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Productivity and sea-surface temperature changes recorded during the late Eocene–early Oligocene at DSDP Site 511 (South Atlantic)

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A B S T R A C T

This study investigates paleoenvironmental changes during the Eocene–Oligocene transition (EOT) at Deep Sea Drilling Project (DSDP) Site 511 (South Atlantic), as inferred from lipid biomarker (long-chain diols, alkenones) and calcareous nannofossil accumulation rates, as well as changes in sedimentation regime (i.e. relative contributions of total organic carbon-TOC-, calcium carbonate, and biogenic silica). Sea-surface temperatures (SSTs) reconstructed from the alkenone unsaturation index $U^{K'}_{37}$ indicate a progressive but significant cooling (~8 °C) from 34.5 Ma to 33.6 Ma, consistent with estimates derived from other temperature proxies (TEX_{86}; $\delta^{18}O$) at the same site and for the same time interval. This cooling is associated with a marked increase in primary productivity, as indicated by high accumulation rates of biogenic silica, TOC, alkenones, long-chain diols, and calcareous nannofossils. Together, these results are consistent with an enhancement of upwelling conditions favorable to the development of siliceous organisms at DSDP Site 511, possibly induced by the Oi-1 glaciation in Antarctica that occurred during this period.

1. Introduction

The Eocene–Oligocene transition (EOT; ~34 Ma) marks the change from a “greenhouse” to an “icehouse” climate, which saw dramatic cooling and the formation of a large and permanent ice-sheet on East Antarctica (e.g., Zachos et al., 2001; Lear et al., 2008). Some drivers proposed for this abrupt cooling include a substantial decrease in atmospheric CO_2 (DeConto and Pollard, 2003; Pagani et al., 2005, 2011), perhaps coupled with an orbital configuration that reduced polar seasonality (Coxall et al., 2005). Alternatively, the thermal isolation of Antarctica from mid-latitude warm currents as a consequence of the opening of the circumpolar passages (Tasmanian Gateway and Drake Passage) and the onset of the Antarctic Circumpolar Current (ACC) may instead have been a major protagonist (e.g., Kennett, 1977; Lawver and Gahagan, 2003; Persico and Villa, 2004; Lagabrielle et al., 2009).

Associated with the EOT is a biotic turnover, both in the marine realm (e.g., Aubry, 1992; Dunkley Jones et al., 2008; Funakawa and Nishi, 2008; Villa et al., 2008; Wade and Pearson, 2008), and in terrestrial fauna and flora (e.g., Hooker et al., 2004; Jaramillo et al., 2006). The interval is also marked by a perturbation of the carbon cycle (Shackleton and Kennett, 1975; Zachos et al., 2001; Merico et al., 2008), linked to an increase of marine primary production (Diester-Haass and Zahn, 1996; Salamy and Zachos, 1999; Nilsen et al., 2003; Anderson and Delaney, 2005), a deepening of the Carbonate Compensation Depth (CCD) (Coxall et al., 2005; Rea and Lyle, 2005), and a sea-level fall (e.g., Pekar et al., 2002; Miller et al., 2008).

These changes are well documented both in oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) isotope records from planktonic and benthic foraminifera (e.g. Kennett and Stott, 1990; Diester-Haass and Zahn, 1996; Zachos et al., 1996, 2001), and by shifts in foraminifera, radiolarian and calcareous nannofossil assemblages (e.g. Boersma and Premoli Silva, 1991; Aubry, 1992; Keller et al., 1992; Lazarus and Caulet, 1993; Villa et al., 2008). Alkenone-based proxies such as $\varepsilon_{p37:2}$, the $\delta^{13}C$ fractionation occurring during algal photosynthesis, and $U^{K'}_{37}$, the alkenone unsaturation index, have been used to reconstruct variations in partial pressure of CO_2 (pCO_2) and sea surface temperatures (SSTs) respectively during the late Eocene–early Oligocene (Pagani et al., 2005, 2011; Liu et al., 2009). While such paleoenvironmental changes during this time interval have been noted at a number of sites in the Southern Ocean, only a few studies have investigated signals from high-latitude sites in the Atlantic Ocean (e.g., Nilsen et al., 2003; Pagani et al., 2005, 2011; Liu et al., 2009). The study of these high-latitude sites is, however, important in better constraining oceanographic changes taking place over the EOT, since subpolar waters also played a major role in global climate regulation at that time (e.g., Diester-Haass and Zahn, 1996; Lagabrielle et al., 2009). In addition, such studies may help to better

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constrain the timing of the onset of Antarctic Circumpolar Current (ACC), a matter which is still subject to some debate (e.g., Barker and Thomas, 2004).

In this study, we used a multi-proxy approach, comparing accumulation rates in calcareous nannofossils, total organic matter, calcium carbonate/biogenic silica and lipid biomarkers (both alkenones and long-chain diols) with reconstructions of sea-surface temperature (SST) from the alkenone unsaturation index ($U^{K'}_{37}$) at Deep Sea Drilling Project (DSDP) Site 511 (South Atlantic) during the Eocene–Oligocene (37.5–31.4 Ma). Through such approaches, we aimed to provide a comprehensive picture of the changes in temperature and trophic conditions occurring at DSDP Site 511, and to infer from these the oceanographic changes associated with to the onset of the ACC during the Eocene–Oligocene transition.

