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Living, dead and fossil benthic foraminifera on a river dominated shelf (northern Gulf of Cadiz) and their use for paleoenvironmental reconstruction

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ABSTRACT

Same-area comparison between patterns of Recent (living) and Holocene benthic foraminiferal assemblage composition is essential to validate their utility as proxies for paleoenvironmental reconstructions. Such reconstructions have scarcely been attempted in shelf environments. In this study, we compared living (stained), dead and Holocene benthic foraminiferal assemblages from the Gulf of Cadiz continental shelf off the Guadiana River. On average, 99% of the living benthic foraminiferal species were preserved in the dead assemblage and 95% in the fossil record. Several common species were assessed as indicators for certain environmental factors, including river discharge, supply of terrestrial organic matter, heavy metal concentrations, oxygen levels, substrate properties, hydrodynamic energy levels, sea-level rise and human impact. The paleoenvironmental reconstruction depicted five stages of Holocene environmental evolution of the Guadiana shelf over the last 11,500 cal yr BP. The characteristics of the stages, and the transitions between them, were in particular driven by changes in sea-level, influx of terrestrial organic matter and limits of productivity.

1. Introduction

The distribution of benthic foraminifera in both, modern and ancient sediments have provided the basis for numerous studies documenting environmental changes over a large range of temporal and spatial scales. In particular, living benthic foraminifera have been used for ecological studies and to monitor modern-day environmental changes in shelf environments (e.g. Schmiedl et al., 1997; de Stigter et al., 1998; de Rijk et al., 2000; Fontanier et al.; 2002; Samir et al., 2003; Duijnstee et al., 2004; Duchemin et al., 2005, 2007; de Nooijer et al., 2008; Milker et al., 2009; Mojtahid et al., 2009; Goineau et al., 2011, 2012). Fossil assemblages have been studied to reconstruct palaeoecological and palaeoceanographic conditions (e.g. Jiang et al., 1997; Evans et al., 2002; Oldfield et al., 2003; Abrantes et al., 2005; Morigi et al., 2005; Bartels-Jónsdóttir et al., 2006; Eiríksson et al., 2006; Martins et al., 2006; Rüggeberg et al., 2007, Rossi and Vaiani, 2008). However, any straightforward interpretation of the fossil record depends largely on the comparison with the modern faunas and their ecological relationships in a particular area (e.g. Schönfeld and Zahn, 2000; Schönfeld and Altenbach, 2005; Murray, 2006).

Various studies have focused on the comparison between living and dead foraminiferal assemblages. There are often profound differences between the composition of the living fauna and dead assemblage in surface sediments from the same sampling sites (e.g. Alve and Murray, 1997; de Stigter et al., 1999; Horton and Murray, 2006; Diz and Francés, 2009; Duros et al., 2012). The composition of the dead assemblage is mainly controlled by taphonomic processes, with several stages of transition that include live and *post-mortem* processes as well as diagenetic effects (Murray, 1976, 2006; Martin et al., 1995). Live processes affect the delivery of empty tests to the sediment by the living fauna, which depends on species-specific reproduction rates, turnover times, and population densities (e.g. Murray, 1976; de Stigter et al., 1999; Jorissen and Wittling, 1999; Gooday and Hughes, 2002). *Post-mortem* processes alter the proportions of tests from different species in the sediment over time. These processes include destruction, in particular disintegration of agglutinated, corrosion and dissolution of calcareous tests, their redeposition, bioturbational mixing and time-averaging (e.g. Culver et al., 1996; Alve and Murray, 1997; Wang and Chappell, 2001; Murray and Pudsey, 2004; Diz and Francés, 2009). Diagenetic effects may further alter the faunal composition beneath the taphonomically active zone (TAZ) in which the material is effectively

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fossilised (Schröder, 1988). Therefore, the final preservation of foraminiferal tests in the sedimentary record depends on a number of factors, such as microhabitat, biogeochemical sediment conditions and test composition (Walker and Goldstein, 1999).

The distribution of living and dead foraminifera in near-surface sediments reveal that the upper 10 cm comprise the most important taphonomically active zone for foraminifera in oxic environments (Walker and Goldstein, 1999). So long as the effects of taphonomic processes are taken into account, it is possible to make palaeoecological interpretations of fossil assemblages (Murray, 2006). Almost all mid-Pleistocene and younger species have living representatives that may serve as analogues for interpretations of fossil assemblages (Kucera and Schönfeld, 2007). Nevertheless, there are fossil associations of species that were not found in modern environments (e.g. Schönfeld and Altenbach, 2005). The existence of such non-analogue assemblages is related to climatic factors, most importantly variations between humid and dry climatic conditions and glacio-eustatic sea-level changes (Murray, 2006). They may also be the product of selective dissolution (Murray and Alve, 2011).

