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New insights in the pattern and timing of the Early Jurassic calcareous nannofossil crisis

Marie-Emilie Clémence [a,*], Silvia Gardin [b], Annachiara Bartolini [c]

[a] University of Innsbruck, Institute of Geology, Faculty of Geo- and Atmospheric Sciences, Innrain 52, Innsbruck 6020, Austria
[b] CR2P Centre de Recherche sur la Paléobiodiversité et les Paléoenvironnements, UMR 7207 CNRS, UPMC, MNHN, Sorbonne Université, 4 place Jussieu, 75252 Paris, cedex 05, France
[c] CR2P Centre de Recherche sur la Paléobiodiversité et les Paléoenvironnements, UMR 7207 CNRS, UPMC, MNHN, Sorbonne Université, 8 rue Buffon, CP38 Paris, cedex 05, France

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ABSTRACT

The Toarcian calcareous nannofossils crisis associated with the early Toarcian Oceanic Anoxic Event (T-OAE) in the Early Jurassic period is thought to represent one of the most important biocalcification crises during the Mesozoic, occurring simultaneously with profound disturbance of the carbon cycle. However, the causes are still under debate, particularly with regard to the pattern, timing of the biocalcification crisis, relative roles of intrinsic and extrinsic processes as drivers of the crisis, and also causal mechanisms of the T-OAE.

In this study, a new quantification of Toarcian calcareous nannofossil abundance and size is presented for the Sancerre borehole (Paris Basin, France). Beyond the recognition of a severe biocalcification crisis defined by the major drop in abundance, and the reduction in size of the most important pelagic carbonate producer *Schizosphaerella punctulata*, for the first time, this study proposes an insight into the pace and timing of the nannoplankton crisis. At Sancerre, the carbonate production of the lower Toarcian sediments previously attributed to obliquity forcing of climate allows estimating a duration of ~210 kyr for the biocalcification crisis and of ~120 kyr for the shift towards lower carbon isotope values. The onset of the biocalcification crisis marked by a fertility event lasted ~60 kyr, and the calcium carbonate values remained low for ~150 kyr; the subsequent recovery of carbonate and nannoplankton lasted ~60 kyr and >550 kyr, respectively. Additionally, a link between the biocalcification crisis, the seawater palaeotemperature, and the carbon isotope steps can be demonstrated. This covariance provides compelling evidence of fundamental change in the response of the climatic warming and the carbon cycle systems triggering the biocalcification crisis. These observations indicate that the biocalcification crisis can be regarded as a direct or indirect consequence of a global warming. Moreover, a deficiency of the biological pump is proposed here, as a complementary causal mechanism for explaining the negative carbon-isotope excursion.

1. Introduction

Profound environmental change occurred in the Early Jurassic along with one of the most significant diversification phase in the history of calcareous nannoplankton (Jenkyns, 1988; Bown et al., 2004). At that time, calcareous nannoplankton (coccoliths and nannoliths) and calcareous dinoflagellates were the only planktonic organisms able to bio-calcify in the oceanic photic zone and to participate to both the organic-carbon pump and carbonate counter-pump (Rost and Riebsel, 2004). However, this diversification event starting in the late Pliensbachian is rapidly marked by a carbonate production crisis during the early Toarcian Oceanic Anoxic Event (T-OAE). Marine depositional settings across Europe shows evidence for a near disappearance of shallow-water platforms (e.g., Dromart et al., 1996), a significant drop in calcium carbonate contents in basinal successions and a drastic nannofossil biocalcification crisis (e.g., Mattioli and Pittet, 2004; Tremolada et al., 2005), suggesting a re-organisation of planktonic communities in response to major environmental changes. The T-OAE corresponded to an interval of widespread organic matter burial, global warming and prominent carbon cycle perturbation in the ocean–atmosphere, as testified by a prominent negative carbon-isotope excursion (CIE) measured in bulk rock carbonate, organic matter and in fossil wood (e.g., Jenkyns, 1988; Hesselbo et al., 2007; Suan et al., 2008a; Hermoso et al., 2009).

