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A Middle Pleistocene Northeast Atlantic coccolithophore record: Paleoclimatology and paleoproductivity aspects

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ABSTRACT

Changes in paleoclimate and paleoproductivity patterns have been identified by analysing, in conjunction with other available proxy data, the coccolithophore assemblages from core MD03-2699, located in the Portuguese margin in the time interval from the Marine Isotope Stage (MIS) 13/14 boundary to MIS 9 (535 to 300 ka). During the Mid-Brunhes event, the assemblages associated with the eccentricity minima are characterised by higher nannoplankton accumulation rate (NAR) values and by the blooming of the opportunistic genus *Gephyrocapsa.* Changes in coccolithophore abundance are also related to glacial–interglacial cycles. Higher NAR and numbers of coccoliths/g mainly occurred during the interglacial periods, while these values decreased during the glacial periods. Superimposed on the glacial/interglacial cycles, climatic and paleoceanographic variability has been observed on precessional timescales. The structure of the assemblages highlights the prevailing long-term influence of the Portugal (PC) and Iberian Poleward (IPC) Currents, following half and full precession harmonics, related to the migration of the Azores High (AH) Pressure System. Small *Gephyrocapsa* and *Coccolithus pelagicus braarudii* are regarded as good indicators for periods of prevailing PC influence. *Gephyrocapsa caribbeanica, Syracosphaera* spp., *Rhabdosphaera* spp. and *Umbilicosphaera sibogae* denote periods of IPC influence. Our data also highlights the increased percentages of *Coccolithus pelagicus pelagicus* during the occurrence of episodes of very cold and low salinity surface water, probably related to abrupt climatic events and millennial-scale oscillations of the AH/Icelandic Low (IL) System.

1. Introduction

The ecological factors that mainly act on the distribution and structure of coccolithophore assemblages are light, the salinity and temperature of water masses, nutrient availability, terrigenous inputs, and water turbidity (McIntyre and Bé, 1967; Samtleben and Schröder, 1992; Giraudeau et al., 1993; Winter and Siesser, 1994; Samtleben et al., 1995; Takahashi and Okada, 2000; Andruleit et al., 2003, 2005; Hagino et al., 2005; Andruleit, 2007). These factors are connected to changes in paleoceanographic and paleoclimatic conditions. Thus the variations in the structure of calcareous nannoplankton assemblages are tools used to investigate paleoceanographic and paleoclimatic changes (e.g., Flores et al., 2003; Baumann and Freitag, 2004; Giraudeau et al., 2004; Baumann et al., 2005; Rogalla and Andruleit, 2005) and the development of the Earth's climate system. Coccolithophores also release CO_2 during the intracellular calcification process and use light energy to convert CO_2 into organic molecules. Through these processes, known as the 'biological carbon pumps' (Rost and Riebesell, 2004), coccolithophores contribute to the CO_2 exchanges between seawater and the atmosphere. Therefore, similar to the foraminiferal fragmentation index (Le and Shackleton, 1992; Becquey and Gersonde, 2002), the reconstruction of coccolith preservation and coccolithophore productivity can be used to evaluate changes in biogenic carbonate preservation and the relationship to variations in carbonate export, biogenic productivity, ocean circulation, and biogeochemistry.

In this study we use coccolithophore assemblages to reconstruct the climate signal and productivity patterns during the mid-Brunhes. Our study area is the Iberian margin, an area known for its good preservation of the record of millennial-scale climate variability for the last several climatic cycles (e.g., de Abreu et al., 2003; Martrat et al., 2007; Voelker et al., 2010). Significant paleoclimatic changes and sea surface temperature (SST) variations occurred during the last 0.6 Ma (McManus et al., 1999; Martrat et al., 2007; Voelker et al., 2010; Rodrigues et al., 2011) influencing North Atlantic Deep

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Water formation and contributing to the related paleoceanographic evolution. During this period, the global climate system underwent a climatic transition: the Mid-Brunhes Event (MBE). The global MBE event is centred around 400 ka (Jansen et al., 1986) and the interval from MIS 11 to MIS 9 (420–300 ka) is considered to be one of the warmest periods during the Pleistocene. Larger continental ice sheets, lower sea level and lower atmospheric CO_2 concentrations characterised the interglacial periods before the MBE compared to the more recent interglacials (Yin and Berger, 2010). The MBE is also characterised by the largest amplitude change in $\delta^{18}O$ in the global ocean preceded by a significant negative $\delta^{13}C$ shift and by generally high carbonate concentrations (and high productivity), with intervals of high carbonate dissolution in the deep ocean. Under steady state conditions, global increase in pelagic carbonate production, probably linked to nutrient availability and upwelling intensity, could have altered ocean geochemistry leading to an increase in dissolution. This increase in carbonate production was most likely linked to the proliferation of *Gephyrocapsa,* a genus of coccolithophores, which intensive calcification could have greatly altered marine carbonate chemistry (Barker et al., 2006) by creating a carbonate-ion undersaturation that led to increased dissolution (Baumann and Freitag, 2004).

Here we present the first mid-Brunhes record for the structure of coccolithophore assemblages and their absolute and relative abundances in the Portuguese upwelling system. We combine these data with the $CaCO_3$ record and with previously published data for SST, ice-rafted debris (IRD) amounts, and planktonic $\delta^{18}O$ and $\delta^{13}C$ isotopes (Voelker et al., 2010; Rodrigues et al., 2011). Our main objectives are:

- to describe the Middle Pleistocene climate variability for the Portuguese margin and to investigate if and how this climate variability influenced the structure of coccolithophore assemblages;
- to investigate the orbital and suborbital-scale productivity variations in the Portuguese upwelling system between the MIS 13/14 boundary and MIS 9 (535 ka to 300 ka).