On the northern Gulf of Cadiz continental shelf (SW Iberian Peninsula), several studies have been made to investigate the distribution patterns of total (living+dead) benthic foraminiferal assemblages (e.g. Galhano, 1963; Ubaldo and Otero, 1978; Levy et al., 1993, 1995; Villanueva, 2000, 2001; Villanueva and Canudo, 1998, 1999, 2008; Villanueva and Cervera, 1998, 1999; Villanueva et al., 1999a, 1999b; González-Regalado et al., 2001; Mendes et al., 2004). Distribution and ecology of the living benthic foraminiferal faunas were also described recently (Mendes et al., 2012a). In contrast, there are only a very few studies that have described the Holocene benthic foraminiferal assemblages in this area (Mendes et al., 2010, 2012b). Furthermore, the comparison between living, dead and fossil benthic foraminiferal assemblages at the same area, which is essential for validating benthic foraminiferal proxies for environmental conditions, is generally scarce in shelf environments and has never been done for the Gulf of Cadiz. Therefore, the aims of the present study are: (a) to evaluate taphonomic effects; (b) to validate the paleoenvironmental significance of benthic foraminifera; and (c) to make a Holocene reconstruction of the Guadiana Shelf environment. For the above purposes, the most abundant living benthic foraminiferal species (> 5%), previously described by Mendes et al. (2012a), were compared with dead assemblages from six selected surface samples near core locations and fossil assemblages from sediment cores. The sediment cores were collected on a middle shelf mud body; an upper middle shelf transgressive prograding terrace; and an inner shelf prodeltaic wedge off the Guadiana River. The most abundant species in sediment cores were previously described by Mendes et al. (2012b).

2. Regional setting

2.1. Present-day sedimentation processes

The study area is located on the northern Gulf of Cadiz continental shelf and receives the discharges of the Guadiana River, which is one of the main regional sediment sources (Fig. 1). This area is characterised by a Mediterranean climate, with hot, dry summers and mild winters. This pattern produces severe droughts and episodic floods in the river basin. For example, monthly mean river discharges recorded at Pulo do Lobo (approximately 50 km upstream from the river mouth), ranged from $< 10\ m^3\ s^{-1}$ to $4660\ m^3\ s^{-1}$ for the period 1947–2001 (Garel et al., 2009). As a consequence, the run-off from the Guadiana River catchment is subject to high seasonal and inter-annual variability. In addition, the area is subject to the influence of larger-scale annual and decadal climatic signals such as the North Atlantic Oscillation (NAO), exerting a severe influence on rainfall and river discharge (e.g. Dias et al., 2004; Trigo et al., 2004). These major variations in climatic conditions can result in episodic floods that play a major role in the sediment supply to the shelf (Morales, 1997; Portela, 2006). The floods also increase the input of suspended particulate matter and dissolved nutrients (nitrate, phosphate, and silicate), however, their major influence is close to the Guadiana River mouth (Cravo et al., 2006). The sediment and energy inputs from land and tidally-driven processes, also contribute to an increased productivity in this area (e.g. Navarro and Ruiz, 2006; García-Lafuente and Ruiz 2007; Prieto et al., 2009). The study area is furthermore influenced by local seasonal upwelling enhanced under westerly winds (e.g. Vargas et al., 2003; García-Lafuente and Ruiz 2007), which is more likely a coastal process with a short time response to changes in wind regime (Criado-Aldeanueva et al., 2006). However, upwelling events could induce new primary production resulting from the vertical advection of nitrate-rich sub-thermocline waters (Ruiz and Navarro, 2006; Fig. 1).

Sandy deposits dominate the modern surficial sediment distribution on the inner shelf down to a water depth of approximately 25 m (Moita, 1985; Fernández Salas et al., 1999; Nelson et al., 1999; Gonzalez et al., 2004, 2007; Rosa et al., 2013). These deposits are interrupted by a prodeltaic wedge, consisting of sandy

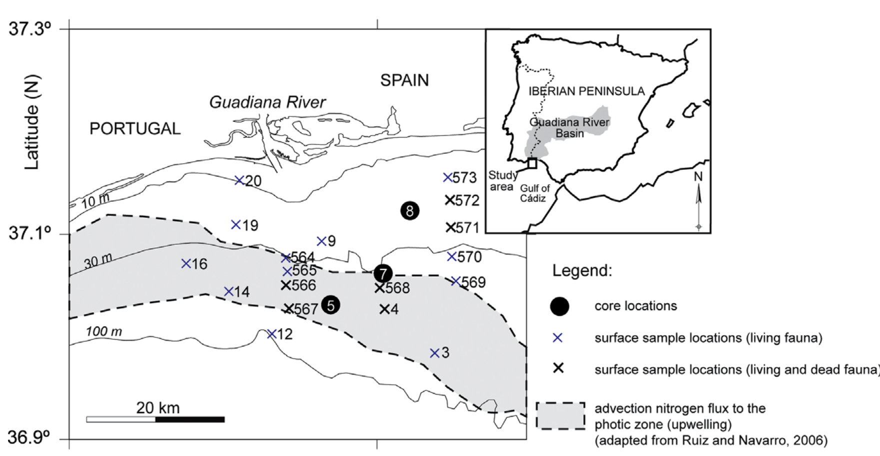

Fig. 1. Location of the surface samples analysed for living and dead faunas and sediment cores on the continental shelf off the Guadiana River. The grey area delineated by the dashed line indicates nitrogen flux to the photic zone (adapted from Ruiz and Navarro, 2006).