Cretaceous Research 45 (2013) 25–42

Contents lists available at ScienceDirect

Cretaceous Research

journal homepage: www.elsevier.com/locate/CretRes

Review paper

Astronomical calibration of the Valanginian "Weissert" episode: The Orpierre marl–limestone succession (Vocontian Basin, southeastern France)

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A R T I C L E I N F O

Article history:
Received 21 December 2012
Accepted in revised form 16 July 2013
Available online 27 August 2013

Keywords:
Positive carbon isotope excursion
Magnetic susceptibility
Cyclostratigraphy
Valanginian
Calcareous nannofossils
Vocontian Basin

A B S T R A C T

A high-resolution, biostratigraphic (calcareous nannofossils, calpionellids), chemostratigraphic (C-isotope) and cyclostratigraphic (magnetic susceptibility) study was performed on the marl–limestone alternations of the Upper Berriasian–Valanginian Orpierre section, deposited in the hemipelagic setting of the Vocontian Basin (SE France). The main aims of this study were to detect orbital forcing, to estimate the duration of the Valanginian "Weissert" episode, and to discuss the palaeoenvironmental implications. Detailed calcareous nannofossil biochronology allowed the recognition of Upper Berriasian–Lower Hauterivian biohorizons. The general trends of the $\delta^{13}C$ curve and the major positive C-isotope excursion (amplitude of 1.8‰) recorded at the Orpierre section are very similar to those found in other sections worldwide. Spectral analysis applied on high-resolution magnetic susceptibility (MS) variations coupled with frequency ratio method reveals a strong cyclic pattern related to the Earth's orbital parameters (precession, obliquity and eccentricity). The prominent 405 kyr eccentricity cycle in the MS signal and has been used as a geochronometer to time calibrate the section. The duration of the Weissert episode was estimated as 2.08 Myr. This duration is coherent with those obtained from the Umbria Marche Basin (~2.3 Myr) and from the Angles section (~2.14 Myr). Durations of more than 2 Myr suggest that a long perturbation in the dynamic of the global carbon cycle that is not compatible with the rapid and intense volcanic activity. Our cyclostratigraphic study indicates a minimal duration of 4.29 Myr for the Valanginian stage. The comparison between the MS signal at Orpierre and the spectral gamma-ray signal recently obtained in two composite sections of the Vocontian Basin allows to propose a revised duration for the Valanginian stage of 4.695 Myr instead of 5.08 Myr.

1. Introduction

The Early Cretaceous is marked by widespread palaeoceanographic and palaeoclimatic changes. Most especially, significant global changes occurred during the Valanginian stage. This time interval was featured by a perturbation in the global carbon cycle, recorded as a positive carbon isotope excursion (CIE) in both marine and continental environments (amplitude: 1.5–2‰) (Cotillon and Rio, 1984; Weissert et al., 1985; Föllmi et al., 1994; Adatte et al., 2001; Erba et al., 2004; Gröcke et al., 2005; Duchamp-Alphonse et al., 2007; Westermann et al., 2010; Nunn et al., 2010; Kujau et al., 2012) and known as the "Weissert" event or episode (WE) (Weissert, 1989; Erba et al., 2004; Föllmi, 2012). The Weissert episode was also characterized by a widespread biocalcification crisis, and biotic turnovers (Schlager, 1981; Föllmi et al., 1994; Graziano, 1999; Danelian and Johnson, 2001; Bersezio et al., 2002; Erba et al., 2004; Duchamp-Alphonse et al., 2007; Bornemann and Mutterlose, 2008; Föllmi, 2012), associated with global warming and elevated CO_2 levels in the ocean–atmosphere system (Duchamp-Alphonse et al., 2011; Morales et al., 2013). According to

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0195-6671/$ – see front matter
http://dx.doi.org/10.1016/j.cretres.2013.07.003

some authors (Lini et al., 1992; Föllmi et al., 1994; Weissert et al., 1998) such perturbations would be linked to the intensification of the Paraná–Etendeka volcanism that occurred between 135.6 and 134.4 Ma according to the last geochronological data (Thiede and Vasconcelos, 2010; Janasi et al., 2011; Pinto et al., 2011).

However, large discrepancies in both absolute ages and relative duration of the Valanginian stage still remain among the different geologic time scales (Odin, 1994; Channell et al., 1995; Gradstein et al., 2004; Ogg et al., 2008; Gradstein et al., 2012). Thus, the duration of the Valanginian stage ranges between 3.8 $\pm$ 3 and 8 $\pm$ 6 Myr. A recent astronomical calibration of the Valanginian stage from sections in the Vocontian Basin provided a duration of 5.08 Myr (Martinez et al., 2013).

According to the previously cited geologic time scales, the intensification of the Paraná–Etendeka eruption occurred either during the Berriasian, Upper Valanginian or the Hauterivian. Such estimations are based on the spreading-rate model of the composite Hawaiian M-sequence (Pacific plate) that served to calculate the duration of each anomaly relative to M0r through M44r. The absence of (i) reliable radiometric ages, and (ii) a robust numerical model for Chrons contribute significantly to explain such discrepancies and more generally the uncertainties observed in the temporal calibration of the Early Cretaceous. It is thus difficult, if not impossible to link the "Weissert" episode to any magmatic activity. Particularly, Martinez et al. (2013), through an astronomical tuning of the Valanginian, show that timings of the WE and the Paraná–Etendeka volcanism are different, and thus causal link between them appears unlikely.

