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Maastrichtian–basal Paleocene charophyte biozonation and its calibration to the Global Polarity Time Scale in the southern Pyrenees (Catalonia, Spain)

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ABSTRACT

A new charophyte biozonation for the non-marine Maastrichtian–lowermost Paleocene deposits in the South-Eastern Pyrenean Vallcebre Basin is proposed and calibrated to the Global Polarity Time Scale (GPTS) using magnetostratigraphic data. Planktonic foraminifera associated with charophyte assemblages provide maximum ages for correlation between non-marine and marine biostratigraphic zonations. The new charophyte biozonation is intended to be useful for terrigenous floodplain facies (red beds) with poorly developed lacustrine intervals and strong palaeoecological constraints for the development of charophytes. The taxonomy of charophytes was revisited and two new species were defined, *Microchara nana* Vicente and Martín-Closas and *Peckichara serrata* Vicente and Martín-Closas. Sedimentological analyses carried out in parallel with taphonomic observations allow us to infer the palaeoecological constraints of charophyte species. The new biozonation encompasses three biozones for the late Campanian–early Paleocene interval. The partial range biozone of Peckichara cancellata starts in chron C32r (~73.91 Ma) according to previous studies, and extends its upper limit to chron C31r, with an age of ~69.90 Ma in the Vallcebre Basin. The new Microchara punctata local biozone includes biozones of Septorella ultima (upper part), Microchara cristata and Peckichara sp. 1 (lower part) previously defined by Feist in Riveline et al. (1996). Some of these biozones were poorly characterized or were based on species with strong palaeoecological constraints. The lower Danian is characterized by the biozone of Peckichara toscarensis, replacing the previous biozone of Peckichara llobregatensis. The latter species was found to occur in the Maastrichtian.

1. Introduction

Calcified charophyte fructifications (gyrogonites and utricles) are well preserved in the fossil record of non-marine deposits dating from the Silurian (Feist et al., 2005) and their relatively high evolutionary rates make them an appropriate biostratigraphic tool in non-marine deposits. Indeed, the charophytes of the Upper Cretaceous and Paleocene deposits of Europe have long been used to characterize the Cretaceous/Paleogene (K/Pg) boundary. Following the pioneering biostratigraphic studies of Grambast (1962, 1964) and Massieux et al. (1979) in southern France, intensive work was carried out in the southern Pyrenees to establish a formal charophyte biozonation. The first biostratigraphic studies by Feist and Colombo (1983) and Médus et al. (1988) were followed by the proposal of the first local biozonation that was calibrated to the GPTS using palaeomagnetic data by Galbrun et al. (1993) in the Fontllonga section, Àger Basin (Serres Marginals thrust sheet). This section was later considered as a reference section for charophyte biostratigraphy and the results obtained there were crucial for the first consensus charophyte biozonation for the Upper Cretaceous–lower Paleogene at the European scale defined by Feist in Riveline et al. (1996) and Feist in Hardenbol et al. (1998). Five charophyte biozones (Peckichara cancellata, Septorella ultima, Microchara cristata, Peckichara sp. 1 and Peckichara llobregatensis), were proposed to characterize the Maastrichtian and early Danian. Since then, this biozonation has been poorly used and most

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biostratigraphic studies have been based directly on the assemblage of particular charophyte species (Mayr et al., 1999; López-Martínez et al., 2001). The Upper Cretaceous charophyte biozonation proposed by Feist in Riveline et al. (1996) needs to be improved in a number of ways. Thus, the S. ultima biozone has a poorly known biostratigraphic range due to the discontinuous occurrence and unknown palaeoecological requirements of the index species. Other biozones remain poorly defined, such as the M. cristata zone, identified solely by the first and last appearances of the species from overlying and underlying zones respectively, and finally the Peckichara sp. 1 zone, which is obviously lacking taxonomic precision.

Here we present a new local biozonation for the Pyrenean Upper Cretaceous–lowermost Paleocene that combines the results from Galbrun et al. (1993) in the Fontllonga section (Àger Basin, Central South Pyrenees) with own results in the Vallcebre Basin (Eastern Pyrenees), taking into account previous data from this basin by Feist and Colombo (1983) and Médus et al. (1988). The proposed biozonation intends to improve the weak-points of the biozonation proposed by Feist in Riveline et al. (1996) for the Upper Cretaceous. Our data were obtained in the same sections and beds that were characterized magnetostratigraphically by Oms et al. (2007), thus allowing us to calibrate the new biozonation against the GPTS. Some samples supplied abundant planktonic foraminifera, providing additional information about minimum ages. The new biozonation takes into account the palaeoecological constraints of charophyte species, shedding light on the use of charophyte biozones in non-lacustrine environments such as floodplains, which were very common in the continental Upper Cretaceous of Eurasia and North America.

2. Material and methods

Three sections of the Upper Cretaceous of the Vallcebre Basin, Pedraforca thrust sheet-Eastern Pyrenees, were sampled systematically (Fig. 1) to identify the charophyte assemblages of the Lower Red Unit: Mina Tumí (42° 12′ 3.64″ N, 1° 47′ 22.17″E base and 42° 12′ 12.91″N, 1° 47′ 13.26″E top coordinates), Coll de Pradell (42° 12′ 11.06″N, 1° 46′ 13.56″E base and 42° 12′ 19.12″N, 1° 46′ 14.99″E top coordinates) and Cal Borni (42° 12′ 6.53″N, 1° 48′ 17.00″E base and 42° 12′ 8.10″N, 1° 48′ 17.73″E top coordinates). These three sections are correlated with each other and with the Fumanya Sud section, which was previously studied by Villalba-Breva and Martín-Closas (2011).

