



New latitude-based nannofossil zonation for the Campanian–Maastrichtian of the South Atlantic Ocean and their paleoceanographic implications



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ARTICLE INFO

Article history:

Received 12 October 2015

Received in revised form 4 April 2016

Accepted 5 April 2016

Available online 13 April 2016

Keywords:

Calcareous nannofossils

Atlantic Ocean

Late Cretaceous

Biostratigraphy

Paleoceanography

ABSTRACT

The global evolution of calcareous nannofossils during the Campanian–Maastrichtian interval is not fully understood, and nannofossil zonation for the central and South Atlantic Ocean are yet to be constructed. Here, we test the applicability of previous calcareous nannofossil zonation developed for other ocean basins, for biostratigraphy in the South Atlantic Ocean, and refine Campanian–Maastrichtian biostratigraphy in the region. We document calcareous nannofossil distributions at Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP) sites from the high, mid and low latitudes in the South Atlantic Ocean (DSDP Sites 354, 356, 511, 525A, and 530A, and ODP Sites 690C; 700B; 661A, and 1258A). Combining nannofossil occurrences with magnetostratigraphic schemes previously constructed for some of the sites, we propose three new zonation tied to the global magnetostratigraphic chrons, with distinct bio-horizons selected at different latitudinal regions. In this study we present detailed definitions of new South Atlantic Ocean Low-latitude (SAL), South Atlantic Mid-latitude (SAM) and South Atlantic High-latitude (SAH) zonation. We identified significant diachronism of some species between latitudes throughout the Campanian and Maastrichtian. These species diachronism, mainly between zonal markers from low and mid latitudes during the late Maastrichtian, was probably related to migration patterns due to fundamental paleoceanographic changes.

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1. Introduction

The Late Cretaceous period records significant paleoceanographic and paleobiological changes related to surface-water temperatures and global climate (Jenkyns et al., 1994; Huber et al., 1995; Clarke and Jenkyns, 1999; Huber et al., 2002; Lees, 2002; Linnert et al., 2014). After the mid-Cretaceous (Albian–Turonian) hot greenhouse climate (e.g., Forster et al., 2007), bottom-water and sea-surface temperatures gradually declined throughout the latest Cretaceous (Coniacian–Campanian) before exhibiting several cooling and warming episodes in the Maastrichtian. The end of the Cretaceous culminated in a significant warming in the latest Maastrichtian (Li and Keller, 1998; Thibault et al., 2010; Friedrich et al., 2012; Thibault and Husson, 2016). These climate changes resulted in nannofossil migrations and provincialism,

which still needs to be fully documented (Thierstein, 1981; Thibault et al., 2010), and some of the highest diversities of calcareous nannofossil species from the Mesozoic to Recent (Bown et al., 1991).

The provinciality and diachronism of calcareous nannofossils pose a challenge for biostratigraphers, leading to unreliable stratigraphic interpretation and correlation. For instance, it has been noted by several authors that the global zonation of Burnett et al. (1998), encompassing three provinces termed Boreal, Tethyan/Intermediate and Austral, cannot be fully applied in several regions due to the absence and diachronism of some marker species (e.g., NW Australian margin, Howe et al., 2003; Campbell et al., 2004; NW Pacific, Lees and Bown, 2005; Equatorial Atlantic, Thibault and Gardin, 2006; Danish Basin, Sheldon, 2008). The Southern Ocean zonation of Watkins et al. (1996) also contains species that are different from those of the Austral scheme of Burnett et al. (1998). Moreover, both the Watkins et al. (1996) and the Burnett et al. (1998) zonation have yet to be tied to the standard magnetostratigraphic time scale so that the correlation of the bio-horizons among ocean basins should be achieved. In an isolated attempt to assess this issue, Thibault et al. (2010) documented the global

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diachronous first occurrence of *Micula murus* in the late Maastrichtian (moving from low to mid latitudes, see the Discussion section), and concluded that further work is needed to construct two distinct biozonations for the low- and mid-latitudes.

Biostratigraphic studies on Campanian and Maastrichtian calcareous nannofossils from the South Atlantic Ocean are limited to Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP) sites, mainly during the 1980s and 90s (Wise and Wind, 1977; Perch-Nielsen, 1977; Wise, 1983; Wind and Wise, 1983; Manivit, 1984; Manivit and Feinberg, 1984; Stradner and Steinmetz, 1984; Manivit, 1989; Pospichal and Wise, 1990; Crux, 1991; Erbacher et al., 2004). In addition to these studies, there are others on the Brazilian Continental Margin (Troelsen and Quadros, 1971; Freitas, 1984; Antunes, 1987; Gomide, 1989; Oliveira and Costa, 1997; Oliveira, 1997; Antunes, 1998; Guerra et al., 2010, 2012) and on the Antarctic Peninsula (Concheyro et al., 1991; Concheyro et al., 1994; Concheyro, 2004; Švábenická et al., 2012; Guerra et al., 2015). However, there is yet no assessment on the applicability of the previous zonations for the South Atlantic Ocean, as well as the degree of provincialism of marker species.

We revise Campanian and Maastrichtian calcareous nannofossil occurrences, taxonomy and biostratigraphy at selected DSDP and ODP sites in the South Atlantic Ocean (354; 356; 511; 525A; 530A; 661A; 690C; 700B and 1258A). Occurrences of marker species are tied to the paleomagnetic records where possible and we propose new separate zonations for the low-, mid- and high-latitudes and discuss their paleoceanographic significance.