Numerous studies have focused on the palaeoenvironmental changes during this episode, but only a few of them attempted to estimate the duration of the CIE (Erba et al., 2004; Sprovieri et al., 2006; Gréselle et al., 2011). In order to better understand the causes and consequences of these geological processes, it is crucial to provide a duration for the "Weissert" CIE. Due to the significant developments in cyclostratigraphic studies in the last decade, astronomical calibration of Mesozoic sequences when coupled with robust biostratigraphic and/or magnetostratigraphic framework is now possible, that have significantly redounded to refine the geologic time scale (e.g., Hinnov and Ogg, 2007).

Palaeoclimatic proxies are frequently used to detect the orbital forcing in the sedimentary series. In particular magnetic susceptibility (MS) constitutes a powerful tool for detecting palaeoclimatic change (e.g. Weedon et al., 1999) and has successfully been used to estimate the duration of Mesozoic strata (e.g. Early Kimmeridgian, Boulila et al., 2008a; Early Oxfordian, Boulila et al., 2008b; Maastrichtian, Husson et al., 2011; Early Hauterivian, Martinez et al., 2012).

We studied a new reference section (Orpierre) located in the central part of the Vocontian Basin (southeastern France) with the aim to (i) detect orbital forcing in the Orpierre marl/limestone alternations using MS variations, (ii) astronomically calibrate the duration of the Weissert episode, and (iii) discuss its palaeoenvironmental implications. We carried out a cyclostratigraphic study using high-resolution sampling and magnetic susceptibility (MS) measurements at Orpierre, and established an astronomical calibration of the whole section. Then, using whole-rock stable carbon isotope data ($\delta^{13}C$ values in ‰ VPDB), we identified the Weissert episode, and inferred a duration for the CIE. We also provide a new temporal framework for the Valanginian stage and compared our results with previous studies.

2. Geological setting and stratigraphic framework

2.1. Geological setting

During the Early Cretaceous the Vocontian Basin (Southeastern France) was an area of hemipelagic sedimentation situated on the northwestern margin of the Tethyan Ocean (Cotillon, 1984; Dercourt et al., 1993) (Fig. 1A). The basin, located at a palaeolatitude of 25–30°N (Dercourt et al., 1993), was characterized by a palaeodepth of a few hundred metres (Ferry, 1976; Donze, 1979; Wilpshaar et al., 1997). It was surrounded by three carbonate platforms, the Jura–Dauphinois Platform to the north, the Ardèche Platform to the west and the Provencal Platform to the south-west (Dercourt et al., 1986; Masse, 1993) (Fig. 1B). It was connected to the Ligurian Tethys to the east and to the Boreal basins through the Polish corridor allowing faunal and floral exchanges between the two realms (Mutterlose, 1991; Williams and Bralower, 1995) (Fig. 1A).

During the Early Cretaceous period, the weathering of Mid-European continents surrounding the basin was the main source of terrigenous material (Adatte, 1988; Bréhéret, 1994). These emergent areas were represented by the Briançonnais terrain to the east, by the Ardenaise area to the north, by the Massif Central to the west, and by the Corso-Sarde block to the south. Thus, sedimentation processes in the Vocontian Basin were mainly influenced by changes in the mode and intensity in weathering on these emergent areas and in the biogenic carbonate production (Reboulet et al., 2003; Erba, 2004; Duchamp-Alphonse et al., 2007, 2011; Gréselle et al., 2011; Kujau et al., 2012). Thus, sediments in the basin were characterized by mixed biogenic carbonate/terrigenous materials recorded as typical marl–limestone couplets (Cotillon et al., 1980; Duchamp-Alphonse et al., 2007).

2.2. Stratigraphic framework

The Orpierre section is located in the region of the "Hautes Alpes", in SE France. This section, firstly described by Moullade (1966), lies in the central part of the Vocontian Basin in a hemipelagic to subpelagic environment (Fig. 1C). It has been considered as a reference section due to its apparent continuous sedimentation (Moullade, 1966). However, contrary to the largely studied Angles or La Charce sections only few authors provided a biostratigraphic framework of this section (Moullade, 1966; Thierstein, 1973). The scarce occurrence of ammonoid fauna compared to the more proximal sections of Angles and La Charce may in part explain this lack of attention.

The lithology and the compiled biostratigraphy of the section are provided in Fig. 2. The outcropping section is characterized by a 250-m thick continuous succession of hemipelagic marl/limestone alternations ranging in age from the Upper Berriasian to the Lower Hauterivian. The deposits are occasionally interrupted by sedimentary perturbations (slumps). Three slumps are recognized along the section: (i) between 90.67 and 94.94 m, (ii) between 200.56 and 202.90 m, and (iii) between 224.91 and 229.21 m. The interval ranging from the Upper Berriasian to the Lower Valanginian is characterized by regular marl–limestone alternations consisting of thick limestone beds (up to 30 cm) and carbonate-rich marls. Up section (100–205 m interval), the lithology is characterized by a progressive change to a more marly interval marked by thinner beds (a few centimetres). The well-known "*Faisceau médian*" and "*Faisceau à Nicklesi*" observed at a regional scale in the Vocontian Basin, are recognized at 138 and 160 m respectively (Cotillon et al., 1980). The top of the section (Upper Valanginian–Lower Hauterivian) is marked again by regular marl/limestone alternations.

3. Materials and methods

3.1. Biostratigraphy

3.1.1. Calcareous nannofossils

A total of 110 samples were investigated through the section for the biostratigraphic study of the calcareous nannofossils. Bulk