

## **Fluctuations of Mediterranean Outflow Water circulation in the Gulf of Cadiz during MIS 5 to 7: Evidence from benthic foraminiferal assemblage and stable isotope records**

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### **Abstract**

We studied variations in benthic foraminiferal assemblages and  $\delta^{13}\text{C}$  for the last 225 kyr at IODP site U1387 which is currently bathed by upper core of the Mediterranean Outflow Water (MOW). The MOW paleocirculation and sea-floor environment (oxygen level, trophic condition, bottom current strength) have been inferred from faunal composition; species diversity, abundances of selected index species/groups, microhabitat preferences combined with  $\delta^{13}\text{C}$  record of the epifaunal *Cibicidoides pachyderma*. The faunal and isotope records indicate relatively better ventilation at sea-floor and low trophic condition during MIS 1, 5 and 7 possibly due to increased influence of upper MOW in the Gulf of Cadiz. Our multi-proxy record reflects significant and rapid changes during cold (stadial) and warm (interstadial) phases within the interglacials MIS 5 and 7 and at Termination II. The faunal and isotope records reveal strong MOW flow and better ventilated, oligotrophic bottom-water conditions during stadials MIS 5b, 5d, 7b and 7d. The study further demonstrates weakened MOW intensity associated with poor ventilation and increased trophic level at sea-floor during interstadials MIS 5a, 5e, 7a and 7c. MOW flow was relatively sluggish at Termination II, followed by its strengthening at the end of MIS 5e. The chronology of these events suggests that periods of weakened MOW correlate with sapropel layers of the Mediterranean Sea, implying strong coupling between glacial-interglacial climate and MOW circulation in the Gulf of Cadiz.

**Keywords:** Gulf of Cadiz; Mediterranean Outflow Water; paleoceanography; benthic foraminifera

## 1. Introduction

Mediterranean Outflow Water (MOW), a warm and high saline water mass flowing out of the Mediterranean Sea through the Gibraltar Strait, contributes potentially to the North Atlantic thermohaline overturning circulation (Reid, 1978; Rahmstorf, 1998), thus influencing global climate (Bigg et al., 2003; Hernández-Molina et al., 2014a). The dynamics of MOW are considered to be controlled by the interplay of the North Atlantic Surface Water (NASW) and the North Atlantic Central Water (NACW) inflow into the Mediterranean Sea and its precipitation-evaporation balance (Bryden and Stommel, 1984). The Levantine Intermediate Water (LIW) and the Western Mediterranean Deep Water (WMDW) formed in the Mediterranean Sea during cold and dry winters contribute to MOW flow (Rohling, 1999). Thus, there is a significant climatic control on the formation of high salinity water masses in the Mediterranean Sea and MOW strength. Upon entering the northeast Atlantic, the contour flow of MOW leads to the development of the ‘Contourite Depositional System’ (CDS) in the Gulf of Cadiz (Garcia-Castellanos et al., 2009; Hernández-Molina et al., 2006, 2011, 2014b). Hence, the CDS developed along the margin depicts the variability of the MOW and its impact on sediment distribution and hydrodynamics in the Gulf of Cadiz (Gonthier et al., 1984).

The geometry of the Gibraltar Strait is determined by sea-level variation and tectonic history of the area and influences strongly the Atlantic-Mediterranean water exchange and MOW intensity on longer time scales (Hernández-Molina et al., 2014a). Previous studies on contourite deposits in the area, using sedimentological (eg. Mulder et al., 2003; Hernández-Molina et al., 2003; Llave et al., 2006; Voelker et al., 2006); mineralogical, geochemical (eg. Moreno et al., 2002; Jiménez-Espejo et al., 2013; Hodell et al., 2013); and foraminiferal assemblage and isotope records (eg. Zahn et al., 1987; Caralp, 1988; Vergnaud-Grazzini et al., 1989; Schönfeld and Zahn, 2000) indicate a close relationship of MOW strength with glacial-interglacial and short-term climatic changes. Recent findings also reveal a strong correlation between D-O climatic oscillations during the last glacial period and the MOW activity (Llave et al., 2006; Toucanne et al., 2007; Voelker et al., 2006, 2009; Bahr et al., 2014). It has also been suggested that past changes in water column ventilation of the Gulf of Cadiz were related to the variations in overturning circulation in the Mediterranean Sea and/or in the Atlantic Ocean (Voelker et al., 2006). Evidences derived from the multi-proxy record point to strong MOW flow and better ventilation during most Greenland stadials and weak MOW, and poor ventilation during the interstadials, similar to the patterns observed from the western Mediterranean Sea (Cacho et al., 2000; Sierro et al., 2005).

Although, many cores have been studied with high resolution, from this region, most of the MOW paleoceanographic reconstructions were limited to the last glacial cycle. In this paper, our main focus is to study the MOW variability pattern and related changes in benthic environment over the upper slope of the Iberian margin mainly beyond MIS 4, between the interglacials MIS 5 and 7.

As, the hydrodynamic regime of MOW strongly influences the benthic environment (oxygen level, trophic condition and bottom current activity) and faunal distribution, the fossil records of benthic foraminiferal assemblages in contourite deposits are remarkable tracers of MOW intensity, its flow pattern and associated environmental variables. The distribution pattern of recent benthic foraminifera in the Gulf of Cadiz and its relationship with the MOW contour current has been described in several studies (eg. Schönfeld, 1997, 2002a, b; Rogerson et al., 2011), and the application of fossil benthic foraminifera as proxies for MOW variability in the past has been very well demonstrated (eg. Caralp, 1988; Schönfeld and Zahn, 2000). Here, we present records of benthic foraminiferal assemblages and epibenthic  $\delta^{13}\text{C}$  at IODP site U1387 located in upper limb of MOW flow over the upper slope of the Iberian margin (Fig. 1) to monitor changes in benthic environments and their relationships with MOW circulation.

## **2. Oceanographic Setting**

At present, the circulation in the Gulf of Cadiz is mainly driven by the exchange of the warm, high saline, near-bottom Mediterranean Outflow Water (MOW) and less saline, colder north Atlantic water masses (Fig. 1). The north Atlantic water mass comprises the North Atlantic Surface Water (NASW; 0-100 m) and the North Atlantic Central Water (NACW; 100-700 m) (Ambar and Howe, 1979a, b; Baringer and Price, 1999). The MOW water mass represents a mixture of water masses formed in the Mediterranean Sea including LIW and WMDW (Millot et al., 2006; Rogerson et al., 2012). After exiting through Gibraltar Strait, MOW flows north and northwestward along the western Iberian margin, as a strong bottom current of  $\sim 1.78$  Sv (Ambar, 1983; Ambar and Howe, 1979a, b). On entering the Gulf of Cadiz, MOW mixes rapidly with ambient NACW (Ambar and Howe, 1979a, b). The buoyancy of MOW being warm and high saline is not in equilibrium with the ambient NACW and it is held upwards by Coriolis force (Baringer and Price, 1997; Schönfeld, 2002a). The complex sea-floor topography splits MOW into two major core layers: an upper core (Mediterranean Upper Water) centered between 400 and 600 m, and a slightly more saline lower core (Mediterranean Lower Water) between 600 and 1200 m (Zenk and Armi, 1990; Baringer, 1993). The MOW water mass flows above the North Atlantic Deep Water (NADW).

### 3. Material and Methodology

The IODP site U1387 (36°48.321'N; 7°43.1321'W; water depth 559.1 mbsl) is situated at the eastern end of Faro Drift (Fig. 1) within the upper MOW core (Stow et al., 2013). Three holes were drilled at this site during the IODP Expedition and a 870 m thick section of sediment was recovered spanning the last ~ 6 m.y. (Stow et al., 2013). A composite depth scale (MCD) has been developed from the parallel holes. The interval from 0 to 53.38 mcd, representing the last 225 kyr has been considered in the present study. Samples for foraminiferal and isotope analyses were taken at intervals of 0.75-1 m from top to 25.5 mcd, and at 15 cm intervals from 25.5 to 53.38 mcd.

About 5 g of dried sediment of each sample were washed through wet sieving over a 63 µm screen. Residues larger than 63 µm were dry sieved again over a 125 µm screen. Benthic foraminiferal assemblages were analysed from the fraction > 125 µm. The processed samples were split into subsamples from which all specimens were separated, identified and counted. The total number of counted ([Supplementary data](#)) specimens in the samples varies from 130 to 770. Relative abundance of individual species was recorded as a percent of total benthic foraminiferal population. For identification and taxonomic classification, we followed Phleger et al. (1953), Barker (1960), Ellis and Messina (1940-1978), Cita and Zocchi (1978), Caralp (1984), Ross and Kennett (1984), Schönfeld (1995, 1997, 2002a, b), Loeblich and Tappan (1988, 1992), Kaminski et al. (2002) and Sen Gupta (2002). Multivariate statistical analyses (i.e. diversity and factor) were performed on benthic foraminiferal abundance data by using PAST software (Version 2.09) (Hammer et al., 2001). In order to place greater stress on the dominant taxa, 43 highest ranked species present in at least three samples with a relative abundance of 2 % or more were included in factor analysis (e.g. Verma et al., 2013).

Mathematical expressions of the diversity indices used in the present study are as follows;

1. Shannon index (entropy); (H)

$$H = - \sum_i \frac{n_i}{n} \ln \frac{n_i}{n} ;$$

where,  $n_i$  is the number of individuals of a taxon and  $n$  is the total number of individuals.

2. Equitability; (E)

$$E = \frac{H}{\ln S} ;$$

where,  $H$  is Shannon index,  $S$  is the no. of species in the sample.

Stable isotope measurements were conducted on the epibenthic foraminifer *Cibicidoides pachyderma* (> 125 µm) by using an Isoprime Dual Inlet-Isotope Ratio Mass Spectrometer at the Marine Stable Isotope Laboratory of National Centre for Antarctic & Ocean Research in Goa, India.

Both oxygen and carbon isotope values are reported relative to the VPDB (Vienna PDB) (Supplementary data). The precision of the  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  measurements are 0.05 ‰ and 0.04 ‰ (1 $\sigma$  standard deviation), respectively obtained by repeatedly running NBS-19 (n=43) as the standard. The AMS radiocarbon dates were measured on two monospecific samples (*Globigerina bulloides* > 125  $\mu\text{m}$ ) and three samples of mixed species (*Globorotalia inflata* + *Globigerina bulloides* > 125  $\mu\text{m}$ ) at NSF-Arizona AMS laboratory (Table 1). AMS  $^{14}\text{C}$  ages were calibrated by using CALIB 7.1 program based on Marine 13 calibrations of Stuiver and Reimer (1993) and reported calibrated ages are based on 2 sigma error bars with reservoir correction of 400 years (Table 1).

For the age model, we considered primarily the chronostratigraphy of the top 33.58 mcd section constructed by Bahr et al. (2014) based on the XRF Br records stacked with Iberian margin core MD01-2444 (Martrat et al., 2007) and NGRIP-Member (2004) (Fig.2). Five radiocarbon ages obtained for the top section agree well to the age model of Bahr et al. (2014). Below 33.58 mcd, the age model is based on the oxygen isotope stratigraphy established by comparison of our benthic foraminiferal oxygen isotope record with the oxygen isotope record of Lisiecki and Raymo (2005) (Fig. 2). Overall, forty two tie points were used for construction of the age model at this site (Table 2).

## 4. Results

### 4.1. Stable isotope records

The stable oxygen and carbon isotope compositions of *C. pachyderma* show significant variations on glacial/interglacial and millennial time scales (Figs. 2, 6, 7). The oxygen isotope record reflects relatively more positive  $\delta^{18}\text{O}$  values during glacial MIS 2, 4 and 6 and negative values in interglacial MIS 1, 3, 5 and 7 (Fig. 2). The transition from MIS 6 to 5 is marked by a rapid and major change from higher to lower  $\delta^{18}\text{O}$  values depicting Termination II. The isotope record shows prominent oscillations within the interglacial MIS 5 and MIS 7 with negative excursions in  $\delta^{18}\text{O}$  values corresponding to interstadials MIS 5a, 5c, 5e and MIS 7a, 7c and positive excursions to stadials MIS 5 b, 5d and MIS 7b, 7d. However, MIS 5c and 7b are less distinct and only later phase of MIS 7d seems to be present in the record. The most negative values are recorded during MIS 5e. The temporal resolution of our record is not sufficient to constrain D-O interstadials and stadials within the isotope stages 2 to 4.

A prominent increase in  $\delta^{13}\text{C}$  values is noticed during MIS 5b, 5d, 7b, 7d and also during 65-70 ka (early MIS 4) and 140-150 ka (late MIS 6) (Figs 6, 7). The lowest values of  $\delta^{13}\text{C}$  are recorded at around 175 ka within MIS 6 and between 205 and 215 ka corresponding approximately to MIS 7c.

The intervals corresponding to MIS 5a, 5c, 5e and MIS 7a are also characterized by low values of  $\delta^{13}\text{C}$ . There have been rapid depletions in heavier carbon isotopes at Termination II.

#### 4.2. Benthic foraminiferal record

##### 4.2.1. General characteristics

A total of 212 species representing 84 genera of benthic foraminifera were recorded (Appendix I). The number of benthic foraminiferal species varies between 20 and 74. The assemblages are composed mainly of uvigerinids, cassidulinids, bolivinids, buliminids, *Melonis* spp., miliolids, cibicidids, *Hyalinea balthica*, *Textularia* spp. and *Sphaeroidina bulloides* (in decreasing order of relative abundances) representing on average about 90 % of the benthic foraminiferal record. Variations in benthic foraminiferal assemblage, species diversity, abundances of environment sensitive species and microhabitat preferences are frequently used as indicators for paleoceanographic reconstructions. Ecological preferences of significant species/groups used in paleoenvironmental interpretations are provided in Table 3. Ecologically sensitive benthic taxa recorded in this study are illustrated in Plate 1.

##### 4.2.2. Temporal variability

The numerical abundance of benthic foraminifera ( $> 125 \mu\text{m}$ ) varies between approximately 3000 and 40000 specimens  $\text{g}^{-1}$  with maximum abundances occurring during glacial stage MIS 6 (Fig. 3). The interglacial stages as compared to the glacial stages are characterized in general by low absolute abundances except for brief periods of increase between 90 and 100 ka within MIS 5. Uvigerinids occur consistently with significant abundance ( $\sim 10 - 60 \%$ ) throughout the studied section with its maximum abundance during the middle of MIS 6 between 155 and 175 ka (Fig. 3). The bolivinids remain relatively more abundant in lower part of the record between 175 and 190 ka; and 205 and 220 ka; showing almost parallel trend with cassidulinids and opposite pattern to the abundance of *Melonis* spp. (Fig. 3). The abundance pattern of buliminids is broadly opposite to that of the cassidulinids. Abundance of miliolids is relatively high during MIS 5b, 5d, 7b and 7d. The abundance pattern of cibicidids broadly parallels to that of miliolids except during the MIS 6 when cibicidids occur with relatively high abundance. The abundance pattern of *Textularia* spp. is closely similar to the pattern of the miliolids.

