has been the only factor considered. Here, we suggest that time could also be a very significant factor controlling the final facies of the sediments that amplifies or minimizes the effect of this energy. During times of low sedimentation rate this energy acted during a time long enough to completely rework the sediments, while during times of high sedimentation rates the energy acts only during a very short time and hence is not able to induce significant changes in the sediment facies. However, it is very difficult to separate both factors because they produce the same results.

## 9. Conclusions

The calcareous plankton studied in six cores from a marginal terrace in the upper slope of the Gulf of Cadiz allowed us to identify the paleoclimatic history from late glacial to recent. From bottom to top, two significant events have been recognized. The first is an increase in the subtropical and tropical forms (*G. ruber* and *G. sacculifer*) following an interval in which these forms were almost absent. This event is correlated with Termination 1A. It is also marked by the reduction in *N. pachyderma* (sinistral) and *G. quinqueloba*, which are frequent during the glacial stage, and the relatively high values of *Umbilicosphaera* and the *G. oceanica*/*G. muellerae* ratio.

The second event is recorded by the sharp reduction in *N. pachyderma* (dextral) parallel to the increase in *G. ruber* and *G. sacculifer* along with the increase in the warm water indicators of the coccolith assemblage. This event is correlated with Termination 1B. An abrupt reduction in the proportion of benthic foraminifera also occurred, coinciding with the second stage of the deglaciation, and was probably due to the inhospitable conditions of the sea bottom developed immediately after this event.

Between both deglaciation events, in some cores, the Bølling–Allerød and the Younger Dryas stages have been identified.

The opposite trend of the coccolith concentration with regards to the sand content in the sediments is due to the strong winnowing produced by the MOW, washing out the fine particles (clay and coccoliths) and thereby concentrating the coarser ones (planktonic and benthic foraminifera and silty or sandy terrigenous material).

As in other studies addressing the Gulf of Cadiz, two or three sandy contourite layers have been identified in the cores following the glacial stage. The first one is correlated with Termination 1A, while the second and third are probably amalgamated in a single layer that started to form during Termination 1B and continues during the Holocene. An exception is core TG-40 in which two silty and sandy layers are found; one of these coincides with Termination 1B and the other was formed during the late Holocene.

Although in previous work these sandy contourite layers have been related to episodes of intensification of the MOW, the present work suggests that these layers could be condensed layers originated during episodes of relative sea-level rise. At these times terrigenous material, which is the main component of the sediments in this region, began to be trapped on land, sharply reducing the sedimentation rate on the continental slope of the Gulf of Cadiz. As a consequence of this, the winnowing produced by bottom currents of the MOW was more efficient because it acted for longer times on the mixed layer and at the same time more generations of benthic organisms were able to rework these sediments.

## Acknowledgements

This research was supported by DGCYT Proyect PB-91-0097 and PB 95-0927 as well as by a European Grant (EV5V-CT94-0445). The authors are very grateful to H. Nelson for critical reading of the manuscript and valuable suggestions. Two anonymous reviewers are also acknowledged. We would like to thank Dr. A. Maldonado for his help in allowing us to sample the sediment cores of several cruises in the Gulf of Cadiz. Thanks also go to Jesús Roncero for his help in sample processing.

## References

Abrantes, F., 1990. The influence of the Guadalquir River on Modern surface sediment diatom assemblages: Gulf of Cadiz. Comun. Serv. Geol. Port. 76, 23–31.

Bard, E., Fairbanks, R.G., Arnold, M., Maurice, P., Duprat, J., Moyes, J., Duplessy, J.C., 1989. Sea level estimates during the last deglaciation based on $\partial^{18}O$ and accelerator mass spectrometry $^{14}C$ ages measured in Globigerina bulloides. Quat. Res. 31, 381–391.

Be, A.W.H., 1977. An ecological, zoogeographic and taxonomic review of recent planktonic foraminifera. In: Ramsay, A.T.S. (Ed.), Oceanic Micropaleontology. Academic Press, London, pp. 1–100.

Bukry, D., 1974. Coccoliths as paleoclimatic indicators — evidence from Black Sea. In: Degens, E.T., Ross, D.A. (Eds.), The Black Sea, Geology, Chemistry and Biology. AAPG 2, 353–363.

Cifelli, R., 1971. On the temperature relationships of planktonic foraminifera. J. Foraminifera Res. 1 (4), 170–177.

Cifelli, R., 1974. Planktonic foraminifera from the Mediterranean and adjacent Atlantic waters (Cruise 49 of the Atlantis II, 1969). J. Foraminifera Res. 4 (4), 171–184.

Devaux, M., 1985. Foraminifères et isotopes légers, indicateurs stratigraphiques et environmentaux de la dernière déglaciation Quaternaire. Golfe de Cadix — Mer d'Alboran. Thesis, Univ. Bordeaux I, pp. 1–216.

Díaz, J.I., Farrán, M., Maldonado, A., 1985. Surficial sediment distribution patterns in the Gulf of Cadiz controlled by the geomorphic features and physical oceanographic parameters. 6th Eur. Reg. Meet. Sedimentol., I.A.S. Lleida' 85.