Assessment of the timing of calcareous nannofossil crisis is a fundamental key point in the understanding of the relative roles of intrinsic (dynamic of the community) and extrinsic (environmental changes) processes as drivers of the crisis, and to decipher causal mechanisms of the T-OAE. Many aspects of calcareous nannofossil crisis have been undertaken, but none have been attempted to estimate its tempo because of a poorly constrained Toarcian timescale (Pálfy et al., 2000; Hinnov and Ogg, 2007) and because the duration of the negative CIE remains still debated (Kemp et al., 2005, 2011; Suan et al., 2008b;

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* Corresponding author. Tel.: +43 512/507 5676.
E-mail address: Marie-Emilie.Clemence@uibk.ac.at (M.-E. Clémence).

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Huang and Hesselbo, 2013). The recent astronomical calibration of the Sancerre core performed by Boulila et al. (2014) along with stable isotopic and biostratigraphic proxy data provide a strong insight into the pace and timing of the nannoplankton crisis.

In this study, quantitative estimates of calcareous nannofossil abundance and size, and palaeoecological analysis from the lower Toarcian sediments of the Paris Basin (France) are presented. These new data, coupled with published geochemical and cyclostratigraphic data (Hermoso et al., 2009, 2012; Boulila et al., 2014) allow addressing significant questions concerning the pattern and timing of the calcareous nannofossil response to T-OAE environmental changes, the drivers of the biocalcification crisis, and the dynamic of *Schizosphaerella*, which was the main pelagic carbonate producer of Early Jurassic oceans. The study is based on core samples from the Sancerre–Couy borehole. The succession provides an exceptionally well-preserved pelagic carbonate which may serve as a suitable archive for micropalaeontological investigations, representing a key stratigraphic framework for this study.

2. The Sancerre Borehole: geological setting and paleogeography of the Paris Basin

During the Early Jurassic, the development and paleogeographic evolution of the epicontinental carbonate platforms of the northern Tethys were largely controlled by extensional tectonics linked to the break-up of Pangea with the opening of the Central Atlantic and Tethys oceans (Fig. 1; Bassoulet and Baudin, 1994). In the Tethyan region, the widespread drowning of carbonate platforms led to progressive invasion of pelagic conditions, typified by the development of deep-water carbonates on subsided continental margins. The northern subtropical margin (~27–35°N) corresponded to a wide north European epicontinental shelf, which was dominated by siliciclastic sedimentation (Bassoulet et al., 1993; Mattioli et al., 2008).

The core material analysed in this study (GPF-Sancerre; 40° 1′ 10.8″ N; 2° 47′ 6″ E; Fig. 1) belongs to the Paris Basin (France). This region was located in the northern margin of the Tethys (30°N; Fig. 1). The integrated ammonite–nannofossil biostratigraphic (Boulila et al., 2014) and lithostratigraphic (Lorenz, 1987) frameworks of the studied borehole are illustrated in Fig. 2, along with geochemical data from Hermoso et al. (2009, 2012). With a thickness of 3000 m, the borehole has provided continuous record from the Carboniferous up to Middle Jurassic strata. The investigated interval is 20 m thick and spans from the upper Pliensbachian *spinatum* zone (357.00 m) to the lower Toarcian *falciferum* zone (336.00 m). The upper Pliensbachian is represented by calcareous siltstones with a high contribution of detrital minerals (illite, chlorite and quartz), mixed with various calcareous particles (Hermoso et al., 2009). The lower Toarcian consists of three distinct organic-rich and laminated intervals (black shales, up to 10% total organic carbon; Hermoso et al., 2009) interrupted by bioturbated marls with low organic content. The first laminated interval occurs in the lowest *tenuicostatum* zone, where TOC increases to 10–12 wt.% (Fig. 2a), and the $\delta^{13}C$ of bulk carbonate ($\delta^{13}C_{carb}$, Fig. 2a) and organic carbon display pronounced negative shifts. Because of the frequent record of tempestites throughout the borehole, the palaeoenvironment is interpreted as a mid-ramp setting, above the storm-wave base, and suggests a palaeodepth of 100–150 m during the early Toarcian (Hermoso et al., 2009).