*Uvigerina peregrina* and *Uvigerina mediterranea* are the main taxa of uvigerinid population. *Uvigerina peregrina* was the most dominant species between 155 and 175 ka. *U. mediterranea* and *M. barleeianum* together are abundantly present during most intervals of the last 165 kyr (Fig. 4). *U. mediterranea* lives today in the epi-bathypelagic zone of the NE Atlantic (Duros

et al., 2011) and is an important constituent taxon of the ‘Upper slope foraminiferal assemblage’ of the Iberian margin (eg. Schönfeld, 1997). Fontanier et al. (2006) reported this species from meso-eutrophic open-slope environment in association with *U. peregrina* and *Melonis barleeaanum*. This species is also linked to intermediate water mass in the Mediterranean Sea (Parker, 1958; Caralp, 1988). Significant occurrence of this species in association with *Planulina arimiensis* has been recorded from the Iberian margin within the MOW flow path. The cassidulinid and bolivinid populations are mainly represented by *Cassidulina carinata* and *Bolivina spathulata* respectively. *Cassidulina carinata* occurs abundantly during glacial stages MIS 2, 4, early part of MIS 6 and 205 – 220 ka within MIS 7 (Fig. 4). *Bolivina spathulata* was among abundant species during 175- 220 ka except a brief interval of prominent decline between 200 and 205 ka (Fig. 4). *Bulimina aculeata* is the main taxon of buliminid group. This species shows its maximum abundance in MIS 6 except during 155-175 ka when its abundance declines significantly. *Hyalinea balthica* in our record is present only since beginning of MIS 6 (Fig. 4). This species shows peak abundances at the end of Termination II, MIS 5d and 5b. *Hyalinea balthica* is an important species of the Iberian margin associated with the cold water mass (Ross, 1984). *Sphaeroidina bulloides* generally follows the pattern of *Melonis barleeaanum* except for a brief interval in MIS 7 showing opposite pattern.

#### 4.2.3. Species diversity

The species diversity of benthic foraminifera is expressed in terms of Simple Diversity (no. of species; S), Shannon Index (H) and Equitability (E’). Various diversity indices show closely parallel trend in their temporal distribution during last 225 kyr (Fig. 5). In general, values of simple diversity, Shannon index and equitability remain relatively high during the interglacial stages with their maximum values occurring during MIS 5 (Fig. 5). Termination II is marked with relatively less diverse and equitable benthic fauna followed by a period of more diverse and equitable fauna during 85-120 ka (Fig. 5). A brief interval of moderate increase between 135 and 150 ka is preceded by a period (155 – 175 ka) of low values of simple diversity, Shannon index and equitability. After a period of marked decline in diversity between 205 and 220 ka, an increase in diversity indices is recorded between 200 and 205 ka. A marked increase in diversity indices is also noticed during 220 – 225 ka.

#### 4.3. Foraminiferal assemblage

Multivariate statistical analysis provides information on interspecies relationships and their dependency on varying environmental factors. Four factors have been identified in the factor analysis

which together account for about 85% of total faunal variance (Table 4). We considered the scores of first three factors with 81 % faunal variance to recognize three distinct faunal assemblages (Fig. 6).

i) Melonis barleeanum-Uvigerina mediterranea Assemblage: Species having a distinct positive score of Factor 1 comprise of *M. barleeanum* and *U. mediterranea* as major faunal components (Table 4). *Angulogerina carinata*, *Bulimina aculeata*, *B. marginata*, *B. striata*, *Cassidulina crassa*, *Globocassidulina oblonga* and *Hyalinea balthica* are the other associated species of this assemblage. This assemblage shows its significant occurrence during interglacial stages particularly in MIS 1, 5 and 7 (Fig. 6). This assemblage occurs prominently during cold substages of MIS 5 (5b, 5d), MIS 7 (7b, 7d) and also during 140-150 ka in glacial MIS 6. Characteristically, low occurrence of *Melonis barleeanum-Uvigerina mediterranea* assemblage is recorded during 170-180 ka in MIS 6 and 205-220 ka in MIS 7. Termination II is also marked by a relative low occurrence of this assemblage. The significant occurrence of this assemblage mostly during intervals of increased benthic  $\delta^{13}\text{C}$  values suggest its association with a better oxygenated deep water with relatively low trophic level (Fig. 6).

ii) Bolivina spathulata-Cassidulina carinata Assemblage: *B. spathulata* and *C. carinata* are the major species of this assemblage having high positive scores of factor 2. *Bulimia aculeata* is another associated species of this assemblage (Table 4). The pattern of variations in loadings of this assemblage is negatively correlated with that of *M. barleeanum-Uvigerina mediterranea* assemblage. We noticed three distinct intervals (i.e. 125-140 ka, 180-195 ka and 205-220 ka) of significant occurrence of this assemblage which also correspond to the decrease in benthic  $\delta^{13}\text{C}$  values. (Fig. 6). Thus, this assemblage appears to be related to relatively less oxygenated deep water with enhanced organic carbon flux to the sea floor.

iii) Uvigerina peregrina Assemblage: This assemblage is dominantly represented by *U. peregrina* with distinctly higher positive score of factor 3 along with *U. mediterranea* and *Bolivina* sp. as other associated taxa (Table. 4). The intervals of prominent occurrence of *Uvigerina peregrina* assemblage are during glacial MIS 6 between 155 and 175 ka and during interglacial MIS 7 between 200 and 205 ka; and 220 and 225 ka (Fig. 6). Interestingly, abundance maximum of this assemblage in MIS 6 shows opposite relationship with benthic  $\delta^{13}\text{C}$  values, whereas, its peak abundances in MIS 7 have positive correlation with the isotope record (Fig. 6). This suggests that probably *U. peregrina* assemblage is broadly related to better trophic condition at the sea-floor and not essentially to the ventilation condition.

#### 4.4. Benthic foraminiferal microhabitats

The benthic foraminifera show species-specific microhabitat preferences depending on their adaptation capabilities to the changing sea-floor environments governed by oxygen and food supply. In order to obtain a convincing picture of the changes in bottom oxygenation and trophic level



through time, we examined variations in composition of benthic foraminiferal assemblages with respect to abundances of major microhabitat categories. Benthic foraminifera based on their microhabitat preferences are grouped into two categories epifauna and infauna ([Appendix II](#); Tabel 3). The relative abundance pattern of the two groups is shown in figure 7. The faunal record reveals that high abundance of epifaunal species occurs in MIS 5 and 7 and low abundances in MIS 6. However, the infaunal taxa show an opposite trend of variation. A close inspection of the record further reveals that there has been gradual increase in relative abundance of epifaunal taxa from MIS 6 to 5. The faunal record indicates that the epifaunal taxa began to increase at the beginning of MIS 5 with prominent occurrences between MIS 5b and 5d (Fig. 7). The two prominent abundance maxima of epifaunal taxa are also noted during MIS 7b and MIS 7d (Fig. 7). The interval between 205 and 220 ka approximately corresponding to MIS 7c was a period of low abundance of epifaunal taxa and high concentration of infaunal species.

The benthic foraminiferal assemblages recorded in this study also contain a considerable presence of certain epibenthic species living on elevated substrate characterizing deep high energy environments (Fig. 7). We recorded seven epibenthic species which are associated with present day with the upper core of MOW (Schönfeld, 1997) ([Appendix II](#); Table 3). The cumulative abundances of these taxa is on average ~ 3 % of total benthic assemblage. The proportion of living elevated epibenthic species in benthic assemblage from the areas within upper MOW has been estimated to be about 8 % (Schönfeld, 2002a). Relatively low abundance of elevated epibenthics in our record is probably due to size-fraction ( $> 125 \mu\text{m}$ ) used in the study. Benthic foraminiferal records of previous studies are based on coarser size-fractions ( $> 250 \mu\text{m}$ ) in which relatively more epibenthics are accumulated. Our record indicates significant increase ( $> 6 \%$ ) in the abundance of elevated epibenthic taxa during MIS 5b, 5d, 7b and 7d (Fig. 7). A prominent peak of abundance is also noticed in early MIS 3 and in later phase of MIS 1.

## **5. Discussion**

Bottom water oxygenation and trophic level at the sea-floor have been suggested as the main factors controlling the spatial and in-sediment distribution of benthic foraminifera (eg. Bernhard, 1992; Jorissen et al., 1992, 1995; Schmiedl et al., 1997). The flow path of upper MOW core and its intensity greatly influence the bottom water mass characteristics and hydrodynamics of the upper slope of the Iberian margin at IODP site U1387 (Voelker and Abreu, 2011 and Stow et al., 2013). Thus, the changing flow path and intensity of MOW govern the oxygenation, trophic condition at the sea-floor and also the variation in the benthic foraminiferal composition. Our multiple benthic foraminiferal proxy records (faunal assemblages, species diversity, abundances of selected index

species/groups, microhabitat groups) and epibenthic  $\delta^{13}\text{C}$  demonstrate glacial/interglacial and millennial scales changes of the sea-floor environment, more distinctly across Termination II and within MIS 5, 6 and 7.

Variation in benthic foraminiferal diversity indices is governed by the environmental stability factor (Stefano et al., 2010). Low values of Shannon index are generally attributed to the stressed environment and high values to the stable environment (Boltovskoy and Wright, 1976; Murray, 1991). The deep-sea temperature, the trophic level and oxygen condition at the sea-floor have significant role in shaping large scale diversity patterns (Rai and Singh, 2001; Yashuhara et al., 2014; Singh et al., 2015). Relative abundances of benthic foraminiferal species/groups and their microhabitat categories (epifauna vs infauna) are considered to be primarily governed by the organic flux to the sea-floor and bottom oxygen condition. Epifaunal taxa are known to prefer generally high-oxygen and oligotrophic bottom water condition, whereas infaunal species prefer low-oxygen condition and more trophic level (Fenchel, 1969; Corliss and Chen, 1988; Kaiho, 1994; Jorissen et al., 1995). The faunal abundance record clearly indicates that the intervals of low diversity are the periods when infaunal taxa including stressed tolerant benthic foraminifera (*Bulimina*, *Bolivina*, *Uvigerina*; Kouwenhoven et al., 2006) predominated the benthic population. Probably, a sustained organic carbon flux to the sea-floor combined with reduced bottom water ventilation would have resulted a low-oxygen, meso-eutrophic condition and stressed environment. On the contrary, the periods of high diversity and corresponding increase of high oxygen, epifaunal taxa such as cibicidids and miliolids point to oxygenated, oligotrophic environment.

Temporal variations in factor loadings of three assemblages related to changes in trophic level and sea-bottom oxygen condition are in good agreement with the results from other faunal proxy records. Thus, it appears that the ventilation and trophic conditions at the sea-floor are the main factors driving changes in benthic foraminiferal records at the examined site. Earlier studies reveal that MOW has strong effects on ecological conditions at sea-floor of the study area. MOW provides an ecological niche occupied by opportunistic epibenthic species preferring elevated substrates (eg. Schönfeld, 1997). Therefore, temporal abundance pattern of elevated epibenthics records the strength of near bottom current associated with the MOW flow paths. In previous studies, epibenthic abundance record has been used as proxy for MOW intensity (eg. Schönfeld, 1997, 2002a; Schönfeld and Zahn, 2000; Rogerson et al., 2011). High proportion of this group in benthic assemblage is suggestive of relatively stronger MOW current. A striking similarity between abundance records of elevated epibenthics and total epifauna; and an opposite relationship of these two groups with total infauna clearly indicate that the sea-bottom environment (ventilation and

trophic level) at the examined site is primarily influenced by the MOW flow strength. Variation in  $\delta^{13}\text{C}$  record of epibenthic foraminifera from the Iberian margin has been suggested to be related to the deep water ventilation condition (Cacho et al., 2000; Voelker et al., 2006). The role of North Atlantic Deep Water (NADW) in affecting ventilation condition at site U1387 is ruled out because of its location at shallow depth. Therefore, bottom oxygenation at the site is probably governed by the past changes in MOW intensity and flow path pattern, as has been suggested earlier by Schönfeld and Zahn (2000) in their studies at the Portuguese margin. Hence, our epibenthic  $\delta^{13}\text{C}$  record displays sea-floor oxygenation history associated to the strength of current flow in the upper MOW core. An increase in  $\delta^{13}\text{C}$  values indicates enhanced ventilation with younger water mass related to MOW, whereas, a decrease in  $\delta^{13}\text{C}$  values is suggestive of poor ventilation and reduced MOW influence. A remarkable coherency in temporal variations of  $\delta^{13}\text{C}$  and elevated epibenthic abundance suggest that both records demonstrate history of MOW related deep water ventilation.

### 5.1. MOW variability and paleohydrographic evolution

#### 5.1.1 Glacial/Interglacial pattern

The faunal and isotope records together show distinct glacial/interglacial patterns of variations at the examined site during past 225 kyr. The significant occurrence of *Melonis barleeanum-Uvigerina mediterranea* assemblage along with more diverse benthic fauna and prominently increased abundances of epifaunal taxa and elevated epibenthic taxa during the interglacial MIS 5 between 85 and 110 ka indicate the influence of unstable, active bottom water possibly due to increased MOW intensity in the Gulf of Cadiz. Several oligotrophic benthic fauna (i.e. miliolid and cibicidids) also increased their relative abundances significantly during this period which correspond with the higher epibenthic  $\delta^{13}\text{C}$  values reflecting more ventilation and low trophic level at the sea-floor. From the faunal and  $\delta^{13}\text{C}$  records, it is clearly evident that the intensity of MOW was its maximum during MIS 5 between 85 and 110 ka in the last 225 kyr. Our records also suggest major MOW intensification during interglacial MIS 7, although for the two short periods. It was not possible to document pattern of changes in the entire period of MIS 7, as the present record represents only its younger part. The faunal pattern in general, indicates relatively sluggish MOW circulation in MIS 2 to 4 and enhanced MOW activity in later phase of MIS 1. An increase of MOW intensity is also evident during MIS 4/3 transition. Our sample resolution for MIS 1 to 4 is insufficient to resolve short-term variability pattern. However, faunal and isotope records do indicate enhanced MOW activity during later phase of MIS 1. The glacial stage MIS 6 in general, is marked with distinct occurrence of *Uvigerina peregrina* and/or *Bolivina spathulata-Cassidulina carinata* assemblages reflecting nutrient-rich and oxygen-poor sea-floor environment that could be attributed

to reduced influence of MOW in this region. The interval of 155 - 175 ka is typically characterized by prominent increase in the occurrence of *U. peregrina* assemblage along with less diverse fauna, increased abundance of uvigerinids and buliminids and low benthic  $\delta^{13}\text{C}$  values reflecting very poor ventilation and increased trophic level at the sea-floor. We infer that the above paleoecological changes are the response of a significant decrease in MOW strength in this region during 155 - 175 ka.

A plausible reason for the intensified MOW flow with high magnitude during MIS 5, as compared to glacial stages (MIS 2, 4 and 6) could be the increased exchange flow through the Strait of Gibraltar due to higher sea level. Moreover, the climate has a major control on the formation of high density deep-sea water in the Mediterranean Sea. Cold climatic periods are favorable for oxygenated deep water formation, and thus increase of MOW intensity (Toucanne et al., 2007). Therefore, it is possible that an intensive and denser MOW would have originated during cold phases within MIS 5 (Thomson et al., 1999; Rogerson, 2002). During warm climatic periods and at high sea-level, only upper core of MOW is better developed because of its lower density (Llave et al., 2006). Our observation of a stronger upper MOW current in the late MIS 1 than the MIS 2 suggests that climate condition combined with sea-level govern the intensity of MOW flow and depth positions of its upper and lower branches through time. This also agrees with earlier studies that proposed the climate and sea-level changes as prime factors controlling magnitude of Mediterranean-Atlantic water mass exchanges through the Strait of Gibraltar and the influence of the MOW in the Gulf of Cadiz (eg. Myers et al., 1998; Llave et al., 2006; Toucanne et al., 2007).