Duplessy, J.C., Delibrias, G., Turon, J.L., Pujol, C., Duprat, J.C., 1981. Deglacial warming of the northeastern Atlantic Ocean: correlation with the paleoclimatic evolution of the European continent. Palaeogeogr. Palaeoclimatol. Palaeoecol. 35 (234), 121–144.

Duprat, J., 1983. Les foraminifères planctoniques du Quaternaire terminal d'un domaine péricontinental (Golfe de Gascogne, cotes ouest-ibériques, Mer d'Alboran): ecologie biostratigraphie. Bull. Inst. Geol. Bassin Aquit. 33, 71–150.

Ericson, D.B., 1959. Coiling direction of Globigerina pachyderma as a climatic index. Science 130 (3369), 219–220.

Ericson, D.B., Wollin, G., Wollin, J., 1954. Coiling direction of Globorotalia truncatulinoides in deep sea cores. Deep-Sea Res. 2, 152–158.

Fairbanks, R.G., 1989. 17 000-year glacio-eustatic sea level record: influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. Nature 342, 637–642.

Faugeres, J.C., Gonthier, E., Pujol, C., Devaux, M., Philipps, I., 1984. La mission Faegas IV: premiers resultat sur les sediments profonds de la marge ouest-ibérique, du Golfe de Cadix et de la mer d'Alboran. Bull. Inst. Geol. Bassin Aquit. 36, 67–83.

Faugeres, J.C., Cremer, M., Monteiro, H., Gaspar, L., 1985a. Essai de reconstitution des processus d'edification de la ride sedimentaire de Faro (Marge sud-Portugaise). Bull Inst. Geol. Bassin Aquit. 37, 229–258.

Faugeres, J.C., Frappa, M., Gonthier, E., Grousset, F., 1985b. Impact de la veine d'eau Mediterraneenne sur la sedimentation de la marge sud et ouest Ibérique au Quaternaire recent. Bull. Inst. Geol. Bassin Aquit. 37, 259–287.

Faugeres, J.C., Gonthier, E., Peypouquet, J.P., Pujol, C., Vergnaud-Grazzini, C., 1986. Distribution et variations des courants de fond sur la ride de Faro (Golfe de Cadiz), temoins des modifications des échanges Mediterranée Atlantique au Quaternaire Récent. Bull. Soc. Geol. Fr. 2 (3), 423–432.

Flores, J.A., Sierro, F.J., Raffi, I., 1995. Evolution of the calcareous nannofossil assemblage as a response to the paleoceanographic changes in the Eastern Equatorial Pacific from 4 to 2 Ma (Leg 138, Sites 849 and 852). In: Pisias, N., Mayer, L., Janecek, T., Palmer-Julson, T.R., Van Andel T. (Eds.), Proc. ODP, Science Results, 138. College Station, TX, pp. 163–176.

Flores, J.A., Sierro, F.J., Francés, G., Vazquez, A., Zamarreño, I., 1997. The last 100,000 years in the Western Mediterranean: sea surface water and frontal dynamics as revealed by coccolithophores. Mar. Micropaleontol. 29, 351–366.

Geitzenauer, K.R., Roche, M.B., McIntyre, A., 1976. Modern Pacific coccolith assemblages: derivation and application to Late Pleistocene paleotemperature analysis. In: Cline, R.M., Hays, J.D. (Eds.), Investigation of Late Quaternary Paleoceanography and Paleoclimatology. Geol. Soc. Am. Mem. 145, 423–448.

Gonthier, E.G., Faugeres, J.C., Stow, D.A.V., 1984. Contourite facies of the Faro Drift, Gulf of Cadiz. In: Stow, D.A.V., Piper, D.J.W. (Eds.), Fine Grained Sediments: Deep Water Processes and Facies. Blackwell, Oxford, pp. 275–292.

Goy, J.L., Zazo, C., Dabrio, C.J., Lario, J., Borja, F., Sierro, F.J., Flores, J.A., 1996. Global and regional factors controlling changes of coastlines in Southern Iberia (Spain) during the Holocene. Quat. Sci. Rev. 15, 1–8.

Imbrie, J., Kipp, N.G., 1971. A new micropaleontological method for quantitative paleoclimatology: application to a Late Pleistocene Caribbean core. In: Turekian, K.K. (Ed.), The Late Cenozoic Glacial Ages. Yale University Press, New Haven, pp. 71–181.

Jordan, R., Mexihun, Z., Eglington, G., Weaver, P.P.E., 1996. Coccolith and alkenone stratigraphy and paleoceanography at an upwelling site off NW Africa (ODP 658C) during the Last 130,000 years. In: Moguilevsky, A., Whatley, R. (Eds.), Microfossils and Oceanic Environments. University of Wales, Aberystwyth, p. 111-130.

Jorissen, F.J., Asioli, A., Borsetti, A.M., Capotondi, L., De Visser, J.P., Hilgen, F.J., Rohling, E.J., Van der Borg, K., Vergnaud-Grazzini, C., Zachariasse, W.J., 1993. Late Quaternary central Mediterranean biochronology. Mar. Micropaleontol. 21, 169–189.

