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Geochemical and paleoenvironmental record of the early to early late Aptian major episodes of accelerated change: Evidence from Sierra del Rosario, Northeast Mexico

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ABSTRACT

The lower to lower-upper Aptian succession of northern Mexico documents the drowning of the shallow-water Cupido/Cupidito carbonate platform system followed by deposition of the deep-water sediments of the La Peña Formation. Using $\delta^{13}C$ stratigraphy, geochemical and mineralogical information coupled with previous microfacies, paleontological and total organic carbon (TOC) data from a stratigraphic section, which includes such lithological change, this study identifies distinctive episodes of accelerated global environmental change, and determines the paleoenvironmental conditions conducive to the deposition of TOC-rich intervals. Within the Cupidito unit, the Oceanic Anoxic Event 1a (OAE 1a) is recorded near the base of the section and the Intra-Furcata Negative Excursion in the topmost beds of the unit. The upper part of the section, within the La Peña Formation, is correlatable with the Noire level. Organic-carbon rich intervals occur in the lower and middle part of the OAE 1a, upper part of the Cupidito unit, base of the La Peña Formation, and in the Noire level equivalent. Reducing conditions within the sediment and oxic–dysoxic at the seafloor, locally controlled, persisted both before and during OAE 1a interval in the Cupidito lagoon. Oxygen-depleted conditions (dysoxic–anoxic) were more permanent and stronger during the deposition of the base of the la Peña Formation and the Noire equivalent level. It is proposed here that deposition of the lower-middle part of the OAE 1a and the base of the La Peña Formation was influenced by climate-controlled increases in detrital and accompanying nutrient influx that supplied especially biolimiting nutrients (Fe, P), fostering marine productivity and TOC burial. Upwelling of nutrient-rich deeper waters and minor arrival of nutrients from runoff, both account for the domination of radiolaria and organic-carbon burial during the Noire level equivalent. Record of the OAE 1a time-equivalent facies in the Cupidito lagoonal sediments confirms the diachronism of the Cupidito–La Peña flooding. Heterozoan carbonate production in the Cupidito ramp was uninterrupted during and after OAE 1a. Periodic arrival of detrital components and nutrients during warmer/humid periods accelerated platform drowning, which peaked during the diachronic deposition of the La Peña Formation.

1. Introduction

The Aptian represents a time of accelerated global change in the lithosphere–ocean–atmosphere system with profound imprint on climatic, paleogeographic, sedimentary and biotic evolutionary patterns. These changes were brought by a battery of interrelated events with positive and negative feedbacks. Increase in ocean crust production and midplate and plate margin volcanism raised the level of atmospheric CO_2 and induced episodes of extreme greenhouse conditions (Menegatti et al., 1998; Larson, 1991; Leckie et al., 2002; Jenkyns, 2003; Weissert and Erba, 2004; García-Mondéjar et al., 2009; Tejada et al., 2009; Keller et al., 2011). These climate conditions accelerated the hydrologic cycle and increased continental weathering and runoff (Erba, 1994; Föllmi et al., 1994; Leckie et al., 2002; Föllmi, 2012). They also resulted in various episodes of global rise in sea-level (Haq et al., 1988); several crises and demises of carbonate platforms in the peri-Tethyan region (Föllmi et al., 1994; Wissler et al., 2003; Barragán and Maurrasse, 2008; Millán et al., 2009); a biocalcification crisis, which affected most of the pelagic biota (Larson and Erba, 1999; Weissert and Erba, 2004); and major global perturbations in carbon cycling (Menegatti et al., 1998; Weissert and Erba, 2004).

