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Distribution of recent benthic foraminifera in shelf carbonate environments of the Western Mediterranean Sea

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ABSTRACT

The distribution of recent shallow-water benthic foraminifera in surface sediment samples from cool-water carbonate environments of the Oran Bight, Alboran Platform and Mallorca Shelf in the Western Mediterranean Sea was studied. Multivariate statistical analyses resulted in the identification of species assemblages, representing different environmental settings. In all three regions the assemblages show a distinct bathymetric zonation that is mainly attributed to the distribution of rhodoliths and related substrates, but also to water turbulence and the availability of food at the sea floor. The live assemblages (Rose Bengal stained individuals) are characterised by rather low diversity and low standing stocks, likely reflecting seasonal population dynamics. In the Oran Bight, elevated standing stocks of "high food"-taxa suggest the impact of anthropogenic eutrophication on the near-coastal benthic ecosystems of this area. The diversity of the dead assemblages is higher than in siliclastic shelf ecosystems of the Mediterranean Sea but lower when compared to carbonate environments of the Levantine Sea. This regional difference is mainly attributed to lower sea surface temperatures and the lack of Lessepsian invaders in the western Mediterranean Sea. In all study areas, a distinct faunal change occurs between approximately 80–90 m water depth. This change coincides with the lower distribution limit of living rhodoliths at the shelf of Mallorca, providing coarse-grained substrates that are dominated by attached taxa. Below this depth interval, the fauna shows regional differences depending on the grain-size and related accumulation of organic material. Fine-grained substrates with infaunal niches are restricted to low-energy environments on the deeper shelf southwest off Mallorca.

1. Introduction

Benthic foraminifera are widely used in ecological and paleoceanographic studies of various marine environments. In deep-sea benthic ecosystems, diversity, species composition and microhabitat preferences of benthic foraminifera basically reflect food and oxygen availability at the sea floor and in the upper surface sediment (e.g., Corliss, 1985; Jorissen et al., 1995; Van der Zwaan et al., 1999; De Rijk et al., 2000). Similar adaptations are observed in shelf ecosystems with fine-grained substrates (Jorissen et al., 1992; Mojtahid et al., 2009). However, shallow-water (littoral and neritic) habitats can be additionally influenced by gradients in light, temperature, salinity, substrate, as well as velocity and turbulence of surface waters currents (Culver et al., 1996; Sen Gupta, 1999). These faunas commonly exhibit high foraminiferal numbers, variable diversity and a dominance of epifaunal and shallow infaunal taxa (e.g. Semeniuk, 2000; Murray, 2006). Particularly, many shallow-water taxa depend on the hydrodynamic energy at the benthic boundary layer and the corresponding substrate on the sea floor. The response of these taxa to oceanographic, trophic and sedimentological parameters is reflected by a stenobathyal distribution pattern.

In the Mediterranean Sea, the distribution of shelf foraminifera is documented in various regional studies (e.g., Jorissen, 1987; Cimerman and Langer, 1991; Sgarrella and Moncharmont Zei, 1993; Mojtahid et al., 2009). These studies revealed significant spatial contrasts in the composition of shelf faunas. In fine-grained sediments of the Adriatic Sea and the Gulf of Lions, the faunas show a distinct microhabitat zonation, depending on food availability and oxygen penetration into the sediment (Barmawidjaja et al., 1992; Jorissen et al., 1992; Schmiedl et al., 2000). In other regions, a strong correlation is observed between

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the diversity and abundance of symbiont-bearing shallow-water foraminifera and water column illumination (Langer et al., 1998). In addition, near-coastal marine ecosystems can be affected by anthropogenic impacts. In this context, Frontalini and Coccioni (2008) and Romano et al. (2008) describe the influence of heavy metal pollution on shallow-water foraminifera on the Adriatic Sea coast and the coastal area of Bagnoli (Naples, Italy). The faunas of these areas contained a higher incidence of test deformations and a higher abundance of pollutant-tolerant species. Recently, the eastern Mediterranean shallow-water ecosystems have been invaded by various taxa from the Red Sea through the Suez Channel (Langer and Hottinger, 2000; Hyams et al., 2002; Hyams-Kaphzan et al., 2008). The number of the so-called Lessepsian invaders is still under debate, since data on the biogeography, diversity and ecology of autochthonous shallow-water faunas from various carbonate environments of the Mediterranean Sea are limited.

In the present study, the diversity, species distribution and ecology of shelf benthic foraminifera in various cool-water carbonate environments of the Western Mediterranean Sea was investigated. A variety of multivariate analyses (Principal Component Analysis, Detrended Correspondence Analysis, and Redundancy Analysis) was applied in order to identify various assemblages and their links to different environmental parameters. In ecological studies, multivariate statistical methods are widely used to characterise community structures and to quantify the relationship between communities and environmental parameters (for summary see Ramette, 2007). Among the different methods, Principal Component Analysis and Cluster Analysis are commonly used in foraminiferal research to quantify the community structure of foraminiferal faunas (e.g. Schmiedl et al., 1997; Schönfeld, 2002; Mendes et al., 2004; Kuhnt et al., 2007). With other multivariate analyses such as Redundancy Analysis or Canonical Correspondence Analysis, faunal data can be directly related to environmental data allowing a more comprehensive analysis of foraminiferal ecology.

To date relatively little is known about the foraminiferal assemblages living in cool-water carbonate environments (Murray, 2006). Therefore, our study is designed to add new information on the diversity, distribution patterns and ecology of the recent Western Mediterranean cool-water carbonate taxa. The established relations between benthic foraminiferal faunas and environmental parameters can provide a basis for reconstructions of past environmental changes, including quantitative sea-level reconstructions.

