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Re-evaluation of the "elevated epifauna" as indicator of Mediterranean Outflow Water in the Gulf of Cadiz using stable isotopes ($\delta^{13}C$, $\delta^{18}O$)

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ABSTRACT

The presence and high abundances of the benthic foraminiferal group "elevated epifauna" has been proposed as indicator of the existence of Mediterranean Outflow Water (MOW) in the Gulf of Cadiz. Here we intend to use this potential proxy to reconstruct MOW in the early Pliocene at the Integrated Ocean Drilling Program (IODP) Hole U1387C. *Cibicides lobatulus*, *Planulina ariminensis* and *Cibicides refulgens* were found at this site, but high abundances of *C. lobatulus* and *C. refulgens* coincide with increases of shelf taxa and grain size, related to episodes of downslope transport. This issue calls into question the applicability of these species as MOW proxies. The present study therefore reassesses the role of these three elevated epifaunal species by means of stable isotope analyses ($\delta^{18}O$, $\delta^{13}C$) by contrasting their isotopic signature with that of shelf dwellers and deep-water taxa from Pliocene and Recent sediments from the Gulf of Cadiz and the western Iberian margin. Since foraminiferal calcite does not always precipitate in equilibrium with seawater, substantial efforts have been taken in order to determine species-specific offset values and to correct the isotopic signature for vital effects. Our corrected results demonstrate that *C. lobatulus* and *C. refulgens* are isotopically similar to the shelf dwellers in the Pliocene dataset, eliminating them as MOW indicators. Recent samples from the Gulf of Cadiz and the western Portugal shelf corroborate the wide bathymetric range of *C. lobatulus* from the shelf to the slope. Our results thus warrant for caution when considering *C. lobatulus* and *C. refulgens* as indicators of bottom current strength in unstable slope settings, particularly when co-occurring with allochthonous shelf dwellers. In contrast, *P. ariminensis* shows a signature close to deep-water taxa, corroborating its reliability as indicator of MOW.

1. Introduction

Exploring the history of Mediterranean Outflow Water (MOW), a warm and saline water mass that enters the North Atlantic through the Strait of Gibraltar (Fig. 1) and being considered a contributor to the Atlantic Meridional Overturning Circulation (AMOC), has been the primary objective of the Integrated Ocean Drilling Program (IODP) Expedition 339 (Stow et al., 2013). The opening of the Strait of Gibraltar occurred at 5.33 Ma (Hsü et al., 1978; Comas et al., 1999; Maldonado et al., 1999; Duggen et al., 2003; García-Castellanos et al., 2009; Hernández-Molina et al., 2014; Roveri et al., 2014; Flecker et al., 2015), leading to the re-establishment of Mediterranean-Atlantic circulation. Sedimentological evidence indicates the presence of MOW in the Gulf of Cadiz since the mid-Pliocene (Hernández-Molina et al., 2014). Little, however, is known for the time interval between the opening of the Strait of Gibraltar and the onset of continuous contourite deposition at ~4.5 Ma due to poor core recovery and the presence of turbidites masking the original signal (Stow et al., 2013; Hernández-Molina et al., 2014). In a recent study at IODP Hole U1387C (Fig. 1), Van der Schee et al. (2016) concluded from sedimentological and geochemical evidence that Mediterranean-Atlantic exchange was established very quickly after 5.33 Ma but remained weak in this first stage. In a related study by García-Gallardo et al. (2017), benthic foraminiferal assemblages from the same core intervals have been analyzed with a particular focus on species known to occupy elevated epifaunal microhabitats where they were exposed to strong bottom currents such as MOW. This group of suspension feeding benthic foraminifers is commonly termed the "elevated epifauna" and considered

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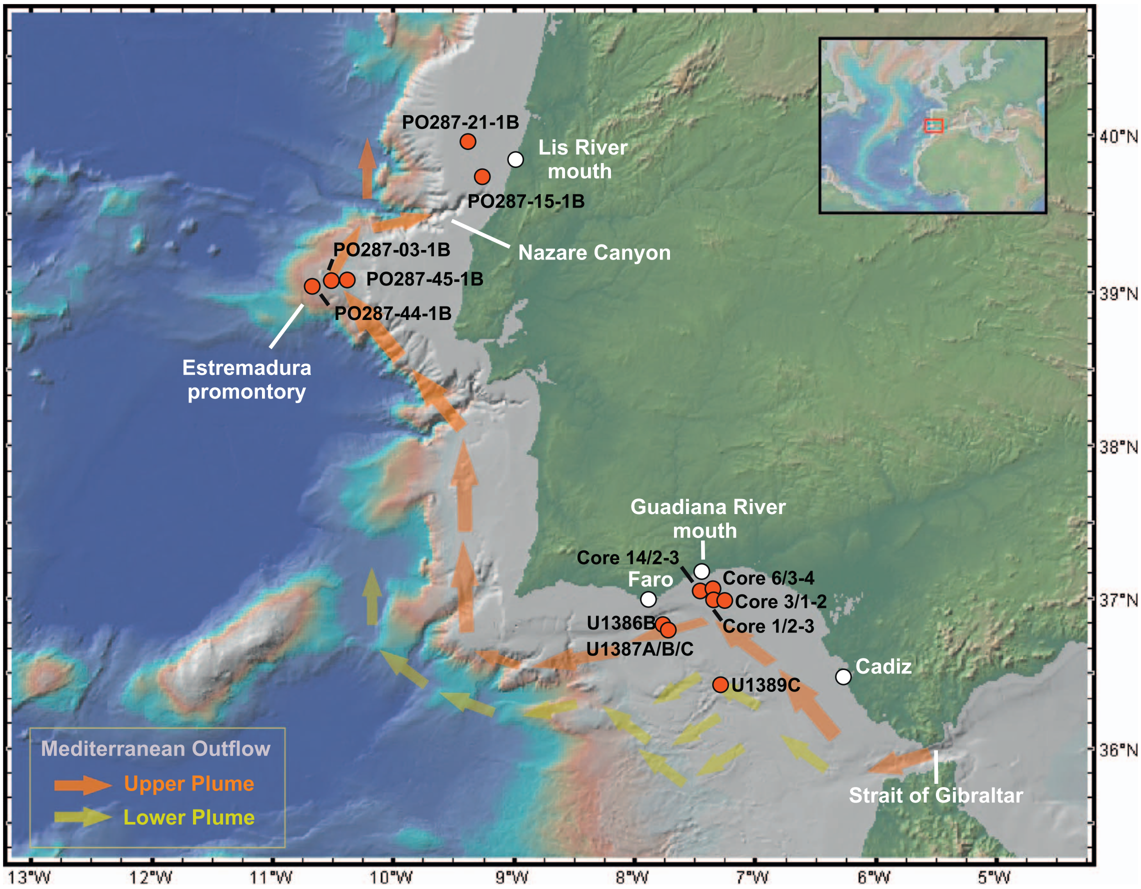


Fig. 1. Location of samples from IODP Sites U1386, U1387, U1389 (IODP Expedition 339), the Guadiana shelf (CRIDA cruises), and the western Portugal shelf and Estremadura promontory (PALEO I POS 287) used in this study. Arrows indicate MOW pathway. The map was generated with GeoMapApp (http://www.geomapapp.org), using the default basemap, the Global Multi-Resolution Topography (GMRT) Synthesis (Ryan et al., 2009).

to take advantage of elevated substrates to harvest organic matter particles carried by bottom currents (Lutze and Thiel, 1989; Schönfeld, 1997, 2002a; Diz et al., 2004; Schönfeld et al., 2011). In the Gulf of Cadiz it has been demonstrated that present-day abundance patterns of the elevated epifauna are directly related to MOW strength and potentially provides a powerful proxy for the reconstruction of MOW in the past (Schönfeld, 1997, 2002a, 2002b; Schönfeld and Zahn, 2000; Rogerson et al., 2011; Singh et al., 2015). The application of this method to lower Pliocene sediments of IODP Hole U1387C, however, shows that highest abundances of the elevated epifauna parallel maxima of allochthonous shelf taxa and sand content (García-Gallardo et al., 2017), indicating a potential bias of the proxy by downslope transport. As gravity deposits are documented for this site up to the Pleistocene (Alonso et al., 2016; Ducassou et al., 2016), the application of the proxy method may be problematic in younger time intervals as well.

The present study compares the stable isotope ($\delta^{13}C$, $\delta^{18}O$) signature of the elevated epifauna to those of benthic foraminifera living in either shelf or deep-water environments from Recent and lower Pliocene samples. The new data shed light on the provenance of individual species associated with the elevated epifauna and help to refine the applicability of the proxy to the fossil record. The comparison of stable isotope data from autochthonous shelf and deep-water species of both investigated time slices further provides new insights into Mediterranean-Atlantic exchange after the opening of the Strait of Gibraltar and before the onset of contourite drift deposition in the Gulf of Cadiz.

2. Regional setting

In this study, samples from different locations and age along the southern (Gulf of Cadiz) and western Iberian margin (Portuguese margin) are analyzed (Fig. 1). In both study areas, sites from the continental slope have been compared to sites from the shelf.

2.1. Continental slope

Most investigated sites on the continental slope are under the influence of MOW. While less saline Atlantic water enters the Mediterranean basin through the Strait of Gibraltar at the surface, warm and highly saline Mediterranean deep waters exit the basin below and form MOW (e.g. Millot, 1999). The complex morphology of the continental slope in the Gulf of Cadiz causes the splitting of MOW into two main plumes with different hydrographic properties: the upper plume, flowing between 500 and 800 m along the SW Iberian Margin, which is warmer and less saline (13–14 °C and 35.7–37) than the lower plume (10.5–11.5 °C and 36.5–37.5), flowing deeper between 800 and 1400 m toward the NW Atlantic (Madelain, 1970; Zenk, 1975; Ambar and Howe, 1979; Borenäs et al., 2002; Serra et al., 2005; Llave et al., 2007; Marchès et al., 2007; García et al., 2009). The influence of MOW in the Gulf of Cadiz has been documented since the mid-Pliocene, which together with tectonic activity results in a complex depositional environment characterized by moats, channels, contourite drifts, turbidites, and debrites (Hernández-Molina et al., 2006, 2014).

Three of the investigated sites are located on the continental slope of

Table 1
Age, study area, Site ID, coordinates, water depth (WD; m: meters) and indication of MOW influence (Y: yes; N: no) for each of the drilled sites used in this study.

Time frame	Study area	Site ID	Latitude (°N)	Longitude (°W)	WD (m)	MOW influence
Pliocene	Faro Drift (Gulf of Cadiz)	U1387C	36.8052	− 7.7188	558	Y
Recent	Faro Drift (Gulf of Cadiz)	U1386B	36.8281	− 7.7753	562	Y
		U1387A	36.8054	− 7.7190	559	Y
		U1387B	36.8054	− 7.7188	558	Y
		U1389C	36.4253	− 7.2779	642	Y
Recent	Guadiana shelf (Gulf of Cadiz)	Core 3/1-2	36.9842	− 7.2441	85	N
		Core 14/2-3	37.0444	− 7.4446	80	N
		Core 1/2-3	36.9999	− 7.3330	90	N
		Core 6/3-4	37.0634	− 7.3459	40	N
Recent	Estremadura promontory (western Portuguese slope)	PO287-45-1B	39.0833	− 10.3742	1216	Y
		PO287-03-1B	39.0738	− 10.4993	1505	Y
		PO287-44-1B	39.0425	− 10.6607	1866	N
Recent	Shelf north of the Nazare Canyon (western Portuguese shelf)	PO287-21-1B	39.9667	− 9.3750	128	N
		PO287-15-1B	39.7367	− 9.2533	111	N

the southern Iberian margin in the Gulf of Cadiz. IODP Sites U1386 and U1387 are situated on the Faro Drift at ~562 and 559 m water depth, respectively (Fig. 1; Table 1). Today, these sites are bathed by the upper MOW plume with bottom current speeds in the order of 20 cm/s (Zenk, 1975; Nelson et al., 1999; Stow et al., 2013). IODP Site U1389 is located to the southeast on the Huelva Drift at a water depth of ~643 m (Fig. 1; Table 1). It is influenced by the lower MOW plume, and bottom current velocities of ~50–100 cm/s have been reported from this area due to its more proximal position with respect to the Strait of Gibraltar (Madelain, 1970; Kenyon and Belderson, 1973; Zenk, 1975; Nelson et al., 1999; Stow et al., 2013).

