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Obliquity pacing of the hydrological cycle during the Oceanic Anoxic Event 2

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A B S T R A C T

The Oceanic Anoxic Event 2 (OAE2, ca. ∼93.5 Ma) represents a major phase of environmental change during the Mesozoic, and is associated with a pronounced positive excursion in the carbon-isotope record. Short-term climate oscillations within the OAE2 are recorded as Milankovitch cycles, which have been used to establish a precise temporal framework for the OAE2. However, few studies discuss the sedimentary expression of Milankovitch cycles during the OAE2, and its paleoenvironmental implications. Here we present carbonate and organic-carbon isotope data from a biostratigraphically well-dated, organic-rich OAE2 interval in a sedimentary succession outcropping in the Briançonnais Domain at Roter Sattel (Fribourg Prealps, Switzerland). We sampled the OAE2 interval (4.28 m) for proxies of detrital sediment quantification (Al, Ti, magnetic susceptibility) at ultra-high resolution (1 cm). Time-series analysis of multiple detrital proxies permits the construction of an orbital timescale for the OAE2 based, for the first time, on the stable 173 kyr (s3–s6) obliquity modulation cycle. The resulting OAE2 orbital timescale at Roter Sattel is consistent with previous timescales obtained in the Western Interior Basin, and in southern Tibet (China). Our cyclostratigraphic results show an unusually strong obliquity signal during the initiation of OAE2. Previous studies have demonstrated that the onset of OAE2 was associated with magmatic pulses coupled with increases in atmospheric pCO_2, followed by an overall, gradual drawdown of CO_2. Accordingly, we suggest that detrital input during the OAE2 was the result of intensified continental weathering related to magmatic activity, the substantially release of greenhouse gases, and an accelerated hydrological cycle modulated by obliquity cycles.

1. Introduction

The Cenomanian–Turonian (C–T) boundary interval recorded one of the most significant oceanic anoxic events (OAEs) of the Mesozoic. Widespread organic-rich deposits such as the Bonarelli level in Italy are the sedimentary hallmark of OAE2 (e.g., Jenkyns, 2010). The corresponding δ^{13}C records in carbonate and organic carbon of marine and continental origin are characterized by a >2‰ positive excursion (CIE) (Paul et al., 1999; Tsikos et al., 2004; Jarvis et al., 2011). The OAE2 is accompanied by profound changes in the ocean–atmosphere system, which includes intensified greenhouse conditions (Huber et al., 2002), and extinction and turnover of marine biota (Leckie et al., 2002).

Numerous cyclostratigraphic studies has been conducted on various sedimentary successions through the C–T boundary interval in order to constrain the duration of the OAE2 and better characterize the CIE (Prokoph et al., 2001; Sageman et al., 2006; Voigt et al., 2008; Meyers et al., 2012a, 2012b; Ma et al., 2014; Eldrett et al., 2015; Batenburg et al., 2016; Li et al., 2017; Kuhnt et al., 2017). Cyclic variations in the sedimentary OAE2 records has been related to Earth's orbital parameters (precession, obliquity, eccentricity), and the cyclostratigraphically inferred duration estimates of OAE2 range from ∼320 to ∼820 kyr, using slightly different definitions of the CIE (e.g., Prokoph et al., 2001; Voigt et al., 2008; Ma et al., 2014; Batenburg et al., 2016; Li et al., 2017). A number of these studies suggest that orbital forcing played a crucial role in triggering oceanic anoxia during the OAE2 (e.g., Mitchell et al., 2008; Meyers et al., 2012a; Batenburg et al., 2016; Kuhnt et al., 2017).

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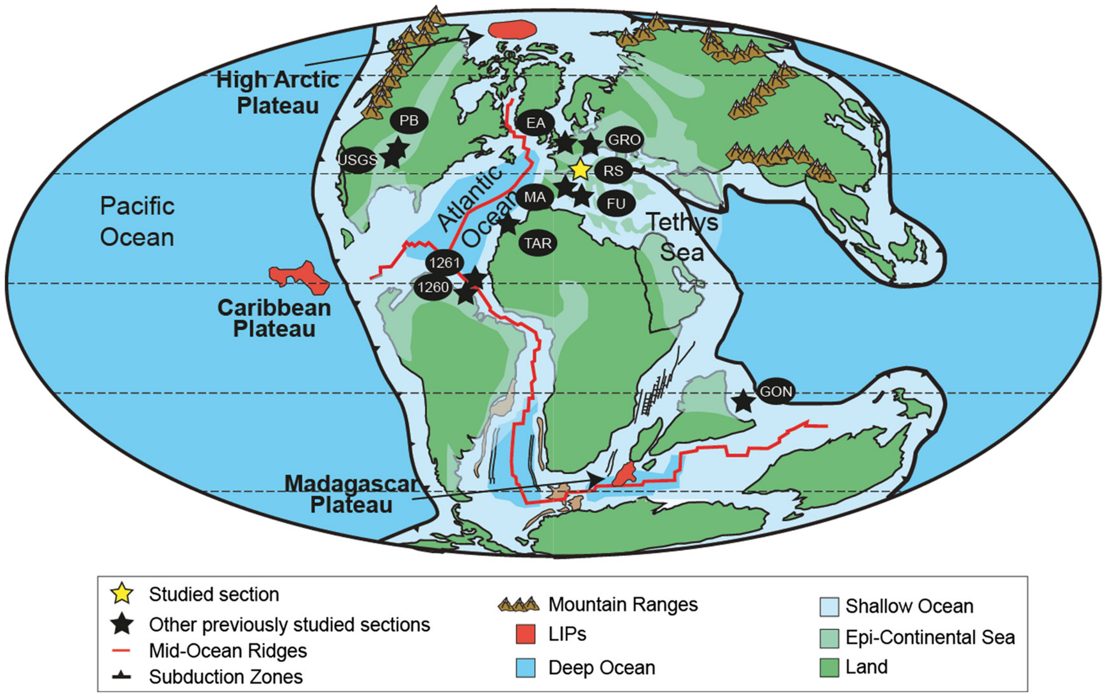