2. Materials and methods

2.1. Site information

Our revised biostratigraphy is based on a quantitative analysis of nine DSDP and ODP sites from different locations of the South Atlantic Ocean (Fig. 1). Important information about each site (locality; water depth; stratigraphic range; main lithologies and number of samples studied) can be seen in Table 1.

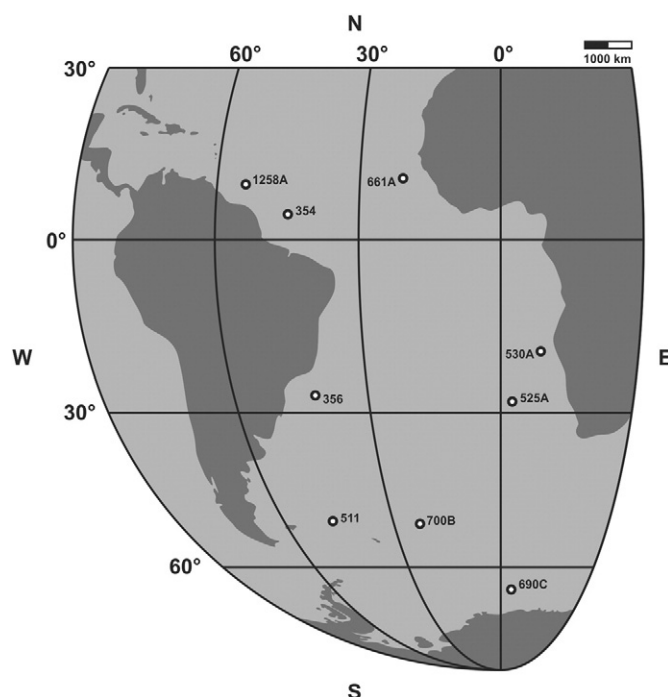


Fig. 1. Location map of sites selected for this study.

2.2. Sampling, preparation and analysis

One sample was taken per section of drillcore, corresponding to a sampling resolution of ~1.5 m. Samples were prepared following the standard smear-slide technique described in Bown and Young (1998).

A quantitative study was performed using a Zeiss Axio Imager A2 microscope at 1000× magnification. At least 300 specimens were counted per sample, followed by the scanning of three more longitudinal traverses (~300 fields of view) for rare taxa missing in the initial counts, indicated in our range charts by “X”. Sometimes, important markers were identified after the counting, denoting species present but do not represent only one specimen.

Preservation of calcareous nannofossils was evaluated under light microscope using qualitative criteria to assess the degree of etching and/or overgrowth, where “good” indicates specimens with little or no etching and/or overgrowth; “moderate” suggest that specimens exhibit moderate etching and/or overgrowth, but still easily recognizable; and “poor” shows specimens with extreme etching and/or overgrowth (Roth and Thierstein, 1972; Roth, 1983).

Although the original taxonomic and biostratigraphical results are available on DSDP and ODP websites, we re-examined 520 samples in order to apply up-to-date taxonomic and biostratigraphic concepts, since most studies were conducted several decades ago. The range charts for each site selected for this study are available as supplementary data Tables S1 to S9, where it is possible to visualize the nannofossil occurrences, preservation and abundances, as well as the biostratigraphic interpretations.

2.3. Taxonomy

The taxonomic identification is based on Perch-Nielsen (1985); Burnett et al. (1998), original descriptions and Nannotax3 (Young et al., n.d. - website that provides important information regarding calcareous nannofossil taxonomy, URL: <http://ina.tmsoc.org/Nannotax3>). We recognized 195 species, also in poorly preserved samples, which are all listed in Appendix 1 (available as Supplementary data) with the ones relevant for biostratigraphic interpretations illustrated in Fig. 2. Some Cretaceous species older than Campanian–Maastrichtian were recognized during the taxonomic analysis, being considered as reworked (e.g., *Braarudosphaera africana*, *Flabellites oblongus*, *Eprolithus eptapetalus*, *Lithastrinus septenarius*, *Nannoconus* sp. and *Assipetra* sp. on Site 530A; *Assipetra* sp. and *Rhagodiscus asper* on Site 356; and *Eprolithus floralis* on Site 661A).

2.4. Biostratigraphic zonations

In order to construct biozonations applicable to the South Atlantic Ocean, we analyzed the position of the first and last occurrences (FO and LO, respectively) of the species within the studied sites. Clear compositional differences were observed at the high-latitude DSDP/ODP Sites 511, 690B, and 700B, when compared to the other locations, confirming the well-known provincialism of the Southern Ocean (Watkins et al., 1996). Mid-latitude Sites 356, 525A and 530A contain similar flora to low-latitude Sites 354, 661A, and 1258A, although it became apparent after analysis of the sequence of bio-horizons and chronostratigraphic comparison that there were significant differences in the timing of the bio-horizons between these regions. We, therefore, propose two further provinces for the low and mid latitudes, based on the sequence of bio-horizons recorded between sites.

We defined bio-horizons for our zonations based on the following criteria: (a) that they occur in the majority of the sites within a given province; (b) that the order of the bio-horizons is consistent among provinces; (c) that each bio-horizon can be correlated to a magnetostratigraphic chronozone; and (d) that the bio-horizons occur in the same chronozone (where this information is available) or so

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