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Record of Albian to early Cenomanian environmental perturbation in the eastern sub-equatorial Pacific

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ABSTRACT

The present paper documents and discusses a new Albian–early Cenomanian carbon isotope ($\delta^{13}C_{carb}$ and $\delta^{13}C_{org}$) curve from the subequatorial Eastern Pacific in Peru. Chemostratigraphic evidences for the expression of the OAE1b set and for OAE1c and OAE1d are presented. This dataset is relevant inasmuch as previous work is strongly biased towards study sites in North America (Western Interior Basin), in Europe (Tethys) and the Pacific realm. A comparison of the carbon isotope stratigraphy obtained in Peru with published sections from the Central and Western Pacific, the Western Atlantic and Northern and Western Tethys reveals an overall good agreement supporting the global nature of the isotope patterns described here. The $\delta^{13}C$ from Peru record is constrained by biostratigraphic evidence and $^{87}Sr/^{86}Sr$ isotope stratigraphy using well-preserved oyster shells. Furthermore, we document the development of a heterozoan epeiric–neritic mixed carbonate–siliciclastic ramp in the Western Platform of Peru and its corresponding sedimentary facies associations. This dataset was used to elucidate the complex interplay of climatic changes, nutrient supply, and platform drowning, leading to the following conclusions: (i) an upper Aptian–lower Albian major change from siliciclastic-dominated to carbonate sedimentation coincided with the impact of the Kilian Level, (ii) a lower Albian incipient platform drowning linked to the impact of the Paquier Level, (iii) A lower middle Albian major demise of neritic carbonate production that coincides with the Leenhardt Level, followed by middle Albian condensed sedimentation that reports prominent negative values in $\delta^{13}C_{carb}$ prior to the onset of OAE1c and (iv) finally, renewed carbonate ramp production during the upper Albian–lower Cenomanian. The data shown here represent the foundation for future work documenting the mid-Cretaceous of Peru and its implications for the palaeoceanography of the SE subequatorial Pacific.

1. Introduction

The Albian–early Cenomanian (mid-Cretaceous, ~113–96.5 Ma; Ogg and Hinnov, 2012) witnessed a series of oceanic anoxic events (OAEs, Leckie et al., 2002; Heimhofer et al., 2004; Jarvis et al., 2006; Sprovieri et al., 2013; Lorenzen et al., 2013). One of the most prominent features related to these events is represented by the accumulation of organic matter in marine sediments (Schlanger and Jenkyns, 1976). These organic-rich sediments (black shales) can be traced in ocean basins worldwide as individual, distinct horizons or as bundles with several layers enriched in organic carbon (Heimhofer et al., 2006; Emeis and Weissert, 2009; Trabucho-Alexandre et al., 2012). This specific facies and related carbon isotope anomalies represent short-lived perturbations of the global carbon cycle (Jenkyns, 2010; Melinte-Dobrinescu and Bojar, 2010; Trabucho-Alexandre et al., 2010; Bodin et al., 2013). OAEs are also associated with minor extinction and rapid turnover phases in marine life, changes in carbonate platform ecology and phases of platform drowning (Hallock and Schlager, 1986; Wilmsen, 2000; Föllmi, 2012; Krencker et al., 2014). Specifically, during the mid-Cretaceous (Gale et al., 2011), OAEs took place (i) during the late Aptian–early Albian (OAE1b, ~114–109 Ma), (ii) during the early late Albian (OAE1c, ~102 Ma) and (iii) at the Albian–Cenomanian boundary (OAE1d, ~99.5 Ma).

Much of the present understanding of mid-Cretaceous climate and its perturbations comes from the carbon-isotope proxy making use of bulk micrite ($\delta^{13}C_{carb}$) and bulk organic matter ($\delta^{13}C_{org}$) sample sets. Obtained chemostratigraphic sections from numerous basins worldwide display excursions in the carbon isotope record that have significance as time or event markers and shed light on processes involved (e.g., Erbacher et al., 1996; Bralower et al., 1999; Herrle et al., 2004; Jarvis et al., 2011; Krencker et al., 2014). Amongst these, OAE1b was a long-lived event lasting about 6.3 Myr, characterized by a bundle of up to four black shale levels and associated perturbations in the carbon cycle recorded as excursions in carbon isotopes (Herrle et al., 2003, 2004; Reichelt, 2005; Madhavaraju et al., 2013). In the Vocontian

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Basin (Western Tethys), these levels are represented by the uppermost Aptian Jacob Level and the lower Albian Kilian, Paquier and Leenhardt levels. Here, the Kilian and Paquier levels are the most widespread, deposited during eustatic highstands (Bréhéret, 1994) and composed by marine organic matter with a low terrigenous input (Trabucho-Alexandre et al., 2011).

