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Progressive palaeoenvironmental change during the Late Barremian–Early Aptian as prelude to Oceanic Anoxic Event 1a: Evidence from the Gorgo a Cerbara section (Umbria-Marche basin, central Italy)

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A B S T R A C T

During Oceanic Anoxic Event 1a (OAE 1a, 120 Ma; Li et al., 2008), organic carbon-rich layers were deposited in marine environments under anoxic conditions on a global scale. In this study, palaeoenvironmental conditions leading to this event are characterised by studying the Upper Barremian to the Lower Aptian succession of the Gorgo a Cerbara section (central Italy). For this, an integrated multi-proxy approach ($\delta^{13}C_{carb}$; $\delta^{13}C_{org}$; $\delta^{18}O$; phosphorus; Total Organic Carbon, TOC; bulk-rock mineralogy, as well as redox-sensitive trace elements — RSTEs) has been applied.

During the Late Barremian, thin organic-rich layers occur episodically, and associated C_{org}:P_{tot} ratios indicate the presence of intermittent dysoxic to anoxic conditions. Coarse correlations are observed between TOC, P and biogenic silica contents, indicating links between P availability, productivity, and TOC preservation. However, the corresponding $\delta^{13}C_{carb}$ and $\delta^{18}O$ records remain quite stable, indicating that these brief periods of enhanced TOC preservation did not have sufficient impact on the marine carbon reservoir to deviate $\delta^{13}C$ records. Around the Barremian–Aptian boundary, TOC-enriched layers become more frequent. These layers correlate with negative excursions in the $\delta^{13}C_{carb}$ and $\delta^{13}C_{org}$ records, possibly due to a warming period as indicated by the $\delta^{18}O$ record. During the earliest Aptian, this warming trend is reverted into a cooling trend, which is then followed by an important warming step near the onset of Oceanic Anoxic Event 1a (OAE 1a). During this time period, organic-rich intervals occur, which are characterised by the progressive increase in RSTE. The warming step prior the onset of OAE 1a is associated with the well-known negative spike in $\delta^{13}C_{carb}$ and $\delta^{13}C_{org}$ records, an important peak in P accumulation, RSTE enrichments and C_{org}:P_{tot} ratios indicating the prevalence of anoxic conditions. The Selli Level itself may document a cooling phase. RSTE enrichments and C_{org}:P_{tot} ratios confirm the importance of anoxic conditions during OAE 1a at this site.

The Gorgo a Cerbara section is interpreted to reflect the progressive impact of palaeoenvironmental change related to the formation of the Ontong-Java plate-basalt plateau, which started already around the Barremian–Aptian boundary and culminated into OAE 1a.

1. Introduction

The Cretaceous is marked by major perturbations in the global carbon cycle associated with considerable environmental change. The latter are expressed by positive excursions in the carbonate and organic-carbon $\delta^{13}C$ records and may be coeval with the widespread deposition of laminated organic-rich sediments, which represent oceanic anoxic events (OAEs, Schlanger and Jenkyns, 1976). The Early Aptian records one of the most significant and intensively studied of these events, the OAE 1a or "Selli Event" (Arthur et al., 1990; Erba, 1994; Erba et al., 2010; Jenkyns and Wilson, 1999; Méhay et al., 2009; Menegatti et al., 1998; Tejada et al., 2009; Weissert, 1989). The latter is characterised by the deposition of organic-rich sediments in pelagic basins and a negative excursion in carbonate organic carbon-isotope records, which is followed by a pronounced positive excursion. Furthermore, OAE 1a is coeval with a sea-level rise and a major change in nannofossil assemblages (Bralower et al., 1999; Erba, 1994; Erba et al., 1999; Menegatti et al., 1998), which are indicative of a period of ocean

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acidification (Erba et al. 2010). Finally, several drowning steps in shallow-water carbonate platforms or mass occurrences of *Lithocodium–Bacinella* straddle the OAE 1a episode (Burla et al., 2008; Föllmi, 2008; Föllmi et al., 1994, 2006; Huck et al., 2010; Weissert et al., 1998). The general mechanism triggering OAE 1a is thought to be a phase of intense volcanism and the emplacement of the large Ontong-Java large igneous province (LIP; Méhay et al., 2009; Tejada et al., 2009; Weissert and Erba, 2004). The associated changes in palaeoceanographic and palaeoenvironmental conditions, which have led to the enhanced preservation of organic carbon in marine sediments, are less well understood. In a first approach, anoxic conditions have been related to the expansion of oxygen-minimum zones (OMZ), due to increased primary productivity in the photic zone of the oceans. This again was related to an increase in nutrient fluxes, both by the enhanced supply of volcanically derived trace metals as well as by increased biogeochemical continental weathering rates (Hasegawa, 2003; Hochuli et al., 1999; Larson, 1991; Larson and Erba, 1999; Pedersen and Calvert, 1990). In a second approach, a stagnant ocean model is presumed, which was caused by reduced oceanic circulation, inducing a highly stratified water column and corresponding widespread anoxic conditions (Bralower and Thierstein, 1984; Rullkötter, 2000; Tyson, 1995). Highly stratified oceans are also proposed to explain the presence of biomarkers indicating eutrophic-zone euxinic conditions (e.g. Pancost et al., 2004).

