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Millennial scale coccolithophore paleoproductivity and surface water changes between 445 and 360 ka (Marine Isotope Stages 12/11) in the Northeast Atlantic

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ABSTRACT

A high resolution coccolithophore study was carried out in order to improve the understanding of the paleoceanographic evolution and changes in paleoproductivity occurring off the Iberian Margin (IM) between 445 and 360 ka, i.e. during late Marine Isotope Stage 12 to 11. Coccolithophore assemblages allowed reconstructing surface water changes characterized by millennial-scale oscillations (~1.5 kyr cycles) involving Portugal or Iberian Poleward Currents (PC and IPC) prevalence. Changes in paleoproductivity, possibly related to the upwelling of Eastern North Atlantic Central Waters (ENACW) – of sub-tropical (ENACWst) or sub-polar origin (ENACWsp) – were also recognized. This study also permitted detecting abrupt events (stadial/interstadial-type oscillations) and revealed that changes in paleoproductivity are related to opposite dynamics during glacial and interglacial stages, with the reversed setting being established during the deglaciation. Furthermore, a possible control of half and fourth precessional cycle components, on the occurrence of abrupt changes within the assemblages' structure, during the deglaciation, is proposed on the basis of wavelet analysis results applied to selected taxa.

1. Introduction

Marine Isotope Stage (MIS) 11 is a key period in the understanding of global climate evolution. Eccentricity minima occurred only five times over the last 2 Myr: one was during MIS 11 (425–360 ka), another one is at present because Earth is entering, nowadays, into a new eccentricity minimum stage (Loutre and Berger, 2003). Due to Earth's similar orbital configuration, several authors (Hodell et al., 2000; Berger and Loutre, 2002; Loutre and Berger, 2003; Barker et al., 2006; among others) considered MIS 11 as an analog of the Holocene. In addition, an important transition, the Mid-Brunhes Event (Jansen et al., 1986), occurred between MIS 13 and MIS 11 separating two climatic modes (Candy et al., 2010) and centered at around 400 ka. Early Middle Pleistocene interglacial periods (780–450 ka) were characterized by only moderate warmth while Middle and Late Pleistocene interglacials (occurring after 450 ka) were characterized by greater warmth consistent with, or warmer than, the Holocene (EPICA members, 2004; Candy et al., 2010).

The Iberian Margin (IM) is a strategic area for studying paleoceanographic and paleoclimatic variability, because high sedimentation rates allow reconstructions at millennial-to-centennial time scale (e.g., Shackleton et al., 2000). Moreover, the western and southern sections of the Iberian Peninsula's Atlantic coast belong to an active seasonal upwelling system (Wooster et al., 1976; Fiuza, 1982, 1983) and the changes of this system over time have been studied using different proxies (Soares and Dias, 2006 and references therein; Salgueiro et al., 2010).

Coccolithophore records have been widely used as valid proxy for surface ocean paleo-reconstructions at glacial-interglacial time scale (McIntyre and Bè, 1967; McIntyre et al., 1972; Flores et al., 1997; Kinkel et al., 2000; Amore et al., 2003, 2004, 2012; Rogalla and Andruleit, 2005; Lopez-Otalvaro et al., 2008; Marino et al., 2008; Triantaphyllou et al., 2009 among others) as well as short-term variability (Colmenero-Hidalgo et al., 2004; Alvarez et al., 2005; Giraudeau et al., 2010) in several basins. Previous studies demonstrated the power of coccolithophore assemblages in studying oceanographic changes off the IM in the present day (Moita, 1993; Abrantes and Moita, 1997; Silva et al., 2008) as well as in Holocene (Cachão and Moita, 2000; Colmenero-Hidalgo et al., 2002; Parente et al., 2004; Abrantes et al., 2005; Alvarez et al., 2005; Narciso et al., 2006; Flores et al., 2010; Incarbona et al., 2010) and Pleistocene sediments (Incarbona et al., 2008; Amore et al., 2012).

Climatic variability off the IM has been widely described for the last four climate cycles (e.g., de Abreu et al., 2003; Tzedakis et al.,

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2003; Martrat et al., 2004; Roucoux et al., 2006; Desprat et al., 2007; Martrat et al., 2007; Salgueiro et al., 2010). More recently, several authors contributed to define the paleoceanographic evolution off Portugal, providing high-resolution data for the period of MIS 15-9 (Voelker et al., 2010; Rodrigues et al., 2011; Amore et al., 2012). A possible role of orbital parameters and insolation on main glacial-interglacial paleoceanographic changes was proposed by Voelker et al. (2010) and Rodrigues et al. (2011). They reconstructed, on the basis of ice-rafted debris (IRD), stable isotope and alkenone records, millennial-scale variability and identified the occurrence of stadial/interstadial cycles and Heinrich-type events (Ht). Successively, Amore et al. (2012) discussed changes in coccolithophore abundances related to glacial–interglacial cycles. Superimposed on these, they also observed variability in the coccolithophore assemblages linked to precession harmonics. However, because a signal interruption occurred during the eccentricity minimum interval of MIS 11, when precession variability was low, Amore et al. (2012) suggested a higher resolution study to better understand paleoproductivity change in this period and the possible influence of higher frequency cycles on coccolithophore assemblages.

Here, for the first time, is presented a millennial-scale analysis of coccolithophore assemblages, between 445 and 360 ka, off the IM. The study, integrated with available data of previous studies on the same core (Voelker et al., 2010; Rodrigues et al., 2011; Amore et al., 2012), is devoted to:

a) better understand coccolithophore production changes during the period of low precession variability of MIS 11;
b) investigate the main changes occurring during the deglaciation;
c) recognize changes in coccolithophore assemblages related to millennial-scale variability and to abrupt events.