#### 5.1.2 Stadial/interstadial pattern

Records of benthic foraminiferal assemblage and epibenthic  $\delta^{13}\text{C}$  display distinct, short-term variability within the interglacials MIS 5 and 7. It is noteworthy that major faunal turnover occurred across Termination II when diversity and abundances of *M. barleeanum-U. mediterranea* assemblage, epifauna and elevated benthics decreased considerably pointing to an under-oxygenated, nutrient rich environment and sluggish MOW. Furthermore, the faunal and isotope records indicate that major strengthening of MOW occurred at the end of warm MIS 5e i.e after a phase of rising sea level. This suggests that after preconditioning due to sea-level rise, an intensification of MOW circulation occurs during the cooling episodes (stadials). Our study reveals enhancement of MOW during the stadials (cold phases) MIS 5b, 5d, 7b and 7d. MIS 5d event although, is not very well expressed in the faunal and isotope records, probably because of age model constraints. The intensification of MOW current during these intervals is also supported by the increased abundances of the elevated epibenthic forms. High abundances of epifaunal taxa and more diverse fauna during

these intervals further suggest well-oxygenated and oligotrophic environment at the sea-floor. Our interpretation of relatively better ventilation associated with the MOW intensification is in good agreement with the  $\delta^{13}\text{C}$  record showing positive excursions during these periods. The interval between 140 and 150 ka within MIS 6 was also the period of enhanced MOW circulation and relative increase in ventilation and low trophic level. Faunal and isotope records further suggest that though there has been some intensification of MOW circulation and deep water ventilation during 180-190 ka, the trophic level at sea-floor remained moderately high. It seems that bottom water mass at site U1387 was mixed with young, oxygenated and dense water formed in the Mediterranean Sea during the cold episodes. Earlier studies have suggested strong MOW and better ventilation during the Greenland stadials (Llave et al., 2006; Voelker et al., 2006; Bahr et al., 2014). The intermediate deep waters in the Mediterranean Sea were more oxygenated during the cold stadials (Cacho et al., 2000; Sierro et al., 2005) possibly due to intensified cool dry winds causing increased formation of Western Mediterranean Deep Water (WMDW). The faunal and isotope records indicate that the periods of the enhanced MOW were punctuated by the intervals of weakened MOW intensity, most prominently during the warm phases (interstadials) within MIS 5 and 7 (substages 5a, 5c, 5e, 7a and 7c). However, MIS 5c event is not clearly resolved probably because our low sample resolution. Our record further suggests a weakened MOW circulation at around 175 ka within the glacial MIS 6, which corresponds approximately to warm interstadial MIS 6d (Sun and An, 2005; Bruce et al., 2015). These warm, interstadials were the periods of poorly ventilated bottom water, indicated by lowered species diversity and abundant infaunal species.

It is intriguing to note that most of the intervals of reduced MOW intensity are correlatable with the sapropel layers [S2 (81 ka) with MIS 5a; S5 (124 ka) with MIS 5e; S6 (172-176 ka) within MIS 6; S7 (190-200 ka) with MIS 7a; S8 (206-216.8 ka) with MIS 7c] of the Mediterranean Sea (Cramp and Sullivan, 1999 and references therein; Emeis et al., 2003) (Fig. 7). Mainly, two theories have been proposed for the mechanism of formation of sapropel layers in the Mediterranean Sea; glacial melt water (Ryan and Cita, 1977; Vergnaud-Grazzini et al., 1977; Thunell and Williams, 1989) and large-scale riverine input (Rossignol-Strick et al., 1982; Hilgen et al., 2007; Gallego-Torres et al., 2010; Rohling et al., 2015) of which, the first one has not been accepted by many workers. We agree with the arguments that increased precipitation over the mid-latitudes and intensified monsoon induced runoff from North Africa during the interglacials, would have resulted high fluvial influx leading to upper water stratification in the Mediterranean Sea and as a consequence inhibiting vertical mixing and reoxygenation of deep waters causing anoxic condition.

Therefore, formation of oxygenated Mediterranean Deep Water was considerably reduced during the warmer interglacials leading to a weakened MOW circulation into the Atlantic.

## **6. Conclusions**

The advection of Mediterranean Outflow Water in the Gulf of Cadiz influences strongly the benthic environment (oxygen level, trophic condition and bottom current strength), and thus benthic foraminiferal composition. Temporal variations in benthic foraminiferal assemblages (species diversity, abundances of selected index species/group, microhabitat preferences) together with epibenthic  $\delta^{13}\text{C}$  record are used to monitor changes of the upper MOW core and associated hydrographic conditions at the sea-floor. Abundance of elevated epibenthics is used as an indicator of bottom current intensity related to MOW flow.

Our multi-proxy record demonstrates glacial/interglacial pattern of variations in benthic environment, more distinctly in the interglacials MIS 5 and MIS 7 and at Termination II. Evidence from our record broadly reveals sluggish MOW circulation during glacial stages as compared to the interglacials. Further, it is inferred that MOW was relatively weaker during Termination II, followed by its major strengthening at the end of warmest period in MIS 5 (i.e. 5e). Our study reveals enhanced MOW circulation and oxygenated, oligotrophic environment at the sea-floor during the stadials in MIS 5 and 7. Low-oxygen condition and increased trophic level at the sea-floor during the interstadials within MIS 5 and MIS 7 are most probably related to weakened MOW circulation. A significant decrease in MOW intensity at around 175 ka during MIS 6 corresponds approximately to the warm interstadial MIS 6d. We found that the periods of weakened MOW flow correlates with sapropels layers of the Mediterranean Sea suggesting a connection between climate and deep ocean overturning between the Mediterranean Sea and the Atlantic Ocean.

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## References

- Ambar, I., 1983. A shallow core of Mediterranean water off western Portugal. *Deep Sea Research*, 30(6A), 677-680.
- Ambar, I., Howe, M.R., 1979a. Observations of the Mediterranean outflow - I: Mixing in the Mediterranean outflow. *Deep Sea Research*, 26A, 535-554.
- Ambar, I., Howe, M.R., 1979b. Observations of the Mediterranean outflow - II: The deep circulation in the vicinity of the Gulf of Cadiz. *Deep Sea Research*, 26A, 555-568.
- Arnold, A.J., 1983. Foraminiferal thanatocoenosis on the continental slope off Georgia and South Carolina. *Journal of Foraminiferal Research*, 13(2), 79-90.
- Bahr, A., Jimenez-Espejo, F.J., Kolasinac, N., Grunert, P., Hernández-Molina, F.J., Rohl, U., Voelker, A.H.L., Escutia, C., Stow, D.A.V., Hodell, D., Alvarez-Zarikian, C.A., 2014. Deciphering bottom current velocity and paleoclimate signals from contourite deposits in the Gulf of Cadiz during the last 140 kyr: an inorganic geochemical approach. *Geochemistry, Geophysics, Geosystems*, 15(8), 3145-3160. doi:10.1002/2014GC005356.
- Baringer, M.O., 1993. Mixing and Dynamics of the Mediterranean outflow. PhD Thesis, Massachusetts Institute of Technology and the Woods Hole Oceanographic Institution Joint Program in Oceanography, Cambridge, Massachusetts, WHOI-93-52, 244 pp.
- Baringer, M.O., Price, J.F., 1997. Momentum and energy balance of the Mediterranean Outflow. *Journal of Physical Oceanography*, 27(8), 1678 - 1692.
- Baringer, M.O., Price, J.F., 1999. A review of the physical oceanography of the Mediterranean outflow. *Marine Geology*, 155(1-2), 63-82.
- Barker, R.W., 1960. Taxonomic notes on the species figures by H.B. Brady in his report on the foraminifera dredged by H.M.S. Challenger during the years 1873-1876. *SEPM Special Publication*, 9, 1-238.
- Bernhard, J.M., 1992. Benthic foraminiferal distribution and biomass related to pore-water oxygen: Central California Continental slope and rise. *Deep Sea Research*, 39, 586-605.
- Bernhard, J.M., Sen Gupta, B.K., 1999. Foraminifera of oxygen-depleted environments. In: Sen Gupta, B.K. (Ed.), *Modern Foraminifera*. Kluwer Academic Publishers, Dordrecht, The Netherlands, 201 - 216.
- Bigg, G.R., Jickells, T.D., Liss, P.S., Osborn, T.J., 2003. The role of the oceans in climate. *International Journal of Climatology*, 23(10), 1127-1159.
- Boltovskoy, E., Wright, R., 1976. *Recent Foraminifera*. Dr. W. Junk b.v. Publishers, The Hague. 515 pp.
- Borsetti, A.M., Laccarino, S., Jorissen, F.J., Poignant, A., Sztrakos, K., Van der Zwaan, G.J., Verhallen, P.J.J.M., 1986. The Neogene development of *Uvigerina* in the Mediterranean. In: Van der Zwaan G.J., Jorissen F.J., Verhallen P.J.J.M., Von Daniels C.H. (Eds.), *Atlantic-European Oligocene to Recent Uvigerina taxonomy, paleoecology and paleobiogeography*. *Utrecht Micropaleontological Bulletins* 35, 183-235.

- Bruce, R.L., Gibbard, P.L., Head, M.J., Voarintsoa, N.R.G., Toucanne, S., 2015. An optimized scheme of lettered marine isotope substages for the last 1.0 million years, and the climatostratigraphic nature of isotope stages and substages. *Quaternary Science Reviews*, 111, 94-106.
- Bryden, H.L., Stommel, H.M., 1984. Limiting processes that determine the basic features of the circulation in the Mediterranean Sea. *Oceanologica Acta*, 7(3), 289–296.
- Cacho, I., Grimalt, J.O., Sierro, F.J., Shackleton, N., Canals, M., 2000. Evidence for enhanced Mediterranean thermohaline circulation during rapid climatic coolings. *Earth and Planetary Science Letters*, 183(3-4), 417-429.
- Caralp, M.H., 1984. Quaternary calcareous benthic foraminifers, Leg 80. In: *Initial Reports of the Deep Sea Drilling Project*, 80 (26). U.S. Government Printing Office, Washington, D.C., 725-755.
- Caralp, M.H., 1988. Late glacial to recent deep-sea benthic foraminifera from the Northeastern Atlantic (Cadiz Gulf) and Western Mediterranean (Alboran Sea): paleoceanographic results. *Marine Micropaleontology*, 13, 265-289.
- Cita, M.B., Zocchi, M., 1978. Distribution patterns of benthic foraminifera on the floor of the Mediterranean Sea. *Oceanologica Acta*, 1(4), 445–462.
- Corliss, B.H., 1985. Microhabitats of benthic foraminifera within deep-sea sediments. *Nature*, 314, 435-438.
- Corliss, B.H., 1991. Morphology and microhabitat preferences of benthic foraminifera from the northwest Atlantic Ocean. *Marine Micropaleontology*, 17(3–4), 195–236.
- Corliss, B.H., Chen, T., 1988. Morphotype patterns of Norwegian Sea deep-sea benthic foraminifera and ecological implications. *Geology*, 16, 716-719.
- Corliss, B.H., Fois, E., 1990. Morphotype analysis of dee-sea benthic foraminifera from the northwest Gulf of Mexico. *Palaios*, 5, 589-605.
- Cramp, A., Sullivan, G.O., 1999. Neogene sapropels in the Mediterranean sea: a review. *Marine Geology*, 153, 11-28.
- Denne, R.A., Sen Gupta, B.K., 1989. Effects of taphonomy and habitat on the record of benthic foraminifera in modern sediments. *Palaios*, 4, 414-423.
- Duros, P., Fontanier, C., Metzger, E., Pusceddu, A., Cesbron, F., de Stigter, H.C., Bianchelli, S., Danovaro, R., Jorissen, F.J., 2011. Live (stained) benthic foraminifera in the Whittard Canyon, Celtic margin (NE Atlantic). *Deep Sea Research Part I*, 58, 128–146. [dx.doi.org/10.1016/j.dsr.2010.11.008](http://dx.doi.org/10.1016/j.dsr.2010.11.008).
- Ellis, B.E., Messina, A.R., 1940-1978. *Catalogue of Foraminifera*. American Museum of Natural History, New York (<http://www.Micropress.org/micropress/eandm/index.php> 3).
- Emeis, K.C., Schulz, H., Struck, U., Rossignol- Strick, M., Erlenkeuser, H., Howell, M.W., Kroon, D., Mackensen, A., Ishizuka, S., Oba, T., Sakamoto, T., Koizumi, I., 2003. Eastern Mediterranean surface water temperatures and  $\delta^{18}\text{O}$  composition during deposition of



sapropels in the late Quaternary. *Paleoceanography*, 18(1), <http://dx.doi.org/10.1029/2000PA000617>.

- Fenchel, T., 1969. The ecology of marine microbenthos. IV. Structure and function of the benthic ecosystem, its chemical and physical factors and the microfaunal communities with special reference to the ciliated protozoa. *Ophelia* 6, 1–182.
- Fontanier, C., Jorissen, F.J., Licari, L., Alexandre, A., Anschutz, P., Carbonel, P., 2002. Live benthic foraminiferal faunas from the Bay of Biscay: faunal density, composition, and microhabitats. *Deep Sea Research Part I*, 49, 751–785.
- Fontanier, C., Jorissen, F.J., Anschutz, P., Chaillou, G., 2006. Seasonal variability of foraminiferal faunas at 1000 m depth in the Bay of Biscay. *Journal of Foraminiferal Research*, 36, 61–76.
- Gallego-Torres, D., Martinez-Ruiz, F., de Lange, G., Jimenez- Espejo, F.J., Ortega-Huertas, M., 2010. Trace-elemental derived paleoceanographic and paleoclimatic conditions for Pleistocene Eastern Mediterranean sapropels. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 293, 76–89. doi:10.1016/j.palaeo.2010.05.001.
- Garcia-Castellanos, D., Estrada, F., Jimenez-Munt, I., Gorini, C., Fernández, M., Verges, J., De Vicente, R., 2009. Catastrophic flood of the Mediterranean after the Messinian salinity crisis. *Nature*, 462, 778–782. doi:10.1038/nature08555.
- Gonthier, E.G., Faugères, 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*. Geological Society of London Special Publication, 15, 275–292. doi:10.1144/GSL.SP.1984.015.01.18.
- Gooday, A.J., 1994. The biology of deep-sea foraminifera: a review of some advances and their applications in paleoceanography. *Palaios*, 9, 14–31.
- Gooday, A.J., 2003. Benthic foraminifera (Protista) as tools in deep-water paleoceanography: environmental influences on faunal characteristics. *Advances in Marine Biology*, 46, 1–90.
- Guichard, S., 1997. Thesis Evolution de l'environnement dans la zone de l'upwelling maturitanien pendant les derviers 236,000 ans, le temoignage de l'ecosysteme benthique. Thesis l'Universite Bordeaux I, N° d'ordre , 199.
- Hageman, J., 1979. Benthic foraminiferal assemblages from Plio-Pleistocene open bay to lagoonal sediments of the Western Peloponnese (Greece). *Utrecht Micropaleontological Bulletins*, 20, 1–171.
- Hammer, Ø., Harper, D.A.T., Ryan, P.D., 2001. PAST: Paleontological Statistics Software package for education and data analysis. *Palaeontologia Electronica*, 4(1), 1–9.
- Hernández-Molina, F.J., Llave, E., Somoza, L., Fernández-Puga, M.C., Maestro, A., León, R., Medialdea, T., Barnolas, A., Garcia, M., Diaz del Rio, V., Fernández-Salas, L.M., Vázquez, J.T., Lobo, F., Alveirinho Dias, J.M., Rodero, J., Gardner, J., 2003. Looking for clues to paleoceanographic imprints: a diagnosis of the Gulf of Cadiz contourite depositional systems. *Geology*, 31(1), 19–22. doi:10.1130/0091-7613(2003)031<0019:LFCTPI>2.0.CO;2.