2. Oceanographic setting

DSDP Site 511 (51°00.28′S, 46°58.30′W), drilled during DSDP Leg 71 at 2589 m water depth, is on the back slope of a cuesta-type ridge in the basin province of the Falkland Plateau (southwest Atlantic Ocean) about 10 km south of Maurice Ewing Bank (Ludwig et al., 1983; Fig. 1).

The Falkland Plateau extends eastwards off southernmost South America, and is bounded by the Falkland Escarpment to the north and by the Falkland Trough and North Scotia Ridge to the south (Fig. 1). Today, DSDP Site 511 is situated north from the Polar Front and other frontal zones presented in Fig. 1. The Sub-Antarctic Front (SAF), after crossing the North Scotia Ridge, hugs the continental shelf before merging with the boundary current of the Argentine Basin (Arhan et al., 2002; Allen et al., 2005). The Polar Front (PF) bifurcates into two branches (one over the sill of the Falkland Plateau and one along the axis of the Falkland Trough) north of Shag Rocks Passage. The relative strengths of these branches may vary through time, and may result in extensions of the PF crossing the Maurice Ewing Bank (Arhan et al., 2002). In addition, the Falkland Plateau is influenced by the deep water components of the ACC, that flow northward through Shag Rocks Passage into the Falkland Trough and eastward toward the Georgia Basin (Arhan et al., 2002; Allen et al., 2005).

During the Paleogene, DSDP Site 511 was located at approximately 55°S, 42°W (Basov and Krasheninnikov, 1983; Ludwig et al., 1983; Syke et al., 1998). A total of 183 m of upper Eocene and lower Oligocene diatom ooze and nannofossil-diatomaceous oozes were deposited at a water depth of about 2500 m, containing well-preserved calcareous nannofossils and diatoms (Ludwig et al., 1983). It should be noted that DSDP Site 511 is characterized at 5 m below the sea floor (mbsf) by a large unconformity between lower Oligocene and Pliocene sediments. This unconformity marks a major widespread erosional hiatus on the Falkland Plateau, interpreted as the result of an intensification of the ACC in response to cooler climatic conditions (Ciesielski and Weaver, 1983).

3. Material and methods

3.1. Sampling and age model

A total of 40 sediment samples were selected from Cores 2 to 20, between 10 and 180 m below the sea floor (mbsf). The studied interval covers the Nannofossil Zones NP19-NP22 of Martini (1971) and spans the latest Eocene–early Oligocene (Ludwig et al., 1983; Wise, 1983).

The age model used in this study is based on the foraminiferal oxygen isotope data ($\delta^{18}O$) from Muza et al. (1983) and on calcareous nannofossil bioevents (first or last occurrences) determined by Liu et al. (2009), Schumacher and Lazarus (2004), and Wise (1983). Age control points are presented in Table 1 and have been recalibrated in the present study according to the latest geological timescale (Gradstein et al., 2012).

3.2. Sediment composition analyses

3.2.1. Total organic carbon

Sub-samples (ca. 100 mg of ground samples) were acidified with 2 N HCl in pre-cleaned (combustion at 450 °C) silver capsules until

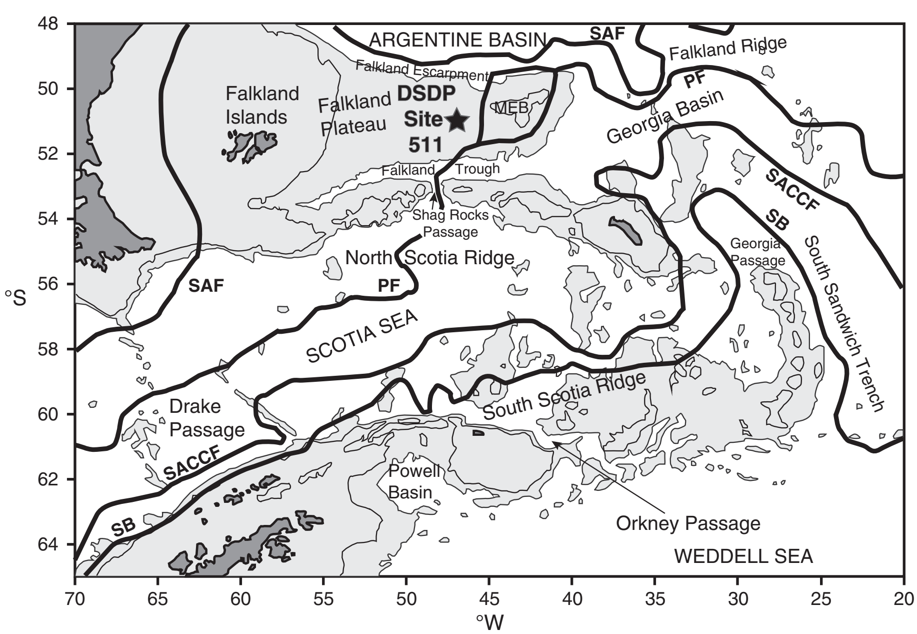

Fig. 1. Location of DSDP Site 511 in the South Atlantic Ocean. Bathymetric configuration (isobaths 1500 and 3000 m) and positions of the main oceanic fronts are shown. Abbreviations are: SAF = Subantarctic Front; PF = Polar Front; SACCF = Southern Antarctic Circumpolar Front; SB = Southern Boundary of the Antarctic Circumpolar Front; SRP = Shag Rocks Passage; MEB = Maurice Ewing Bank (adapted from Allen et al., 2005).