The time interval immediately preceding OAE 1a is of interest to this regard, since it may offer information on the prelude and onset of OAE 1a. Based on biostratigraphic correlations between DSDP/ODP cores and sections in the Italian Apennines, and more specifically on the evolution of calcareous nannoplankton, Bralower et al. (1994) studied the evolution of redox conditions during the Late Barremian to Early Aptian by means of nannofossils evolution. Mutterlose and Böckel (1998) described laminated sediments of Late Barremian age in northwestern Germany and concluded that their formation is related to the presence of thermally-induced water stratification. On a larger scale, both significant eustatic sea-level variations, as well as important climate and ecological changes are documented in the shallow-marine environment during the Barremian–Aptian boundary interval and the earliest Aptian (e.g. Bralower et al., 1994; Burla et al., 2008; Föllmi et al., 2006; Hillgärtner et al., 2003; Mutterlose and Böckel, 1998; Pittet et al., 2002; Ruffell and Worden, 2000; Vilas et al., 1995).

In this study, we focus on the reconstruction of palaeoenvironmental conditions during the Late Barremian and Early Aptian in order to identify if OAE 1a was preceded by anoxic precursor events or if the Selli Event represents a truly singular event. In order to achieve this, we investigated the Gorgo a Cerbara section in central Italy, which may be considered as the OAE 1a type locality (Pancost et al., 2004) and includes the proposed GSSP for the Barremian–Aptian boundary (Erba, 1996). By employing a suite of geological and chemical parameters, we show that a series of organic-rich sediments were deposited throughout the Late Barremian and earliest Aptian, which are the consequence of progressively important environmental change preceding and leading to OAE 1a.

2. Geological setting

Gorgo a Cerbara is a well-studied section located in the Umbria Marche Basin (northern Apennines, central Italy), 4 km east of the town of Piobbico, along the Candigliano River (Cecca and Pallini, 1994; Coccioni et al., 2006; Fig. 1). Previous studies dealt with magnetostratigraphic analyses of the entire section (Channell et al., 2000; Lowrie and Alvarez, 1984). Calcareous nannofossils, planktonic foraminifera and ammonites were studied in order to refine the dating of the section (Bralower, 1987; Cecca and Pallini, 1994; Coccioni et al., 1992, 2006); an attempt of correlation between magnetostratigraphy and biostratigraphy and some of the aforementioned biostratigraphical schemes has been proposed by Coccioni et al. (1992). In terms of

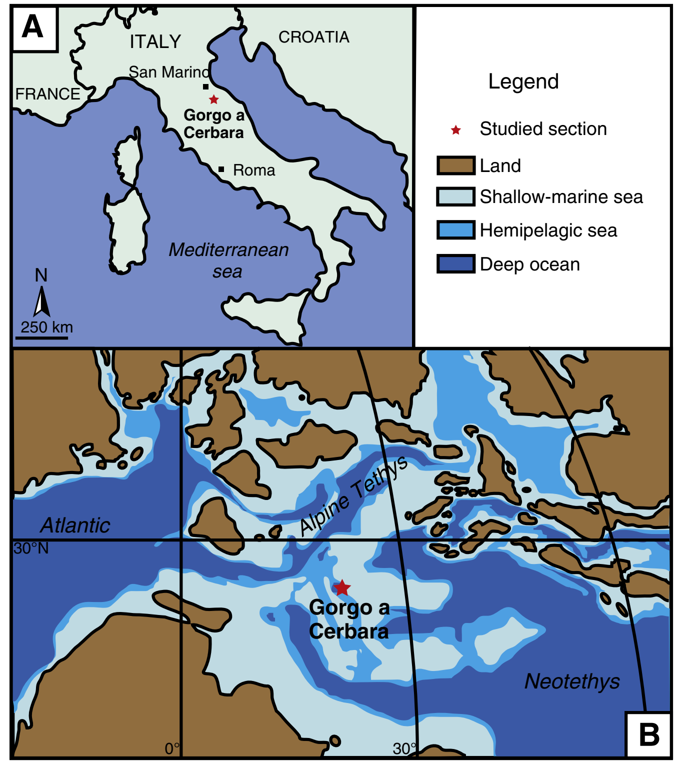

Fig. 1. Location of the studied section on present-day geography (A), as well on Early Aptian paleogeographic reconstruction (B).
Map of the western Tethys redrawn after Ron Blakey, NAU Geology. http://jan.ucc.nau.edu/~rcb7/.

Milankovitch cyclicity, the pioneering work of Herbert (1992) has been supplemented by the cyclostratigraphic analysis of Fiet (2000) and Fiet and Gorin (2000). Finally, Baudin et al. (1998) characterised organic-matter contents, whereas Sprovieri et al. (2006) presented a detailed carbon- and oxygen-isotope analysis, which they combined with orbital tuning of the Maiolica Formation.

The base of the measured section is represented by the upper 20 m of the Maiolica Formation (Late Barremian to earliest Aptian), which consists of rhythmic alternations of up to several dm-thick pelagic limestone beds including frequent chert layers and nodules, and up to several cm-thick dark marly intervals. The upper part of the section contains the lower part of the Scisti a Fucoidi Formation including the "Livello Selli". The Selli Level is dominated by dark and organic-rich shales, and includes cm-thick alternations of green, pink and white marl and limestone (Fiet, 2000). The boundary between the Maiolica and the Fucoidi Formations corresponds to the last occurrence of chert, according to Cecca and Pallini (1994) and Coccioni and Cocon (1987). The Barremian–Aptian boundary has been identified with the help of magnetostratigraphy (Channell et al., 2000) and corresponds to the base of the chron CM0.

3. Methods

3.1. Carbon and oxygen isotopes

Carbon and oxygen isotope analyses were carried out on powdered bulk-rock samples at the University of Bern, Switzerland, using a Finnigan Delta V Advantage mass spectrometer. The results were calibrated to the PDB scale with the standard deviation of 0.06‰ for $\delta^{13}C$ and 0.07‰ for $\delta^{18}O$.

Organic carbon-isotope measurements were performed on organic-carbon fractions of samples, which were decarbonated using 10% HCl at the University of Neuchatel, Switzerland, and analysed at the