Cretaceous Research 56 (2015) 716–731

Contents lists available at ScienceDirect

Cretaceous Research

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

Black shales – from coolhouse to greenhouse (early Aptian)

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ARTICLE INFO

Article history:
Received 27 April 2014
Accepted in revised form 5 December 2014
Available online 20 March 2015

Keywords:
OAE1a black shales
Orbital cyclicity
Early Cretaceous
Negative carbon isotope excursion
Ontong Java volcanism
Paleoceanography

ABSTRACT

Approximately 120 Ma major volcanic outgassing on the Ontong Java Plateau resulted in perturbations of the global carbon cycle, in a change from cool to greenhouse climate conditions and in major changes in oceanography leading to widespread deposition of black shales during the early Aptian Oceanic Anoxic Event 1a (OAE1a). However, onset of black-shale deposition was diachronous and prior to OAE1a occurred under specific paleogeographic and paleoceanographic conditions. The goal of this study is to identify paleoceanographic constraints during coolhouse conditions that resulted in pre-OAE1a black-shale deposition and to investigate if and to what extent the short-term orbitally induced climate changes are also recorded in the sedimentary archive. We compared four lower Aptian pelagic sections from the former southern and northern continental margins of the Alpine Tethys Ocean and traced the evolution of carbon isotopes, carbonate and organic carbon content as well as palynofacies before and at the onset of OAE1a. Throughout the studied interval, the sections record frequent precession-controlled changes in carbonate content, which are reflected by limestone-marlstone alternations in the shallowest and most proximal Cismon core and by limestone-black-shale couplets in the deepest Pusiano section. Depth controlled sub-/anoxia is also suggested by the prominent OAE1a black shales, which occurred first in the deeper Pie del Dosso and Roter Sattel sections and only subsequently in the shallower Cismon core. However, contrary to expectations, the deepest Pusiano section exhibits – instead of an earliest onset of prominent OAE1a black shales – only a minor increase in TOC and a decrease in carbonate content. This suggests that the orbitally driven climate changes most strongly influenced water stratification and hence are most prominently expressed in the deepest sections. Conversely, the volcanically induced long-term climate changes seemed to more strongly affect organic matter production, the extension of the oxygen minimum zone and hence had the strongest impact on sections at intermediate depth.

1. Introduction

Several episodes of intense volcanism related to the formation of Large Igneous Provinces are proposed as a cause of episodic climate warming pulses during the Early and mid-Cretaceous (e.g., Larson and Erba, 1999; Méhay et al., 2009; Tejada et al., 2009). PCO_{2atm} increased at geologically short-time scales ranging from 10^3 to 10^5 years, and it triggered changes in Cretaceous climate and in physical, chemical and biological oceanography (e.g., Arthur, 2000; Jahren et al., 2001; van Breugel et al., 2007). Oceanographic changes resulted in deep-water anoxia across the Atlantic and Tethys Oceans and in anoxia caused by an expansion of the oxygen minimum zone in the Pacific Ocean (Schlanger and Jenkyns, 1976). Schlanger and Jenkyns (1976) defined two time intervals, the Aptian-Albian and the Cenomanian–Turonian transition, as Oceanic Anoxic Events (OAE 1 and 2), during which oceanographic conditions favoured repeated black-shale formation in all the major oceans. The sedimentary expression of the Oceanic Anoxic Event 1a (=OAE1a) is defined by the Selli Level in the Umbria-Marche Basin (central Italy), consisting of a thick (50–100 cm) black-shale layer, and has equivalents in many other basins around the globe. This OAE1a-related, black-shale deposition initiated ~120.2 Ma ago (Malinverno et al., 2010) and these conditions persisted for ~1.1 Ma (Malinverno et al., 2010). OAE1a is preceded by a prominent short-term negative carbon isotope

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http://dx.doi.org/10.1016/j.cretres.2014.12.003
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"spike" (Erba et al., 1999; Menegatti et al., 1998), the origin of which has been a long-standing controversy (e.g., Arthur, 2000; Jahren et al., 2001; Van Breugel et al., 2007). A detailed study of isotope trends in marine and terrestrial biomarkers and analyses of osmium isotope ratios across OAE1a indicate that volcanism on the Ontong Java Plateau was a major source of isotopically light carbon and that the resulting elevated pCO_{2atm} concentrations triggered major changes in phytoplankton fractionation (Méhay et al., 2009; Tejada et al., 2009; Bottini et al., 2012). Terrestrial vegetation changes indicating a long-term climatic warming starting ~100 ka before OAE1a (Keller et al., 2011), and pronounced changes in calcareous nannoplankton assemblages reflecting surface-water acidification (Erba et al., 2010, 2011) are also attributed to a substantial increase in pCO_2. Another indirect consequence of a rise in pCO_2 was a change in palaeoceanography leading to increased productivity, to deep-water oxygen deficiency and to enhanced preservation of organic matter (OM) in the black-shale deposits of OAE1a (e.g., Bralower et al., 1994; Menegatti et al., 1998). However, the onset of anoxic conditions was not globally synchronous (Robinson et al., 2008) and precedes the OAE1a in certain basinal settings. In addition, some of the black shales preceding the OAE1a appear to be controlled by orbitally induced changes in palaeoceanography (e.g., Bersezio et al., 2002).