On the western Portuguese continental slope, sites PO287-45-1B, PO287-03-1B and PO287-44-1B are located on the Estremadura promontory at water depths of 1216, 1505 and 1866 m, respectively, and under the influence of MOW, within the MOW/Northeast Atlantic Deep Water (NEADW) mixing zone and within the NEADW, respectively (Fig. 1; Table 1; Daniault et al., 1994). Submarine canyons (Porto, Aveiro Nazaré, Lisboa, Setúbal and São Vicente) might promote transport of shelf material to deeper settings (Mil-Homens et al., 2006b; de Stigter et al., 2007, 2011; Puig et al., 2014).

2.2. *Shelf*

The Guadiana shelf is located in the northern Gulf of Cadiz (Fig. 1). The surface circulation is governed by a branch of the larger-scale Portuguese-Canary Eastern Boundary Current, which leads to a general anticyclonic circulation due to the southeastward movement of the Surface Atlantic Water (SAW) (Criado-Aldeanueva et al., 2006; García-Lafuente et al., 2006). Major river discharges occur during winter months associated with high-precipitation episodes of negative North Atlantic Oscillation (NAO) phases, in contrast to significant decrease in river flows favored during the positive phase of NAO (Trigo et al., 2004). Positive NAO predominated during sampling of sediment cores 1/2-3, 3/1-2 and 6/3-4 (July 2002; Hurrell and National Center for Atmospheric Research Staff, 2016), while negative NAO prevailed during sampling of sediment core 14/2-3 (April 2005; Hurrell and National Center for Atmospheric Research Staff, 2016). All of them are located in the northern Gulf of Cadiz off the Guadiana River mouth, at water depths of 90, 85, 40 and 80 m, respectively (Fig. 1; Table 1).

The western Iberian margin is in general affected by high levels of precipitation and discharges from the Ave, Douro, Lis, and Mira rivers. This area is characterized by the occurrence of seasonal coastal upwelling during spring and summer, induced by northern winds (Fiúza, 1983) and favored during the positive phase of NAO (Lebreiro et al., 2006). Sites PO287-15-1B and PO287-21-1B are located on the western Portugal shelf, north of the Nazare Canyon close to the Lis river mouth at water depths of 111 and 128 m (Fig. 1; Table 1; Mil-Homens et al., 2006a).

3. Material and methods

3.1. *Pliocene samples*

Upper Miocene to Holocene sediment cores from IODP Hole U1387C were recovered in the Gulf of Cadiz during IODP Expedition 339 with a total drilling depth of 870 m below sea-floor (mbsf). Lower Pliocene hemipelagic sediments of cores 51R to 30R (764.92–625.7 mbsf; Stow et al., 2013; Hernández-Molina et al., 2013; Van der Schee et al., 2016) have been analyzed. Based on the available stratigraphic data, this interval ranges from ~5.1 to 4.5 Myrs (Stow et al., 2013; Van der Schee et al., 2016). The lower interval is mainly composed of nannofossil-rich mud with intercalated silty beds. Some beds of fine and medium sands, interpreted as turbidites, occur in cores 50R and 49R (Stow et al., 2013; Van der Schee et al., 2016). Core 47R consists of silty mud with medium sand while cores 42R, 37R and 33R are composed of nannofossil and silty mud. Samples were collected at the Bremen Core Repository. They were freeze-dried overnight, weighed, disaggregated in water, and the residues > 63 μm were weighed.

3.2. *Surface sediment samples*

3.2.1. *Gulf of Cadiz*

Mudline samples from IODP Holes U1386B, U1387A, U1387B, and U1389C have been recovered during IODP Expedition 339 (Table 1). Samples were stained with Rose Bengal, washed over a 63 μm sieve and dried. Based on the absence of stained (live) epifaunal species and the presence of intermediate (*Melonis barleeanum*) and deep infaunal elements (*Chilostomella oolina*, *Globobulimina affinis*), the mudline samples most likely represent unconsolidated sediment 1–2 cm below the surface layer (Grunert et al., 2015; Balestra et al., 2017). Holocene sedimentation rates in the order of 16–30 cm/kyr suggest a modern age < 100 years for the samples (Stow et al., 2013; Singh et al., 2015). Unstained benthic foraminifera > 125 μm have been picked for this study as stained specimens of the herein analyzed species are rare or absent.

Sediment cores from the Guadiana shelf were retrieved aboard the vessel *Aguayo* during campaigns CRIDA0702 and CRIDA0405, in July 2002 and April 2005, respectively, in the frame of Project CRIDA (POCTI/P/MAR/15289/99). The cores were retrieved using a light-weighted vibro-corer with water injection, characterized by a core barrel of 4 m length and an inner diameter of 9 cm. Core-tops were sampled in 1 cm slices, stained with Rose Bengal, washed over a 63 μm sieve and dried. Samples from levels 1–2 cm (core 3), 2–3 cm (cores 1 and 14) and 3–4 cm (core 6), were used in this study (Table 1). Within the middle shelf mud body, late Holocene sedimentation rates ranged between 61 and 166 cm/kyr indicating a modern age for these samples (Mendes et al., 2012b; Rosa, 2014).

3.2.2. Western Portuguese margin

Box cores PO287-15-1B and PO287-21-1B from the western coast of Portugal and PO287-45-1B, PO287-03-1B and PO287-44-1B from the Estremadura promontory were retrieved during the scientific cruise POS287-PALEO I aboard the RV POSEIDON during April–May 2002 (Monteiro et al., 2002). Sedimentation rates and dry bulk density are unpublished. Based on a ^{14}C age at 3.5–4.0 cm depth (KIA 26157: uncorrected ^{14}C age of 1890 ± 25 yr BP for a *Globorotalia inflata* > 315 μm sample), the surface of core PO287-44-1B is recent (Mil-Homens et al., 2006b).

3.3. Benthic foraminifera selected for analyses

Twelve benthic foraminiferal taxa are compared in the present study. Each species is assigned to one of the following groups based on a thorough review of available biogeographic, bathymetric and ecological data (e.g., Berggren and Haq, 1976; Corliss, 1985; Van Morkhoven et al., 1986; Murray, 1991; Jones and Brady, 1994; Schönfeld, 1997; González-Regalado et al., 2001; Schönfeld, 2002a, 2002b; Mendes et al., 2004; Murray, 2006; Schönfeld, 2006; Rogerson et al., 2011; Mendes et al., 2012a): shelf taxa; deep-water taxa; elevated epifaunal taxa. Shelf taxa comprise *Ammonia* spp., *Asterigerinata* spp., *Elphidium crispum*, and *Nonion fabum*. *Ammonia beccarii* and its varieties (e.g., *A. beccarii* forma *parkinsoniana*) are the most abundant in our samples, including closely related species such as *A. falsobeccarii*. Due to the scarcity of individuals in some cases and identification problem due to abrasion, it is probable that some other varieties were included for analysis. The same applies for *Asterigerinata*. *Cassidulina laevigata* is characteristic from the slope; however, it occurs only in our surface sediment samples from the Guadiana shelf, where it was also recorded in the living assemblage and throughout the Middle-Late Holocene, with peaks of abundance associated with upwelling processes and increased silt and clay content (Mendes et al., 2012a, 2013). For this reason, *C. laevigata* has been included in the shelf group. *Cibicidoides pachyderma*, *Globobulimina* spp., *Uvigerina celtica*, and *U. pigmea* are considered to have their upper depth limit at the shelf break and are autochthonous to the continental slope. The elevated epifauna is represented by *Cibicides lobatulus*, *Cibicides refulgens* and *Planulina ariminensis*. Those species were picked separately from the 150–250 μm and > 250 μm fraction to address potential ontogenetic effects on the isotopic signal. Scanning electron microscope pictures of representative specimens from each setting are displayed in Plate 1.

3.4. Isotope analyses (δ^{13}C, δ^{18}O)

Isotopic data for *C. pachyderma* from the herein studied samples of IODP Hole U1387C have been taken from Van der Schee et al. (2016). For the rest of the samples, the following analytical protocols have been applied: 10 to 20 foraminiferal tests with suitable preservation, minimum fillings and no overgrowths were picked, crushed between glass slides, and transferred into vials containing an H_2O_{dest}: Methanol (2:1) mixture. These vials were put in an ultrasonic bath for 1 min to remove sediment and fillings from the tests. Once the liquid was removed and the clean fragments were dry, they were transferred into a vial for isotopic measurements.

Pliocene and Recent samples from the Gulf of Cadiz and Recent samples from the Estremadura promontory and the shelf north of the Nazare Canyon were reacted with oversaturated 100% orthophosphoric acid at 70 °C in a Kiel II automated reaction system and measured with a Delta Plus isotope-ratio mass spectrometer at the Institute of Earth Sciences, University of Graz. Reproducibility of replicate analyses for standards (in-house and NBS 19) was better than ± 0.1‰ for δ^{13}C and ± 0.15‰ for δ^{18}O. All carbonate isotopic values are quoted relative to Vienna Pee Dee Belemnite (VPDB).