- Hernández-Molina, F.J., Llave, E., Stow, D.A.V., Garcia, M., Somoza, L., Vázquez, J.T., Lobo, F.J., Maestro, A., Diaz del Rio, V., León, R., Medialdea, T., Gardner, J., 2006. The contourite depositional system of the Gulf of Cadiz: a sedimentary model related to the bottom current activity of the Mediterranean outflow water and its interaction with the continental margin. *Deep Sea Research Part II*, 53 (11-13), 1420–1463. doi:10.1016/j.dsr2.2006.04.016.
- Hernández-Molina, F.J., Serra, N., Stow, D.A.V., Llave, E., Ercilla, G., Van Rooij, D., 2011. Along-slope oceanographic processes and sedimentary products around the Iberian margin. *Geo-Marine Letters*, 31(5-6), 315–341. doi:10.1007/s00367-011-0242-2.
- Hernández-Molina, F.J., Stow, D.A.V., Alvarez-Zarikian, C.A., Acton, G., Bahr, A., Balestra, B., Ducassou, E., Flood, R., Flores, J.A., Furota, S., Grunert, P., Hodell, D., Jimenez-Espezo, F., Kim, J.K., Krissek, L., Kuroda, J., Li, B., Llave, E., Lofi, J., Lourens, L., Miller, M., Nanayama, F., Nishida, N., Richter, C., Roque, C., Pereira, H., Sanchej, Goni, M.F., Sierro, F.J., Singh, A.D., Sloss, C., Takashimizu, Y., Tzanova, A., Voelker, A., Williams, T., Xuan, C., 2014a. Onset of Mediterranean outflow into the North Atlantic. *Science*, 1244-1250. doi:10.1126/science.1251306.
- Hernández-Molina, F.J., Llave, E., Preu, B., Ercilla, G., Fontan, A., Bruno, M., Serra, N., Gomiz, J.J., Brackenridge, R.E., Sierro, F.J., Stow, D.A.V., Garcia, M., Juan, C., Sandoval, N., Arnaiz, A., 2014b. Contourite processes associated to the Mediterranean Outflow Water after its exit from the Gibraltar Strait: Global and conceptual implications. *Geology*, 42, 227–230.
- Hess, S., Jorissen, F.J., 2009. Distribution patterns of living benthic foraminifera from Cap Breton Canyon, Bay of Biscay: Faunal response to sediment instability. *Deep Sea Research Part I*, 56 (9), 1555–1578. doi:10.1016/j.dsr.2009.04.003.
- Hilgen, F.J., Kuiper, K., Krijgsman, W., Snel, E., van der Laan, E., 2007. Astronomical tuning as the basis for high resolution chronostratigraphy: the intricate history of the Messinian Salinity Crisis. *Stratigraphy*, 4(2-3), 231–238.
- Hodell, D., Crowhurst, S., Skinner, L., Tzedakis, P.C., Margari, V., Channell, J.E.T., Kamenov, G., MacLachlan, S., Rothwell, G., 2013. Response of Iberian Margin sediments to orbital and suborbital forcing over the past 420 ka. *Paleoceanography*, 28, 185–199.
- Jannink, N.T., Zachariasse, W.J., Van der Zwaan, G.J., 1998. Living (Rose Bengal stained) benthic foraminifera from the Pakistan continental margin (northern Arabian Sea). *Deep Sea Research Part I*, 45, 1483-1513. doi:http://dx.doi.org/10.1016/s0967-0637(98)00027-2.
- Jiménez-Espejo, F.J., Rodríguez-Vidal, J., Finlayson, C., Martínez-Ruiz, F., Carrion, J.S., García-Alix, A., Paytan, A., Giles Pacheco, F., Fa, D.A., Finlayson, G., Cortes-Sánchez, M., Rodrigo Gamiz, M., González-Donoso, J.M., Dolores Linares, M., Cáceres, L.M., Fernández, S., Iijima, K., and Martínez Aguirre, A., 2013. Environmental conditions and geomorphologic changes during the Middle--Upper Paleolithic in the southern Iberian Peninsula. *Geomorphology*, 180-181, 205-216.
- Jorissen, F.J., 1987. The distribution of benthic foraminifera in the Adriatic Sea. *Marine Micropaleontology*, 12 (21–48), 902.

- Jorissen, F.J., Barmawidjaja, D.M., Puskaric, S., Van der Zwaan, G.J., 1992. Vertical distribution of benthic foraminifera in the Northern Adriatic Sea: The relation with high organic flux. *Marine Micropaleontology*, 19, 131-146.
- Jorissen, F.J., De Stigter, H.C., Widmark, J.G.V., 1995. A conceptual model explaining benthic foraminiferal microhabitats. *Marine Micropaleontology*, 22, 3-15.
- Jorissen, F.J., Wittling, I., Peypouquet, J.P., Rabouille, C., Relexans, J.C., 1998. Live benthic foraminiferal faunas off Cape Blanc, NW-Africa: Community structure and microhabitats. *Deep Sea Research Part I*, 45(12), 2157-2188.
- Jorissen, F.J., Fontanier, C., Thomas, E., 2007. Paleoceanographical proxies based on deep-sea benthic foraminiferal assemblage characteristics. In: Hillaire-Marcel, C., Vernal, de A., (Eds.), *Proxies in Late Cenozoic Paleoceanography Pt. 2: Biological tracers and biomarkers*. Elsevier, 263-326.
- Kaiho, K., 1994. Benthic foraminiferal dissolved-oxygen index and dissolved-oxygen levels in the modern ocean. *Geology*, 22, 719-722.
- Kaiho, K., 1999. Effect of organic carbon flux and dissolved oxygen on the benthic foraminiferal oxygen index (BFOI). *Marine Micropaleontology*, 37, 67-76. [http://dx.doi.org/10.1016/S0377-8398\(99\)00008-0](http://dx.doi.org/10.1016/S0377-8398(99)00008-0).
- Kaminski, M.A., Aksu, A.E., Box, M., Hiscott, R.N., Filipescu, S., Al-Salameen, M., 2002. Late Glacial to Holocene benthic foraminifera in the Marmara Sea: implications for Black Sea-Mediterranean Sea connections following the last deglaciation. *Marine Geology*, 190(122), 165-202. doi:10.1016/s0025-3227(02)00347-x.
- Kouwenhoven, T.J., Morigi, C., Negri, A., Giunta, S., Krijgsman, W., Rouchy, J.M., 2006. Paleoenvironmental evolution of the eastern Mediterranean during the Messinian: Constraints from integrated microfossil data of the Pissouri Basin (Cyprus). *Marine Micropaleontology*, 60, 17-44.
- Lisiecki, L.E., Raymo, M.E., 2005. A Pliocene-Pleistocene stack of 57 globally distributed benthic  $\delta^{18}\text{O}$  records. *Paleoceanography*, 20, PA1003. <http://dx.doi.org/10.1029/2004PA001071>.
- Llave, E., Schönfeld, J., Hernández-Molina, F.J., Mulder, T., Somoza, L., Diaz del Rio, V., Sanchez-Almazo, I., 2006. High-resolution stratigraphy of the Mediterranean outflow contourite system in the Gulf of Cadiz during the late Pleistocene: the impact of Heinrich events. *Marine Geology*, 227(3-4), 241-262. doi:10.1016/j.margeo.2005.11.015.
- Loeblich, A.R., Tappan, H., 1988. *Foraminiferal Genera and their classification*. Van Nostrand Reinhold, New York, 970 pp.
- Loeblich, A.R., Tappan, H., 1992. Present status of foraminiferal Classification. In: Takayanagi, Y., Saito, T. (Eds.), *Studies in Benthic Foraminifera*. Proceedings of the Fourth International Symposium on Benthic Foraminifera, Sendai, 1990, Tokai University Press, Tokyo, 93-102.
- Lutze, G.F., Coulbourn, W.T., 1984. Recent benthic foraminifera from the continental margin of northwest Africa: Community structure and distribution. *Marine Micropaleontology*, 8, 361-401.

- Lutze, G.F., Pflaumann, U., Weinholz, P., 1986. Jungquartäre Fluktuationen der benthischen Foraminiferenfaunen in Tiefsee-Sedimenten vor NW-Afrika – Eine Reaktion auf Productivitätsänderungen im Oberflächenwasser. 'Meteor' Forschungs-Ergebnisse, C40, 163-180.
- Mackensen, A., Schmiedl, G., Harloff, J., Giese, M., 1995. Deep-sea foraminifera in the South Atlantic Ocean: Ecology and assemblage generation. *Micropaleontology*, 41, 342–358.
- Martrat, B., Grimalt, J.O., Shackleton, N.J., de Abreu, L., Hutterli, M.A., Stocker, T.F., 2007. Four climate cycles of recurring deep and surface water destabilizations on the Iberian Margin. *Science*, 317(5837), 502-507. doi:10.1126/science.1139994.
- Millot, C., Candela, J., Fuda, J.L., Tber, Y., 2006. Large warming and salinification of the Mediterranean outflow due to changes in its composition. *Deep Sea Research Part I*, 53, 655-666.
- Moreno, E., Thouveny, N., Delanghe, D., McCave, I.N., Shackleton, N.J., 2002. Climatic and oceanographic changes in the Northeast Atlantic reflected by magnetic properties of sediments deposited on the Portuguese margin during the last 340 ka. *Earth and Planetary Science Letters*, 202, 465-480.
- Mulder, T., Voisset, M., Lecroart, P., Le Drezen, E., Gonthier, E., Hanquiez, V., Faugères, J.-C., Habgood, E.L., Hernández-Molina, F.J., Estrada, F., Llave-Barranco, E., Poirier, D., Gorini, C., Fuchey, Y., Voelker, A., Freitas, P., Lobo Sanchez, F.J., Fernández, L.M., Kenyon, N.H., Morel, J., 2003. The Gulf of Cadiz: an unstable giant contouritic levee. *Geo-Marine Letters*, 23, 7–18. doi:10.1007/s00367-003-0119-0.
- Murray, J.W., 1991. *Ecology and Palaeoecology of Benthic Foraminifera*. Longman, Harlow, 397 pp.
- Murray, J.W., 2006. *Ecology and Applications of Benthic Foraminifera*. Cambridge University Press, 426 pp.
- Myres, P.G., Haines, K., Rohling, E.J., 1998. Modeling the paleocirculation of the Mediterranean: The last glacial maximum and the Holocene with emphasis on the formation of sapropel S1. *Paleoceanography*, 13, 586-606.
- North Greenland Ice Core Project (NGRIP) members, 2004. High-resolution record of Northern Hemisphere climate extending into the last interglacial period. *Nature*, 431(7005), 147-151. doi: 10.1038/nature02805.
- Parker, F.L., 1958. Eastern Mediterranean foraminifera. Reports of the Swedish deep-sea expedition 1947-1948, VIII: Sediment cores from the Mediterranean and Red Sea, 4, 283 pp.
- Pflum, C.E., Frerichs, W.E., 1976. Gulf of Mexico deep water foraminifers. Cushman Foundation for Foraminiferal Research, Special Publication, 14, 125 pp.
- Phleger, F.B., Parker, F.L., Peirson, J.F., 1953. North Atlantic Foraminifera. Reports of the Swedish Deep Sea Expedition, vol. VII: Sediments cores from the North Atlantic Ocean, 1. Edit. Pettersson, Goteborg, 121 pp.

- Rahmstorf, S., 1998. Influence of Mediterranean outflow on climate. *EOS* 79(24), 281-282. doi:10.1029/98EO00208.
- Rai, A.K., Singh, V.B., 2001. Late Neogene deep-sea benthic foraminifera at ODP site 762B, eastern Indian Ocean: diversity trends and paleoceanography. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 173(1-2), 1-8.
- Rathburn, A.E., Corliss, B.H., 1994. The ecology of living (stained) deep-sea benthic foraminifera from the Sulu Sea. *Paleoceanography*, 9(1), 87–150.
- Rathburn, A.E., Corliss, B.H., Tappa, K.D., Lohmann, K.C., 1996. Comparison of the ecology and stable isotopic compositions of living (stained) benthic foraminifera from the Sulu and South China Sea. *Deep Sea Research Part I*, 43, 1617-1646.
- Reid, J.L., 1978. On the mid-depth circulation of the salinity field in the North Atlantic Ocean. *Journal of Geophysical Research*, 83, 5063-5067.
- Ricketts, E.R., Kennett, J.P., Hill, T.M., Barry, J.P., 2009. Effects of carbon dioxide sequestration on California margin deep-sea foraminiferal assemblages. *Marine Micropaleontology*, 72, 165-175.
- Rogerson, M., 2002. Climatic influence on sediment transport in the Mediterranean outflow current (Gulf of Cadiz, Spain). *Newsletter of Micropalaeontology*, 66, 16-17.
- Rogerson, M., Schönfeld, J., Leng, M.J., 2011. Qualitative and quantitative approaches in palaeohydrography: A case study from core-top parameters in the Gulf of Cadiz. *Marine Geology*, 280, 150-167. doi:10.1016/j.margeo.2010.12.008.
- Rogerson, M., Rohling, E.J., Bigg, G.R., Ramirez, J., 2012. Paleoceanography of the Atlantic-Mediterranean Exchange: overview and first quantitative assessment of climatic forcing. *Reviews of Geophysics*, 50, RG2003. <http://dx.doi.org/10.1029/2011RG000376>.
- Rohling, E.J., 1999. Environmental control on Mediterranean salinity and  $\delta^{18}\text{O}$ . *Paleoceanography*, 14, 706–715.
- Rohling, E.J., Marino, G., Grant, K.M., 2015. Mediterranean climate and oceanography, and the periodic development of anoxic events (sapropels). *Earth-Science Reviews*, 143, 62-97. <http://dx.doi.org/10.1016/j.earscirev.2015.01.008>.
- Ross, C.R., 1984. *Hyalinea balthica* and its late Quaternary paleoclimatic implications: Strait of Sicily. *Journal of Foraminiferal Research*, 14(2), 134-139.
- Ross, C.R., Kennett, J.P., 1984. Late Quaternary paleoceanography as recorded by benthonic foraminifera in Strait of Sicily sediments sequences. *Marine Micropaleontology*, 8, 315-337.
- Rossignol-Strick, M., Nesteroff, V., Olive, P., Vergnaud-Grazzini, C., 1982. After the deluge; Mediterranean stagnation and sapropel formation. *Nature*, 295, 105-110. doi:10.1038/295105a0.
- Ryan, W.B.F., Cita, M.B., 1977. Ignorance concerning episodes of ocean-wide stagnation. *Marine Geology*, 23, 193-215.

- Schiebel, R., 1992. Rezente benthische Foraminiferen in Sedimenten des Schelfes und oberen Kontinentalthanges im Golf von Guinea (Westafrika). *Berichte - Reports, Geologisch-Paläontologisches Institut der Universität Kiel* 51, 1-179.
- Schmiedl, G., Mackensen, A., Müller, P.J., 1997. Recent benthic foraminifera from the eastern South Atlantic Ocean: Dependence on food supply and water masses. *Marine Micropaleontology*, 32, 249-287.
- Schmiedl, G., De Bovée, F., Buscail, R., Charrière, B., Hemleben, C., Medernach, L., Picon, P., 2000. Trophic control of benthic foraminiferal abundance and microhabitat in the bathyal Gulf of Lions, western Mediterranean Sea. *Marine Micropaleontology*, 40, 167–188.
- Schönfeld, J., 1995. Biostratigraphy and assemblage composition of benthic foraminifera from the Manihiki Plateau, southwestern tropical Pacific. *Journal of Micropalaeontology*, 14, 165–175.
- Schönfeld, J., 1997. The impact of Mediterranean Outflow Water (MOW) on benthic foraminiferal assemblages and surface sediments at the southern Portuguese continental margin. *Marine Micropaleontology*, 29, 211-236. doi:10.1016/S0377-8398(96)00050-3.
- Schönfeld, J., 2002a. Recent benthic foraminiferal assemblages in deep high-energy environments from the Gulf of Cadiz (Spain). *Marine Micropaleontology*, 44, 141–162.
- Schönfeld, J., 2002b. A new benthic foraminiferal proxy for near-bottom current velocities in the Gulf of Cadiz, northeastern Atlantic Ocean. *Deep Sea Research Part I*, 49(10), 1853 - 1875. [http://dx.doi.org/10.1016/S0967-0637\(02\)00088-2](http://dx.doi.org/10.1016/S0967-0637(02)00088-2).
- Schönfeld, J., Zahn, R., 2000. Late Glacial to Holocene history of the Mediterranean outflow. Evidence from benthic foraminiferal assemblages and stable isotopes at the Portuguese Margin. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 159 (1-2), 85-111. doi:10.1016/S0031-0182(00)00035-3.
- Seiglie, G.A., 1968. Foraminiferal assemblages as indicators of high organic carbon content in sediments and of polluted waters. *The American Association of Petroleum Geologists Bulletin*, 52 (11), 2231–2241.
- Sen Gupta, B.K., 2002. *Modern foraminifera*. Kluwer Academic Publisher, Boston, 371pp.
- Sen Gupta, B.K., 2007. Attachment of foraminifera to vestimentiferan tubeworms at cold seeps: Refuge from seafloor hypoxia and sulfide toxicity. *Marine Micropaleontology*, 62(1), 1-6.
- Sierro, F.J., Hodell, D.A., Curtis, J.H., Flores, J.A., Reguerra, I., Colmenero-Hidalgo, E., Barcena, M.A., Grimalt, J.O., Cacho, I., Frigola, J., Canals, M., 2005. Impact of iceberg melting on Mediterranean thermohaline circulation during Heinrich events. *Paleoceanography*, 20, A2019, doi:10.1029/2004PA001051.
- Singh, A.D., Rai, A.K., Verma, K., Das, S., Bharti, S.K., 2015. Benthic foraminiferal diversity response to the climate induced changes in the eastern Arabian Sea oxygen minimum zone during the last 30 ka BP. *Quaternary International*, 374, 118-125 <http://dx.doi.org/10.1016/j.quaint.2014.11.052>.
- Stefano, A.D., Verducci, M., Lirer, F., Ferraro, L., Laccarino, S.M., Hüsing, S.K., Hilgen, F.J., 2010. Paleoenvironmental conditions preceding the Messinian Salinity Crisis in the Central