Keigwin, L.D., Jones, G.A., 1989. Glacial–Holocene stratigraphy, chronology and paleoceanographic observations on some North Atlantic sediment drifts. Deep-Sea Res. 36 (6), 845–867.

Kenyon, N.H., Belderson, R.H., 1973. Bed forms of the Mediterranean undercurrent observed with side-scan sonar. Sediment. Geol. 9, 77–99.

Loutit, T.S., Hardenbol, J., Vail, P.R., Baum, G.R., 1988. Condensed sections: the key to age dating and correlation of continental margin sequences. In: Wilgus, Ch.K., Hastings, B.S., Kendall, Ch.G.St.C., Posamentier, H.W., Ross, Ch.A., Van Wagoner, J.C. (Eds), Sea-level Changes: An Integrated Approach. Soc. Econ. Paleontol. Mineral. Spec. Publ. 42, 183–213.

Madelain, F., 1970. Influence de la topographie du fond sur l'écoulement méditerranéen entre le detroit de Gibraltar et la Cap Saint Vincent. Cah. Oceanogr. 22, 43–61.

McIntyre, A., 1967. Coccoliths as paleoclimatic indicators of Pleistocene Glaciation. Science 158, 1314–1317.

Mougenot, D., Vanney, J., 1982. Les rides de contourites plio–quaternaires de la pente continentale sud-portugaise. Bull. Inst. Geol. Bassin Aquit. 31, 131–139.
Nelson, C.H., Baraza, J., Maldonado, A., 1993. Mediterranean undercurrent sandy contourites, Gulf of Cadiz, Spain. Sediment. Geol. 82, 103–132.
Nelson, C.H., Baraza, J., Barber Jr., J.H., 1999. Influence of the Atlantic inflow and Mediterranean outflow currents in late Pleistocene and Holocene sedimentary facies of the Gulf of Cadiz continental margin. Mar. Geol. 155, 99–129.
Posamentier, H.W., Vail, P.R., 1988. Eustatic controls on clastic deposition II — Sequence and systems tract models. In: Wilgus, Ch.K. et al. (Eds.), Sea-level Changes: an Integrated Approach. Soc. Econ. Paleontol. Mineral. Spec. Publ. 42, 125–154.
Pujol, C., 1980. Les Foraminifères planctoniques de l'Atlantique nord au Quaternaire. Ecologie, stratigraphie, environnement. Thèse Doctoral, Université Bordeaux, 254 pp.
Pujol, C., Caralp, M., 1974. Variations du sens d'enroulement des Foraminifères planctoniques dans l'interpretation stratigraphique du Quaternaire terminal de l'Ocean Atlantique Nord. Bull. Inst. Geol. Bassin Aquit. 16, 31–50.
Pujol, C., Vergnaud-Grazzini, C., 1989. Paleoceanography of the last deglaciation in the Alboran Sea (Western Mediterranean). Stable isotopes and planktonic foraminiferal records. Mar. Micropaleontol. 15, 153–179.
Rohling, E.J., Jorissen, F.J., Vergnaud-Grazzini, C., Zachariasse, W.J., 1993. Northern levantine and Adriatic Quaternary planktonic foraminifera; reconstruction of paleoenvironmental gradients. Mar. Micropaleontol. 21, 191–218.
Stow, D., Faugeres, J.C., Gonthier, E., 1986. Facies distribution and textural variations in Faro drift contourites: velocity fluctuation and drift growth. Mar. Geol. 72, 71–100.
Thierstein, H.R., Geitzenauer, K.R., Molfino, B., Shackleton, N.J., 1977. Global synchroneity of Late Quaternary coccolith datum levels: Validation by oxygen isotopes. Geology 5, 400–404.
Vergnaud-Grazzini, C., Borsetti, A.M., Cati, F., Colantoni, P., D'Onofrio, S., Saliege, J.F., Sartori, R., Tampieri, R., 1988. Paleoceanographic record of the last deglaciation in the strait of Sicily. Mar. Micropaleontol. 13, 1–21.
Weaver, P.P.E., Pujol, C., 1988. History of the last deglaciation in the Alboran Sea (Western Mediterranean) and adjacent North Atlantic as revealed by coccolith floras. Palaeogeogr. Palaeoecol. Palaeoclimatol. 64, 35–42.
Yingst, J.Y., Aller, R.C., 1982. Biological activity and associated sedimentary structures in Hebble-area deposits, Western North Atlantic. Mar. Geol. 48, M7–M15.
Zazo, C., Dabrio, C.J., Goy, J.L., 1992. The evolution of the coastal lowlands of Huelva and Cadiz (Southwest Spain) during the Holocene. In: Tooley, M.J., Jelgersma, S. (Eds.), Impacts of Sea-level Rise on European Coastal Lowlands. IBG Spec. Publ. 27. Blackwell, Oxford, pp. 204–217.
Zenk, W., 1970. On the Mediterranean Outflow West of Gibraltar. Meteorol. Forsch. Ergeb. 16, 23–34.