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The combination of these events produced stressful conditions triggering conspicuous global episodes of environmental change that can be indentified in the stratigraphic record by their specific carbon-isotope signature and/or by the presence of organic-carbon rich sediments (Föllmi, 2012). For the late Barremian–early late Aptian age, such events include: (a) several perturbations during the Barremian–Aptian transition marking the switch from an interval with normal conditions, to an episode of intensified greenhouse conditions and accelerated paleoceanographic change associated with several organic-carbon rich levels (Menegatti et al., 1998; Föllmi, 2012; Sanchez-Hernandez and Maurrasse, 2014); (b) the early Aptian OAE 1a (Livello Selli event) considered as one of the most important global perturbations in the carbon cycle in the Cretaceous, defined by a negative spike in the carbon-isotope curve followed by a shift toward positive values, and usually concomitant organic-carbon rich sediments deposited under poorly-oxygenated conditions (Schlanger and Jenkyns, 1976; Jenkyns, 1980, 1999; Menegatti et al., 1998; Erba et al., 1999); and (c) a set of early late Aptian episodes associated with the Noire and Fallot levels in the Vocontian Basin, France (Bréhéret, 1997; Herrle et al., 2004); and with an organic-carbon rich level reported in Italy (Cobianchi et al., 1997; Luciani et al., 2006), which is equivalent to the Aparein level in the Basque–Cantabrian Basin, Spain (García-Mondéjar et al., 2009; Millán et al., 2009). Recently, Núñez-Useche et al. (2014) proposed a new chemostratigraphic event, termed Intra-Furcata Negative Excursion (IFNE) for the Prebetic Domain in Spain. It is characterized by a negative excursion in $\delta^{13}C$ record within the *Dufrenoyia furcata* ammonite Zone.

The Francisco Zarco Dam section of the south-facing paleomargin of the Cupido carbonate platform, northeastern Mexico (Durango State) contains a transgressive Barremian–Aptian succession that records several organic-carbon rich intervals and the gradual drowning of the carbonate platform (Araujo and Martínez, 1981; Barragan, 2001; Barragán-Manzo and Díaz-Otero, 2004; Barragán-Manzo and Méndez-Franco, 2005; Núñez-Useche and Barragán, 2012; Moreno-Bedmar et al., 2012a, 2013). The section exhibits a completely outcropping succession composed of the transgressive shallow-water Cupidito unit (upper part of the Cupido Formation; Wilson and Pialli, 1977), and the overlying deep-water facies of the La Peña Formation. In the present study we integrate previous biostratigraphic and total organic carbon (TOC) information with new geochemical ($\delta^{13}C$ of the carbonate fraction and whole-rock major and trace elements) and mineralogical (mineral composition and pyrite framboid size) data to unravel the evolution of paleoenvironmental conditions in response to global and local changes. The specific objectives are: (a) to describe $\delta^{13}C$ major trends and correlate them with global and local episodes of environmental changes that took place during the early–early late Aptian interval; and (b) to understand the paleoenvironmental conditions that resulted in organic-carbon sequestration in sediments and its possible causes and forcing mechanisms. We further address the apparent inconsistency regarding the lithostratigraphic position of the OAE 1a in northeastern Mexico, previously identified in the base of the La Peña Formation (Bralower et al., 1999; Li et al., 2008) but recorded in this study within the Cupidito unit. Altogether, the data presented herein provide an excellent case to investigate the local response to episodes of global accelerated change and its link with detrital flux and nutrient input coupled with marine productivity, oxygen consumption in the water column and organic-carbon burial.

2. Geological setting

The development of extensive shallow-water carbonate platforms around the Gulf of Mexico reached its maximum extent during the early Aptian (Scott, 1990; Wilson and Ward, 1993; Lehmann et al., 1999) (Fig. 1). This paleogeographic configuration was favored by post-Berriasian tectonic subsidence related to the crustal cooling and opening of the Gulf of Mexico (Goldhammer et al., 1991). In northeastern Mexico, the Cupido and Coahuila carbonate platforms developed around the Coahuila basement block during Barremian through Albian time (Fig. 1). This block controlled the geometry and stacking pattern of carbonate facies and also acted as a source area for detrital sediments (Wilson and Selvius, 1984; Goldhammer et al., 1991).