- Mediterranean: Integrated data from the Upper Miocene Trave section (Italy). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 297, 37-53. doi:10.1016/j.palaeo.2010.07.012.
- Stow, D.A.V., Hernández-Molina, F.J., Alvarez, Zariqian, C.A. and the Expedition 339 Scientists, 2013. Proceedings of Integrated Ocean Drilling Program, 339, Tokyo (Integrated Ocean Drilling Program Management International, Inc.). doi: 10.2204/iodp.proc.339.105.2013.
- Stuiver, M., Reimer, P.J., 1993. Extended  $^{14}\text{C}$  data base and revised CALIB 3.0  $^{14}\text{C}$  age calibration program. In: Stuiver, M., Long, A., Kra, R.S. (Eds.), Calibration 1993. *Radiocarbon*, 35(1), 215-230.
- Sun, Y., An, Z., 2005. Late Pliocene-Pleistocene changes in mass accumulation rates of eolian deposits on the central Chinese Loess Plateau. *Journal of Geophysical Research*, 110, D23101. doi:10.1029/2005JD006064.
- Thomson, J., Mercene, D., De Lange, G.J., Van Santvoort, P.J.M., 1999. Review of recent advances in the interpretation of eastern Mediterranean sapropel S1 from geochemical evidence. *Marine Geology*, 153(1-4), 77-89.
- Thunell, R.C., Williams, D.F., 1989. Glacial-Holocene salinity changes in the Mediterranean Sea: hydrographic and depositional effects. *Nature*, 338, 493-496.
- Toucanne, S., Mulder, T., Schönfeld, J., Hanquiez, V., Gonthier, E., Duprat, J., Cremer, M., Zaragosi, S., 2007. Contourites of the Gulf of Cadiz: A high-resolution record of the paleocirculation of the Mediterranean outflow water during the last 50,000 years. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 246, 354-366. doi:10.1016/j.palaeo.2006.10.007.
- Van der Zwaan, G.J., 1982. Paleogeology of late Miocene Mediterranean Foraminifera. *Utrecht Micropaleontological Bulletin*, 25, 1- 202.
- Vergnaud-Grazzini, C., Ryan, W.B.F., Cita, M.B., 1977. Stable isotope fractionation, climate change and episodic stagnation in the eastern Mediterranean during the late Quaternary. *Marine Micropaleontology*, 2(4), 353-370.
- Vergnaud-Grazzini, C., Caralp, M., Faugères, J.-C., Gonthier, E., Grousset, F., Pujol, C., Saliège, J.-F., 1989. Mediterranean outflow through the Strait of Gibraltar since 18,000 years BP. *Oceanologica Acta*, 12, 305-324.
- Verma, S., Gupta, A.K., Singh, R.K., 2013. Variations in deep-sea benthic foraminifera at ODP Hole 756B, southeastern Indian Ocean: Evidence for changes in deep ocean circulation. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 376, 172-183.
- Voelker, A.H.L., de Abreu, L., 2011. A review of abrupt climate change events in the Northeastern Atlantic Ocean (Iberian Margin): latitudinal, longitudinal, and vertical gradients. In: Rashid, H., Polyak, L., Mosley-Thompson, E. (Eds.), *Abrupt Climate Change: Mechanisms, Patterns, and Impacts*. Geophysical Monograph Series. AGU, Washington D.C., 193, 15-37, doi: 10.1029/2010GM001021.

- Voelker, A.H.L., Lebreiro, S. M., Schönfeld, J., Cacho, I., Erlenkeuser, H., Abrantes, F., 2006. Mediterranean outflow strengthening during northern hemisphere coolings: A salt source for the glacial Atlantic? *Earth and Planetary Science Letters*, 245(1-2), 39-55.
- Voelker, A.H.L., de Abreu, L., Schönfeld, J., Erlenkeuser, H., Abrantes, F., 2009. Hydrographic conditions along the western Iberian margin during marine isotope stage 2. *Geochemistry, Geophysics, Geosystems*, 10(12), Q12U08, doi: 10.1029/2009GC002605.
- Von Rad, U., Schulz, H., Riech, V., den Dulk, M., Berner, U., Sirocko, F., 1999. Multiple monsoon controlled breakdown of oxygen minimum conditions during the past 30,000 years documented in laminated sediments off Pakistan. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 152(1-2), 129–161.
- Yasuhara, M., Okahashi, H., Cronin, T.M., Rasmussen, Tine L., Hunt, G., 2014. Response of deep-sea biodiversity to abrupt deglacial and Holocene climate changes in the North Atlantic Ocean. *Global Ecology and Biogeography*, 23, 957-967.
- Zahn, R., Sarnthein, M., Erlenkeuser, H., 1987. Benthic isotope evidence for changes of the Mediterranean outflow during the late Quaternary. *Paleoceanography*, 2, 543-559.
- Zenk, W., Armi, L., 1990. The complex spreading pattern of Mediterranean water off the Portuguese continental slope. *Deep Sea Research*, 37(12), 1805-1823.



**Appendix I** : Benthic foraminiferal species recorded from the site U 1387.

Note: Taxonomic references were given by Phleger et al., (1953), Barker (1960), Ellis and Messina (1940-1978), Cita and Zocchi (1978), Caralp (1984), Ross and Kennett (1984), Loeblich and Tappan (1988, 1992), Schönfeld (1995, 1997, 2002), Kaminski et al. (2002) and Sen Gupta (2002).

*Ammomassilina alveoliniformis* (Millett) = *Massilina alveoliniformis* Millett, 1898

*Amphicoryna hirsuta* (d'Orbigny) = *Nodosaria hirsuta* d'Orbigny, 1826

*Amphicoryna scalaris* (Batsch) = *Nautilus (Orthoceras) scalaris* Batsch, 1791

*Amphicoryna separans* (Brady) = *Nodosaria scalaris* var. *separans* Brady, 1884

*Amphicoryna sublineata* (Brady) = *Amphicoryna hirsuta* off. *sublineata* Brady, 1884

*Angulogerina carinata* Cushman, 1927

*Anomalina colligera* Chapman and Parr, 1937

*Anomalina globulosa* Chapman and Parr, 1937

*Anomalina* sp.

*Astrononion* sp.

*Astrononion stelligerum* (d'Orbigny) = *Nonionina stelligera* d'Orbigny, 1839

*Astrononion tumidum* Cushman and Edwards, 1937

*Bigenerina nodosaria* d'Orbigny, 1826

*Biloculina* sp.

*Bolivina alata* Seguenza, 1862

*Bolivina earlandi* Parr, 1950

*Bolivina pygmaea* Brady, 1881

*Bolivina* sp. nov. Thalmann, 1933

*Bolivina spathulata* (Williamson) = *Textularia variabilis* var. *spathulata* Williamson, 1858

*Bolivina* sp.

*Bolivina subspinescens* Cushman, 1922

*Bolivinita quadrilatera* (Schwager) = *Textularia quadrilatera* Schwager, 1866

*Bulimina aculeata* d'Orbigny, 1826

*Bulimina alazanensis* Cushman, 1927

*Bulimina gibba* Fornasini, 1902

*Bulimina marginata* d'Orbigny, 1826

*Bulimina notovata* Chapman, 1941

*Bulimina pyrula* d'Orbigny, 1846

*Bulimina striata* d'Orbigny, 1826

*Buliminella* sp.

*Cassidulina carinata* Silvestri, 1896

*Cassidulina crassa* d'Orbigny, 1839

*Cassidulinoides bradyi* (Norman) = *Cassidulina bradyi* Norman, 1881

*Cassidulinoides orientale* (Cushman) = *Cassidulina orientale* Cushman, 1925

*Chilostomella oolina* Schwager, 1878  
*Cibicides lobatulus* (Walker and Jacob) = *Nautilus lobatulus* Walker and Jacob, 1798  
*Cibicides* aff. *lobatulus* (Walker and Jacob) = *Nautilus lobatulus* Walker and Jacob, 1798  
*Cibicides wuellerstorfi* (Schwager) = *Anomalina wuellerstorfi* Schwager, 1866  
*Cibicides* aff. *wuellerstorfi* (Schwager) = *Anomalina wuellerstorfi* Schwager, 1866 *Cibicidoides Cibicides* sp.\*  
*kullenbergi* (Parker) = *Cibicides kullenbergi* Parker, 1953  
*Cibicidoides mundulus* (Brady, Parker & Jones) = *Truncatulina mundula* Brady, Parker & Jones, 1888  
*Cibicidoides pachyderma* (Rzehak) = *Truncatulina pachyderma* Rzehak, 1886  
*Cornuspira carinata* (Costa) = *Operculina carinata* Costa, 1856  
*Cornuspira incerta* (d'Orbigny, 1839)  
*Cornuspira involvens* (Reuss) = *Operculina involvens* Reuss, 1850  
*Cornuspira* sp.  
*Dentalina advena* (Cushman) = *Nodosaria advena* Cushman, 1923  
*Dentalina communis* d'Orbigny, 1826  
*Dentalina filiformis* (d'Orbigny) = *Nodosaria filiformis* d'Orbigny, 1826  
*Dentalina guttifera* d'Orbigny, 1846  
*Dentalina intorta* d'Orbigny, 1826  
*Dentalina* sp.  
*Dentalina subemaciata* Parr., 1950  
*Discopulvinulina* sp.  
*Discopulvinulina subbertheloti* (Cushman) = *Discorbis subbertheloti* Cushman, 1924  
*Discorbina mira* (Cushman) = *Discorbis mira* Cushman, 1922  
*Dorothia bradyana* Cushman, 1936  
*Eggerella bradyi* (Cushman) = *Verneuilina bradyi* Cushman, 1911  
*Elphidium macellum* (Fichtel and Moll) = *Nautilus macellum* Fichtel and Moll, 1798  
*Elphidium* sp.  
*Epistominella exigua* (Brady) = *Pulvinulina exigua* Brady, 1884  
*Eponides punctulatus* (d'Orbigny) = *Anomalina punctulata* d'Orbigny, 1826  
*Eponides* (?) *tenera* (Brady) = *Truncatulina tenera* Brady, 1884  
*Eponides* (?) *procera* (Brady) = *Pulvinulina procera* Brady, 1881  
*Fissurina alveolata* (Brady) = *Lagena alveolata* Brady, 1884  
*Fissurina annectens* (Burrows & Holland) = *Lagena annectens* Burrows & Holland, 1895  
*Fissurina bradyi* Silvestri = *Fissurina bradyi* Silvestri, 1902  
*Fissurina cucullata* Silvestri, 1902  
*Fissurina fimbriata* (Brady) = *Lagena fimbriata* Brady, 1881  
*Fissurina kerguelensis* Parr, 1950  
*Fissurina orbignyana* Seguenza, 1862  
*Fissurina semimarginata* Reuss, 1870  
*Fissurina* sp.  
*Fissurina submarginata* (Boomgart, 1949)

*Fursenkoina fusiformis* (Williamson) = *Bulimina fusiformis* Williamson, 1858  
*Gavelinopsis* sp.  
*Glandulina laevigata* (d'Orbigny) = *Nodosaria laevigata* d'Orbigny, 1826  
*Globobulimina pacifica* (Cushman) = *Cassidulina pacifica* Cushman, 1925  
*Globocassidulina oblonga* (Reuss) = *Cassidulina oblonga* Reuss, 1850  
*Globocassidulina subglobosa* (Brady) = *Cassidulina subglobosa* Brady, 1881  
*Globulina minuta* (Roemer) = *Polymorphina minuta* Roemer, 1838  
*Globulina rotunda* (Bornemann) = *Polymorphina rotundata* Bornemann, 1855  
*Gyroidinoides lamarckiana* d'Orbigny, 1839  
*Gyroidinoides nitidula* (Schwager) = *Rotalia nitidula* Schwager, 1866  
*Gyroidinoides orbicularis* d'Orbigny, 1826  
*Hoeglundina elegans* (d'Orbigny) = *Rotalia (Turbinulina) elegans* d'Orbigny, 1826  
*Hyalinea balthica* (Schröter) = *Nautilus balthicus* Schröter, 1783  
*Karrerella bradyi* (Cushman) = *Gaudryina bradyi* Cushman, 1911  
*Lagena gracilis* Williamson, 1848  
*Lagena laevis* (Montagu) = *Vermiculum laeve* Montagu, 1803  
*Lagena nebulosa* Cushman, 1923  
*Lagena* sp. nov.  
*Lagena* sp.  
*Lagena striata* (d'Orbigny) = *Oolina striata* d'Orbigny, 1839  
*Lagena sulcata* (Walker and Jacob) = *Serpula sulcata* Walker and Jacob, 1798  
*Lenticulina altiformis* Parr, 1950  
*Lenticulina calcar* (Linnaeus, 1767)  
*Lenticulina convergens* (Bornemann) = *Cristellaria convergens* Bornemann, 1855  
*Lenticulina denticulifera* (Cushman) = *Cristellaria denticulifera* Cushman, 1913  
*Lenticulina gibba* (d'Orbigny) = *Cristellaria gibba* d'Orbigny, 1826  
*Lenticulina iota* (Cushman) = *Cristellaria iota* Cushman, 1923  
*Lenticulina peregrina* (Schwager, 1866)  
*Lenticulina* sp.  
*Loxostomum karrerianum* (Brady) = *Bolivina karreriana* Brady, 1881  
*Loxostomum* sp.  
*Marginulina obesa* Cushman, 1923  
*Marginulinopsis* sp.  
*Martinotiella bradyana* (Cushman) = *Listerella bradyana* Cushman, 1936  
*Martinotiella communis* (d'Orbigny) = *Clavulina communis* d'Orbigny, 1826  
*Martinotiella* sp.  
*Melonis barleeana* (Williamson) = *Nonionina barleeana* Williamson, 1858  
*Melonis pompilioides* (Fichtel and Moll) = *Nautilus pompilioides* Fichtel and Moll, 1798  
*Miliolinella oblonga* (Montagu) = *Vermiculum oblonga* Montagu, 1803  
*Miliolinella* sp.