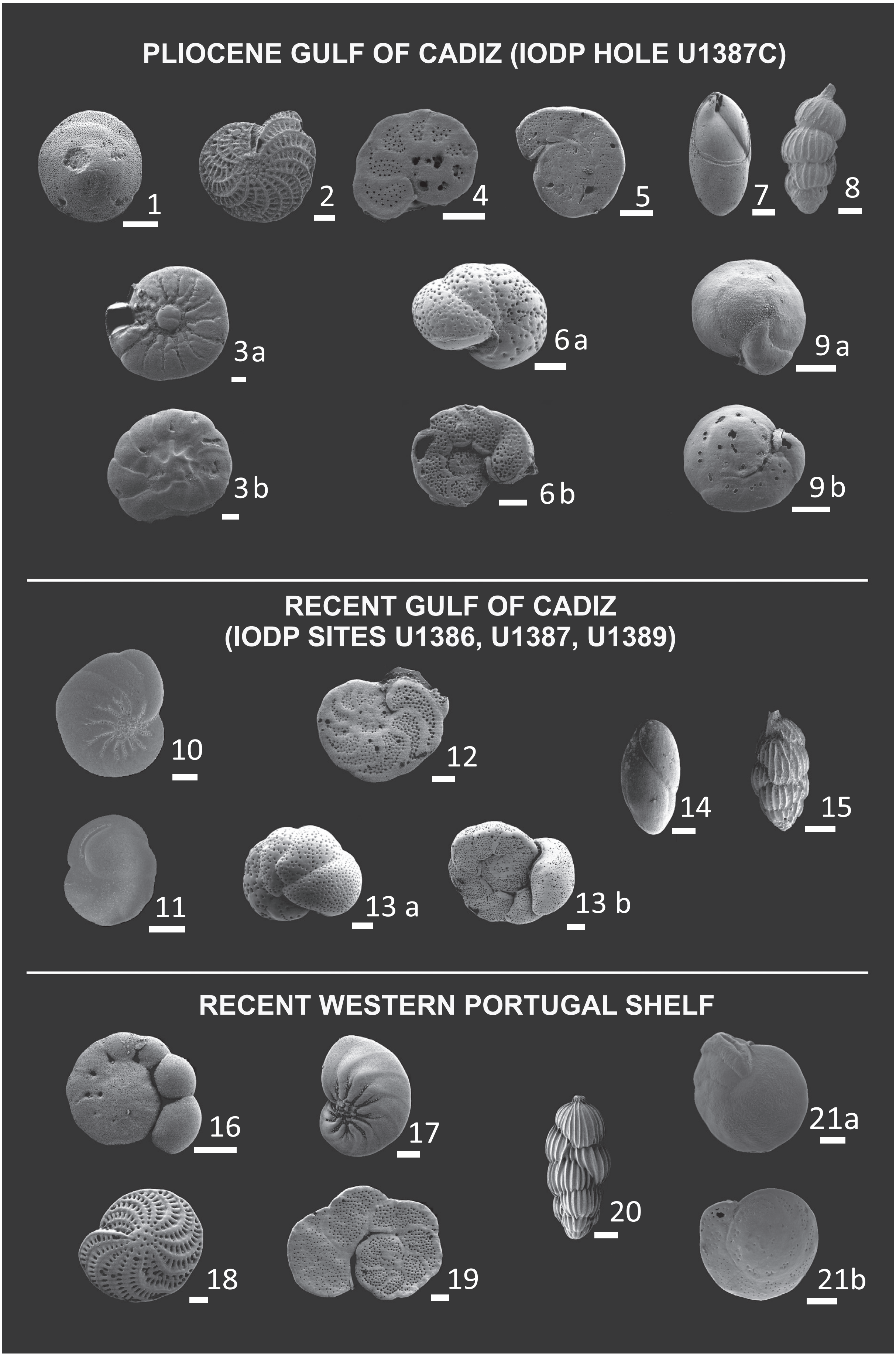
In samples from the Guadiana shelf, the fraction > 63 μm was covered with ethanol (99.9%) and dried in open air. This procedure was repeated to make sure all the water has been removed, in order to avoid dissolved carbonates within the sediment to crystalize and disturb the original isotopic signal. Five to ten foraminiferal specimens were picked, stored in vials and sent for analyses to the Leibniz-Laboratory for Radiometric Dating and Stable Isotope Research at Kiel University (Germany). Isotope measurements were conducted with the automated Finnigan-MAT Kiel Device Type I, coupled to a Finnigan-MAT 251 mass spectrometer and calibrated to the VPDB (Vienna Pee Dee Belemnite) scale by means of the NBS-19 carbonate isotope standard and several other lab-internal standard compounds. The analytical precision was < ± 0.04‰ for δ^{13}C and < ± 0.07‰ for δ^{18}O.

Specimens from the Estremadura promontory (western Portuguese slope) were picked from the fraction > 315 μm and analyzed in the Finnigan MAT 252 mass spectrometer at Marum (University Bremen, Germany), which is coupled to an automated Kiel carbonate preparation system. Based on repeated analyses of internal (Solnhofen limestone) and external (NBS-19) carbonate standards the long-term precision is ± 0.05‰ for δ^{13}C and ± 0.07‰ for δ^{18}O (Voelker et al., 2010).

The obtained isotopic data must be corrected for species-specific offsets from the equilibrium due to vital effects. Correction values applied to the individual taxa are described and discussed in Chapters 5.1 and 5.2.

3.5. Modern hydrographic data

A summary of modern hydrographic parameters (bottom water temperature (BWT), salinity, $\delta^{18}O_{sw\ (seawater)}$) for the Gulf of Cadiz and the Western Iberian margin have been compiled from Daniault et al. (1994), Mendes et al. (2012a), Stow et al. (2013), Voelker et al. (2015b), Balestra et al. (2017) and the World Ocean Atlas (WOA) (Table 2). For the three sites from the western Iberian slope (Table 2), seawater was analyzed on the DeltaPlusXL mass spectrometer coupled to a Gasbench II of the Leibniz Laboratory of Kiel University (see Voelker et al., 2015b for details on standards and precision). In this context, it is important to consider that $\delta^{18}O_{c\ (calcite)}$ is reported relative to the Vienna Pee-Dee Belemnite (VPDB) standard, while $\delta^{18}O_{sw}$ is reported in reference to Standard Mean Ocean Water (VSMOW) (Craig, 1961). Differential CO_2 liberated from VPDB $CaCO_3$ and CO_2 equilibrated with VSMOW results in an offset between both standards (Coplen et al., 1983). $\delta^{18}O_{sw}$ (‰ VSMOW) has been thus converted to $\delta^{18}O_{sw}$ (‰ VPDB) by subtracting 0.27‰ from the VSMOW value (Hut, 1987) (Table 2). Predicted δ^{18}O (‰ VPDB) of foraminiferal calcite at equilibrium with seawater has been calculated for each sampling point by using the paleotemperature equation ($t = 16.9–4.0\ (\delta^{18}O_c - \delta^{18}O_{sw} + 0.2)$) in Marchitto et al. (2014) derived from Shackleton (1974) (t is temperature in degrees Celsius, $\delta^{18}O_c$ is the predicted foraminiferal δ^{18}O calcite composition relative to VPDB, and $\delta^{18}O_{sw}$ is the δ^{18}O composition of seawater) (Table 2).



(caption on next page)

Plate 1. Scale bar = 100 μm.

1. *Asterigerinata* sp.
2. *Elphidium crispum* (Linnaeus, 1758).
3. *Ammonia beccarii* forma *parkinsoniana* (d'Orbigny, 1839). a) Umbilical side. b) Spiral side.
4. *Planulina ariminensis* (d'Orbigny, 1826).
5. *Cibicides refulgens* (de Monfot, 1808).
6. *Cibicides lobatulus* (Walker and Jakob, 1798). a) Umbilical side. b) Spiral side.
7. *Praeglobobulimina ovata* (d'Orbigny, 1846).
8. *Uvigerina pigmea* (d'Orbigny, 1826).
9. *Cibicidoides pachyderma* (Rzehak, 1886). a) Umbilical side. b) Spiral side.
10. *Nonion fabum* (Fichtel and Moll, 1978).
11. *Cassidulina laevigata* (d'Orbigny, 1826).
12. *Planulina ariminensis* (d'Orbigny, 1826).
13. *Cibicides lobatulus* (Walker and Jakob, 1798). a) Umbilical side. b) Spiral side.
14. *Praeglobobulimina ovata* (d'Orbigny, 1846).
15. *Uvigerina celtica* (Schönfeld, 2006).
16. *Ammonia falsobeccarii* (Rouvillois, 1974). Spiral side.
17. *Nonion fabum* (Fichtel and Moll, 1798).
18. *Elphidium crispum* (Linnaeus, 1758).
19. *Cibicides lobatulus* (Walker and Jakob, 1798). Spiral side.
20. *Uvigerina celtica* (Schönfeld, 2006).
21. *C. pachyderma* (Rzehak, 1886). a) Umbilical side. b) Spiral side.

4. Results

4.1. Pliocene Gulf of Cadiz

In the Pliocene samples, tests of *Ammonia* spp., *Asterigerinata* spp., *C. lobatulus*, *C. refulgens*, *C. pachyderma*, *E. crispum*, *Globobulimina* spp., *N. fabum*, *P. ariminensis*, and *U. pigmea* have been analyzed (Fig. 2-A1, Table 3a). Carbon and oxygen isotope values show a range of − 2.03 to + 1.08‰ and from − 1.60 to + 2.41‰, respectively.

The ranges and mean values of δ^{13}C and δ^{18}O values for each analyzed species are: *Ammonia* spp. (δ^{13}C: − 0.47 to − 0.31‰, mean: − 0.36‰; δ^{18}O: − 0.45 to + 0.18‰, mean: − 0.07‰) *Asterigerinata* spp. (δ^{13}C: − 0.46 to + 0.43‰, mean: + 0.03‰; ^{18}O: − 1.6 to − 0.3‰, mean: − 0.8‰), *C. lobatulus* (δ^{13}C: + 0.18 to + 0.73‰, mean: + 0.45‰; δ^{18}O: − 0.64 to + 0.34‰, mean: − 0.14‰), *C. refulgens* (δ^{13}C: + 0.71‰, δ^{18}O: − 0.03‰) *C. pachyderma* (δ^{13}C: − 0.34 to + 1.03‰, mean: + 0.34‰; δ^{18}O: + 0.72 to + 2.03‰, mean: + 1.18‰), *E. crispum* (δ^{13}C: + 0.2 to + 0.79‰, mean: + 0.38‰; δ^{18}O: + 0.04 to + 1.21‰, mean: + 0.45‰), *Globobulimina* spp. (δ^{13}C: − 2.03 to − 1.79‰, mean: − 1.91‰; δ^{18}O: + 0.91 to + 2.03‰, mean: + 1.47‰), *N. fabum* (δ^{13}C: − 0.75‰, δ^{18}O: + 0.34‰) *P. ariminensis* (δ^{13}C: + 0.58 to + 1.08‰, mean: + 0.81‰; δ^{18}O: + 0.92 to + 1.57‰, mean: + 1.34‰) and *U. pigmea* (δ^{13}C: − 1.64 to − 0.57‰, mean: − 1.13‰; δ^{18}O: + 1.25 to + 2.41‰, mean: + 2.03‰).

4.2. Recent Gulf of Cadiz

In the mudline and core-top samples from the Gulf of Cadiz, *C. laevigata*, *C. lobatulus*, *Globobulimina* spp., *N. fabum*, *P. ariminensis*, and *U. celtica* have been analyzed (Fig. 2-A2, Table 3b). *C. lobatulus*, *Globobulimina* spp., *P. ariminensis*, and *U. celtica* come from the IODP Holes U1386B, U1387A, U1387B and U1387C, while *C. laevigata* and *N. fabum* are samples from the Guadiana shelf (Table 1). Carbon and oxygen isotopes show a total range from − 2.54‰ to + 1.47‰ and from 0.07‰ to + 1.69‰, respectively. The range and mean values of δ^{13}C and δ^{18}O values for each analyzed species are: *C. laevigata* (δ^{13}C: − 1.14 to − 0.84‰, mean: − 1‰; δ^{18}O: + 1.24 to + 1.3‰, mean: + 1.28‰), *C. lobatulus* (δ^{13}C: + 0.5 to + 0.82‰, mean: + 0.67‰; δ^{18}O: + 0.07 to + 1.35‰; mean: + 0.68‰), *Globobulimina* spp. (δ^{13}C: − 1.07‰, δ^{18}O: + 1.69‰), *N. fabum* (δ^{13}C: − 2.54 to − 0.74‰, mean: − 1.54‰; δ^{18}O: + 1.42 to + 1.64‰, mean: + 1.56‰), *P. ariminensis* (δ^{13}C: + 1.28 to + 1.47‰, mean: + 1.39‰; δ^{18}O: + 0.85 to + 1.25‰, mean: + 1.08‰), and *U. celtica* (δ^{13}C: − 0.39 to + 0.24‰, mean: − 0.09‰; δ^{18}O: + 1.53 to + 1.68‰, mean: + 1.61‰).

4.3. Recent western Portugal shelf

In the samples from the western Portugal shelf, *Ammonia* spp., *C. lobatulus*, *C. pachyderma*, *E. crispum*, *N. fabum, and U. celtica* have been analyzed (Fig. 2-A3, Table 3c). Carbon and oxygen isotopes show a

Table 2
Hydrographic parameters in the Gulf of Cadiz (deep slope and Guadiana shelf) and Western Iberian Margin (slope and shelf north of the Nazare Canyon). WD: water wepth. BWT: bottom water temperature.

