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Astronomically-paced coccolith size variations during the early Pliensbachian (Early Jurassic)

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ABSTRACT

Though climate and environmental changes are known to influence diversity and assemblages of coccolithophorids, unicellular photoautotroph algae, the relationships between the size fluctuations of coccoliths, the small calcite plates covering the coccolithophorid cell, and environmental parameters remain unclear. To understand possible interactions between coccolith size and environmental changes, a high-resolution (every 5 cm) biometric study of *Crepidolithus crassus* coccoliths was performed in the Lower Pliensbachian (Lower Jurassic; ~188 Myr) hemipelagic deposits of Peniche (Portugal). The six measured parameters show covariant patterns related to size variations rather than morphological changes. The size variations are cyclic, and they occur in opposite phase to changes in the sedimentary calcium carbonate content. Spectral analyses performed on the size measurements of the *C. crassus* coccoliths and the calcium carbonate contents show that changes in both parameters are paced by the Earth's eccentricity and precession orbital cycles. As revealed by mixture analyses, the observed size variations result from changes in the relative abundance of two distinct biometric groups that are statistically stable through the analysed time interval. These two groups are classified as: "small crassus" with a major axis mean size of 6.5 ± 0.75 μm, and "large crassus", which averages at 8.5 ± 0.75 μm and dominates the assemblages in the studied interval. *Crepidolithus crassus* has been recently interpreted as a deep-dweller (living in the lower photic zone) and its development may have been greatly dependent on light availability and nutrient concentration. Accordingly, the two size groups likely developed at different water-depths due to differential coccolith (and cell) masses and buoyancies. Consequently, we propose that changes in the transparency of the water column may have been an important factor controlling the replacement between the two groups and hence the resulting coccolith mean size fluctuations. Ultimately, both water transparency and nutrient recycling within the photic zone were mainly influenced by the frequency and intensity of storms that occurred under orbital control.

1. Introduction

Coccolithophores are one of the major planktonic micro-algae in modern oceans. Coccolithophores produce intra-cellular carbonate platelets named coccoliths that are exported to the cell surface to form the coccosphere. Because they act simultaneously as organic and inorganic carbon pumps, coccolithophores are largely studied for their possible influence on the carbon cycle (e.g., Rost and Riebesell, 2004; Langer et al., 2006; Rickaby et al., 2007; Iglesias-Rodriguez et al., 2008). Since the first appearance of coccolithophorids during the late Triassic, climate changes are known to have had a major influence on coccolith production and distribution in the past oceans (e.g., McIntyre, 1967; McIntyre et al., 1970; Molfino and McIntyre, 1990; Westbroek et al., 1993; Erba, 2006). These patterns indicate the close relationship between climate and biosphere, and they are of major interest in palaeontology and palaeoceanography.

Over sub-million-year timescales, climate changes are modulated by orbital cycles (Milankovitch, 1941; Berger, 1978), which control the solar radiance received by the Earth. In turn, orbitally-forced changes in climate, weathering, continental runoff, oceanic circulation and productivity control the amount of carbonate or clay inputs that are exported to deep-sea regions and are ultimately preserved in sedimentary successions (Einsele, 1982; Einsele and Ricken, 1991). Hence, cyclic patterns of sedimentation are increasingly used to reconstruct ocean/atmosphere climate dynamics on short- and long-term timescales for periods covering the Paleozoic to the Neogene (Weedon and Jenkyns, 1990; Claps et al., 1995; Elrick and Hinnov, 1996; Hinnov and Park, 1999; Hilgen et al., 2003; Weedon, 2003; Suan et al., 2008b). Despite the major role of orbital cycles on sub-million-year climate changes, their influence on the development and assemblages of coccolithophores remain relatively poorly-documented and understood.

Orbitally-paced cyclic patterns have been identified in fluctuations of the abundance of the modern species *Florisphaera profunda* (Beaufort et al., 1997), or in the relative abundance of Cretaceous species (Erba et al.,

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1992; Mutterlose and Ruffel, 1999; Herrle et al., 2003; Bornemann et al., 2005) and Jurassic taxa (Claps et al., 1995; Mattioli, 1997; Walsworth-Bell et al., 2000; Olivier et al., 2004). These studies suggested an intimate coupling between the abundance of a given taxon and orbitally-forced fertility changes of the sea-surface waters where the organism developed. Recent biometric studies have shown the predominant role of climatic variations on Paleogene and Neogene coccolith and nannolith sizes (Parente et al., 2004; Narciso et al., 2006; Henderiks and Pagani, 2008; Tremolada et al., 2008). Furthermore, estimates of coccolith size variations are of fundamental importance to assessing pelagic carbonate fluxes and, hence, for our understanding of global biogeochemical cycles on the sub-million-year timescale (Young and Ziveri, 2000; Baumann, 2004). Nevertheless, biometric studies that unambiguously relate coccolith size to orbital cycles are still rare, and previous attempts to establish any relationship between size variations and a given cycle have been inconclusive (e.g., Bralower and Parrow, 1996; Colmenero-Hidalgo et al., 2002; Bornemann and Mutterlose, 2006).