2. Methods

2.1. Modern hydrographic and atmospheric conditions of the study area

Deep-sea core MD03-2699 (Fig. 1) was recovered at the western IM (39°02.20′N, 10°39.63′W; Estremadura spur) about 100 km offshore and from 1895 m water depth. The IM (eastern North Atlantic) is characterized by seasonal upwelling (May to October; Wooster et al., 1976; Fraga, 1981; Fiuza, 1983, 1984) associated with high primary productivity that leaves an imprint in the sediment beneath these areas, as reported by Monteiro et al. (1983), Abrantes and Sancetta (1985) and Abrantes (1988).

The mechanism behind the seasonality of the surface ocean flow along Western Iberia is the seasonal migration of the semi-permanent subtropical high-pressure system (Azores High, AH; Coelho et al., 2002): during spring/summer the center of the AH migrates southward (Fig. 1a), between 27°N (March) and 33°N (August), leading to stronger north/north-westerly winds in summertime, which are favorable to upwelling (Coelho et al., 2002).

The predominately equatorward winds start to prevail in late spring/early summer and drive an offshore Ekman Transport with the upwelled waters being transport southward with the Portugal Current (PC; Fig. 1a) causing the upwelling of colder, less salty and nutrient-rich subsurface waters along the coast (Smyth et al., 2001; Soares and Dias, 2006; Relvas et al., 2007). During the winter, the northerly component of the winds weakens, or even reverses, leading to a reversal of the surface flow that can be identified in satellite images as the warm Iberian Poleward Current (IPC; Fig. 1b; Coelho et al., 2002). The poleward flow is characterized by a transport of warm, poorer in nutrients and salty waters, the Eastern North Atlantic Central Waters (ENACW) sub-tropical origin (ENACWst, Fig. 1b), and by a coastal downwelling on the western coast of the Iberian Peninsula during the fall/winter seasons until the spring transition in April–May, when the northerly winds begin to dominate (Relvas et al., 2007).

The upwelled waters are replenished by ENACWst or its subpolar counterpart (ENACWsp; Fig. 1a, b), forming a permanent thermocline at water depths below 100 m. The ENACWsp flows below the ENACWst and, depending on the wind strength, either type can be upwelled. The ENACWsp is formed in the eastern North Atlantic near 46°N (Fiuza, 1984; Rios et al., 1992; Fiuza et al., 1998). It was hypothesized (Rios et al., 1992; Peliz et al., 2005) that the poleward flow off western Iberia could also be connected to a northward recirculation of the Azores Current (AzC; Fig. 1b); this would explain

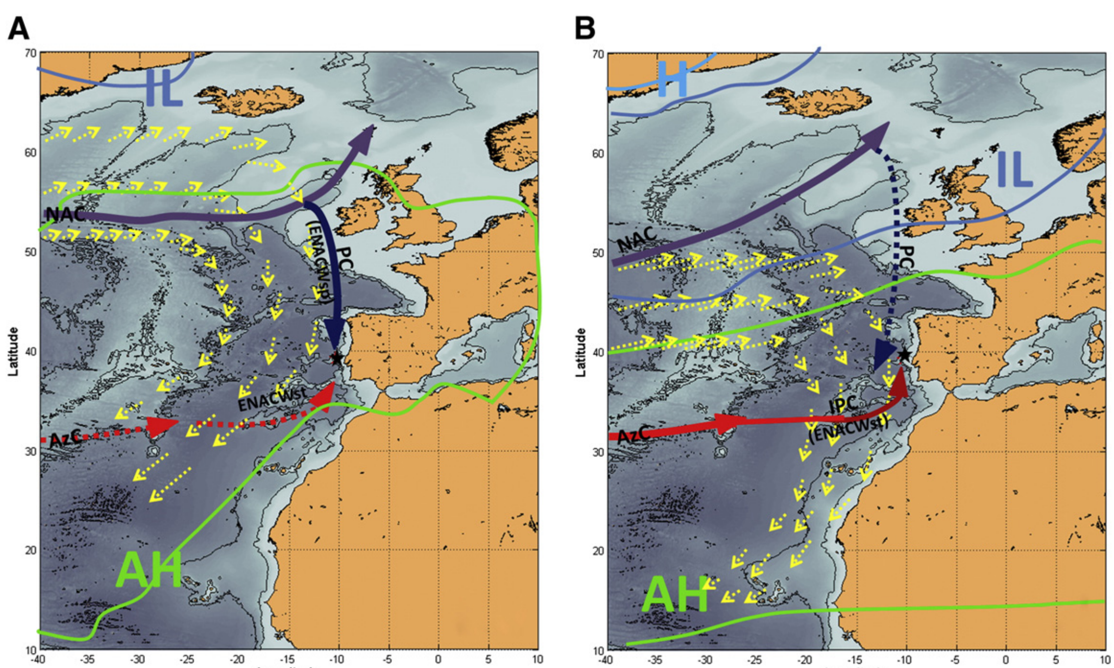

Fig. 1. Core location (black star) and modern oceanography of the study area in spring/summer [A] and autumn/winter [B], modified from Voelker et al. (2010) and Amore et al. (2012). AH = Azores High pressure center. IL = Icelandic Low pressure center. H = Polar High pressure center. AzC = Azores Current. ENACWst = Eastern North Atlantic Central Water of sub-tropical origin. ENACWsp = Eastern North Atlantic Central Water of sub-polar origin. IPC = Iberian poleward Current. PC = Portugal Current. NAC = North Atlantic Current. Yellow, dotted line arrows = direction of winds; arrow length reflects wind intensity.