Expedition	Area	Site	WD	BWT	Salinity	$\delta^{18}O_{sw}$ (‰ VSMOW)	$\delta^{18}O_{sw}$ (‰ VPDB)	Predicted $\delta^{18}O_c$ (‰ VPDB)	Source
IODP 339	Gulf of Cadiz/Slope	U1386	562	13.1	36.1	0.84	0.57	1.32	Stow et al. (2013),
		U1387	559	13.1	36	0.8	0.53	1.28	Voelker et al. (2015b),
		U1389	644	13.4	36	0.8	0.53	1.21	Balestra et al. (2017)
CRIDA 0405	Gulf of Cadiz/Guadiana shelf	Core 3/1-2	85	13.5	36.1	0.9	0.63	1.28	Mendes et al. (2012a),
		Core 14/2-3	80	13.5	36.2	0.9	0.63	1.28	Voelker et al. (2015b),
		Core 1/2-3	90	13.5	36.2	0.9	0.63	1.28	WOA
		Core 6/3-4	40	14	36.2	0.9	0.63	1.16	
PALEO I (POS 287)	Western Portuguese slope	45-1B	1216	11.1	36.2	0.72	0.45	1.7	Daniault et al. (1994),
		03-1B	1505	9.2	35.9	0.66	0.39	2.12	Voelker et al. (2015b),
		44-1B	1866	5.1	35.3	0.42	0.15	2.90	WOA
PALEO I (POS 287)	Western Portuguese shelf	21-1B	128	14.1	35.9	0.8	0.53	1.03	Voelker et al. (2015b),
		15-1B	111	13.5	35.9	0.8	0.53	1.18	WOA

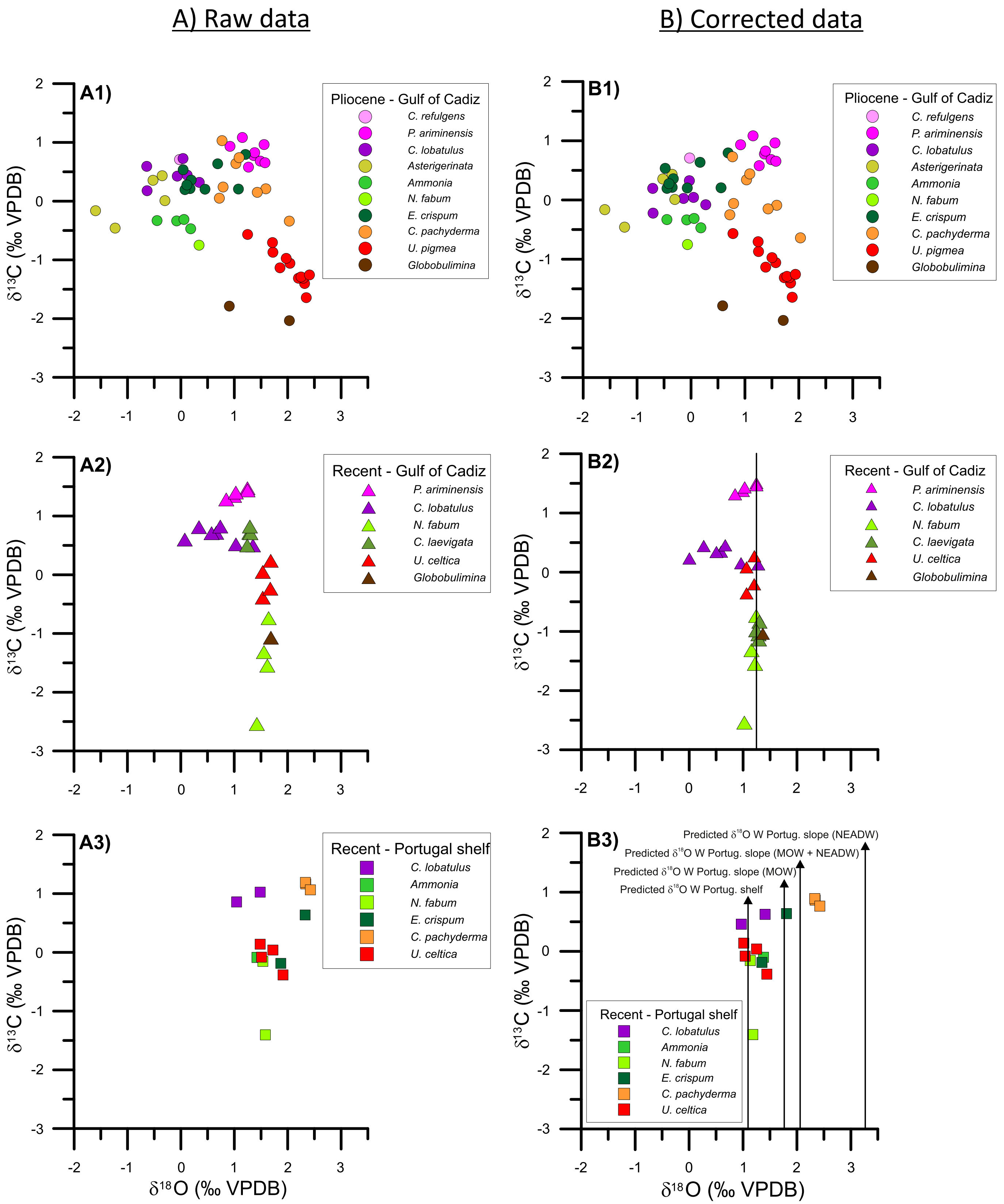


Fig. 2. Isotopic composition on A) raw data of A1) Pliocene samples from IODP Hole U1387C, A2) Mudline (Recent) samples from IODP Sites U1386, U1387 and U1389 in the Gulf of Cadiz (IODP Expedition 339) and the Guadiana shelf samples (CRIDA cruises), A3) Recent western Portugal shelf samples from the shelf north of the Nazare Canyon and Estremadura promontory (PALEO I POS 287 cruise); B) corrected data of B1) Pliocene samples from IODP Hole U1387C, B2) Mudline (Recent) samples from IODP Sites U1386, U1387 and U1389 in the Gulf of Cadiz (IODP Expedition 339) and the Guadiana shelf samples (CRIDA cruises), B3) Recent western Portugal shelf samples from the shelf north of the Nazare Canyon and Estremadura promontory (PALEO I POS 287 cruise). Black vertical bars in Figs. B2 and B3 indicates the Predicted $\delta^{18}O_{sw}$ (‰ VPDB) according to Table 2.

Table 3

Raw and corrected δ^{13}C and δ^{18}O data-set obtained from isotopic measurements for a) Pliocene Gulf of Cadiz; b) recent Gulf of Cadiz; c) recent western Portugal shelf. Corrected values are the result after offset correction. Location area, core ID and size fraction are indicated.

3a) Pliocene Gulf of Cadiz							
	Raw data		Corrected		Core-section	Top-bottom (cm)	Fraction (μm)
	δ^{13}C (‰ VPDB)	δ^{18}O (‰ VPDB)	δ^{13}C (‰ VPDB)	δ^{18}O (‰ VPDB)			
Ammonia spp.	− 0.33	− 0.45	− 0.33	− 0.45	49R-1	10–12	> 250
	− 0.34	− 0.08	− 0.34	− 0.08	50R-1	83–85	150–250
	− 0.47	0.18	− 0.47	0.18	51R-3	42–44	150–250
	− 0.31	0.06	− 0.31	0.06	49R-5	71–73	> 250
Min.	− 0.47	− 0.45	− 0.47	− 0.45			
Max.	− 0.31	0.18	− 0.31	0.18			
Average	− 0.36	− 0.07	− 0.36	− 0.07			
Standard deviation	0.07	0.27	0.07	0.27			
Asterigerinata spp.	− 0.16	− 1.6	− 0.16	− 1.6	30R-5	82–84	150–250
	− 0.46	− 1.23	− 0.46	− 1.23	48R-5	60–62	150–250
	0.43	− 0.35	0.43	− 0.35	50R-1	83–85	150–250
	0.01	− 0.3	0.01	− 0.3	51R-3	42–44	150–250
	0.35	− 0.52	0.35	− 0.52	48R-5	60–62	150–250
Min.	− 0.46	− 1.6	− 0.46	− 1.6			
Max.	0.43	− 0.3	0.43	− 0.3			
Average	0.03	− 0.8	0.03	− 0.8			
Standard deviation	0.37	0.58	0.37	0.58			
C. lobatulus	0.18	− 0.63	− 0.22	− 0.7	48R-4	40–42	150–250
	0.43	− 0.07	0.03	− 0.14	48R-5	60–62	> 250
	0.73	0.04	0.33	− 0.03	49R-1	10–12	> 250
	0.32	0.34	− 0.08	0.27	49R-5	71–73	> 250
	0.6	− 0.64	0.2	− 0.71	50R-1	83–85	150–250
	0.44	0.12	0.04	0.05	49R-5	71–73	> 250
Min.	0.18	− 0.64	− 0.22	− 0.71			
Max.	0.73	0.34	0.33	0.27			
Average	0.45	− 0.14	0.05	− 0.21			
Standard deviation	0.2	0.41	0.19	0.41			
C. refulgens	0.71	− 0.03	0.71	− 0.03	50R-1	83–85	150–250
C. pachyderma	0.21	1.59	− 0.09	1.59	48R-3	100–102	> 315
	0.64	1.03	0.34	1.03	48R-4	50–52	> 315
	0.24	0.79	− 0.06	0.79	48R-5	10–12	> 315
	0.15	1.43	− 0.15	1.43	49R-1	30–32	> 315
	1.03	0.77	0.73	0.77	49R-3	0–2	> 315
	0.05	0.72	− 0.25	0.72	49R-5	90–92	> 315
	0.74	1.09	0.44	1.09	50R-1	83–85	> 315
	− 0.34	2.03	− 0.64	2.03	51R-3	122–124	> 315
Min.	− 0.34	0.72	− 0.64	0.72			
Max.	1.03	2.03	0.73	2.03			
Average	0.34	1.18	0.04	1.18			
Standard deviation	0.44	0.47	0.44	0.47			
E. crispum	0.36	0.19	0.36	− 0.33	49R-1	10–12	> 250
	0.21	0.17	0.21	− 0.35	49R-5	71–73	> 250
	0.53	0.04	0.53	− 0.48	50R-1	83–85	150–250
	0.2	0.07	0.2	− 0.45	47R	Shipboard	150–250
	0.28	0.11	0.28	− 0.41	42R-2	3–5	150–250
	0.79	1.21	0.79	0.69	33R-5	82–84	150–250
	0.2	0.45	0.2	− 0.07	51R-3	42–44	150–250