Gyrogonites and utricles were obtained by disaggregating a normalized weight of 3 kg of variegated claystones and siltstones in a solution of water and hydroxide peroxide (H_2O_2). Sodium carbonate was added in some cases to deflocculate the clay. The sieves used during the process had mesh sizes of 1, 0.5 and 0.2 mm. To eliminate the possibility of contamination, the sieves were cleaned, dried and submerged in methylene blue before each sample was washed. Hand-picking of the fructifications was done using a Wild M5A binocular stereo microscope. Specimens were cleaned using EDTA (6%) to eliminate the residual particles or cleaned with ultrasound. Thin sections of limestone bed were prepared for microfacies analyses and studied under a Motic BA310 microscope. These sections were ca. 30 μm thick and were cut parallel with the bedding surface. The disaggregated samples were quantitatively analysed to give the relative abundance of charophytes in the section. About 100 charophyte gyrogonites and utricles obtained from non-consolidated samples were measured for biometric purposes using a Motic BA310 stereo microscope with the help of Motic Images Plus 2.0 ML software. Selected fossil remains were photographed using a Quanta 200 Scanning Electron Microscope (SEM) at the Serveis Cientificotècnics of the University of Barcelona. All material is housed in the collections of the Departament d'Estratigrafia, Paleontologia i Geociències Marines (University of Barcelona), with the exception of the type material, which is stored in the Museu de Geologia del Seminari Conciliar de Barcelona.

For planktonic foraminifera studies, the samples were disaggregated in water with diluted H_2O_2 for 4 h. The suspension was then washed through a 100 μm-mesh sieve and the >100 μm fraction oven-dried at 50 °C. The disaggregated samples were semi-quantitatively analysed to give the relative abundance of planktonic foraminifera, which was recorded as abundant, common or rare. Representative specimens of all taxa were fixed to a standard 60-square micropalaeontological slide to provide a permanent record. Some specimens were selected for scanning electron microscopy (SEM) analysis, using a JEOL JSM 6400 SEM at the Microscopy Service of the Universidad de Zaragoza (Spain). All residues, images and the specimens themselves are stored in the Departamento de Ciencias de la Tierra of the Universidad de Zaragoza (Spain).

3. Geological setting

The Pyrenees were formed due to the collision between the Iberian and European plates from the Campanian to the Oligocene. This collision resulted in the formation of an Alpine fold-thrust running east to west alongside northern Spain (Muñoz et al., 1986). The anticlockwise rotation of Iberia and the oblique collision between the two plates determined the first closing and continentalization of the South Pyrenean basin in the Late Cretaceous (Capote et al., 2002). The deposition during that period shows a general marine regression progressing from east to west (Mey et al., 1968; Rosell et al., 2001), with a south to north component (Villalba-Breva and Martín-Closas, 2013). As a result of thrusting, a number of small basins or depocentres were individualized in the South Pyrenean basin during the Late Cretaceous and were later included in Alpine thrust sheets forming strongly asymmetrical synclines. These are, from east to west, the Vallcebre, Coll de Nargó and Tremp-Graus basins, the latter is bordered to the south by the Àger Basin (Fig. 1A). The sections studied here are located in the Vallcebre Basin, within the allochthonous unit of the Lower Pedraforca thrust sheet (Muñoz et al., 1986).

The Upper Cretaceous–lower Paleocene non-marine clastic materials belong to the so-called "Garumnian" facies in classical regional studies (Leymerie, 1862). A number of formations were created later to subdivide formally the Garumnian, such as the Tremp Formation in the Tremp-Graus Basin (Mey et al., 1968). The Garumnian was also divided by Rosell et al. (2001) into four lithological units, which are from base to top (1) the transitional marine to lacustrine Grey Unit, (2) the fluvial Lower Red Unit, (3) the lacustrine Vallcebre Limestone Formation and finally (4) the fluvial Upper Red Unit. The K/Pg boundary was identified near the top of the Lower Red Unit (Rosell et al., 2001; López-Martínez et al., 2006; Oms et al., 2007). Above the Garumnian units the lower Eocene *Alveolina* limestone is the most conspicuous rock at the regional scale.

In the Vallcebre Basin the Garumnian overlies the marine nearshore deposits of the Terradets Formation, and the Grey Garumnian begins with a succession of grey marl followed by alternating lignite and charophyte limestones (Fig. 1B). These rocks indicate evolution from a brackish mud flat and lagoon to freshwater lacustrine and palustrine deposits (Villalba-Breva et al., 2012). The Lower Red Unit is the main subject of this study. In the Vallcebre Basin it comprises up to 400 m of claystones and siltstones, with the development of palaeosoils with variegated grey, ochre, purple and reddish colours. The Lower Red Unit has been attributed to sedimentation mainly in marginal lagoon and fluvial floodplain depositional settings (Rosell et al., 2001;