*Miliolinella subrotunda* (Montagu) = *Vermiculum subrotundum* Montagu, 1803  
*Nodosaria* sp.  
*Nonion scaphum* (Fichtel and Moll) = *Nautilus scapha* Fichtel and Moll, 1798  
*Nonionella bradii* (Chapman, 1917)  
*Nonionella clavata* Cushman, 1931  
*Nonionella* sp.  
*Nonionella stella* (Cushman and Moyer) = *Nonionella stella* Cushman and Moyer, 1930  
*Nonionella turgida* (Williamson) = *Rotalina turgida* Williamson, 1858  
*Nummoloculina contraria* (d'Orbigny) = *Biloculina contraria* d'Orbigny, 1846  
*Nummoloculina irregularis* (d'Orbigny) = *Biloculina irregularis* d'Orbigny, 1839  
*Oolina globulosa* (Montagu) = *Vermiculum globosum* Montagu, 1803  
*Oolina hexagona* (Williamson) = *Entosolenia hexagona* Williamson, 1848  
*Oolina* sp.  
*Operculina gaimardi* d'Orbigny, 1826  
*Osangularia* sp.  
*Patellina corrugata* Williamson, 1858  
*Pileolina* sp.  
*Planctostoma* sp.  
*Planularia australis* Chapman, 1915  
*Planulina ariminensis* d'Orbigny, 1826  
*Pseudoclavulina humilis* (Brady) = *Clavulina parisiensis* var. *humilis* Brady 1884  
*Pseudoclavulina* sp.  
*Pyrgo lucernula* (Schwager) = *Biloculina lucernula* Schwager, 1866  
*Pyrgo depressa* (d'Orbigny) = *Biloculina depressa* d'Orbigny, 1826  
*Pyrgo elongata* (d'Orbigny) = *Biloculina elongata* d'Orbigny, 1826  
*Pyrgo fornasinii* Chapman and Parr, 1935  
*Pyrgo laevis* Defrance, 1824  
*Pyrgo serrata* (Bailey) = *Biloculina serrata* Bailey, 1861  
*Pyrgo* sp.  
*Pyrgo vespertilio* (Schlumberger) = *Biloculina vespertilio* Schlumberger, 1891  
*Pyrulina gutta* d'Orbigny, 1839  
*Pullenia bulloides* (d'Orbigny) = *Nonionina bulloides* d'Orbigny, 1826  
*Pullenia quadriloba* Reuss, 1867  
*Pullenia quinqueloba* (Reuss) = *Nonionina quinqueloba* Reuss, 1851  
*Pullenia salisburyi* Stewart and Stewart, 1930  
*Quinqueloculina* cf. *Q. pygmaea* (Reuss) = *Quinqueloculina pygmaea* Reuss, 1850  
*Quinqueloculina lamarckiana* d'Orbigny, 1839  
*Quinqueloculina seminulum* (Linnaeus) = *Serpula seminulum* Linnaeus, 1758  
*Quinqueloculina* sp.  
*Rectobolivina columellaris* (Brady) = *Sagrina columellaris* Brady, 1881

*Rectobolivina* sp.  
*Rectoglandulina* sp.  
*Rectoglandulina torrida* (Cushman) = *Nodosaria laevigata* var. *torrida* Cushman, 1923  
*Rectuvigerina bononiensis* (Fornasini) = *Uvigerina bononiensis* Fornasini, 1888  
*Rectuvigerina cylindrica* (d'Orbigny) = *Clavulina cylindrica* d'Orbigny, 1826  
*Robertina tasmanica* (Parr) = *Robertina tasmanica* Parr, 1950  
*Robulus* aff. *orbicularis* (d'Orbigny, 1826)  
*Robulus* aff. *thalmanni* (Hessland) = *Robulus thalmanni* Hessland, 1943  
*Robulus atlanticus* Barker, 1960  
*Robulus orbicularis* (d'Orbigny) = *Robulina orbicularis* d'Orbigny, 1826  
*Robulus pliocene* (Silvestri) = *Polymorphina pliocaena* Silvestri, 1898  
*Robulus* sp.  
*Robulus thalmanni* Hessland, 1943  
*Robulus vortex* (Fichtel and Moll) = *Nautilus vortex* Fichtel and Moll, 1798  
*Rosalina concinna* (Brady) = *Discorbina concinna* Brady, 1884  
*Rosalina* sp. nov.  
*Rosalina* sp.  
*Saracenaria italica* DeFrance, 1824  
*Saracenaria latifrons* (Brady) = *Cristellaria latifrons* Brady, 1884  
*Schlumbergerina* sp.  
*Sigmoilina tenuis* (Czjzek) = *Quinqueloculina tenuis* Czjzek, 1848  
*Sigmoilopsis asperula* (Karrer) = *Spiroloculina asperula* Karrer, 1868  
*Sigmoilopsis schlumbergeri* (Silvestri) = *Sigmoilina schlumbergeri* Silvestri, 1904  
*Siphonia bradyana* Cushman, 1917  
*Siphonia tubulosa* Cushman, 1924  
*Siphotextularia caroliniana* (Cushman, 1922)  
*Siphotextularia concava* (Karrer) = *Plecanium concavum* Karrer, 1868  
*Siphotextularia rolshauseni* Phleger and Parker, 1951  
*Siphotextularia* sp.  
*Siphotextularia* sp. nov.  
*Sphaeroidina bulloides* d'Orbigny, 1826  
*Spirillina limbata* Brady, 1884  
*Spiroloculina depressa* d'Orbigny, 1826  
*Spiroloculina rotunda* d'Orbigny, 1826  
*Spiroloculina* sp.  
*Spiroloculina tenuiseptata* Brady, 1884  
*Spirophthalmidium pusillum* (Earland) = *Spiroloculina pusilla* Earland, 1934  
*Stilostominella* sp.  
*Textularia laxata* (Schwager) = *Plecanium laxatum* Schwager, 1866  
*Textulaia sagittula* DeFrance, 1824

*Textularia* aff. *pseudogramen* Chapman and Parr, 1937  
*Trifarina bradyi* Cushman, 1923  
*Trifarina fornasinii* (Selli) = *Angulogerina fornasinii* Selli, 1948  
*Triloculina* sp.  
*Triloculina tricarinata* d'Orbigny, 1826  
*Triloculina trigonula* (Lamarck) = *Miliolites trigonula* Lamarck, 1804  
*Uvigerina elongatastriata* (Colom) = *Angulogerina elongatastriata* Colom, 1952  
*Uvigerina hispidocostata* Cushman and Todd, 1945  
*Uvigerina mediterranea* Hofker, 1932  
*Uvigerina peregrina* Cushman, 1923  
*Uvigerina proboscidea* Schwager, 1866  
*Vaginulina patens* Brady, 1884  
*Valvulineria araucana* (d'Orbigny) = *Rosalina araucana* d'Orbigny, 1839  
*Valvulineria humilis* (Brady) = *Truncatulina humilis* Brady, 1884  
*Valvulineria rugosa* (d'Orbigny) = *Rosalina rugosa* d'Orbigny, 1839  
*Valvulineria* sp.  
*Virgulina davisi* Cushman and Parr, 1937  
*Virgulina rotundata* Parr, 1950

**Appendix II.** Constituent species of elevated epibenthics, epifaunal and infaunal benthic foraminiferal groups [data source of benthic faunal association with microhabitat preferences are from Corliss, 1985, 1991; Corliss and Chen, 1988; Denne and Sen Gupta, 1989; Corliss and Fois, 1990; Rathburn and Corliss, 1994; Rathburn, et al., 1996; Gooday, 1994; Kaiho, 1994, 1999; Mackensen et al., 1995; Guichard, 1997; Jorissen et al., 1998, 2007; Schönfeld, 1997, 2002; Jannink et al., 1998; Sen Gupta, 2007; Schönfeld and Zahn, 2000; Ricketts et al., 2009].

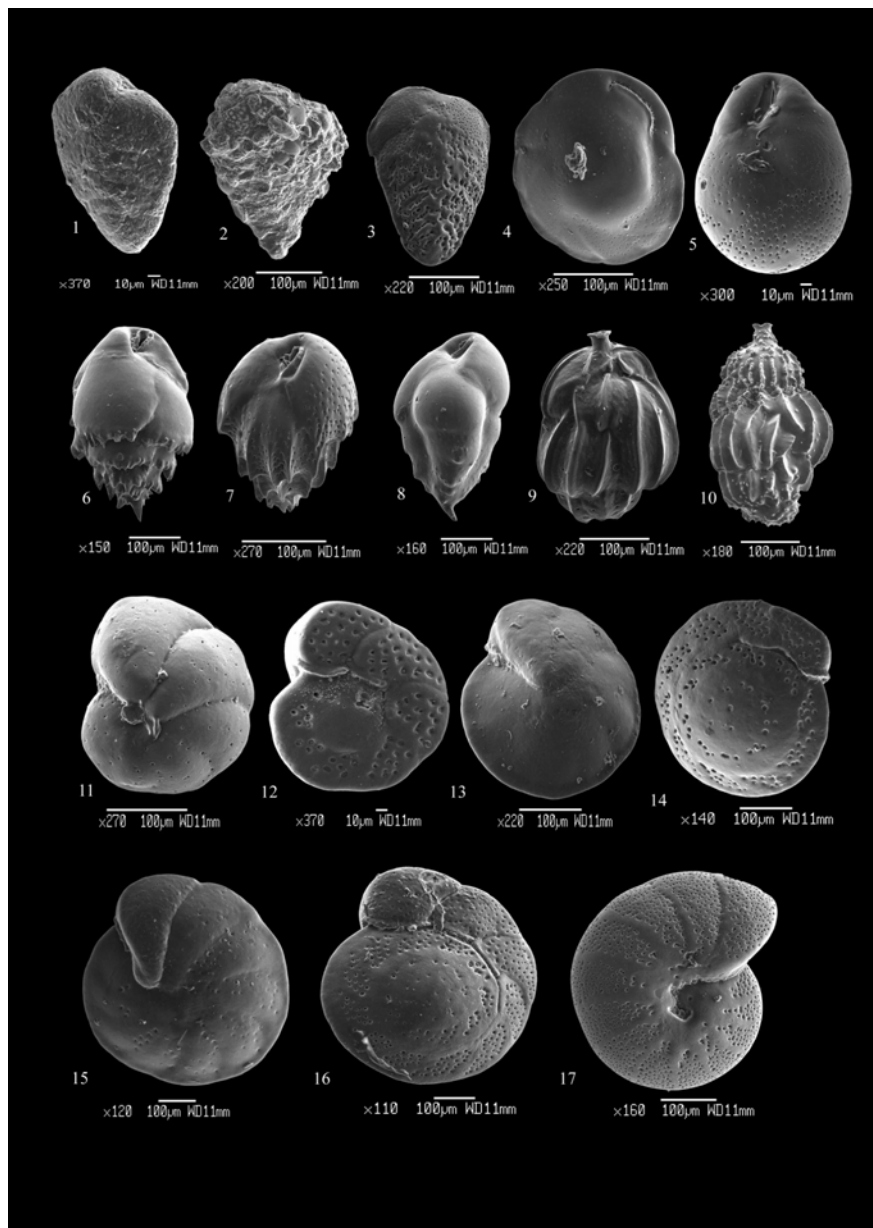
1. Elevated epibenthic assemblage: *Cibicides lobatulus*, *Cibicides* aff. *lobatulus*, *Cibicides wuellerstorfi*, *Cibicides* aff. *wuellerstorfi*, *Epistominella exigua*, *Planulina ariminensis*, *Textularia* aff. *pseudogramen*

2. Epifaunal assemblage: *Biloculina* spp., *Cibicides* spp., *Cibicidoides* spp., *Gyroidinoides* spp., *Nummuloculina* spp., *Pyrgo* spp., *Quinqueloculina* spp., *Spiroloculina* spp., *Triloculina* spp., *Valvulineria* spp., *Hoeglundina elegans*, *Hyalinea balthica*, *Planulina ariminensis*, *Sigmoilina tenuis*, *Sphaeroidina bulloides*, *Spirophthalmidium pusillum*

3. Infaunal assemblage: *Bolivina* spp., *Bulimina* spp., *Cassidulina* spp., *Cassidulinoides* spp., *Globocassidulina* spp., *Melonis* spp., *Pullenia* spp., *Rectouvigerina* spp., *Trifarina* spp., *Uvigerina* spp., *Angulogerina carinata*, *Globobulimina pacifica*

**Plate 1.** The illustration of the important benthic foraminiferal species recorded from the site U 1387. (Sample detail and view of illustrated specimen are given).

1. *Textularia sagittula* DeFrance, Front view: A/7X-1, 122-124cm; 2. *Textularia* aff. *pseudogramen* Chapman and Parr, Front view: B/4H-5, 2-4 cm; 3. *Bolivina spathulata* (Williamson), Front view: B/4H-5, 2-4cm; 4. *Cassidulina carinata* Silvestri, Front view: B/4H-6, 107-109cm; 5. *Globocassidulina oblonga* (Reuss), Front view: B/4H-5, 62-64cm; 6. *Bulimina aculeata* d'Orbigny, Front view: B/4H-5, 92-94cm; 7. *Bulimina striata* d'Orbigny, Front view: B/4H-6, 107-109cm; 8. *Bulimina gibba* Fornasini, Front view: B/4H-6, 92-94cm; 9. *Uvigerina mediterranea* Hofker, Front view: B/4H-5, 2-4cm; 10. *Uvigerina peregrina* Cushman, Front view: B/5H-5, 92-94cm; 11,12. *Cibicides lobatulus* (Walker and Jacob), Umbilical view (11): B/3H-6, 92-94cm, Spiral view (12): B/4H-5, 62-64cm; 13,14. *Cibicoides kullenbergi* (Parker), Umbilical view (13): B/5H-3, 92-94cm, Spiral view (14): B/5H-3, 92-94cm; 15,16. *Cibicoides pachyderma* (Rzehak), Umbilical view (15): B/4H-5, 62-64cm, Spiral view (16): B/4H-5, 62-64cm; 17. *Melonis berleeianum* (Williamson), Spiral view: B/4H-6, 92-94cm





### **Caption of Tables and Figures**

**Table 1.** Radiocarbon ages determined by accelerator mass spectrometry.

**Table 2.** Tie points used for constructing the age model of Site U1387 based on calibrated radiocarbon ages, XRF Br counts from the Site U1387 (Bahr et al., 2014), and oxygen isotope stratigraphy (Lisiecki and Raymo, 2005).

**Table 3.** Ecological preferences of benthic foraminifera used as proxy for deep-sea changes at site U1387.

**Table 4.** Factor score of four factors for 43 highest ranked benthic foraminiferal species along with faunal variance at site U1387.

**Fig. 1.** Hydrography of the Gulf of Cadiz and main flow paths of the Mediterranean Outflow Water (MOW) [after Stow et al., 2013]. Location of IODP site U1387 is indicated.

**Fig. 2.** Age model for the site U1387 based on the oxygen isotope record of *Cibicidoides pachyderma* (a benthic foraminifer) and calibrated AMS radiocarbon ages (denoted by plus sign). AMS radiocarbon ages obtained for the top section agree well to the age model of Bahr et al. (2014) that was adopted in this study till 33.58 mcd representing the first 131 kyr. Thereafter, the age model is based on oxygen isotope stratigraphy by comparison with the oxygen isotope record of benthic foraminifera (Lisiecki and Raymo, 2005). Indo-Arabic numerals denote the Marine Isotope Stages (MIS 1-7). Isotope measurements made at closer intervals for MIS 5-7, enabled to identify Termination II and the Substages (warm substages (interstadials): 5a, 5c, 5e, 7a, 7c with negative excursions; cold substages (stadials): 5b, 5d, 7b, 7d with positive excursions; MIS 7d in this record represents only its younger part).

**Fig. 3.** Temporal variations in relative abundances of important benthic foraminiferal groups at site U1387. Marine isotope stages (MIS) 1-7; and intervals of stadials and interstadials within MIS 5 and 7 are shown at the right of the figure.

**Fig. 4.** Temporal variations in relative abundances of major benthic foraminiferal taxa at site U1387. Marine isotope stages (MIS) 1-7 and intervals stadials and interstadials within MIS 5 and 7 are shown at the right of the figure.

**Fig. 5.** Temporal variations in Simple Diversity (S); Shannon Index (H) and Equitability (E') at site U1387. Marine isotope stages (MIS) 1-7 are shown at the right of the figure.