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Table 3 *(continued)*

3a) Pliocene Gulf of Cadiz

	Raw data		Corrected		Core-section	Top-bottom (cm)	Fraction (μm)
	$\delta^{13}C$ (‰ VPDB)	$\delta^{18}O$ (‰ VPDB)	$\delta^{13}C$ (‰ VPDB)	$\delta^{18}O$ (‰ VPDB)			
	0.21	1.08	0.21	0.56	50R	Shipboard	150–250
	0.64	0.69	0.64	0.17	49R-5	71–73	150–250
Min.	0.2	0.04	0.2	−0.48			
Max.	0.79	1.21	0.79	0.69			
Average	0.38	0.45	0.38	−0.07			
Standard deviation	0.22	0.45	0.22	0.45			
Globobulimina spp.	−1.79	0.91	−1.79	0.59	48R-5	60–62	150–250
	−2.03	2.03	−2.03	1.71	48R-1	110–112	150–250
Min.	−2.03	0.91	−2.03	0.59			
Max.	−1.79	2.03	−1.79	1.71			
Average	−1.91	1.47	−1.91	1.15			
Standard deviation	0.17	0.8	0.17	0.8			
N. fabum	−0.75	0.34	−0.75	−0.06	49R-5	71–73	150–250
P. ariminensis	0.78	1.36	0.78	1.36	42R-2	3–5	150–250
	0.96	1.56	0.96	1.56	42R-1	10–12	150–250
	1.08	1.15	1.08	1.15	30R-5	42–44	150–250
	0.58	1.27	0.58	1.27	48R-5	60–62	> 250
	0.93	0.92	0.93	0.92	49R-3	30–32	150–250
	0.68	1.49	0.68	1.49	50R-1	83–85	150–250
	0.83	1.38	0.83	1.38	51R-5	2–4	150–250
	0.65	1.57	0.65	1.57	49R-5	0–2	150–250
Min.	0.58	0.92	0.58	0.92			
Max.	1.08	1.57	1.08	1.57			
Average	0.81	1.34	0.81	1.34			
Standard deviation	0.17	0.22	0.17	0.22			
U. pigmea	−1.4	2.32	−1.4	1.85	48R-2	140–142	> 250
	−1.06	2.04	−1.06	1.57	49R-1	10–12	> 250
	−0.57	1.25	−0.57	0.78	49R-3	30–32	150–250
	−1.31	2.2	−1.31	1.73	49R-5	71–73	> 250
	−1.31	2.29	−1.31	1.82	51R-3	42–44	150–250
	−0.87	1.72	−0.87	1.25	37R-1	20–22	150–250
	−1.13	1.86	−1.13	1.39	42R-2	03–05	150–250
	−0.97	1.97	−0.97	1.5	33R-5	82–84	150–250
	−1.64	2.35	−1.64	1.88	48R-2	140–142	> 250
	−1.29	2.25	−1.29	1.78	51R-3	42–44	150–250
	−1.26	2.41	−1.26	1.94	49R-5	0–2	> 250
	−0.71	1.72	−0.71	1.25	51R-1	42–44	150–250
Min.	−1.64	1.25	−1.64	0.78			
Max.	−0.57	2.41	−0.57	1.94			
Average	−1.13	2.03	−1.13	1.56			
Standard deviation	0.31	0.35	0.31	0.35			

3b) Recent Gulf of Cadiz

	Raw data		Corrected		Site/core ID	Fraction (μm)
	$\delta^{13}C$ (‰ VPDB)	$\delta^{18}O$ (‰ VPDB)	$\delta^{13}C$ (‰ VPDB)	$\delta^{18}O$ (‰ VPDB)		
C. laevigata	−1.05	1.28	−1.05	1.28	Core 3/1-2	> 63

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Table 3 *(continued)*

3b) Recent Gulf of Cadiz

	Raw data		Corrected		Site/core ID	Fraction (μm)
	δ^{13}C (‰ VPDB)	δ^{18}O (‰ VPDB)	δ^{13}C (‰ VPDB)	δ^{18}O (‰ VPDB)		
	− 0.84	1.3	− 0.84	1.3	Core 14/2-3	> 63
	− 1.14	1.29	− 1.14	1.29	Core 1/2-3	> 63
	− 0.98	1.24	− 0.98	1.24	Core 6/3-4	> 63
Min.	− 1.14	1.24	− 1.14	1.24		
Max.	− 0.84	1.3	− 0.84	1.3		
Average	− 1	1.28	− 1	1.28		
Standard deviation	0.13	0.03	0.13	0.03		
C. lobatulus	0.71	0.66	0.31	0.59	U1386B	> 250
	0.71	0.58	0.31	0.51	U1386B	150–250
	0.82	0.74	0.42	0.67	U1387B	150–250
	0.5	1.35	0.1	1.28	U1389C	150–250
	0.52	1.03	0.12	0.96	U1389C	150–250
	0.81	0.34	0.41	0.27	U1389C	150–250
	0.6	0.07	0.2	0	U1386B	150–250
Min.	0.5	0.07	0.1	0		
Max.	0.82	1.35	0.42	1.28		
Average	0.67	0.68	0.27	0.61		
Standard deviation	0.13	0.42	0.13	0.39		
Globobulimina spp.						
	− 1.07	1.69	− 1.07	1.37	U1386B	150–250
N. fabum	− 1.55	1.62	− 1.55	1.22	Core 3/1-2	> 63
	− 0.74	1.64	− 0.74	1.24	Core 14/2-3	> 63
	− 1.32	1.56	− 1.32	1.16	Core 1/2-3	> 63
	− 2.54	1.42	− 2.54	1.02	Core 6/3-4	> 63
Min.	− 2.54	1.42	− 2.54	1.02		
Max.	− 0.74	1.64	− 0.74	1.24		
Average	− 1.54	1.56	− 1.54	1.16		
Standard deviation	0.75	0.1	0.75	0.1		
P. ariminensis	1.34	1	1.34	1	U1389C	> 250
	1.47	1.25	1.47	1.25	U1387A	> 250
	1.28	0.85	1.28	0.85	U1387B	> 250
	1.44	1.25	1.44	1.25	U1389C	150–250
	1.4	1.03	1.4	1.03	U1386B	150–250
Min.	1.28	0.85	1.28	0.85		
Max.	1.47	1.25	1.47	1.25		
Average	1.39	1.08	1.39	1.08		
Standard deviation	0.08	0.17	0.08	0.17		
U. celtica	0.24	1.68	0.24	1.21	U1389C	150–250
	− 0.39	1.53	− 0.39	1.06	U1386B	150–250
	− 0.24	1.68	− 0.24	1.21	U1387B	150–250
	0.05	1.53	0.05	1.06	U1389C	150–250
Min.	− 0.39	1.53	− 0.39	1.06		
Max.	0.24	1.68	0.24	1.21		
Average	− 0.09	1.61	− 0.09	1.14		

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Table 3 *(continued)*

3b) Recent Gulf of Cadiz

	Raw data		Corrected		Site/core ID	Fraction (μm)
	$\delta^{13}C$ (‰ VPDB)	$\delta^{18}O$ (‰ VPDB)	$\delta^{13}C$ (‰ VPDB)	$\delta^{18}O$ (‰ VPDB)		
Standard deviation	0.28	0.08	0.28	0.08		

3c) RECENT WESTERN PORTUGAL SHELF

	Raw data		Corrected		Core ID	Fraction (μm)
	$\delta^{13}C$ (‰ VPDB)	$\delta^{18}O$ (‰ VPDB)	$\delta^{13}C$ (‰ VPDB)	$\delta^{18}O$ (‰ VPDB)		
Ammonia spp.	− 0.09	1.42	− 0.09	1.42	PO287-15-1B	> 250
C. lobatulus	1.02	1.48	0.62	1.41	PO-287-21-1B	150–250
	0.86	1.04	0.46	0.97	PO-287-21-1B	> 250
Min.	0.86	1.04	0.46	0.97		
Max.	1.02	1.48	0.62	1.41		
Average	0.94	1.26	0.54	1.19		
Standard deviation	0.12	0.31	0.12	0.22		
C. pachyderma	1.17	2.34	0.87	2.34	PO287-45-1B	
	1.19	2.33	0.89	2.33	PO287-03-1B	
	1.06	2.43	0.76	2.43	PO287-44-1B	
Min.	1.06	2.33	0.76	2.33		
Max.	1.19	2.43	0.89	2.43		
Average	1.14	2.36	0.84	2.36		
Standard deviation	0.07	0.05	0.07	0.05		
E. crispum	− 0.19	1.87	− 0.19	1.35	PO-287-21-1B	150–250
	0.64	2.33	0.64	1.81	PO-287-21-1B	> 250
Min.	− 0.19	1.87	− 0.19	1.35		
Max.	0.64	2.33	0.64	1.81		
Average	0.22	2.1	0.22	1.58		
Standard deviation	0.58	0.32	0.58	0.32		
N. fabum	− 0.15	1.53	− 0.15	1.13	PO-287-21-1B	> 250
	− 1.41	1.58	− 1.41	1.18	PO-287-15-1B	150–250
Min.	− 1.41	1.53	− 1.41	1.13		
Max.	− 0.15	1.58	− 0.15	1.18		
Average	− 0.78	1.56	− 0.78	1.16		
Standard deviation	0.88	0.03	0.88	0.03		
U. celtica	− 0.38	1.91	− 0.38	1.44	PO-287-15-1B	125
	0.04	1.72	0.04	1.25	PO-287-15-1B	> 250

(continued on next page)

Table 3 *(continued)*

3c) RECENT WESTERN PORTUGAL SHELF

	Raw data		Corrected		Core ID	Fraction (µm)
	δ^{13}C (‰ VPDB)	δ^{18}O (‰ VPDB)	δ^{13}C (‰ VPDB)	δ^{18}O (‰ VPDB)		
	− 0.08	1.51	− 0.08	1.04	PO-287-21-1B	150–250
	0.14	1.48	0.14	1.01	PO-287-21-1B	> 250
Min.	− 0.38	1.48	− 0.38	1.01		
Max.	0.14	1.91	0.14	1.44		
Average	− 0.07	1.66	− 0.07	1.19		
Standard deviation	0.23	0.2	0.23	0.2		

range from − 1.41‰ to + 1.19‰ and + 1.04‰ to + 2.43‰, respectively. The range and average δ^{13}C and δ^{18}O values for each analyzed species are: *Ammonia* spp. (δ^{13}C: − 0.09, δ^{18}O: + 1.42‰), *C. lobatulus* (δ^{13}C: + 0.86 to + 1.02‰, mean: + 0.94‰; δ^{18}O: + 1.04 to + 1.48‰, mean: + 1.26‰), *C. pachyderma* (δ^{13}C: + 1.06 to + 1.19‰, mean: + 1.14‰; δ^{18}O: + 2.33 to + 2.43‰, mean: + 2.36‰), *E. crispum* (δ^{13}C: − 0.19 to + 0.64‰, mean: + 0.22‰; δ^{18}O: + 1.87 to + 2.33‰, mean: + 2.1‰), *N. fabum* (δ^{13}C: − 1.41 to − 0.15‰, mean: − 0.78‰; δ^{18}O: + 1.53 to + 1.58‰, mean: + 1.56‰), and *U. celtica* (δ^{13}C: − 0.38 to + 0.14‰, mean: − 0.07‰; δ^{18}O: + 1.48 to + 1.91‰, mean: + 1.66‰).

5. Discussion

The isotopic signature of benthic foraminifera theoretically reflects the composition of the ambient seawater in which they live. However, it is usually biased as a result of different factors that divert the isotopic composition of the shell calcite from equilibrium (e.g., Duplessy et al., 1970; Woodruff et al., 1980; Vincent et al., 1981; Wefer and Berger, 1991; Bemis et al., 1998). For benthic foraminifera, in particular, it has been demonstrated that vital effects (e.g., ontogeny, carbonate ion concentration) and microhabitat effects may cause species-specific deviations from isotopic equilibrium (Emiliani, 1954; Grossman, 1987; McCorkle et al., 1990; Spero et al., 1997; Fontanier et al., 2006; Rogerson et al., 2011). For this reason, and before any meaningful deduction from our multi-species data-set, these biases on the isotopic signals have to be constrained.

5.1. Species-specific corrections of δ^{18}O

For the purpose of our study, we have accounted for vital effects in δ^{18}O in two ways to ensure a meaningful interpretation. First, a thorough review of available data shows that many of the herein analyzed species are well studied with respect to their specific offsets from isotopic equilibrium, and respective correction values have been suggested (Table 4). Second, information on the oxygen isotope composition of the seawater ($\delta^{18}O_{sw}$; Table 2) enable us to critically evaluate the applicability of published species-specific correction values at our sites as well as to estimate offset values for those taxa which have not been considered in previous studies.