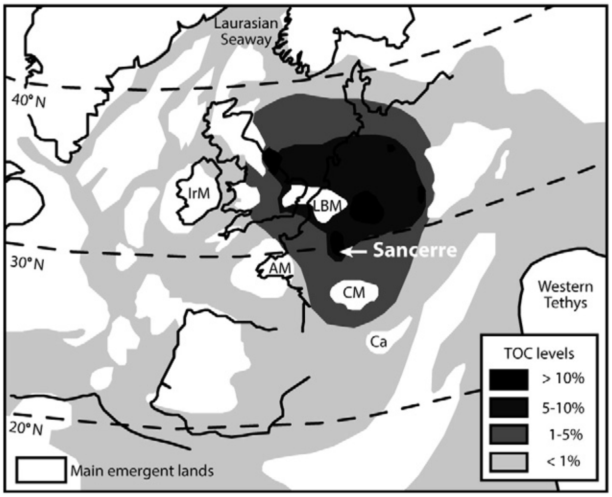

Fig. 1. Paleogeographical map for the Toarcian in NW Europe showing the Sancerre–Couy borehole location (modified after Bassoulet et al., 1993) and the geographic distribution of organic-rich rock (after Baudin et al., 1990). Emerged lands are in white (LBM: London–Babant Massif, AM: Armorican Massif, CM: Central Massif, IrM: Irish Massif, Ca: Calabria).

3. Material and methods

3.1. Quantification of nannofossils abundance and volume

A total of 55 samples were collected from the Sancerre borehole. The corresponding smear slides were prepared following the smear slide preparation technique described by Thibault and Gardin (2006).

In each smear slide, at least 300 nannofossils were counted using a Zeiss Axioplan II polarising microscope (1575×). With the same equipment, the diameter of *Schizosphaerella* was measured on digital images using a CDD-video camera. An error of measurement has been estimated with an accuracy of ±0.1 μm, by repetitive measurement (10 times) of 10 schizospheres (Suan et al., 2008a). The amount of carbonate produced by *Schizosphaerella* ($CaCO_{3schizo}$) was calculated using its absolute abundance and volume. For each stratigraphical level, the mean volumes of *Schizosphaerella* hemivalves were inferred from the mean size of 30 specimens (error bar: ± 0.4 μm) (Table 1; Mattioli and Pittet, 2002; Suan et al., 2008a). The nannolith *Schizosphaerella* represents the biggest and heaviest taxon of the Jurassic (e.g., Mattioli and Pittet, 2002; Erba, 2004; Suan et al., 2008a). For this reason, in this study, *Schizosphaerella* is considered as the most important carbonate producer in the assemblages, and the $CaCO_{3schizo}$ is used to estimate the overall pelagic carbonate production. The relative abundances of the species identified were calculated as percentages. Due to the different affinities of the extinct coccoliths and the nannolith *Schizosphaerella punctulata*, the percentage of each coccolith species was estimated with respect to the total number of coccoliths and the percentage of the nannolith *Schizosphaerella* was estimated with respect to the total calcareous nannofossil content.

3.2. Analytical analysis

Relative abundance data are termed “closed” or “compositional” data because the components or proportions of the taxa are interrelated and subjected to the constant sum constraint. The most important point for statistical analysis of compositional data is that the non-natural (or intrinsic) dependence that characterises them prevents the rigorous application of statistical methodologies to investigate the correlation structure of the data. For this, the “log-centred” transformation was applied to the original matrix, expressed by percentage abundance of data (Aitchison, 2002). This is based on the use of transformed variables instead of the original ones. They are obtained as follows:

$$z_i = \frac{x_i - \text{mean } x_i}{\text{stdev } x_i}$$

where i is a species, mean x_i is the mean of individuals per species, and stdev x_i is the standard deviation of the mean.

The new matrix expressed by the log-centred abundances has been investigated through a principal component analysis (PCA). Due to the different biological affinities of the extinct coccoliths and nannoliths *Orthogonoides hamiltoniae* and *S. punctulata*, only those coccolith species