In this study, we analysed the size variations of the early Jurassic coccolith *Crepidolithus crassus* (Deflandre, 1954) Noël, 1965 to investigate the possible influence of orbitally-related climatic cycles on coccolith size variations through time. This species is represented by robust, dissolution-resistant coccoliths and is one of the most abundant taxa in lower Jurassic assemblages. We investigated the Pliensbachian sedimentary succession from the Peniche section (Lusitanian Basin, Portugal), where marlstone–limestone alternations crop out spectacularly and continuously along the Atlantic coast. Coccoliths were measured at high-resolution (every 5 cm) over a relatively short time interval (~200 000 years).

2. Materials and methods

2.1. The Peniche section

The Peniche section (Middle-West coast of Portugal; Fig. 1) is one of the most complete and continuous sedimentary successions of the western Tethys for the Pliensbachian/Toarcian interval (~190–180 My ago). Several ammonite bio-events provide a detailed biostratigraphic framework (Mouterde, 1955; Elmi et al., 1988), making this section a good candidate for the Pliensbachian/Toarcian Global Stratotype Section and Point (GSSP) (Duarte et al., 2004; Elmi, 2006). Peniche belongs to the Jurassic Lusitanian Basin (Fig. 1A and B), which is limited eastwards by the Iberian Meseta and westwards by the Berlenga–Farilhões Horst (Wright and Wilson, 1984). The Pliensbachian part of the Peniche section (Fig. 2) is represented by marlstone–limestone alternations rich in belemnites and ammonites. The presence of levels enriched in microbialitic nodules is a remarkable sedimentary feature (Elmi et al., 1988).

Across the Jamesoni and Ibex ammonite zones, 23 m of the Peniche section have been sampled at high resolution every 5 cm (455 samples). In this interval, the variations of calcium carbonate content were measured (Fig. 2), and the obtained data were subjected to spectral analysis to evaluate the impact of orbital cycles on carbonate sedimentation during the Early Pliensbachian. A shorter interval (3.2 m) was then selected for high-resolution biometric analyses of *C. crassus* coccoliths. This part of the section, which encompasses the Jamesoni–Ibex ammonite zones boundary, has been selected because the marlstone–argillaceous limestone alternations there are remarkably regular. Moreover, microbialitic nodules are relatively rare in this interval (Elmi et al., 1988).

2.2. Sample preparation

Calcium carbonate ($CaCO_3$) contents were determined using a Dietrich-Frühling calcimeter. For each sample, the amount of CO_2 was measured after the acidification of an aliquot of about 300 mg of powdered bulk sediment (Fig. 2). The biometric study of coccoliths has been performed on samples from the same stratigraphic level analysed for wt.%$CaCO_3$ contents.

The preparation of slides for coccolith observation was performed using the Random Settling method (Beaufort, 1991; modified in

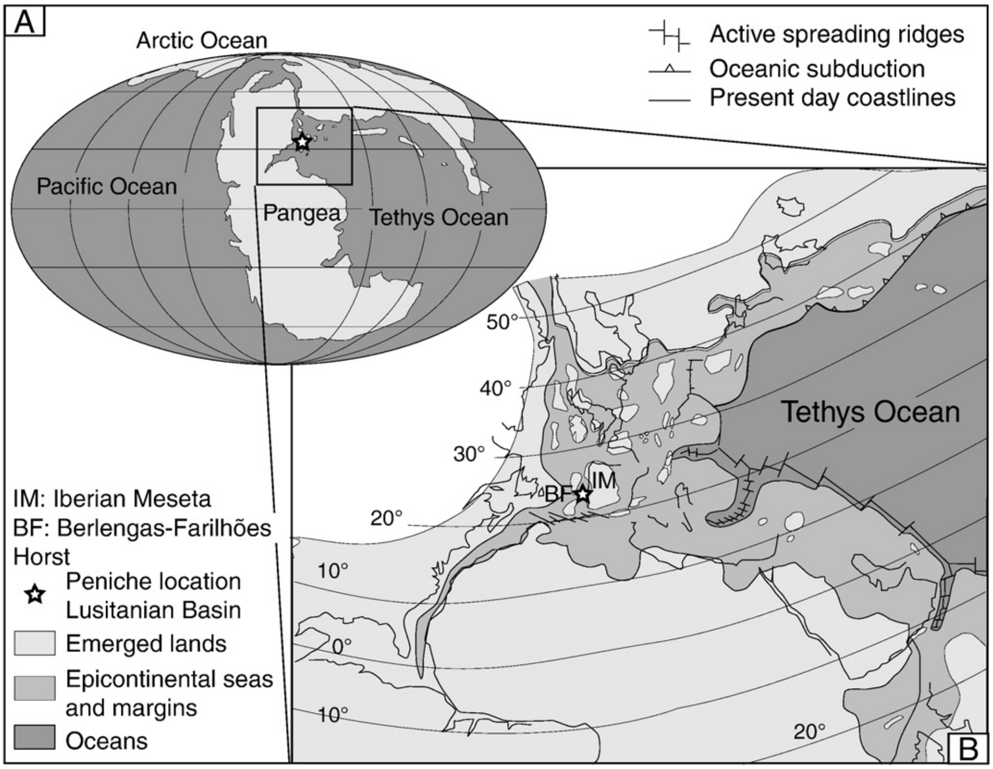

Fig. 1. A: Palaeogeography during the Early Jurassic (Scotese, 2001). B: Zoom showing the location of Peniche within the Lusitanian Basin during the Early Jurassic (modified from Bassoulet et al., 1993).