The herein analyzed deep-water species and some elevated epifaunal species are particularly well studied with respect to vital effects. *C. pachyderma* and *P. ariminensis* have been considered to calcify at isotopic equilibrium with the ambient bottom water due to their epifaunal microhabitat (Zahn et al., 1986; Bemis et al., 1998; Rohling and Cooke, 1999; Katz et al., 2003; Marchitto et al., 2014). Accordingly, δ^{18}O of *C. pachyderma* fits perfectly into the predicted δ^{18}O values for Estremadura promontory today (Table 2) and no offset correction has been applied to their isotopic values.

Correction values for *U. pigmea* and *U. celtica* have not been established, whereas a wide number of studies have focused on the closely related shallow infaunal species *U. peregrina.* It has been suggested that this species calcifies in equilibrium with pore water δ^{18}O (e.g. Shackleton, 1974; Woodruff et al., 1980; Grossman, 1987; McCorkle et al., 1990). However, in a recent study that re-evaluates the temperature dependency of foraminiferal δ^{18}O from a global data-set, Marchitto et al. (2014) suggest that *U. peregrina* shows a positive offset of 0.47‰ from isotopic equilibrium. In the present study, this correction value is applied to *U. pigmea* and *U. celtica* from the Pliocene and Recent samples. Both species are considered closely related species of *U. peregrina* (Schönfeld, 2006) and our isotopic data from the surface samples in the Gulf of Cadiz and the shelf area north of the Nazare Canyon (Table 2) are in the range of the correction value established for *U. peregrina.*

Species of *Globobulimina* precipitate their tests in a deep infaunal microhabitat and are thus considered to reflect pore water rather than bottom water δ^{18}O. Available studies suggest that *Globobulimina* precipitates its tests with a positive offset from equilibrium between ∼0.1 to 0.3‰ (McCorkle et al., 1990, 1997; Rogerson et al., 2011). Rogerson et al. (2011) determined an offset value of − 0.15‰ with respect to *U. peregrina.* This correction value has been used in this study, resulting in the offset value applied to *Globobulimina* (Table 4).

For *C. lobatulus*, a negative offset up to ∼ − 1‰ with respect to equilibrium has been proposed by Vilks and Deonarine (1988), McCorkle et al. (1997) and Scourse et al. (2004). Cage and Austin (2008) revealed an offset from equilibrium of − 0.24‰ to − 0.21‰ with a signature close to equilibrium δ^{18}O seawater in summer. They state that $\delta^{18}O_{foram}$ deviations are more influenced by a seasonal isotopic effect rather than vital effects. A negative offset-value of − 0.55‰ was further proposed by Mackensen and Nam (2014) for *C. lobatulus* and *C. refulgens* from Arctic regions. In contrast, positive offset- values between + 0.3 and + 0.8‰ are suggested in Polyak et al. (2003), Hald and Vorren (1987) and Poole et al. (1995); however, the former does not report direct measurements and the latter studies are performed in Northern regions. Since these previous studies do not reach a consensus for an offset value of *C. lobatulus*, probably related to low sample numbers (McCorkle et al., 1997) or samples from regions of variable temperatures and salinity, further assessment of offset values is required for this species. A new offset value for *C. lobatulus* has been estimated in this study with respect to the average value of the shallow infaunal *U. celtica* from the western Portugal shelf data-set considering that all species are autochthonous. According to this, the difference

Table 4
Offset values used to correct $\delta^{18}O$ and $\delta^{13}C$ deviations from equilibrium. Equilibrium reference indicates the reference object to which the offset value is applied for each species.

Taxon	Offset $\delta^{18}O$ (‰)	Reference
Ammonia	Equilibrium	Scourse et al. (2004)
Cibicides lobatulus	+ 0.07	This study
Cibicidoides pachyderma	Equilibrium	Katz et al. (2003)
Elphidium crispum	+ 0.52	This study
Globobulimina	+ 0.32	Rogerson et al. (2011)
Nonion	+ 0.4	Duplessy and Pujol (1980)
Planulina ariminensis	Equilibrium	Marchitto et al. (2014)
Uvigerina celtica	+ 0.47	Marchitto et al. (2014)

Taxon	Offset $\delta^{13}C$ (‰)	Reference
Cibicides lobatulus	+ 0.4	Mackensen et al. (2000)
Cibicidoides pachyderma	+ 0.3	Voelker et al. (2015a)

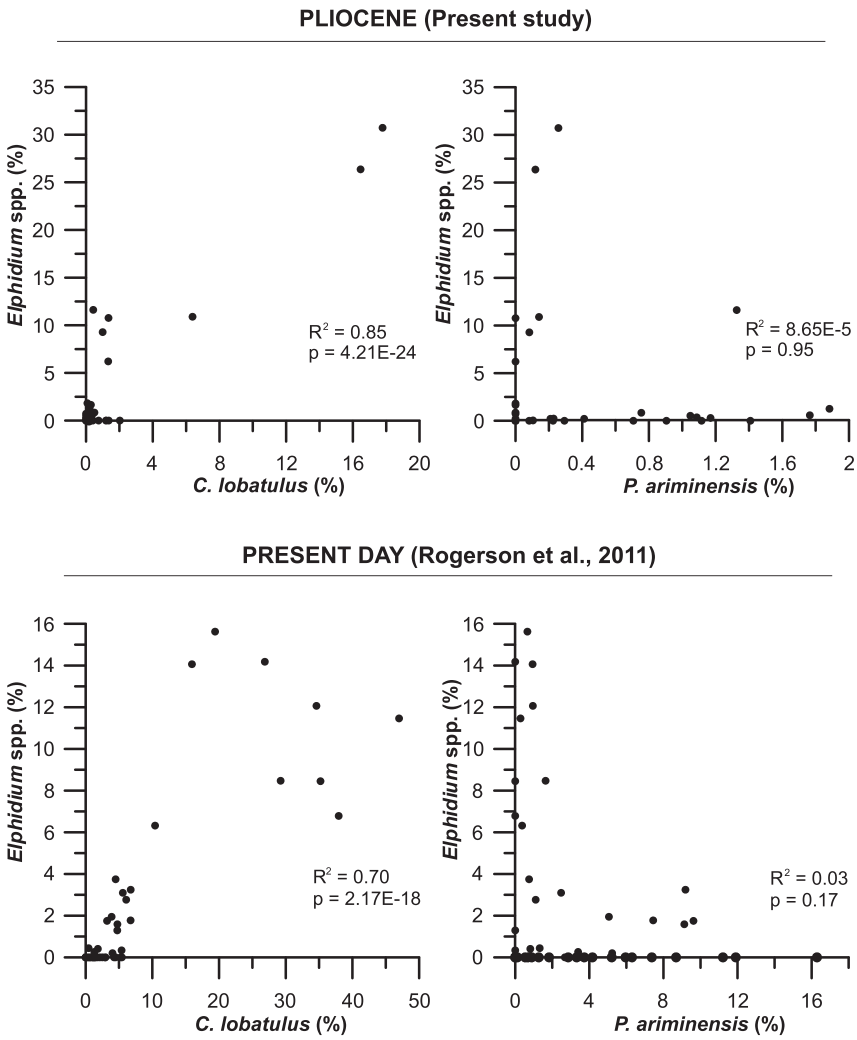

Fig. 3. Correlation *C. lobatulus* - *Elphidium* spp. and *P. ariminensis* - *Elphidium* spp. from the Pliocene samples of IODP Hole U1387C (top panel) and the mudline samples of U1387C and surface sediment samples of Rogerson et al. (2011; bottom).

between the average un-corrected $\delta^{18}O$ values of *C. lobatulus* and corrected ones of *U. celtica* results in the offset value for *C. lobatulus* applied in this study (Table 4).

For shelf dwellers, it is important to consider that variable environmental conditions (e.g. salinity, temperature) in shallow-water settings complicate the calculation of a reliable offset value, and scarce information on correction values is available. *A. beccarii* has been demonstrated to calcify enriched by + 0.29‰ in Cage and Austin (2008) with seasonal variability. However, in a study by Scourse et al. (2004) *A. batavus* has been considered to calcify in or close to equilibrium with seawater. This could be caused by a difference of $\delta^{18}O$ due to vital effects between either species or seasonality. In our dataset, *Ammonia* is close to equilibrium with the rest of taxa in the Portuguese shelf (Fig. 2-B3).

A correction factor of + 0.4‰ for *Nonion* has been adopted from Duplessy and Pujol (1980). This offset value is consistent with our data from the Guadiana and the shelf north of the Nazare Canyon areas.

In the case of *Elphidium*, *E. crispum* is the predominant species in the present study. No data are available for this specific species, but previous studies have evaluated several other *Elphidium* species. McCorkle et al. (1990) revealed a negative offset for $\delta^{18}O$ of *E. excavatum*. Lécuyer et al. (2012) suggested a negative $\delta^{18}O$ offset of − 0.7‰ for *Elphidium* sp. Other studies (Erlenkeuser and von Grafenstein, 1999; Polyak et al., 2003; Bauch et al., 2004) are focused on *Elphidium excavatum* forma *clavata* from the Laptev Sea and Arctic environments and reveal positive and negative offsets for that taxon that varies seasonally due to a vital effect. Therefore, local differences in temperatures and salinities between the Arctic and Gulf of Cadiz shelf areas may cause different isotopic disequilibria of *Elphidium* species in particular and/or shallow water taxa in general. Consequently, values and considerations indicated in these studies should not be directly comparable with our results. Thus, it is necessary to reconsider this value. The offset value for *E. crispum* has been calculated with respect to the $\delta^{18}O$ from *Ammonia* in the Pliocene Gulf of Cadiz data-set since their abundances are similar and the number of data-points is larger than the Recent data-sets (see Table 3). The difference between the average original (not corrected) $\delta^{18}O$ values of *E. crispum* and *Ammonia* spp. results in an offset value for *E. crispum* of + 0.52‰ in this study.

For some species, subsamples from different fractions (150–250 μm, > 250 μm) were analyzed (Table 3) in order to evaluate if ontogeny affects isotopic composition. Results reveal that the isotopic composition, while showing some scatter, does not show any systematic positive or negative offset between both fractions. Thus, potential variations on the isotopic signature due to ontogeny have been discarded.

5.2. Species-specific corrections of $\delta^{13}C$

In contrast to oxygen isotopes, little information was found in relation to the $\delta^{13}C$ offsets from isotopic equilibrium; available data was found only for *C. lobatulus* and *C. pachyderma* (Table 4). A positive offset of + 0.4‰ was estimated for $\delta^{13}C$ of *C. lobatulus* by Mackensen et al. (2000) and Wilfert et al. (2015) and also applied to our specimens (Table 4). *C. pachyderma* has been suggested to be offset from $\delta^{13}C_{DIC}$ (Dissolved Organic Carbon) and Voelker et al. (2015a) estimated this value in samples from IODP Site U1387, resulting in a positive deviation of + 0.3‰ that has been assumed in this study (Table 4).

5.3. Corrected isotopic values

Correcting the isotopic data results in a different arrangement of the isotopic composition of each taxon (Fig. 2-B; Table 3).

In the Pliocene Gulf of Cadiz, two groups of taxa can be distinguished. *C. pachyderma*, *Globobulimina* spp., *P. ariminensis*, and *U. pigmea* group together within a larger $\delta^{13}C$ gradient (− 2.03 to + 1.08‰; Fig. 2-B1, Table 3a) and narrower range of $\delta^{18}O$ (+ 0.59 to + 2.03‰). The second group comprises *Ammonia*, *Asterigerinata* spp., *C. lobatulus*, *C. refulgens*, *E. crispum*, and *N. fabum*, characterized by $\delta^{13}C$ values ranging from − 0.75 to + 0.79‰ and lighter $\delta^{18}O$ values with a comparably wider range of − 1.60 to + 0.69‰.