The late Barremian Cupido platform was a flat-topped, rimmed shelf with a broad interior shallow lagoon isolated by a variable margin (Fig. 1). The southern part of this margin is a high-energy shoal that changes along strike to a discontinuous coral-rudist reef in the east margin facing the ancestral Gulf of Mexico (Lehmann et al., 1999). These settings are recorded by massive, shallow-water limestone of the Cupido Formation (Imlay, 1937; Humphrey, 1949; Conklin and Moore, 1977; Wilson and Pialli, 1977; Goldhammer et al., 1991; Lehmann et al., 1999). The hemipelagic mudstone of the Lower Tamaulipas Formation (Stephenson, 1922; Muir, 1936) represent the down-dip, low energy deposits accumulated on the surrounding deeper water shelf (Fig. 1).

During the latest Barremian–earliest Aptian (Fig. 1), deposition of transgressive facies of the Cupidito unit across a homoclinal ramp profile (Wilson and Pialli, 1977) marked the retrogradational backstep and beginning of the drowning of the Cupido platform, in response to a major second-order marine transgression (Goldhammer et al., 1991; Lehmann et al., 1999). According to Conklin and Moore (1977), the Cupidito unit contains isolated rudist pinnacle reefs, which are interpreted by Lehmann et al. (1999) as the fossil record of the response of the platform system to the drowning event. The flooding event continued through the deposition of the deep-water carbonates of the La Peña Formation throughout the early Aptian-earliest Albian (Fig. 1).

The Cupidito–La Peña flooding event has been widely accepted as diachronic, usually interpreted as a time-transgressive facies boundary above which the base of the La Peña Formation rise biostratigraphically toward shelfal sections (Goldhammer et al., 1991; Goldhammer, 1999; Lehmann et al., 1999). However, the results of recent investigations focused on ammonite data suggest that the base of the La Peña Formation is rather isochronous and assignable everywhere to the upper part of the late early Aptian *Dufrenoyia furcata* Zone (Barragán-Manzo and Méndez-Franco, 2005; Barragán and Maurrasse, 2008; Moreno-Bedmar et al., 2011, 2012a; Moreno-Bedmar and Delanoy, 2013). Since the transition from the Cupidito to the La Peña facies occurred simply by landward migration of the shallow-water marine depositional sites toward the Coahuila block, Goldhammer et al. (1991) and Lehmann et al. (2000) consider that the Cupidito–La Peña contact cannot be interpreted either a drowning unconformity or a standard sequence boundary. This lithostratigraphic boundary is not a prominent unconformity, but rather is a transitional flooding surface. The termination of this platform has been correlated with the early to early late Aptian episode of shallow carbonate platform demise throughout the peri-Tethyan region (Föllmi et al., 1994).

The La Peña Formation records a sudden moderate increase in detrital components evidenced by the appearance of fine-grained siliciclastic components in limestone and calcareous shale. Siliciclastic components were derived from distal highlands to the north and west (Goldhammer et al., 1991). The shale beds of this unit contain frequent ammonites and small rounded clasts of phosphorite. With a highly variable thickness controlled by both the accommodation space and the paleorelief, this unit blankets large extensions of the southwest Gulf of Mexico (Goldhammer et al., 1991; Lehmann et al., 1999; Barragan, 2001).

Once the deposition of the La Peña Formation ended, the significantly backstepped Coahuila carbonate platform was established during the early Albian (Fig. 1). It consisted of a restricted evaporitic lagoon (interbedded massive carbonates and evaporites of the Acatita Formation) isolated by a shallow shoal margin (massive shallow-water limestone of the Aurora Formation). On the surrounding areas of this platform took place the deposition of the deep-water carbonates of the Upper Tamaulipas Formation characterized by hemipelagic mudstone (Goldhammer et al., 1991; Lehmann et al., 1999).