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Original article

Calcareous nannofossil biostratigraphy (Upper Bajocian–Lower Bathonian) of the Ravin du Bès section (Bas Auran, Subalpine Basin, SE France): Evolutionary trends of *Watznaueria barnesiae* and new findings of "*Rucinolithus*" morphotypes☆

Biostratigraphie à nannofossiles calcaires (Bajocien supérieur–Bathonien inférieur) de la coupe du Ravin du Bès (Bas Auran, Bassin Subalpin, SE France) : tendances évolutives chez Watznaueria barnesiae et nouvelles découvertes de morphotypes du genre « Rucinolithus »

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Abstract

A biostratigraphic study based on calcareous nannofossils was performed on the Ravin du Bès section (Bas Auran area, SE France). Semi-quantitative estimates of total nannofossil and single species abundances showed that calcareous nannofloras are rare to common and their preservation is poor to moderate. The following biohorizons were identified and calibrated to ammonite biozonation: the first occurrence (FO) of *Watznaueria* aff. *W. communis*, the FO of *Pseudoconus enigma*; the FO of "*Rucinolithus*"; the last occurrence (LO) of *Carinolithus magharensis*; the FO of *Stephanolithion speciosum octum* and the FO of *Watznaueria barnesiae*. These results confirm that calcareous nannofossils are good biostratigraphic markers for the Bajocian/Bathonian boundary interval. Moreover, the occurrence of *P. enigma* allows a direct calibration between Tethyan and Boreal nannofossil events and biozones. Morphometric analyses were performed on the *W. communis–W. barnesiae* group in order to quantify changes between the two taxa. The intermediate form *W.* aff. *W. communis* has been identified; it comprises coccoliths very similar to *W. communis*, but with central area length ≤ 0.9 µm. This study allowed the detailed reconstruction of the evolutionary trends from *W. communis* to *W. barnesiae*: the intermediate taxon *W.* aff. *W. communis* appears abruptly in the latest Bajocian and persists after the FO of *W. barnesiae* in the earliest Bathonian. Our results support the model of punctuated equilibrium rather than a phyletic gradualism. The finding of "*Rucinolithus*" morphotypes, very similar to the Cretaceous taxa *R. terebrodentarius* and *R. terebrodentarius youngii*, is intriguing. They might represent nannoliths strongly affected by a recurrent "Lazarus effect" or be diagenetic artifacts or of bacterial bioprecipitation.

Keywords: Calcareous nannofossils; Bajocian/Bathonian boundary; Biostratigraphy; Punctuated equilibrium; "*Rucinolithus*" nannoliths

Résumé

Une étude biostratigraphique basée sur les nannofossiles calcaires a été effectuée sur la coupe du Ravin du Bès (Bas Auran, Bassin Subalpin, SE France). Une analyse semi-quantitative de l'abondance totale et de l'abondance des différentes espèces de nannofossiles calcaires montre que la nannoflore est rare à commune et que sa préservation est mauvaise à moyenne. Différents horizons ont été identifiés et calibrés par rapport à la biozonation des ammonites. Ces horizons sont dans l'ordre stratigraphique : première apparition (FO) de *Watznaueria* aff. *W. communis* ; FO de *Pseudoconus enigma* ; FO de « *Rucinolithus* » ; dernière apparition (LO) de *Carinolithus magharensis* ; FO de *Stephanolithion speciosum octum* ;

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FO de *Watznaueria barnesiae*. Ces résultats confirment que les nannofossiles calcaires sont de bons marqueurs biostratigraphiques pour l'intervalle recouvrant la limite Bajocien/Bathonien. De plus, la première apparition de *P. enigma* permet une calibration directe entre les bioévénements et les biozones à nannofossiles calcaires des domaines téthysien et boréal. Des analyses biométriques ont été réalisées sur le groupe *W. communis–W. barnesiae* afin de quantifier les changements entre les deux taxons. Une forme intermédiaire, *W.* aff. *W. communis*, a été identifiée. Elle comprend des coccolithes très similaires à ceux de *W. communis*, mais avec une aire centrale de taille inférieure ou égale à 0,9 µm. Cette étude permet une reconstruction détaillée des tendances évolutives depuis *W. communis* jusqu'à *W. barnesiae* : le taxon intermédiaire *W.* aff. *W. communis* apparaît brutalement au Bajocien terminal et persiste après la première apparition de *W. barnesiae* au début du Bathonien. Nos résultats supportent plutôt un modèle d'équilibres ponctués qu'un gradualisme phylétique. La découverte de morphotypes de « *Rucinolithus* », très similaires aux taxons du Crétacé, *R. terebrodentarius* et *R. terebrodentarius youngii*, est surprenante. Ces formes pourraient représenter des nannolithes fortement affectés par un « effet Lazare » récurrent, ou des artéfacts d'origine diagénétique, ou des bioprécipitations d'origine bactérienne.