**Fig. 6.** Temporal variations in loadings of the first three factors extracted on the basis of factor analysis of the benthic foraminiferal relative abundance data. (Factor 1: *Melonis barleeanum-Uvigerina mediterranea* Assemblage; Factor 2: *Bolivina spathulata-Cassidulina carinata* Assemblage; Factor 3: *Uvigerina peregrina* Assemblage). Faunal records are compared with benthic isotope records. (MIS 5a, 5c, 5e, 7a and 7c : interstadials; MIS 5b, 5d, 7b and 7d : stadials; T II : Termination II).

**Fig. 7.** Temporal variations in cumulative percentages of epifaunal, infaunal and elevated epibenthic taxa and benthic carbon and oxygen isotopes. The intervals of major changes in faunal and isotope records during warm substages MIS 5a, 5e, 7a and 7c (as discussed in the text) are correlated with the sapropel layers (S2, S5, S7 and S8) in the Mediterranean Sea; shown at the right of the figure. Sapropel layer S6 corresponds approximately to MIS 6d. (Chronology of the sapropel layers; after Cramp and Sullivan, 1999 and Emeis et al., 2003). (MIS 5a, 5c, 5e, 7a and 7c : interstadials; MIS 5b, 5d, 7b and 7d : stadials; T II : Termination II).

Table 1

AMS Lab code	Depth (mcd)	$^{14}\text{C}$ Age (year BP)	Calibrated calendar age (years)	Planktic foraminifera
X27343	0.02	1659 $\pm$ 31	1220	<i>G. bulloides</i>
X27344	2.02	11341 $\pm$ 49	12800	<i>G. bulloides</i>
X27345	4.02	15956 $\pm$ 59	18810	<i>G. bulloides</i> + <i>G. inflata</i>
X27346	6.02	18900 $\pm$ 84	22380	<i>G. bulloides</i> + <i>G. inflata</i>
X27347	7.88	22430 $\pm$ 130	26230	<i>G. bulloides</i> + <i>G. inflata</i>

Table 2

<b>Depth U1387 (mcd)</b>	<b>Age (ka)</b>	<b>Reference data</b>
0.02	1.22	Calibrated Radiocarbon Ages; Present study
1.80	11.40	Bahr et al., 2014
2.02	12.80	Calibrated Radiocarbon Ages; Present study
2.64	14.65	Bahr et al., 2014
3.54	17.45	Bahr et al., 2014
4.02	18.81	Calibrated Radiocarbon Ages; Present study
6.02	22.38	Calibrated Radiocarbon Ages; Present study
7.88	26.23	Calibrated Radiocarbon Ages; Present study
9.64	31.70	Bahr et al., 2014
9.88	32.20	Bahr et al., 2014
10.48	33.55	Bahr et al., 2014
10.70	34.45	Bahr et al., 2014
11.18	35.35	Bahr et al., 2014
11.49	36.60	Bahr et al., 2014
12.43	38.27	Bahr et al., 2014
12.59	40.15	Bahr et al., 2014
12.71	41.25	Bahr et al., 2014
13.94	42.70	Bahr et al., 2014
14.51	44.75	Bahr et al., 2014
15.32	47.40	Bahr et al., 2014
15.50	48.90	Bahr et al., 2014
17.24	55.00	Bahr et al., 2014
17.89	57.65	Bahr et al., 2014
18.28	60.20	Bahr et al., 2014
21.61	70.15	Bahr et al., 2014
21.88	71.65	Bahr et al., 2014
22.27	72.90	Bahr et al., 2014
22.87	77.10	Bahr et al., 2014
25.20	85.40	Bahr et al., 2014
25.93	88.20	Bahr et al., 2014
27.57	104.65	Bahr et al., 2014
28.07	106.10	Bahr et al., 2014
29.56	109.19	Bahr et al., 2014
29.77	110.90	Bahr et al., 2014
32.92	128.33	Bahr et al., 2014
33.58	130.68	Bahr et al., 2014
33.78	135	Lisiecki and Raymo, 2005 ; Present study
38.07	155	Lisiecki and Raymo, 2005 ; Present study
41.81	167	Lisiecki and Raymo, 2005 ; Present study
44.06	174	Lisiecki and Raymo, 2005 ; Present study
49.05	199	Lisiecki and Raymo, 2005 ; Present study
51.75	217	Lisiecki and Raymo, 2005 ; Present study

Table 3

Species	Microhabitat	Ecological Preference
<i>Uvigerina peregrina</i>	Shallow /Intermediate infaunal	'Organic matter' rich sediment (Seiglie, 1968) and low to moderate oxygen concentration (Van der Zwaan, 1982, Lutze and Coulbourn, 1984; Lutze et al., 1986) More tolerant to low oxygen condition than hispid uvigerinids (Borsetti et al., 1986)
<i>Uvigerina mediterranea</i>	Shallow infaunal	Lives in the epibathypelagic zone of the NE Atlantic (Duros et al., 2011) Meso-eutrophic open-slope environment (Fontanier et al., 2006) Linked to intermediate water mass in the Mediterranean Sea (Parker, 1958; Caralp, 1988).
<i>Cassidulina carinata</i>	Shallow infaunal	Prefers organic matter rich sediment (Guichard, 1997; Schmiedl et al., 2000; Hess and Jorissen, 2009)
<i>Bolivina spathulata</i>	Shallow infaunal	Prefers high nutrient environment and tolerant to a wider range of bottom hydrographic conditions (Hageman, 1979).
<i>Bulimina aculeata</i>	Intermediate/ Deep infaunal (>2 cm)	Preference for low oxygen condition and high organic matter (Van der Zwaan, 1982; Jorissen et al., 1992; Bernhard and Sengupta, 1999).
<i>Melonis barleeaanum</i>	Intermediate /Deep infaunal	Associated with moderately organic matter rich sediment (Pflum and Frerichs, 1976; Jorissen, 1987). Labile, intermediate to high organic matter (Arnold, 1983). Feeds upon degraded organic detritus buried in sediment (Fontanier et al., 2002).
<i>Sphaeroidina bulloides</i>	Not well known	Prefers high productive and low oxygen environment (Gooday, 2003). Wide range of tolerance to oxygen level (von Rad et al., 1999). Seasonal upwelling (Schiebel, 1992)
<i>Hyalinea balthica</i>	Shallow Infaunal	Associated with the cold water mass (Ross, 1984)
<i>Pullenia</i> spp.	Infaunal	Less tolerant to oxygenated bottom environment (Kaiho, 1994)
Cibicidids	Epifaunal	Related to oxic environment and low organic flux (Van der Zwaan, 1982; Corliss and Fois, 1990; Kaiho, 1994, 1999) Cibicidids population includes elevated epibenthic taxa ( <i>Cibicides lobatulus</i> , <i>Cibicides</i> aff. <i>lobatulus</i> , <i>Cibicides wuellerstorfi</i> , <i>Cibicides</i> aff. <i>wuellerstorfi</i> ) characterizing high energy environment (Schönfeld, 1997, 1998, 2002; Schönfeld and Zahn, 2000; Rogerson et al., 2011)
Miliolids	Epifaunal	Associated with oxic environment and low organic carbon flux (Kaiho, 1994; 1999)
<i>Textularia</i> spp.	Epifaunal	Lives in oxic and low organic matter rich sediment (Murray, 1971, 2006) <i>Textularia</i> aff. <i>pseudogramen</i> prefers elevated substrate in high energy environment (Jorissen et al., 1998; Schönfeld, 1997, 2002; Schönfeld and Zahn, 2000 )
<i>Planulina ariminensis</i>	Epifaunal	Prefers elevated substrates in high energy environment (Jorissen et al., 1998; Schönfeld, 1997, 2002; Rogerson et al., 2011)
<i>Epistominella exigua</i>	Epifaunal	Prefers elevated microhabitat (Jorissen et al., 1998; Schönfeld, 1997, 2002)

Table 4

Species Name	Factor 1	Factor 2	Factor 3	Factor 4
<i>Amphicoryna scalaris</i>	0.50298	-0.00807	-0.183	0.13028
<i>Angulogerina carinata</i>	<b>1.1906</b>	-0.50319	0.54212	-1.2386
<i>Bigenerina nodosaria</i>	0.35293	0.003439	-0.02565	0.12187
<i>Bolivina alata</i>	0.14977	0.16239	-0.09715	-0.11375
<i>Bolivina spathulata</i>	0.15296	<b>5.6776</b>	0.20121	1.3319
<i>Bolivina</i> sp.	0.20397	0.50348	<b>1.0929</b>	-0.05851
<i>Bolivinita quadrilatera</i>	0.19013	-0.04482	-0.1538	-0.38098
<i>Bulimina aculeata</i>	<b>1.9145</b>	<b>1.5088</b>	0.001797	1.6009
<i>Bulimina gibba</i>	0.23302	-0.87771	0.98304	-1.646
<i>Bulimina marginata</i>	<b>1.1036</b>	0.27153	-0.06224	0.28448
<i>Bulimina pyrula</i>	0.038929	0.24103	-0.06381	0.018733
<i>Bulimina striata</i>	<b>1.1263</b>	0.45968	0.3139	0.62407
<i>Cassidulina carinata</i>	0.32755	<b>2.3888</b>	-1.0082	-5.5734
<i>Cassidulina crassa</i>	<b>1.2917</b>	-0.04211	-0.50543	0.42308
<i>Cibicides lobatulus</i>	0.36047	0.020174	-0.03813	0.11746
<i>Cibicoides kullenbergi</i>	0.9549	0.36116	0.16721	0.56607
<i>Cibicoides pachyderma</i>	0.15807	0.064348	0.033895	-0.01402
<i>Dissopuluinulina subbertheloti</i>	0.55354	-0.04629	-0.23488	0.10058
<i>Globocassidulina oblonga</i>	<b>1.1806</b>	-0.09608	0.013101	0.46111
<i>Globocassidulina subglobosa</i>	0.81473	-0.12309	0.029743	0.11551
<i>Gyroidinoides lamarkiana</i>	0.28035	0.19304	-0.02548	0.18003
<i>Gyroidinoides orbicularis</i>	0.3079	-0.0249	-0.0846	0.077931
<i>Gyroidinoides neosoldanii</i>	0.4351	0.042617	-0.05491	0.17633
<i>Hoeglundina elegans</i>	0.14469	-0.03925	0.089508	0.035608
<i>Hyalinea balthica</i>	<b>1.4873</b>	-0.31395	-0.83016	-1.2542
<i>Lenticulina calcar</i>	0.26626	-0.00991	-0.07261	0.12689
<i>Melonis barleeaanum</i>	<b>4.0689</b>	-0.4133	-0.30547	0.019203
<i>Miliolinella</i> sp.	0.2791	-0.06847	-0.06224	-0.05204
<i>Nonionella turgida</i>	-0.1533	0.66531	-0.27095	-0.10874
<i>Planulina ariminensis</i>	0.42826	-0.02767	0.053243	0.179
<i>Quinqueloculina seminulum</i>	0.2302	-0.1548	0.23002	-0.29792
<i>Sigmoilopsis schlumbergeri</i>	0.73128	-0.04221	0.23425	0.075431
<i>Siphonia tubulosa</i>	0.28122	-0.00574	-0.11666	0.13275
<i>Siphotextularia carloiniana</i>	0.26978	-0.07038	-0.07641	-0.14715
<i>Siphotextularia</i> sp.	0.23032	-0.0211	-0.06339	0.028869
<i>Sphaeroidina bulloides</i>	0.90671	0.38357	-0.18782	0.41573
<i>Textularia sagittula</i>	0.91373	-0.08204	-0.39171	-0.03754
<i>Textularia</i> aff. <i>pseudogramen</i>	0.542	-0.0146	0.17825	0.39583
<i>Uvigerina hispidocostata</i>	0.020757	0.035707	0.24353	-0.0128
<i>Uvigerina mediterranea</i>	<b>2.8623</b>	-0.88265	<b>1.5705</b>	-0.59558
<i>Uvigerina peregrina</i>	-0.34478	0.47668	<b>6.003</b>	-0.62103
<i>Uvigerina proboscidea</i>	0.31433	-0.01663	-0.07047	0.094525
<i>Valvulineria araucana</i>	0.06734	-0.04102	0.062678	-0.04315
<b>Faunal Variance (%)</b>	<b>65.2</b>	<b>10.02</b>	<b>5.96</b>	<b>3.8</b>