2. Study area

The Mediterranean Sea is a semi-enclosed basin between Europe in the north and Africa in the south and can be divided into two nearly equal-sized basins (Western Mediterranean and Eastern Mediterranean basins) connected by the Strait of Sicily (Robinson et al., 2001).

The history of the Western Mediterranean basin dates back to the late Oligocene and its present-day configuration was achieved during the early Pliocene (Comas et al., 1999). It consists of the Alboran-, Valencia-, Provencal-, Algeria- and Tyrrhenian sub basins. The Mediterranean Sea is characterised by four main water masses. The surface waters consist of inflowing Atlantic Water (AW) (e.g. Robinson et al., 2001; Masque et al., 2003; Rixen et al., 2005). At intermediate depths the Levantine Intermediate Water is present, which is formed in the eastern Mediterranean Sea (Robinson et al., 2001; Rixen et al., 2005). Below 600 m water depth, the basins are bathed by Western Mediterranean Deep Water formed in the Gulf of Lions, and by Eastern Mediterranean Deep Water formed in the Adriatic and Aegean seas (Robinson et al., 2001; Rixen et al., 2005).

In the Alboran Basin, the AW forms two anticyclonic gyres: the Western Alboran Gyre (WAG) and the Eastern Alboran Gyre (EAG). Surface water velocities on the Alboran Platform are relatively high, e.g. WAG velocities in October 1996 ranged between 124 and 140 cm/s (Velez-Belchi et al., 2005). In contrast, surface water velocities southwest off Mallorca are generally lower, ranging between <15 cm/s and a maximum of 50 cm/s during storm events (Werner et al., 1993). Associated with the Alboran gyres are zones of enhanced vertical mixing and nutrient entrainment, including the Almeria-Oran-Front. This front is marked by higher levels of primary production when compared to other open-ocean areas of the Western Mediterranean Sea (L'Helguen et al., 2002; Masque et al., 2003; Velez-Belchi et al., 2005). In the Alboran basin, the annual primary production ranges between 150 and >250 gC/m^2 and year, whereas the Balearic region, with estimated annual values of 100 to 150 gC/m^2, has a more oligotrophic character than the Alboran region (Antoine et al., 1995).

In the Western Mediterranean Sea cool-water carbonates form in areas protected from major siliciclastic input. A first comprehensive report of such carbonates was a significant part of the seminal work of Pérès and Picard (1964). Later publications corroborated and expanded these facies concepts (for example Blanc, 1972; Caulet, 1972; Fornos and Ahr, 1997; Ros et al., 1984; Carannante et al., 1988a,1988b; Fornos and Ahr, 2006). The shallow subtidal facies zone (inner ramp) is dominated by *Posidonia* meadows with bioclastic sand patches down to 40 m of water depth. The middle ramp facies are dominated by coarse sediments with branching and foliose red algae, neighbouring rhodoliths may coalesce and generate a rigid coralline algal framework (corraligène de plateau) (Basso, 1997). At water depths below 90 m, muddy sands with a mixed biotic content occur.

3. Materials and methods

For the present study, 47 surface sediment samples were collected during Meteor cruise 69/1 in August 2006 from the Alboran Platform (14 samples), the Oran Bight (19 samples) and southwestern off Mallorca (14 samples) using a grab or box corer (Fig. 1, Table 1). The application of a multicorer for sampling of the sediment–water interface was not possible because of the generally coarse-grained sediments. Samples 341, 342 and 343 from the Alboran Platform were taken from the top of sediment cores drilled with a vibrocorer. The sampling depth ranges between 20 m and 235 m. After retrieval, the upper 1 to 2 cm of surface sediment was preserved in a Rose Bengal solution (1.0–1.5 g Rose Bengal per litre 96%-ethanol) to separate living (Rose Bengal stained) from unstained individuals except for core-top samples 341, 342 and 343. All samples were wet-sieved over a 63 µm sieve and the sample volumes were calculated. The fraction > 63 µm was dried at 40 °C.

For determination of the grain-size distribution, samples were wet-sieved and the weight percentages of the >1000 µm, 1000–500 µm, 500–200 µm, 200–100 µm, 100–63 µm and <63 µm fraction were calculated (supplementary data A). Sea surface temperature and salinity data were measured during Meteor cruise 69/1 (supplementary data A). As a proxy for regional primary productivity values, annual averages for chlorophyll concentration in surface waters were extracted from the NASA SeaWiFS database (Feldman and McClain, 2006) (supplementary data A).

For counting of foraminifera, all samples were split into two equal aliquots in order to generate sub-samples with 300 to a maximum of 1000 individuals. The sub-samples were dry-sieved over a 125-µm sieve. From the > 125 µm fraction, all stained and non-stained benthic foraminifera, and all planktonic foraminifera were picked and counted (supplementary data B and C). Only monothalamous tests with a clear pink staining and multichambered tests with more than one completely pink-stained chamber were considered as “living”. For an accurate identification of living miliolids and agglutinated specimens, the tests were moistened with water. The identification of the benthic foraminiferal taxa was mainly based on the publications of Cimerman and Langer (1991), Sgarrella and Moncharmont Zei (1993) and Jones (1994). From most of the taxa, SEM pictures were taken with a Zeiss Leo VP 1455 in order to provide a solid taxonomic base for western Mediterranean benthic foraminifera from shallow-water carbonate environments (Pl. 1–Pl. 4, supplementary data D). Test fragments