Mots clés : Nannofossiles calcaires ; Limite Bajocien/Bathonien ; Biostratigraphie ; Équilibres ponctués ; Nannolithes de « *Rucinolithus* »

1. Introduction

In the Bas Auran area (Digne-Barrême, SE France), the Middle Jurassic succession, consisting of a thick and well-exposed sequence of limestones, marlstones and shales, belongs to the Sub-Mediterranean province of the Tethyan Domain (Fernández-López et al., 2007; Pavia et al., 2008). It has been the focus of several detailed lithostratigraphic and biostratigraphic investigations due to the exceptional exposures and abundance of fossils. The Digne-Barrême area is one of the most important sites for ammonite zonations of the Bajocian and Bathonian stages (e.g., Sturani, 1967), and ammonites have been extensively used for global bio-chronostratigraphic correlations of the Bajocian/Bathonian boundary (Fernández-López, 2007; Pavia et al., 2008).

In general, calcareous nannofossils are proved to be very useful for the biostratigraphy of Jurassic successions (Perch-Nielsen, 1985; Bown, 1987, 1996; Bown et al., 1988; De Kænel et al., 1996; Bown and Cooper, 1998; Mattioli and Erba, 1999), reaching a resolution higher than ammonites in some Lower-Middle Jurassic intervals. The Ravin du Bès section has been recently proposed as formal candidate of Global Boundary Stratotype Section and Point (GSSP) for the base of Bathonian stage (Fernández-López et al., 2007). Calcareous nannofossils are common in the Bajocian–Bathonian interval of the Digne-Barrême area and have been investigated to further characterize the Bajocian/Bathonian transition and correlate the Sub-Boreal province with the Mediterranean province (Erba, 1990b).

The objectives of this study are:

- the biostratigraphic characterization based on calcareous nannofossils of the Upper Bajocian to Lower Bathonian interval of the Ravin du Bès section;
- the calibration of nannofloral bioevents against ammonite biozones proposed by Sturani (1967), Pavia (1973), Fernández-López (2007) and Pavia et al. (2008);
- the detailed documentation of the evolutionary transition from *Watznaueria communis* to *Watznaueria barnesiae* in the Bajocian/Bathonian boundary interval;
- the first documentation of "*Rucinolithus*" nannoliths in the Jurassic.

2. Geological setting and lithology

The study area is located in the French Subalpine Basin, corresponding to a gulf of the north-western margin of the Tethys Ocean (Fernández-López et al., 2007; Fig. 1). During the Middle Jurassic, the basin margin was a transitional area between the epicontinental sea of the Paris Basin and the deep Piedmont oceanic domain (Lemoine, 1984, 1985). In the Middle-Late Jurassic, the maximum depth of the central part of the basin was probably about 300–500 m (Ferry, 1990; Olivero, 2003, 2008). The Ravin du Bès section (Bas Auran Area) is located in southeastern France, in the "Alpes de Haute Provence", some 25 km at South-Southeast of Digne-les-Bains (Fig. 2). The studied section extends over 13 m in thickness and ranges from the *Bonfordi* Subzone (*Parkinsoni* Zone, Upper Bajocian) to the *Tenuiplicatus* Subzone (*Algerinus* Zone, Lower Bathonian; Fernández-López et al., 2007; Pavia et al., 2008).

It is a hemipelagic succession, showing no stratigraphic gaps or hiatuses. It is characterized by "*Calcaires à Cancellophycus*" consisting of a thick sequence of black to grey limestones alternating with marlstones (Graciansky et al., 1982; Olivero and Atrops, 1996). In the Ravin du Bès section, and in general in the Bas Auran Area, disconformities, synsedimentary or tectonic disturbance and alteration by metamorphism are absent (Fernández-López, 2007; Fernández-López et al., 2007).

3. Material and methods

3.1. Biostratigraphy

Nannofossil biostratigraphic investigation was performed on 59 samples of limestone and marlstone (approximately every 20 cm). Simple smear slides were prepared for both lithologies, using standard techniques without centrifuging cleaning and concentration in order to retain the original sediment composition. A few milligrams of powdered sediment were fixed on a glass slide with Norland Optical Adhesive. Calcareous nannofossils were investigated using a light polarizing microscope, at 1250 × magnification. Semiquantitative estimates of total abundance (number of nannofossils/