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Original article

Biometry of Upper Cretaceous (Cenomanian–Maastrichtian) coccoliths – a record of long-term stability and interspecies size shifts

Biométrie des coccolithes du Crétacé supérieur (Cénomanien–Maastrichtien) – un enregistrement de stabilité sur le long-terme et changements de tailles interspécifiques

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Abstract

Biometric measurements of Mesozoic coccoliths (coccolith length and width) have been used in short-term biostratigraphic, taxonomic and palaeoecologic studies, but until now, not over longer time scales. Here, we present a long time-series study (∼ 30 million years) for the Upper Cretaceous, which aims to identify broad trends in coccolith size and to understand the factors governing coccolith size change over long time scales. We have generated biometric data for the dominant Upper Cretaceous coccolith groups, *Broinsonia*/*Arkhangelskiella*, *Prediscosphaera*, *Retecapsa* and *Watznaueria*, from 36 Cenomanian–Maastrichtian (100.5–66 Ma) samples from Goban Spur in the northeast Atlantic (DSDP Site 549). These data show that the coccolith sizes within *Prediscosphaera*, *Retecapsa* and *Watznaueria* were relatively stable through the Late Cretaceous, with mean size variation less than 0.7 μm. Within the *Broinsonia*/*Arkhangelskiella* group there was more pronounced variation, with a mean size increase from ∼ 6 μm in the Cenomanian to ∼ 10 μm in the Campanian. This significant change in mean size was largely driven by evolutionary turnover (species origination and extinctions), and, in particular, the appearance of larger species/subspecies (*Broinsonia parca parca*, *Broinsonia parca constricta*, *Arkhangelskiella cymbiformis*) in the early Campanian, replacing smaller species, such as *Broinsonia signata* and *Broinsonia enormis*. Shorter-term size fluctuations within *Broinsonia*/*Arkhangelskiella*, observed across the Late Cenomanian–Turonian and Late Campanian–Maastrichtian intervals, may, however, reflect changing palaeoenvironmental conditions, such as sea surface temperature and nutrient availability.

Keywords: Calcareous nannofossils; Biometry; Late Cretaceous; *Broinsonia*/*Arkhangelskiella* group; DSDP Site 549

Résumé

Les dimensions des coccolithes du Mésozoïque (longueur et largeur) ont été utilisées dans des études biostratigraphiques, taxonomiques et paléoécologiques sur le court-terme mais jusqu'à présent, jamais sur le long-terme. Ici, nous présentons l'étude d'une série chronologique à échelle de temps longue (∼ 30 millions d'années) du Crétacé supérieur, visant à identifier les tendances générales de leur taille et de comprendre les facteurs gouvernant les changements de taille des coccolithes sur une échelle de temps longue. Nous avons généré des données biométriques pour les groupes de coccolithes dominants au Crétacé supérieur, *Broinsonia*/*Arkhangelskiella*, *Prediscosphaera*, *Retecapsa* et *Watznaueria*, sur 36 échantillons du Cénomanien–Maastrichtien (100,5–66 Ma) provenant du Goban Spur dans l'Atlantique Nord-Est (DSDP Site 549). Ces données montrent que la taille des coccolithes appartenant aux groupes *Prediscosphaera*, *Retecapsa* et *Watznaueria* fut relativement stable durant tout le Crétacé supérieur, avec une variation de la taille moyenne inférieure à 0,7 μm. Au sein du groupe *Broinsonia*/*Arkhangelskiella*, les variations furent plus prononcées, avec une augmentation de la taille moyenne de ∼ 6 μm au Cénomanien jusqu'à ∼ 10 μm au Campanien. Ce changement significatif de la taille moyenne fut largement dû aux processus évolutifs (spéciations et extinctions), et en particulier à l'apparition d'espèces/sous-espèces plus larges (*Broinsonia parca parca*, *Broinsonia parca constricta*, *Arkhangelskiella cymbiformis*) au Campanien inférieur,

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remplaçant des espèces plus petites, telles que *Broinsonia signata* et *Broinsonia enormis*. Cependant, les fluctuations à court-terme au sein du groupe *Broinsonia/Arkhangelskiella*, observées aux transitions Cénomanien–Turonien et Campanien–Maastrichtien, pourraient refléter un changement des conditions paléoenvironnementales, telles que la température superficielle des eaux océaniques et la disponibilité en nutriment.