Fig. 1. A palaeogeographic reconstruction during the Cenomanian–Turonian boundary time interval, showing the locations of both the studied section and other key sections, as well as of Caribbean, Madagascar, and High Arctic LIPs (modified after Takashima et al., 2006). GON: Gongzha, TAR: Tarfaya, FU: Furlo, MA: Manilva, PB: Pueblo, RS: Roter Sattel, EA: Eastbourne, and GRO: Gröbern borehole. (For interpretation of the colours in the figure(s), the reader is referred to the web version of this article.)

Mitchell et al. (2008) used the Laskar et al.'s (2004) solution to show that the OAE2 coincided with an interval of unusually weak insolation variation in the long-period orbital cycles (minimum in amplitude), which they predicted to occur with a periodicity of 2.4 Myr. Recently, Batenburg et al. (2016) used the more recent astronomical solution of Laskar et al. (2011), and suggested that the exact timing of the major carbon cycle perturbation may be linked to a maximum in the 405-kyr eccentricity cycle that impacts seasonal variability. Similarly, in the Tarfaya Basin (southern Morocco), Kuhnt et al. (2017) used multiple paleoclimate proxies calibrated with the age model of Meyers et al. (2012a) and correlated with recent astronomical solutions (Laskar et al., 2011). They suggested obliquity forcing in the lower part of OAE2. However, these results were not the outcome of direct observation, but based on a coincidence between the onset of the event and Earth's orbital variations (minimum/maximum) observed in the astronomical solution.

Meyers et al. (2012a) is the only study that has directly observed the dominance of the obliquity cycle in the upper part of the CIE in Proto-North Atlantic sites (including the Tarfaya Basin) and across a latitudinal transect. They suggested that high-latitude intermediate/deep-water formation affected oxygen availability and the development of organic-rich/organic-poor sediment cycles, expressed as ventilation cycles. However, from Tibetan records, Li et al. (2017) have suggested a weak obliquity signal, thus discarding the potential influence of high-latitude climate on the northern Indian plate.

Consequently, the establishment of a precise astronomical timescale for the OAE2 is crucial for the assessment of the timing and duration of the associated geological processes (Meyers et al., 2012b), but also for deciphering the differential expression of astronomical forcing, which may reflect specific responses of continent–ocean processes to global paleoenvironmental perturbations (Meyers et al., 2012b; Boulila and Hinnov, 2017). Here we use highly resolved (1 cm, ∼2.5 kyr) detrital proxy data (magnetic susceptibility, Al and Ti contents) along with carbonate and organic ($\delta^{13}C_{carb}$, $\delta^{13}C_{org}$) data from an organic-rich OAE2 interval in the reference section of the Briançonnais domain at Roter Sattel (Fribourg Prealps, Switzerland). The objectives of this study are to (i) detect orbitally-forced detrital cycles in the Roter Sattel section, (ii) use the detected orbital cycles in order to estimate duration of the OAE2, and (iii) explore the dominance of the obliquity cycle across the OAE2 interval in the Tethyan realm and its implications for paleoenvironmental change.

2. Material and methods

2.1. Material

The Briançonnais domain, which represents an important structural element of the western and Ligurian Alps, is interpreted as a terrane or microcontinent (Stampfli, 1993). During the Late Jurassic–Early Cretaceous, it separated from the southern European-northern Iberian margin due to the progressive formation of the northern Pennic Valais Basin (Stampfli, 1993) (Fig. 1).

The Roter Sattel section is located in the "Prealps Médianes Plastiques" (Fribourg Prealps, 46°35′09.8″N–7°15′19.3″E) and is characterized by 68 m of continuously exposed hemipelagic marl/limestone alternations of latest Barremian to earliest Turonian age, interbedded with three organic-rich intervals (Strasser et al., 2001). The temporal framework is based on planktonic foraminiferal assemblages and carbon-isotope stratigraphy (Strasser et al., 2001).

The Cenomanian/Turonian boundary sequence is a 4.28 m thick at Roter Sattel. The lower part is composed of light-white massive carbonate beds. The middle part corresponds to the Bonarelli level and is characterized by a 2.8 m thick interval of laminated organic-rich sediments (TOC values up to 6 wt.%; Strasser et al., 2001) alternating with dark grey siliceous marl, diatoms, and radiolarite (Fig. 2). The upper part consists of alternations of grey marly limestone with white massive limestone beds. The C–T boundary interval was continuously sampled from 0 to 4.28 m at a sampling step of 1 cm.