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Research paper

Coccoliths from recent sediments of the central Portuguese margin: Taphonomical and ecological inferences

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ABSTRACT

In this study we describe recent coccolith assemblages from surface sediments of the central Portuguese continental margin. By investigating variation in coccolith concentrations and relative abundances along north–south and onshore–offshore gradients and between submarine canyons and open shelf and slope areas, and by correlation of coccolith distribution with sediment characteristics (sediment bulk composition and particle-size, C_{org}/N_{tot} and sediment accumulation rate), we assess to what extent (paleo)ecological information can be distinguished from taphonomical effects (dissolution and mechanical destruction, lateral transport and dilution with terrigenous material).

The main finding of this study is that original distribution patterns reported for living coccolithophores from the Portuguese margin surface waters are reflected by patterns in relative abundances of coccoliths in the underlying sediment, despite the vigorous current dynamics and active sediment transport on the shelf and in the canyons. Like in the surface water assemblages, *Gephyrocapsa oceanica*, *Coronosphaera mediterranea*, *Helicosphaera carteri* and *Coccolithus pelagicus* are more prevalent in sediments of the continental shelf and upper canyon reaches, whereas *Gephyrocapsa muellerae*, *Calcidiscus leptoporus* and the group comprising *Umbilicosphaera sibogae*, *Umbellosphaera irregularis* and *Rhabdosphaera* spp. have higher relative abundances in sediments of the open slope. Greater abundance of the coastal assemblage in sediments of the upper Nazaré Canyon appears associated with persistent high productivity driven by amplification of coastal upwelling and internal tidal pumping in the canyon head and the shelf area south of it. Enrichment of oceanic species in the upper reaches of both the Nazaré and Lisbon–Setúbal Canyon, compared with adjacent shelf areas, suggests displacement of oceanic coccolithophores in oceanic surface water masses advected coastwards along the canyon axes.

While coccolith relative abundances in the sediment thus seem to reflect original distribution patterns, precluding major post-mortem redistribution of coccoliths, we found a distinct inverse relationship between coccolith concentration and sediment particle size, suggesting that sedimentary processes control the accumulation of coccoliths in the sediment. We propose a taphonomy-driven scenario, in which coccolith preservation is favored by rapid incorporation in the sediment near their area of origin, while coccoliths reworked by currents and transported away from their area of origin are subject to non-selective destructive processes, including dissolution and mechanical abrasion. This scenario would explain the observed apparent paradox of the preservation of the primary ecological signal in an environment known for its dynamic sedimentary processes.

This study provides important insights on the processes governing the preservation of the ecological signature in the sedimentary record and testifies on the enormous potential of coccoliths in paleoapplications.

1. Introduction

Calcareous nannoplankton, predominantly represented by coccolithophores, has the best fossil record of all marine phytoplankton, except in polar regions (Ziveri et al., 2004). Their calcitic cell-covers (coccoliths sensu lato) are produced by biomineralization of tiny calcite crystals arranged with preferential orientations, and represent morphological elements which are relevant for taxonomy and phylogeny (Pienaar, 1994; Young, 1994). The preservation of coccoliths in the geological archives provides valuable information on paleoenvironmental conditions for the photic zone (McIntyre and Bé, 1967; Roth, 1994; Andruleit et al., 2000; Baumann et al., 2000; Andruleit and Rogalla, 2002; Boeckel and Baumann, 2008). As such, they can be used as

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indicators of paleoceanographic processes, sea surface water masses, productivity and climate change (e.g. Flores et al., 2000; Beaufort et al., 2001; Ziveri et al., 2004; Silva et al., 2008; Beaufort et al., 2011).

The correspondence between the coccolith species assemblages preserved in the seabed and the living communities thriving in the overlying photic layer is, however, complex, particularly on the continental shelf (e.g. Andruleit et al., 2000; Ziveri et al., 2000a,b; Andruleit and Rogalla, 2002; Andruleit et al., 2003; Baumann et al., 2005). Complexity increases even more in heterogeneous and dynamic areas such as submarine canyons, which often act as traps of particulate matter derived from the continent and shelf, and also as preferential conduits for transport of sediment from the coastal area to the deep sea (e.g. dense-water cascading and sediment gravity flows) (Schmidt et al., 2001; Van Weering et al., 2002; Canals et al., 2006; De Stigter et al., 2007; Oliveira et al., 2007; De Stigter et al., 2011).

In modern ecosystems, submarine canyons may show increased phytoplankton density, resulting from upwelling and enhanced vertical mixing in the upper canyon reaches (e.g. Hickey, 1995; Ryan et al., 2005; Kampf, 2006; Skliris and Djenidi, 2006; Ryan et al., 2010; Mendes et al., 2011). Concentration of marine fauna in and around the canyons, related to local enhancement of primary production, has been reported in several studies (Macquart-Moulin and Patriti, 1996; Allen et al., 2001; Bosley et al., 2004; Palanques et al., 2005; David and Di-Méglio, 2012). Whether any of this enhanced biological productivity is reflected in fossil assemblages in canyon sediments is problematic, since high terrigenous sediment input and strong bottom dynamics typical of submarine canyons are expected to dilute and disturb the paleoecological signal.