Finally, we relate these climatic variations to changes in regional surface water circulation patterns, and to the migration of Intertropical Convergence Zone (ITCZ) and Azores High (AH) Pressure System.

2. Oceanographic setting

Calypso piston core MD03-2699 (39°02.20′N, 10°39.63′W) was retrieved from the Estremadura promontory north of Lisbon from a water depth of 1895 m (Fig. 1). The studied core is located between the northern Iberian Margin, which is mostly influenced by rather subpolar water masses, and the southern margin, which is affected by the subtropical water masses from the Azores current. Thus the core location offers the opportunity to document changes resulting from both subpolar and subtropical gyre behaviour (Voelker et al., 2010). Modern hydrographic conditions in the area are influenced by the Portugal Current (PC) system whose waters are mainly derived from the intergyre zone of the North Atlantic, a region of weak circulation limited in the north by the North Atlantic Current and to the south by the Azores Current (Pérez et al., 2001; Bischof et al., 2003). The PC system is also influenced by the neighbouring Canary and Azores Currents (Pérez et al., 2001). During summer, this current system is characterised by the southward flowing PC and by the upwelling filaments that form off the capes along the western Iberian margin such as Cape Roca. During winter, the PC is displaced further offshore by the Iberian Poleward Current (IPC) (Fig. 1), which transports the warm subtropical surface and subsurface waters, formed at the Azores front, northward to the site (Peliz et al., 2005). The underlying water masses of the PC system originate from about 200 m to 300 m by a northward moving layer of subtropical origin, i.e., the subtropical Eastern North Atlantic Central Water (ENACW), and from about 300 m to 400 m by the subpolar ENACW moving south (Ambar and Fiuza, 1994; Fiuza et al., 1998; Peliz and Fuiza, 1999). The Mediterranean Outflow Water dominates from depths of 400 m to approximately 1300 m. The Northeast Atlantic Deep Water, characterised by a very low temperature and salinity (Bischof et al., 2003), lies beneath the Mediterranean Outflow Water.

Current upwelling in this area is most likely related to the migration of the Azores High (AH) pressure System. This subtropical high-pressure system migrates northward during spring/summer, which results in strong northerly winds. The AH is significantly weaker in fall and winter months (Maze et al., 1997; Coelho et al., 2002). During summer, the strong winds cause the upwelling of colder, nutrient-rich waters from depths of 100 m to 300 m along the coast of the Iberian Peninsula. These nutrient-rich waters feed filaments that can extend more than 200 km offshore (Sousa and Bricaud, 1992). During winter, the dominant northward winds suppress the upwelling conditions and favour downwelling (Smyth et al., 2001). However, upwelling of a smaller magnitude than during the spring/summer, produced by northerly winds blowing across the shelf, can also occur in autumn or winter (Relvas et al., 2007; de Castro et al., 2008).

3. Material and methods

3.1. Age model

We present a study of Calypso piston core MD03-2699 (39°02.20′N, 10°39.63′W) in order to reconstruct the climate signal and the productivity patterns in the central area of the Portuguese margin. The oxygen isotope stratigraphy and three coccolithophore biostratigraphic events (Table 1) provided the stratigraphic constraints. The age model for core MD03-2699 is based on the correlation of its benthic oxygen isotope record (Fig. 2; Voelker et al., 2010; Rodrigues et al., 2011) with the record of ODP Site 980 (McManus et al., 1999; Flower et al., 2000). The age model is supported by three coccolithophore biostratigraphic events: the Last Occurrence (LO) of *Pseudoemiliania lacunosa*, the First Common Occurrence (FCO) of *Gephyrocapsa caribbeanica* and the First Occurrence (FO) of *Helicosphaera inversa* (Fig. 2). The LO of *P. lacunosa*, dated at about 460–440 ka (Raffi et al., 2006), occurs at 1895 cm corresponding to 452.47 ka (Table 1). The FCO of *G. caribbeanica,* equivalent to the progressive increase in *G. caribbeanica* percentage with values above 50–70% and dated at about 560–540 ka (Flores et al., 2003; Baumann and Freitag, 2004), is found at 2450 cm/546.39 ka (Table 1). The FO of *H. inversa*, dated at 510 ka (Sato et al., 1999), is identified at 2170 cm, corresponding to 514.94 ka (Table 1). The age of each sample between age control points was calculated by linear interpolation. The age of the studied interval ranges from the lowest sample that has an age of 535 ka, i.e., near the MIS 13/14 boundary, to MIS 9 (300 ka).

3.2. Coccolithophore slide preparation and counting methods

Slides for coccolith analyses were prepared using the technique described by Flores and Sierro (1997). A total of about 200 samples from core MD03-2699 collected at a sample interval of approximately 5 to 10 cm, yielding an average age resolution of about 1 to 2 ka, were analysed. Because of a lower sedimentation rate, a lower age resolution occurs mainly in MIS 12.

A quantitative analysis, considering both coccoliths/g and percentages of selected species, was conducted using a light microscope at 1250× magnification. At least 300 specimens larger than 3 μm were counted per slide in a varying number of fields of view. In the same fields, a separated count of specimens smaller than 3 μm was performed in order to quantify the absolute and percentage values of all taxa (Figs. 3, 4). The taxonomic concept of Raffi et al. (1993) and Flores et al. (1999, 2000) for the gephyrocapsids was followed. The large to medium-sized *Gephyrocapsa*, such as *Gephyrocapsa oceanica*,