On the other hand, in the Tethys realm, the early late Albian OAE1c is a black shale level characterized by abundant terrigenous organic matter (Amadeus Level; Coccioni and Galeotti, 1993; Galeotti, 1998; Luciani et al., 2007). The chemostratigraphic pattern of this event is not uniform, a feature most likely related to differences in sedimentation rates, the interaction of local and global processes and other, so far not well constrained factors. In this sense, only a weakly developed negative $\delta^{13}C_{carb}$ shift has been reported in Central Europe for OAE1c (Erbacher et al., 1996), whereas a prominent negative excursion in $\delta^{13}C_{org}$ has been identified in Mexico (Bralower et al., 1999) or in sections on Japan (Takashima et al., 2010). At the Albian–Cenomanian transition, OAE1d has been ascribed to a black shale level known as the Breistroffer Level in France (Gale et al., 1996). A long-lasting positive excursion of $\delta^{13}C_{carb}$ within this interval has led several authors to suggest globally significant organic-carbon burial (Nederbragt et al., 2001; Schröder-Adams et al., 2012; Scott et al., 2013). It is likely, however, that different OAEs have different driving mechanisms and differential organic matter-rich sedimentation in different localities during an event as reflected in different types of organic matter found in specific black shale intervals (Kuypers et al., 2001).

Much of the present knowledge of the Albian–early Cenomanian OAE records is biased towards data derived from sections in Europe (Tethys) and North America (Western Interior Basin). In contrast, very limited information on mid-Cretaceous OAEs is available from the eastern sub-equatorial Pacific and generally, the western South American realm. A limited series of relatively well dated, albeit usually incomplete records of Albian to Cenomanian marine strata from the Pacific stems from ocean drilling projects (e.g., Hess Rise, Shatsky Rise, Resolution Guyot: Price, 2003; Robinson et al., 2004; Dumitrescu et al., 2006; Ando et al., 2008). Other outcrop-based studies from the Pacific realm have been reported from Japan (Nemoto and Hasegawa, 2011 and references therein). Judging from available data, OAE1a and OAE2 seem to be more represented in the Pacific region whilst other OAEs show a less pronounced record. Albian–early Cenomanian occurrences of organic-rich black shales seem to be less thick and rather patchy in distribution (Robinson et al., 2004). In conclusion, the eastern sub-equatorial Pacific is remarkably underrepresented and poorly constrained with respect to continuous and well-dated chemostratigraphic reference sections for the mid-Cretaceous interval.

In order to close this gap, a field-based project in northern Peru has been undertaken and extended Albian–early Cenomanian sections are here reported. The results shown indicate that OAE1b, 1c and 1d are recorded in the Andean Basin of Peru. This paper has the following aims as follows: to (i) document and interpret the sedimentology of well-exposed Albian–early Cenomanian sections of the Andean Basin of Peru; to (ii) provide a carbon-isotope reference curve from these sections for the marginal SE Pacific and to (iii) discuss and correlate the Peruvian findings with coeval records documented from the Tethyan, the proto-Atlantic and the Pacific domains.