Mots clés : Nannofossiles calcaires ; Biométrie ; Crétacé supérieur ; Le groupe *Broinsonia/Arkhangelskiella* ; DSDP Site 549

1. Introduction

Since Stradner (1963) and Perch-Nielsen (1968) first measured the morphometric features of Mesozoic calcareous nannofossils (coccolith length, coccolith width, ellipticity, etc.), biometry has been applied in a range of different studies, including biostratigraphy (e.g., Girgis, 1987), taxonomy (e.g., Hattner et al., 1980) and palaeoecology (e.g., Bornemann et al., 2003). Some of these studies have used relatively arbitrary biometric limits to aid taxonomic subdivision of otherwise morphologically identical nannofossil taxa (e.g., Wise, 1983; Varol, 1989; Burnett, 1997; Shamrock and Watkins, 2009), while others have applied statistical techniques to discriminate distinct populations of size delineated groups (e.g., Tremolada and Erba, 2002; Mattioli et al., 2004; Fraguas and Erba, 2010). Other studies have investigated the possible environmental forcing of size change, by looking at biometric trends through intervals of significant palaeoceanographic or palaeoclimatic change (e.g., oceanic anoxic event (OAE) 1a: Erba et al., 2010; OAE2: Linnert and Mutterlose, 2013). In some cases, it has been claimed that these records reveal size changes across intervals of environmental change (e.g., *Biscutum* – Erba et al., 2010; *Broinsonia* – Linnert and Mutterlose, 2013; *Discorhabdus* – López-Otálvaro et al., 2012; and *Watznaueria britannica* – Giraud et al., 2006), whereas other studies have shown very little or no change (*Watznaueria* – Bornemann and Mutterlose, 2006).

The majority of these biometric studies are focused on short intervals of palaeoenvironmental change (e.g., OAEs and stage boundaries) and there are no long-term records available for the Cretaceous. A small number of long-term records have been documented for the Cenozoic interval (e.g. Henderiks and Rickaby, 2007; Hannisdal et al., 2012), and the most comprehensive of these highlights the influence of evolutionary controls on coccolith size changes (Herrmann and Thierstein, 2012). Several medium term (10–30 million years) Cenozoic studies have focused on specific taxonomic groups, such as *Reticulofenestra* (Young, 1990) and *Calcidiscus* (Knappertsbusch, 2000). Here, we document the size record of four dominant Cretaceous taxonomic groups, *Broinsonia/Arkhangelskiella*, *Prediscosphaera*, *Retecapsa* and *Watznaueria*, through ~ 30 million years of the Upper Cretaceous, a time interval of considerable environmental change, including OAEs, extreme warmth and the onset of long-term climate cooling (Huber et al., 1995, 2002; Miller et al., 2005; Friedrich et al., 2012). The use of generic groups allows the collection of relatively large amounts of data representing the dominant Cretaceous taxa over long time scales. This enables us to assess the role of intra-generic evolution (species extinctions, originations) and species composition changes, on the size record of nannoplankton. We also present single species data (e.g., *Arkhangelskiella cymbiformis*, *Broinsonia signata*) although these have shorter stratigraphic ranges.

2. Section and material

The study section of Goban Spur (DSDP Site 549) was chosen for its relatively comprehensive coverage of the entire Upper Cretaceous interval (Cenomanian–Maastrichtian) and for the good preservation of calcareous nannofossils. We also have existing quantitative nannofossil assemblage data for this section, providing valuable background information (Linnert et al., 2011). DSDP Site 549 is located 400 km west of Ireland (Fig. 1) (49°05.28′N, 13°05.88′W) at a water depth of 2533 m (De Graciansky et al., 1985a,b). The study interval includes a 59 m thick Middle Cenomanian–Upper Maastrichtian sequence, but core recovery is poor through the Middle Cenomanian–Upper Santonian interval (Fig. 2) (De Graciansky et al., 1985a). An unconformity is present between the Upper Campanian and the Uppermost Maastrichtian cutting out most of the lower, and part of the Upper Maastrichtian (~ 4–5Ma). All the 36 study samples are nannofossil chalks and the calcareous nannofossils are moderately to well-preserved (De Graciansky et al., 1985a; Müller, 1985, Linnert et al., 2011). The site was located at a palaeolatitude of ~ 35°N in the Cenomanian and ~ 40°N in the late Campanian (Voigt et al., 2004, 2008).

3. Methods

3.1. Experimental methods

The samples were processed for calcareous nannofossil study using the settling method of Geisen et al. (1999) adapted from the original description of Beaufort (1991). The biometric work was performed using an Olympus BX51 light microscope with a Colour View II digital camera and the imaging software analySIS®. For each of the 36 samples, 60 specimens of each of the four taxonomic groups (*Arkhangelskiella/Broinsonia*, *Prediscosphaera*, *Retecapsa* and *Watznaueria*) were digitally imaged, a total of 240 specimens per sample. Specimens were chosen by scanning random traverses and all specimens were analysed, up to the total count, excluding those that were broken or heavily overgrown. Coccolith lengths and widths were measured using the measuring tool in analySIS®. The morphometric results were processed for mean values, standard deviations and 95% confidence intervals, using the software Statistica9.1. The terms small (3–5 μm), medium (5–8 μm), large (8 μm–12 μm)