In the Recent data-set from the Guadiana shelf, all species show corrected values within a small range of $\delta^{18}O$ from + 0.85‰ to + 1.37‰, except *C. lobatulus* which shows a wider range (0.00‰ to + 1.28‰). *P. ariminensis* is considered to calcify in equilibrium with seawater and deeper settings in the Gulf of Cadiz at IODP Sites U1386, U1387 and U1389 (Table 2) verify it reflecting $\delta^{18}O$ values of + 1.03, + 1.05 and + 1.12‰ (average for each site in Table 3b, respectively), a bit lighter to the predicted $\delta^{18}O$ values for the area (+ 1.32, + 1.28 and + 1.21‰, respectively; table 2). Similarly, *C. laevigata* recorded in the Guadiana shelf at depths of 85, 80, 90 and 40 m values of + 1.28, + 1.30, + 1.29, and + 1.24‰, respectively (Table 3b), that match the corresponding + 1.28, + 1.28, + 1.28, and 1.16‰ predicted values (Fig. 2-B2; Table 2).

On the western Portugal shelf and margin, no distinct differentiation occurs between species, except for *C. pachyderma* (Estremadura promontory) which shows heavier $\delta^{13}C$ average composition (0.84‰) than the rest ($\delta^{13}C$: − 0.08‰; Fig. 2-B3; Table 3c). In the shelf samples from north of the Nazare Canyon, at 128 and 111 m, respectively, $\delta^{18}O$ values from *N. fabum* are + 1.13 and + 1.18‰, fitting the predicted values for this setting (+ 1.03 and + 1.18‰; Fig. 2-B3; Table 2). At the Western Iberian Margin slope (Estremadura promontory), heavier $\delta^{18}O$ values of *C. pachyderma* (+ 2.34, + 2.33 and + 2.43‰) are consistent with predicted $\delta^{18}O$ values (+ 1.70, + 2.12 and + 2.90‰; Fig. 2-B3; Table 2). The shelf-slope gradient on $\delta^{18}O$ is probably resulting from the different water masses affecting each sample location since it gets heavier with more NEADW influence (see Chapter 2.1; Table 2).

5.3.1. Microhabitat effect on $\delta^{13}C$

A distinct $\delta^{13}C$ gradient between epifaunal and infaunal foraminifers is well known (Corliss, 1985; McCorkle et al., 1990; Rathburn et al., 1996; McCorkle et al., 1997; Mackensen et al., 2000; Ravelo and Hillaire-Marcel, 2007). This microhabitat effect reflects the depletion of pore waters in $\delta^{13}C$ relative to seawater due to respiration of organic matter in the sediment and it is clearly reflected in all our data-sets. In the Pliocene samples from IODP Hole U1387C (Fig. 2-B1), the deep-water taxa *Globobulimina* spp., *U. pigmea*, *C. pachyderma*, and *P. ariminensis* display a wide range of 3.11‰ in their $\delta^{13}C$ values with a clear gradient along microhabitat preferences. Lightest $\delta^{13}C$ values of the deep-water taxa are recorded by the deep infaunal *Globobulimina*, while the elevated epifaunal *P. ariminensis* shows highest values. $\delta^{13}C$ values of the shallow infaunal *U. pigmea* and epifaunal *C. pachyderma* are intermediate between those two taxa, whereby the *C. pachyderma* $\delta^{13}C$ values from the Estremadura promontory in Recent samples from the western Iberian margin agree well with the seawater $\delta^{13}C_{DIC}$ values for that region (unpublished results). The characteristic gradient between epifaunal and infaunal species has been described frequently in studies on Recent foraminifera and support the reliability of our isotopic signal (Shackleton, 1974; Woodruff et al., 1980; Dunbar and Wefer, 1984; Zahn et al., 1986; Van der Zwaan and Jorissen, 1991; Sen Gupta and Machain-Castillo, 1993; Loubere, 1994; Jorissen et al., 1995; Loubere, 1996, 1997; Kaiho, 1999; Van der Zwaan et al., 1999; Schönfeld, 2001; Fontanier et al., 2006; Okazaki et al., 2016). A similar trend occurs between the deep-water taxa *Globobulimina* spp., *U. celtica* and *P. ariminensis* in the Recent samples from the deep Gulf of Cadiz (Fig. 2-B2).

Microhabitat effects can be observed in the shelf taxa as well (Fig. 2-B3). Probably due to its infaunal character with a more depleted $\delta^{13}C$ environment of *N. fabum* (Moodley, 1990; Fontanier et al., 2002; Hill et al., 2003; Duchemin et al., 2008; Mojtahid et al., 2010), they show the lightest $\delta^{13}C$ in contrast to the epifaunal *Elphidium* spp. and *Asterigerinata* spp. (Murray, 1991).

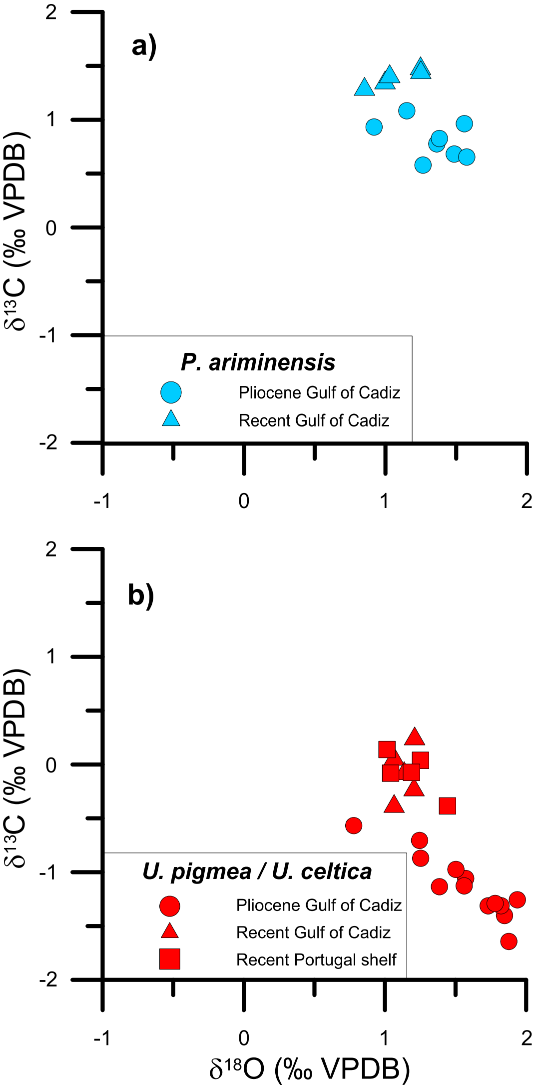

Fig. 4. Pliocene and Recent isotopic composition of a) *P. ariminensis* and b) *U. pigmea* (Pliocene) and *U. celtica* (Recent).

5.4. Applicability of the elevated epifauna as a proxy for bottom currents

5.4.1. Potential bias of downslope transport on abundances of elevated epifaunal foraminifera

Abundances of the elevated epifauna in the Gulf of Cadiz have been linked to MOW strength today and have been proposed as a proxy for the reconstruction of bottom current strength (Schönfeld, 1997, 2002a, 2002b). Of this group, only *C. lobatulus*, *C. refulgens* and *P. ariminensis* were present in lower Pliocene samples of IODP Site U1387C. García-Gallardo et al. (2017) have observed a positive correlation between maximum abundances of *C. lobatulus* and *C. refulgens*, shelf taxa and grain-size whereas no such correlation occurs with *P. ariminensis*. The positive correlation between the abundances of *C. lobatulus* and *Elphidium* spp. in IODP Hole U1387C ($R^2 = 0.85$; $p = 4.21 \times 10^{-24}$) is highlighted in Fig. 3. In contrast, no correlation occurs between *P. ariminensis* and *Elphidium* spp. ($R^2 = 8.65E\text{-}05$, $p = 0.95$). It is well known (and corroborated by our own samples from the Portuguese shelf) that *C. lobatulus* and *C. refulgens* show a broad bathymetric range with an upper depth limit extending into shelf areas < 100 m of the Atlantic and the Mediterranean Sea (Murray, 1973; Alexander and DeLaca, 1987; Polyak et al., 2003; Diz et al., 2004; Murray, 2006; Dorst and Schönfeld, 2013). In contrast, *P. ariminensis* is most commonly recorded at settling heights > 550 m (e.g., Schönfeld, 2002a, 2002b). García-Gallardo et al. (2017) thus concluded that in tectonically active settings such as the Gulf of Cadiz the applicability of the elevated epifauna proxy might be at times compromised by downslope transport. Ducassou et al. (2016) include *C. lobatulus* and *Elphidium* in the species group that indicates downslope transport from the shelf in the early Pleistocene sediments of nearby Site U1386. The trends observed in the Pliocene samples are further supported by a re-evaluation of quantitative data-sets of benthic foraminifera from core tops in the Gulf of Cadiz presented by Rogerson et al. (2011). Correlations obtained were positive (R^2: 0.70; p: 2.17×10^{-18}) for *C. lobatulus* – *Elphidium* spp. and non-existent ($R^2 = 0.03$; $p = 0.17$) for *P. ariminensis* – *Elphidium* spp. (Fig. 3).

On the basis of corrected δ^{13}C and δ^{18}O data, the isotopic signal of the elevated epifauna present in our samples can now be assessed in order to identify their provenance in either shallow or deep waters in the Pliocene and Recent Gulf of Cadiz.

5.4.2. Pliocene - Gulf of Cadiz

In the Pliocene samples, δ^{18}O values show a clear gradient between shelf (lighter δ^{18}O: − 1.60 to + 0.69‰) and deep-water taxa (heavier δ^{18}O: + 0.59 to + 2.03‰). We interpret this gradient as a substantial difference in temperature between warmer waters (lighter $\delta^{18}O_c$) on the shelf and colder waters (heavier $\delta^{18}O_c$) on the slope. While salinity may affect the δ^{18}O signal to some degree, the large gradient nonetheless suggests a primary control of temperature (Voelker et al., 2015a).

In this setting, the corrected isotope values of *C. lobatulus* (mean δ^{13}C: + 0.05‰, mean δ^{18}O: − 0.21‰) and *C. refulgens* (δ^{13}C: + 0.71‰, δ^{18}O: − 0.03‰) range well within those of the shelf dwellers *Ammonia* spp. (mean δ^{13}C: − 0.36‰, mean δ^{18}O: − 0.07‰), *E. crispum* (mean δ^{13}C: + 0.38‰, mean δ^{18}O: − 0.07‰), *N. fabum* (δ^{13}C: − 0.75‰, δ^{18}O: − 0.06‰), and *Asterigerinata* spp. (mean δ^{13}C: + 0.03‰, mean δ^{18}O: − 0.80‰). The evidence thus strongly supports the allochthonous nature of *C. lobatulus* and *C. refulgens* hypothesized by García-Gallardo et al. (2017). It is reasonable to assume that large amounts of tests of these two species have been transported from the shelf during periods of downslope transport. In contrast, the isotopic signal of *P. ariminensis* (mean δ^{13}C: + 0.81‰, mean δ^{18}O: + 1.34‰) appears within the range of deep-water taxa δ^{18}O, showing values only slightly higher than those of *C. pachyderma* (mean δ^{13}C: + 0.04‰, mean δ^{18}O: + 1.18‰; see Fig. 2-B1). The data spread observed for deep-water taxa is best explained by calcification during different glacial and interglacial stages covered by our data-set (Van der Schee et al., 2016; García-Gallardo et al., 2017). Notably, the clear separation between δ^{18}O values of shelf and deep-water taxa is evident in spite of the data spread (Fig. 2-B1). For this reason, *P. ariminensis* is interpreted as an autochthonous deep-water taxon in this setting and remains the only component of the elevated epifauna at this site useful as a possible indicator of enhanced bottom current strength related to Mediterranean-derived waters in the early Pliocene Gulf of Cadiz.