2. Regional tectonic and stratigraphic setting

During the mid-Cretaceous, the Andean Basin was located within the sub-equatorial humid belt of the Southern Hemisphere (Hay and Floegel, 2012) and separated from the Pacific Ocean by a volcanic arc extending some 10,000 km from South America to the North Scotia Ridge in the South Atlantic (Fig. 1; Larson and Pitman, 1972; Atherton and Aguirre, 1992). Owing to a long-term transgression during the Albian (Pindell and Tabbutt, 1995; Robert, 2002), broad portions of the Andean Basin were flooded and mixed carbonate–siliciclastic sedimentation was accentuated overlying Lower Cretaceous siliciclastic units. Deposition was controlled by NNW–SSE-trending structures (Figs. 2 and 3). The Paracas Massif, consisting of Precambrian continental basement, limits the western part of the Albian volcanic Huarmey Trough (Soler and Bonhomme, 1990). Further east, the Albian Huarmey Trough evolved into an aborted marginal volcanic basin characterized by the deposition of basaltic pillow lavas of the Casma Group (Atherton and Webb, 1989). Volcanic activity in the Andean Basin was directly related to the break-up of the Gondwana arc, culminating with the opening of the South Atlantic Ocean (Torsvik et al., 2009; Moulin et al., 2010; Winter et al., 2010; Fig. 1) and the emplacement of the Coastal Batholith in the Huarmey Trough in the Late Cretaceous (Soler and Bonhomme, 1990). In the middle part of the Andean Basin, the Western Platform was characterized as a back-arc basin, developed on an extensional tectonic margin and activated during Jurassic–Cretaceous times (Jaillard, 1987). Towards the southeast, the Western Platform was attached to the Marañon Massif, a generally submerged locally also emerged massif, separating the Western Platform and the Eastern Basin (Benavides-Caceres, 1956). The Eastern Basin was bound to the east by the Brazilian shield and comprises deltaic coarse grained deposits (Figs. 2 and 3).

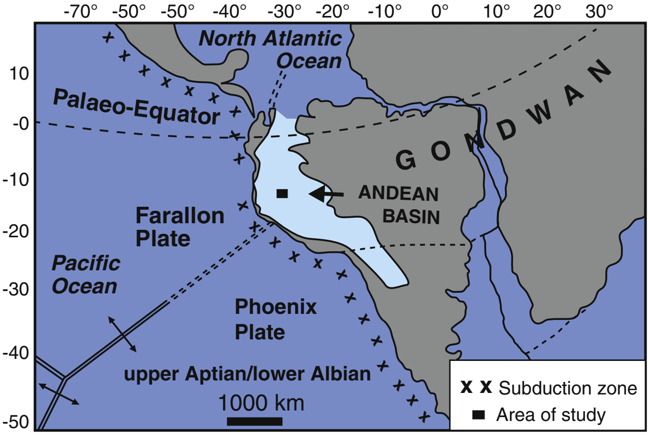

Fig. 1. Palaeogeographic map of Gondwana during the mid-Cretaceous (modified after Larson and Pitman, 1972; Torsvik et al., 2009; Moulin et al., 2010) indicating position of what today is the Andean Basin. Black square denotes approximate position of study area.

Given the scarcity of stratigraphic data on the Albian–early Cenomanian of Peru, a summary of the existing knowledge is given for reference (Fig. 4; Benavides-Caceres, 1956; Jaillard, 1987; Robert et al., 2009). In the northern Andes (Cajamarca region), the Lower Cretaceous is represented by the Goyllarisquizga Group that encompasses the Chimu, Santa, Carhuaz and Farrat formations (Benavides-Caceres, 1956). The Goyllarisquizga Group is assigned to the *Valanginites broggii* Zone at the base and an Aptian age was assumed for the top (Benavides-Caceres, 1956). This group is overlain by Albian transgressive deposits that resulted in shelf deposition of the Inca, Chulec, Pariatambo and Yumagual formations reaching the onset of the early Cenomanian.

The Inca Formation consists of iron-rich, sandy and marl–limestones beds, assigned an early Albian age based on the ammonite *Neodeshayesites nicholsoni* (Robert and Bulot, 2004; Robert et al., 2009). The Inca is unconformably overlain by the Chulec Formation with a discontinuity surface separating the two units. The Chulec Formation is characterized by marl–limestone alternations with a very abundant and diversified outer shelf fauna (Jaillard, 1987). Numerous ammonites have been reported and were assigned to the *Knemiceras raimondii* Zone (Robert and Bulot, 2004; Robert et al., 2009), indicating a middle early Albian–early middle Albian age. The Chulec Formation is conformably overlain by the Pariatambo Formation.

The Pariatambo Formation is characterized by fossiliferous, black, bituminous, fetid marly limestones facies and includes fine lamination