The goal of this study is to elucidate how Ontong Java volcanism and its consequences affected different palaeoenvironmental settings in the early Aptian Tethys Ocean. It investigates under which circumstances these global, volcanically induced changes led to black-shale deposition and what the expressions of the same global changes were in environmental settings not prone to anoxia. Given this focus, results from three sections along the southern Tethys margin are compared with data from a succession located on the former northern margin of the Alpine Tethys Ocean. This allows for differentiation between global and local effects and, hence, for a detailed understanding of the relationships between causes, consequences and their lithological expressions. Another goal is to investigate how the continuously changing orbital variations affected early Aptian greenhouse climatic conditions as well as if and how these changes are recorded in the sedimentary deposits of the various studied palaeoenvironmental settings. Sedimentology and palynofacies studies serve to identify pre-OAE1a and OAE1a oxygenation levels, whereas C-isotope geochemistry provides information on carbon-cycle history and on chemostratigraphy. Detailed chemostratigraphy serves as a tool for identification of discontinuities or sedimentary gaps in pelagic successions along the studied continental margin.

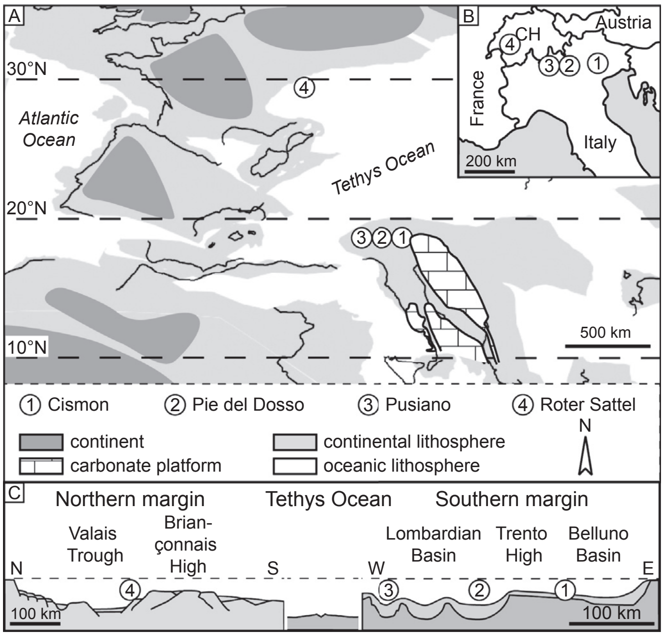

Fig. 1. A) Palaeogeographic map of the early Aptian (~120 Ma, according to He et al., 2008) with locations of the investigated sections (circles with numbers 1–4). Map adapted from Heimhofer et al. (2004) and Global Paleogeography from Jon Blakey, NAU Geology (http://jan.ucc.nau.edu/~rcb7/120moll.jpg). Location of Mesozoic carbonate platforms from Bosellini (2002). B) Geographic map with the present-day locations of the studied sections. C) Palaeogeographic transect through the northern and southern Tethys margin showing the locations of the studied sections in the various basins and sub-basins (Bernoulli, 1981).

2. Regional setting, geology and stratigraphy

During the Early Cretaceous, the passive continental margins of the Tethys Ocean were characterised by a basin-platform morphology resulting from the Jurassic rifting (Bernoulli, 1981; Bernoulli et al., 1979; Winterer and Bosellini, 1981). Three of the studied sections are located along a proximal-distal transect of the southern margin of the Alpine Tethys (Southern Alps, northern Italy; ~20°N). They are compared with a section from the northern Tethys margin located several hundreds of kilometres to the northwest (Swiss Prealps; ~25°N; Fig. 1; Heimhofer et al., 2004; Wortmann et al., 2001). The studied transect covers a distance of approximately 200 km from the rather proximal Belluno Basin, across the Trento High into the distal Lombardian Basin; the latter was divided into various sub-basins by several structural highs (Fig. 1). All four sections feature pelagic sediments deposited in different sub-basins and at various paleodepths. For the time interval around 120–115 Ma, Winterer and Bosellini (1981) estimated the water depths on the Trento Plateau at ~1300 m and for the Lombardian Basin at up to 3000 m.

The reference section chosen for this study is the Cismon core (southern Tethys margin; for locality description see Erba et al., 1999; Menegatti et al., 1998), the sediments of which were deposited along the gentle slope between the Trento Plateau and the proximal Belluno Basin at a water depth estimated at ~1000–1500 m (Erba et al., 1999; Winterer and Bosellini, 1981). Stratigraphically, lower Aptian micritic nannofossil limestones are overlain by the black-shale-limestone deposits of OAE1a. The Polaveno-Pie del Dosso section (southern Tethys margin) belongs to the Sebino Halfgraben located in the eastern part of the Lombardian Basin (Bersezio, 1994; Bersezio et al., 2002; Erba and Quadrio, 1987) and consists of lower Aptian micritic limestones overlain by organic-carbon-rich marlstone deposits. The sediments of the Pusiano section (southern Tethys margin; Bersezio, 1994; Channell et al., 1995) were deposited in the Monte Generoso Sub-basin of the Lombardian Basin only a few km west of the Corni di Canzo structural high (Bersezio, 1993). This section reflects the most distal conditions along the transect and features a succession of lower Aptian limestone-black shale couplets. This series of deep basins was flanked by various carbonate platforms connected to the African Plate (Fig. 1), where a large number of herbivorous and carnivorous dinosaur tracks have been found (Dalla Vecchia, 2000, 2008; Bosellini, 2002). This indicates the presence of hinterlands around the southern Tethys where vegetation and freshwater were sufficiently abundant to sustain large animals. As stated by Keller et al. (2011), these areas are the most probable source of the terrestrial organic matter recovered in the sediments from Pusiano and Cismon.

The hemipelagic sediments of the Roter Sattel section (northern Tethys margin) were deposited in a relatively stable, slowly subsiding basin compartment in the Subbriançonnais Zone between the Briançonnais High and the deeper depositional environments