5.4.3. Recent - Gulf of Cadiz

The δ^{18}O gradient observed for the Pliocene samples is not apparent in the present-day samples from IODP Sites U1386, U1387 and U1389 from the Gulf of Cadiz. Shelf dwellers *Elphidium*, *Ammonia* and *Asterigerinata* were absent or too scarce to obtain reliable data in the recent samples from the Gulf of Cadiz. Instead, *N. fabum* and *C. laevigata* from the Guadiana shelf have been used (Table 1). *N. fabum* is considered intermediate infaunal and associated with eutrophic environments and high organic matter of low quality from terrestrial runoff (Fontanier et al., 2002; Duchemin et al., 2008; Mojtahid et al., 2010; Pérez-Asensio and Aguirre, 2010; Pérez-Asensio et al., 2012). *C. laevigata* is a shallow infaunal taxon living under high supply of organic matter frequent in muddy sediments off the Guadiana River and found in samples until 2520 m depth (Corliss, 1991; de Rijk et al., 2000;

Mendes et al., 2004, 2012a; Pérez-Asensio et al., 2012). Although this taxon is commonly considered a deep dweller, in this case it occurs in our recent samples from the Guadiana shelf as a response to high silt and clay content and increased nutrient availability due to upwelling processes (Mendes et al., 2012a, 2013). For this reason, the isotopic composition of both species would be expected to reflect lower $\delta^{18}O$ than the deep-water taxa. However, the isotopic signature is similar to that of the deep-water taxa (Fig. 2-B2) as it is measured in the Gulf of Cadiz, showing that temperature and salinity values are indistinguishable between the Guadiana shelf and the IODP Sites (Table 2). From these deductions, Fig. 2-B2 thus shows the differential $\delta^{13}C$ signature likely due to microhabitat and carbon flux on the shelf reflected by the shelf taxa.

The elevated epifaunal elements *C. lobatulus* and *P. ariminensis* were also evaluated within this context. The assessment of $\delta^{18}O$ signals of *C. lobatulus* is complicated in this case. In Fig. 4b, *C. lobatulus* from U1386 and U1387 shows slightly heavier $\delta^{13}C$ (0.31‰) and lower $\delta^{18}O$ (0.44‰ in average) than specimens from U1389 (0.21‰ and 0.84‰, respectively; see Table 3b), which have similar values to the infaunal *U. celtica* and fit well into the narrow range of $\delta^{18}O$ in which deep taxa appear. At first glance, those samples showing lighter $\delta^{18}O$ may be interpreted to reflect higher temperatures due to their origin in shelf areas and have been later transported, such as in the Pliocene setting. However, this idea is not consistent since shelf taxa (e.g. *Elphidium* spp., *Ammonia* spp., *Asterigerinata* spp.) are absent in samples from U1386 and U1387, and most importantly, there is no $\delta^{18}O$ gradient observed. If the isotopic values of *C. lobatulus* are not related to a transport from the shelf, one possible explanation could be the differential position of the upper and lower plumes of MOW. IODP Site U1389, affected by lower MOW is 80–90 m deeper than Sites U1386 and U1387, within upper MOW (Table 1). Considering that Sites U1386 and U1387 are affected by the upper MOW plume while U1389 by the lower MOW plume (Stow et al., 2013), they may reflect different isotopic composition. However, hydrographic measurements (Table 2) show similar $\delta^{18}O$ composition for all sites (U1386: 0.84‰, U1387: 0.8‰ and U1389: 0.8‰ VSMOW). A third explanation for these lower $\delta^{18}O$ values of *C. lobatulus* is their possible transport from upper parts of the slope, which would be affected by NACW that has a similar $\delta^{18}O$ composition (~0.5‰, Voelker et al., 2015b). Nevertheless, in our records, the isotopic composition of *C. lobatulus* is closer to the $\delta^{18}O$ composition of the deep-water taxa and predicted $\delta^{18}O$. With respect to $\delta^{13}C$, *C. lobatulus* appears closer to those from the deep-water *U. celtica* instead of the shelf infaunal taxon *C. laevigata*, which appears $\delta^{13}C$ depleted by 1‰ with respect to *U. celtica*. For these reasons, we tempt to state that the isotopic composition of this taxon is responding to MOW influence in the present day in the Gulf of Cadiz, according to Schönfeld (1997, 2002a, 2002b). Finally, the spread of $\delta^{18}O$ values could result from time averaging (i.e. the samples integrate variations of MOW, probably on seasonal to decadal scales) and/or the location in relation to their position within MOW. In any case, the $\delta^{18}O$ data for *C. lobatulus* together with its correlation to shelf taxa (Fig. 3) in the Gulf of Cadiz warrant for caution in general.

P. ariminensis is spatially restricted to the northern Gulf of Cadiz under the influence of strong MOW (Rogerson et al., 2011). It has been previously observed that *P. ariminensis* prefers elevated positions above the sediment surface having the opportunity to catch suspended food particles from enhanced current systems (Altenbach et al., 1987; Lutze and Thiel, 1989; Linke and Lutze, 1993). Our results are accordingly explained by this feature. In addition, this taxon, calcifying in equilibrium with seawater, shows average $\delta^{18}O$ values close to the MOW $\delta^{18}O$ composition (Table 2). For these reasons, we conclude that *P. ariminensis* is the most reliable taxon that can be used as proxy for MOW reconstruction in the Gulf of Cadiz, always under a cautious analysis of the settings.

5.5. *Implications for early Mediterranean-Atlantic exchange*

Present-day hydrographic parameters (bottom-water temperature, salinity, $\delta^{18}O_{sw}$ (VSMOW)) were accessible for the locations and water depths used in this study (see Chapter 3.5.; Table 2). Obtaining those parameters is not directly possible in the Pliocene setting, but they can be inferred from the isotopic composition of foraminiferal calcite. The good correspondence between $\delta^{18}O_{sw}$ (VSMOW) and predicted $\delta^{18}O_{C}$ (VPDB), as well as the differential $\delta^{18}O$ in the western Portugal shelf-slope due to influences of different water masses (e.g. MOW-NEADW) has been demonstrated in Chapter 3.5. This means that $\delta^{18}O_{C}$ from autochthonous taxa from the Pliocene samples probably provide reasonable estimates of the hydrographic parameters in the Pliocene. Following this assumption, the difference between shelf and deep-water $\delta^{18}O$ is on average +1.62‰ in the Pliocene Gulf of Cadiz, contrasting rather uniform $\delta^{18}O$ values of the present-day water column (Fig. 2-A2). A larger difference in the $\delta^{18}O$ values from the early Pliocene might reflect a larger temperature offset, suggesting that either deep waters in the Gulf of Cadiz were colder and thus not influenced by warm Mediterranean water, or that Pliocene surface waters were warmer by several degrees (Tzanova and Herbert, 2015).

Pliocene and Recent $\delta^{18}O_{c}$ from *P. ariminensis* and *U. pigmea*/*U. celtica* have been compared separately (Fig. 4) in order to figure out water temperature differences between the Pliocene and the present-day and possible influence of MOW. *P. ariminensis* values from the Pliocene and the present-day samples in the Gulf of Cadiz are displayed in Fig. 4a. We consider this elevated epifaunal species autochthonous to deeper settings. Higher $\delta^{18}O$ and lower $\delta^{13}C$ suggest a colder and lesser ventilated environment in the early Pliocene (mean $\delta^{13}C$: +0.81‰, mean $\delta^{18}O$: +1.34‰), indicating a major influence of the colder Atlantic water and a eutrophic environment in the early Pliocene Gulf of Cadiz (García-Gallardo et al., 2017). Today there is a shift toward warmer and better ventilated waters likely due to the influence of MOW (mean $\delta^{13}C$: +1.39‰, mean $\delta^{18}O$: +1.08‰). A similar trend can be observed for *Uvigerina* (Fig. 4b). *U. celtica* values from the present-day Mudline samples from the Gulf of Cadiz (mean $\delta^{13}C$: −0.09‰, mean $\delta^{18}O$: +1.14‰) are higher in $\delta^{13}C$ and lower in $\delta^{18}O$ than *U. pigmea* in the Pliocene deep Gulf of Cadiz samples (mean $\delta^{13}C$: −1.13‰, mean $\delta^{18}O$: +1.56‰). However, since *Uvigerina* is considered a shallow infaunal taxon, differences in the carbon isotope composition are affected by the microhabitat effect and should be treated with caution (Zahn et al., 1986).

In summary, the isotopic data together with diminished occurrences of *P. ariminensis* (García-Gallardo et al., 2017) suggest the presence of relatively cold and poorly ventilated bottom waters and reduced bottom current strength in the early Pliocene compared to today. This water mass was likely primarily sourced from the Atlantic; if and to which degree Mediterranean-sourced waters might have contributed cannot be determined from our data.

6. Conclusions

The elevated epifauna, which has been suggested as proxy for MOW reconstruction, has been re-assessed in this study using stable isotopes ($\delta^{13}C$, $\delta^{18}O$). Species-specific offset values have been determined in Pliocene and Recent samples and contrasted with recent hydrographic data. After correction, results show good correspondence between Recent foraminiferal $\delta^{18}O$ and seawater $\delta^{18}O$.

Corrected isotopic values reveal that *C. lobatulus* and *C. refulgens* in the Pliocene slope of the Gulf of Cadiz have been transported from the shelf to greater depths, thus they do not provide suitable indicators of the first Mediterranean Outflow. Isotope data from Recent samples from the Gulf of Cadiz and the western Portugal shelf have also demonstrated that *C. lobatulus* can either inhabit shelf and deep environments. The results warrant for caution when *C. lobatulus* is intended to be used as proxy for strong bottom current, and samples should be checked carefully for the presence of other allochthonous taxa. In contrast, *P. ariminensis* is shown to be autochthonous to deeper settings in the Pliocene and the present day, resulting in a more reliable proxy for bottom current reconstruction.

In addition, past and present $\delta^{18}O$ and $\delta^{13}C$ of *P. ariminensis* and *U. pigmea* suggest that intermediate waters in the Gulf of Cadiz were colder and less ventilated in the early Pliocene. This likely reflects considerable admixture of Atlantic waters and diminished influence of Mediterranean water at IODP Site U1387 just after the opening of the Strait of Gibraltar compared to today.

Taxonomic references

Ammonia beccarii forma *parkinsoniana* (d'Orbigny, 1839). Walton and Sloan (1990). Plate I, Figs. 5, 6; Plate II, Figs. 1, 3.

Ammonia falsobeccarii (Rouvillois, 1974). Jones and Brady (1994). Plate 107, Fig. 5.

Cassidulina laevigata (d'Orbigny, 1826). Murray (2003). Pag. 21. Figs. 6.8–6.10.

Cibicides lobatulus (Walker and Jakob, 1798). Jones and Brady (1994). Plate 93, Figs. 1, 4, 5.

Cibicides refulgens (de Monfort, 1808). Holbourn et al. (2013). Pag. 154, Figs. 1-3.

Cibicidoides pachyderma (Rzehak, 1886). Holbourn et al. (2013). Pag 198. Figs. 1-3.

Elphidium crispum (Linnaeus, 1758). Holbourn et al. (2013), Pag. 236, Figs. 1-3.

Nonion fabum (Fichtel and Moll, 1798). Jones and Brady (1994). Plate 109, Figs. 12, 13.

Planulina ariminensis (d'Orbigny, 1826). Holbourn et al. (2013). Pag. 402, Figs. 1, 2.

Praeglobobulimina ovata (d'Orbigny, 1846). Jones and Brady (1994). Plate 50 Fig. 13.

Uvigerina celtica (Schönfeld, 2006). Schönfeld (2006). Plate 1, Fig. 14–18.

Uvigerina pigmea (d'Orbigny, 1826). Schönfeld (2006). Plate 1, Figs. 6–11.

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