Here we report the results of a study of recent coccolith assemblages obtained from 92 surface sediment samples collected from the central Portuguese margin, where two major submarine canyons are located: the Nazaré Canyon and Lisbon–Setúbal Canyon. Although information on the effect of physical processes operating in these canyons on phytoplankton ecology is scarce, there is some evidence suggesting that these canyons promote phytoplankton production near the coast. Mendes et al. (2011), investigating the distribution and composition of phytoplankton assemblages in Nazaré Canyon during an upwelling event, reported the highest Chl-a concentrations to occur in the canyon head. According to these authors, persistently high concentrations of diatoms south of the canyon reflect intensified upwelling along the southern rim of the canyon, a phenomenon persisting even during the relaxation of winds causing upwelling. In a study of late-winter coccolithophore assemblages from the Nazaré Canyon region, Guerreiro et al. (2014) hypothesized the presence of local diversity and productivity "hotspots" related to the canyon topography. While *Emiliania huxleyi*, *Gephyrocapsa ericsonii*, *Coronosphaera mediterranea* and *Gephyrocapsa muellerae* were the dominant species overall, *Gephyrocapsa oceanica* was relatively more abundant at the canyon head and adjacent shelf south of the canyon, whereas *Syracosphaera* spp. and *Ophiaster* spp. were consistently more abundant further offshore above the middle Nazaré Canyon. Persistently high Chl-a concentrations in the Nazaré Canyon head observed from satellite data were interpreted by the same authors as indicative of persistent high phytoplankton production.

In the present analysis of coccoliths from surface sediments of the central Portuguese margin, we aim to assess whether the ecological differentiation as observed in living coccolithophore assemblages from surface waters can still be discerned in coccolith assemblages preserved in the underlying seabed sediments, or whether this differentiation is obliterated by the dynamic sedimentary processes typical for this heterogeneous continental margin area. We use the term "(paleo)ecology" to highlight that we are dealing with sediment thanatocoenoses representing very recent geological timescales, which are expected to present reduced diagenetic effects. With our study we aim to contribute to the knowledge of this phytoplankton group, in particular its potential as paleoecological and paleoceanographic proxies in continental margin areas.

2. Regional setting

2.1. Central Portuguese margin

The central Portuguese margin has a relatively narrow shelf with a variable width of 20–50 km and a gradient of <1°, at the shelf break at 160–200 m depth passes into a steep irregular slope with a gradient of 6–7° (Fig. 1). The shelf is underlain by a thick accumulation of Cenozoic detritical formations, filling structural basins formed during earlier rifting phases. The margin is dissected by a number of long submarine canyons, of which the Nazaré and Lisbon–Setúbal canyons are the most remarkable (e.g. Vanney and Mougenot, 1981; Mougenot, 1989; Alves et al., 2003).

Surface sediments on the shelf are generally very coarse and sand-dominated, and include old littoral deposits formed during the Holocene transgression preserved at shallow water depths. Fine-grained sediments generally increase with depth on the shelf, but also occur in muddy deposits located off river estuaries, in structural depressions at the middle shelf and in the upper reaches of the canyons. Fluvial discharge, coastal erosion and biogenic production are the main present day sources of fine sediment (Dias, 1987; Oliveira et al., 2002; Van Weering et al., 2002). Further down the continental slope, sediments change from slightly coarser and compositionally variable muds on the upper slope towards more uniform fine-grained and carbonate-richer hemipelagic muds on the deeper slope (De Stigter et al., 2007, 2011).

Surface water circulation along the Portuguese margin is directly dependent on two major current systems that transport surface water masses from west to east across the Atlantic: the North Atlantic Current extending to the north of the Iberian Peninsula, and the Azores Current south of Iberia (Saunders, 1982; Pollard and Pu, 1985; Barton, 2001; Peliz et al., 2005). As the Azores Current flows eastwards, branches of this current smoothly loop northward of Portugal, eventually feeding into the Portugal Current, and southward into the Canary Current, both flowing equatorward along the Portuguese and the NW African margins (Saunders, 1982; Barton, 2001). Beneath the near-surface equatorward flow of the Portugal and Canary currents, the Iberian Poleward Current (IPC) can be recognized traveling northward, opposite to the general circulation and closely bound to the continental slope, its core extending about 300–400 m vertically. This current is mostly restricted to the subsurface layers along most of the eastern subtropical gyre, but it surfaces whenever the Trade Winds weaken or turn northward (Barton, 2001) (Fig. 1).

Circulation over the Portuguese shelf and upper slope displays a marked seasonal variation associated with seasonal shifts in the position of the Azores high and Iceland low pressure systems (e.g. Haynes et al., 1993; Barton, 2001; Relvas et al., 2007). During summer, the Azores high migrates towards the central Atlantic, typically inducing *trade winds* to become northerly, inducing an equatorward circulation over the upper 150–200 m of the water column off Portugal. Under such conditions, the ~30 m thick surface layer of relatively warmer and lighter water is swept offshore by Ekman transport, allowing colder, less salty and nutrient enriched subsurface water to rise to the surface along the coast (e.g. Fiúza, 1983; Haynes et al., 1993; Barton, 2001; Relvas et al., 2007; Alvarez et al., 2011). During winter, the Iceland low intensifies and the dominant wind regime becomes southerly along the western Portuguese margin. This induces the IPC to rise over the upper slope and shelf, where the poleward flow produces an onshore Ekman transport, in turn resulting in downwelling conditions over the shelf (Fiúza, 1983; Vitorino et al., 2002). River runoff is an important feature of the winter circulation over the western Portuguese margin. Important discharge particularly from the NW Portuguese rivers (Mondego, Douro, Minho, Lima, Vouga) results in the formation of low salinity water lenses in the coastal ocean (Peliz et al., 2005).

The upper 500 m of water column off Portugal is constituted by the Eastern North Atlantic Central Water (ENACW), representing the main