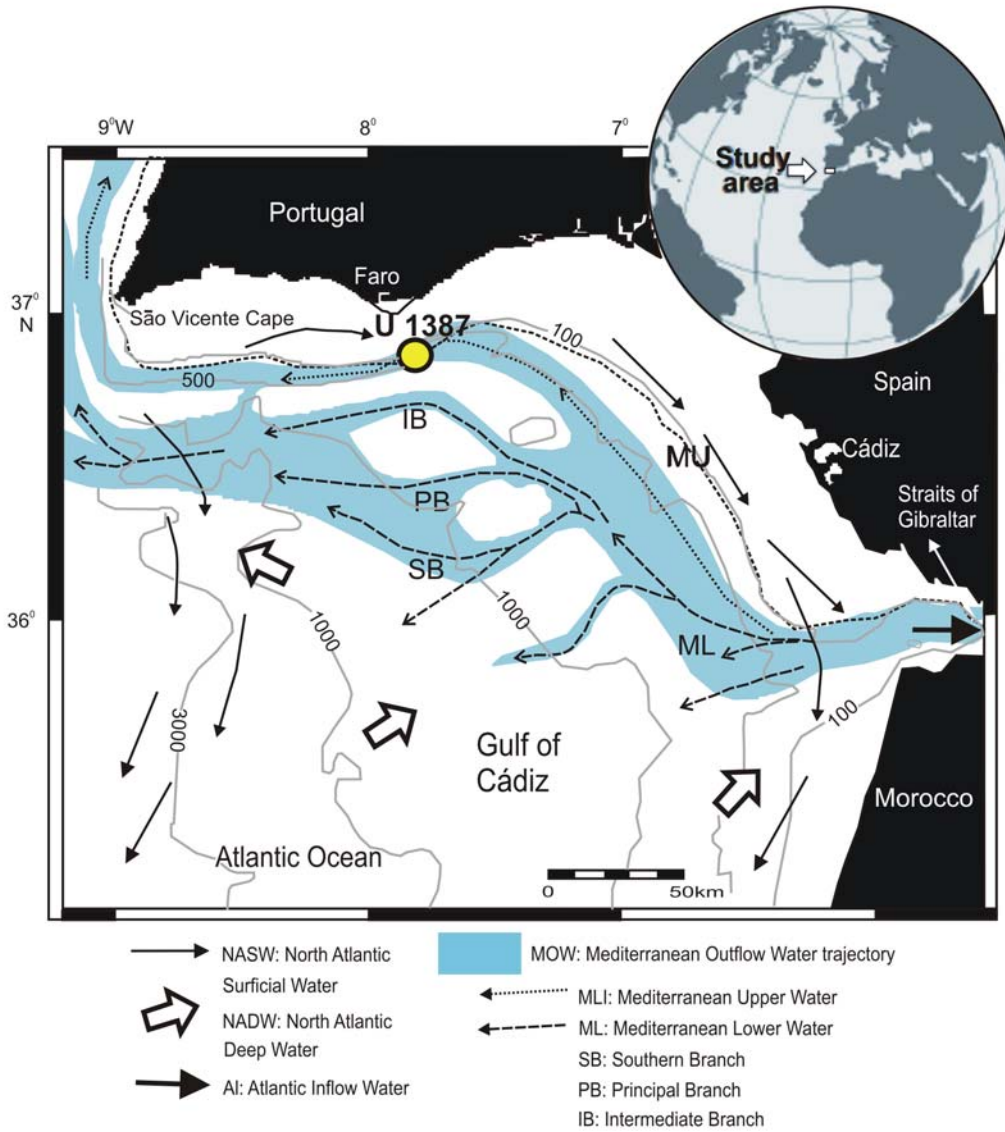


Fig. 1

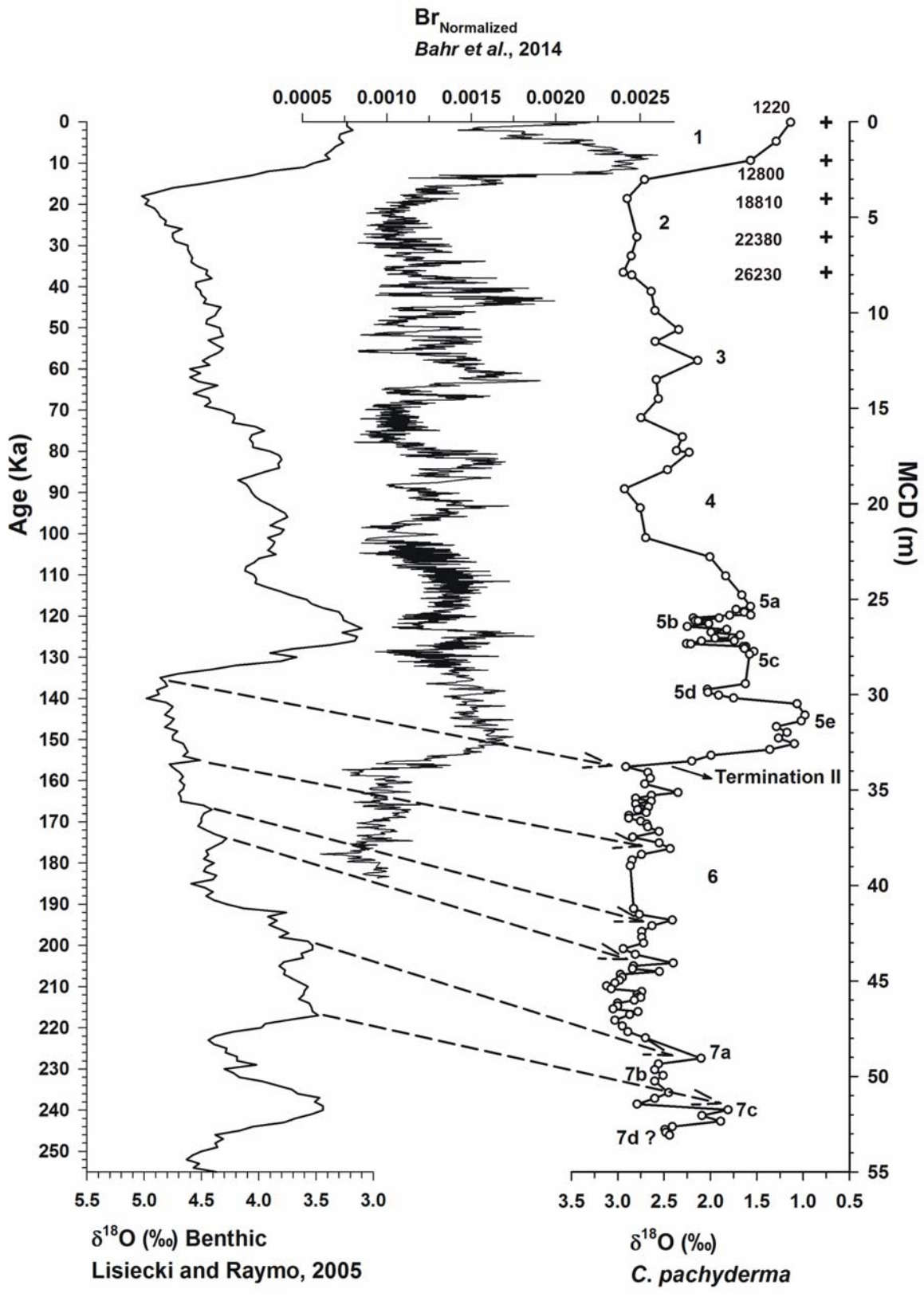


Fig. 2

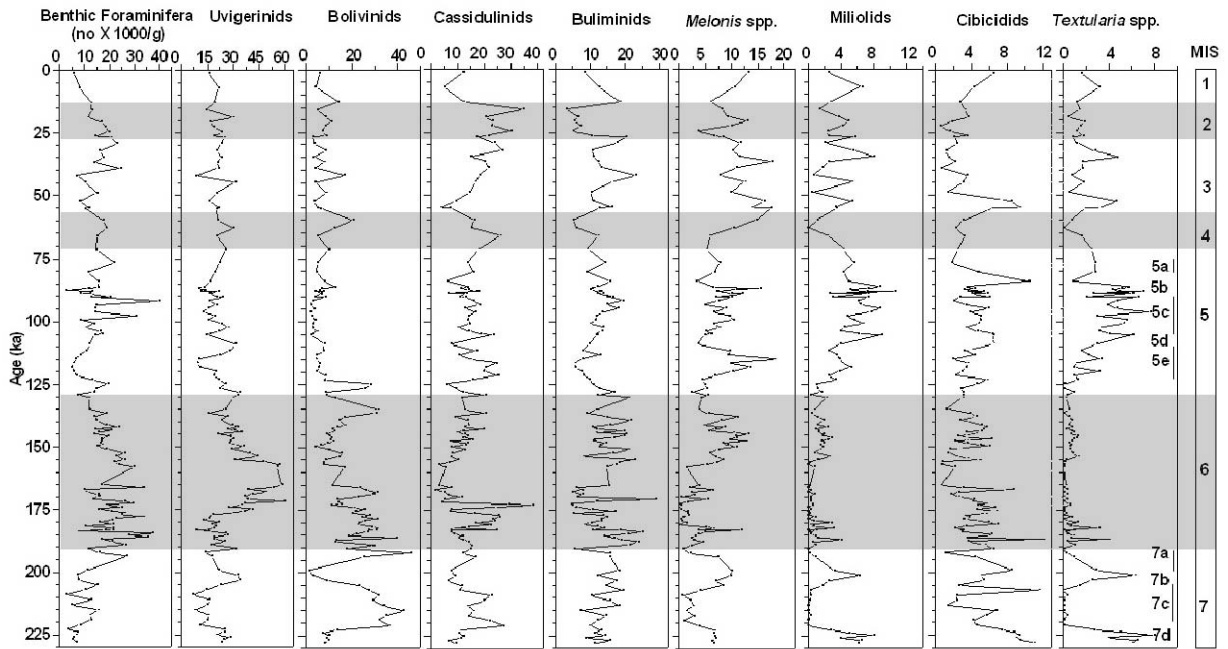


Fig. 3

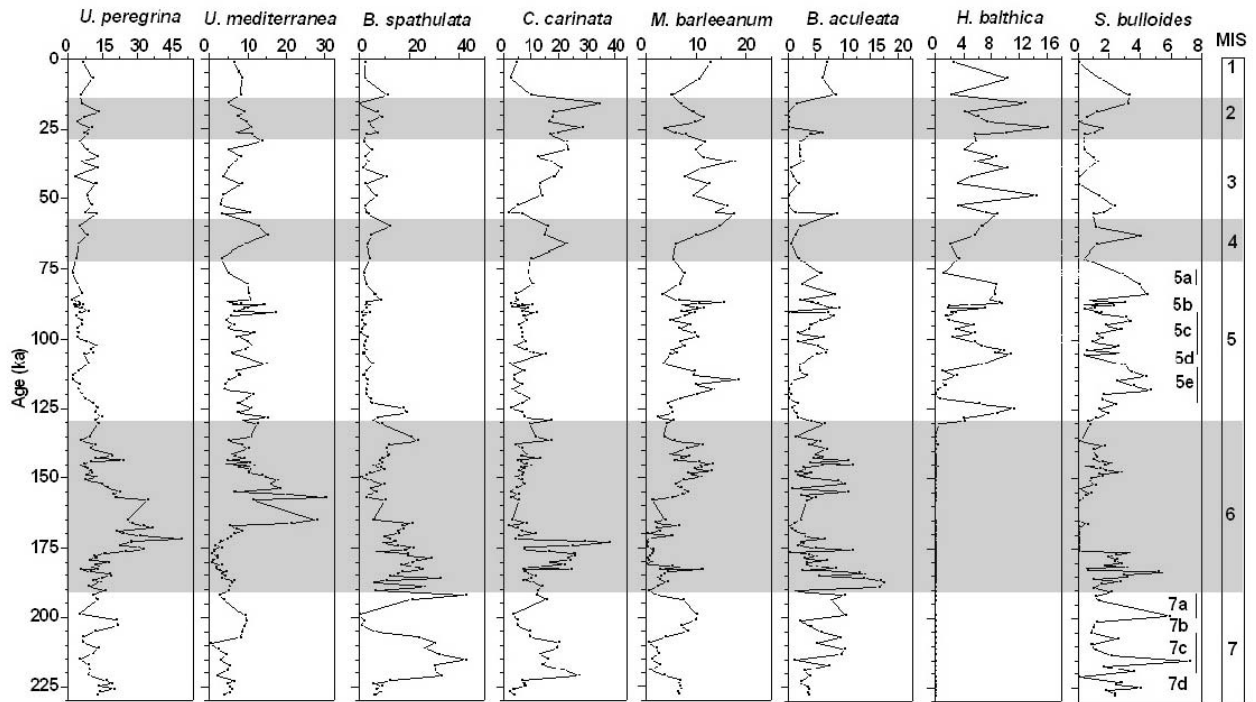


Fig. 4



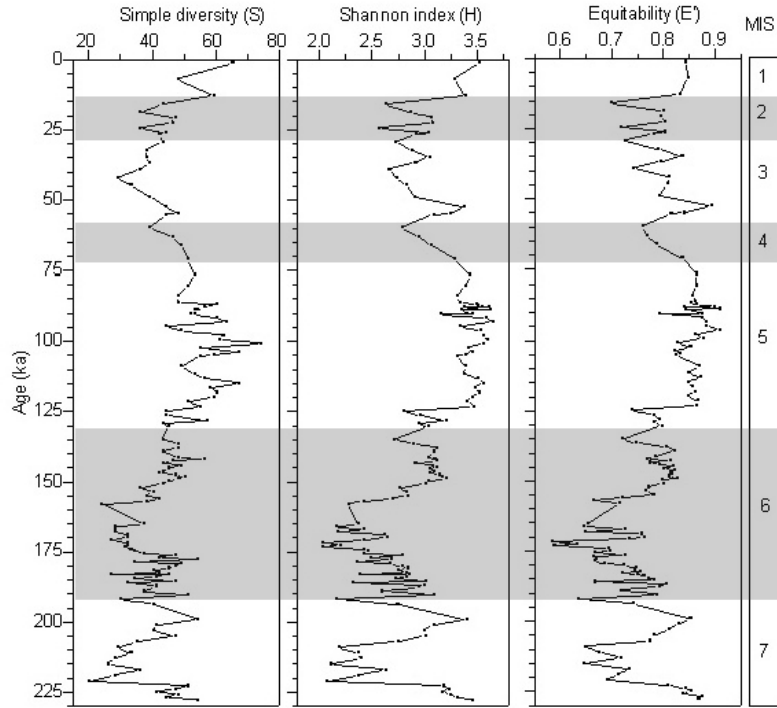


Fig. 5

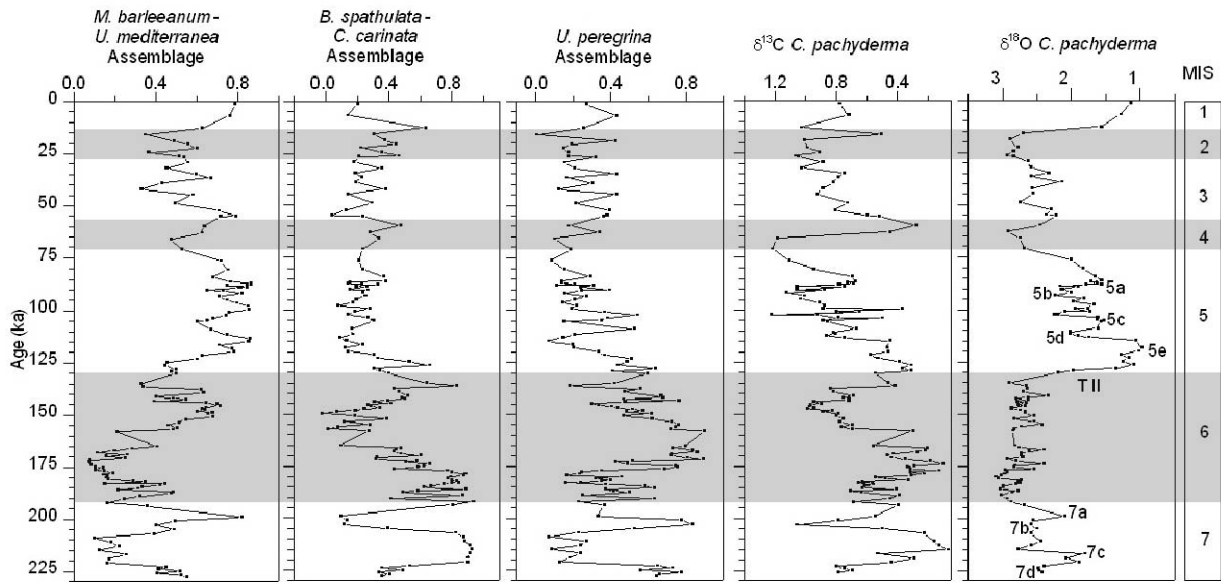


Fig. 6

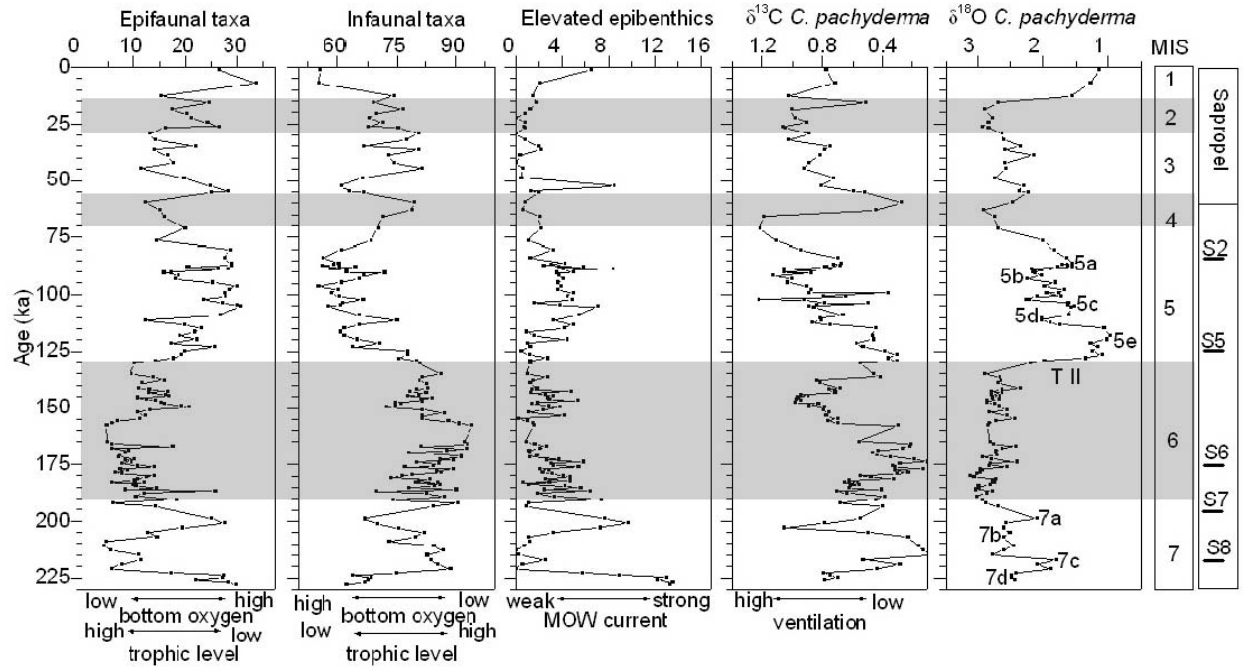


Fig. 7