Sedimentary Geology 228 (2010) 184–204

Contents lists available at ScienceDirect

Sedimentary Geology

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

The Eocene storm-dominated foralgal ramp of the western Pyrenees (Urbasa–Andia Formation): An analogue of future shallow-marine carbonate systems?

Aitor Payros [a,*], Victoriano Pujalte [a], Josep Tosquella [b], Xabier Orue-Etxebarria [a]

[a] Department of Stratigraphy and Palaeontology, Faculty of Science and Technology, University of the Basque Country, P.O. Box 644, E-48080 Bilbao, Spain
[b] Department of Geodynamics and Palaeontology, Faculty of Experimental Sciences, University of Huelva, Campus del Carmen, Avenida 3 de Marzo s/n, E-21071 Huelva, Spain

ARTICLE INFO

Article history:
Received 30 January 2009
Received in revised form 18 December 2009
Accepted 15 April 2010
Available online 29 April 2010

Editor: G.J. Weltje

Keywords:
Eocene
Carbonate ramp
Climate
Larger foraminifera
Sea level
Storm

ABSTRACT

If the ongoing phenomenon of global warming prevails, three main consequences are expected in tropical seas: a higher sea level, a reduction in coral reefs and more intense cyclones. What will shallow-marine carbonate systems be like? Insights can be gained from the Pyrenean Urbasa–Andia Formation, a transgressive heterozoan-like foralgal (larger foraminiferal and red algal) ramp that formed in Middle Eocene times, a greenhouse interval characterized by high atmospheric CO_2 content. Firstly, the evolution of future tropical shallow-marine systems subject to a sea-level rise is very likely to be similar to that seen in the backstepping architecture of the Urbasa–Andia Formation. Secondly, Eocene larger foraminifers rose when the Paleocene–Eocene hyperthermal event caused a decline in corals in tropical seas. Coral reefs are again among the ecosystems that are likely to be particularly affected by current global warming. It is therefore probable that future shallow-marine tropical ecosystems will be devoid of platform margin coral reefs, heterozoan ramps being far more common. Thirdly, strong storm influence was common on the Urbasa–Andia carbonate ramp, the most distinctive feature being a distal dune field that was formed below storm wave base by high-energy return currents. Similar features also characterize other Eocene carbonate ramps. Furthermore, numerical simulations highlighted the effect of strong tropical cyclones during the equable climate of the Eocene. Together this information supports the hypothesis that tropical cyclone activity may increase under future greenhouse conditions. Taking everything into account, the transgressive storm-dominated foralgal ramp represented by the Urbasa–Andia Formation can be used as a virtual analogue of future shallow-marine carbonate sedimentary environments developed under greenhouse conditions.

1. Introduction

From the very beginnings of the industrial revolution, fossil-fuel emissions have led to the accumulation of large amounts of carbon gases in the atmosphere. Under the leadership of the Intergovernmental Panel on Climate Change (IPCC), it has been demonstrated that the atmospheric build-up of greenhouse gases has caused a notable increase in global temperature and an incipient sea-level rise, which suggest that these changes mark the trend for the future (IPCC, 2007; Trenberth et al., 2007; Bindoff et al., 2007). In order to foresee what conditions are likely to prevail on a greenhouse Earth, climate modellers are making projections of future changes using mathematical models (Randall et al., 2007). Although confidence in model estimates of future climate evolution has been enhanced, the resulting projections are not always or completely accurate, mainly because it is not well understood how potential feedbacks may affect climate evolution.

This problem can be mitigated by the study of the geological record, as it provides a historical view of past climates (Jansen et al., 2007). The Quaternary climate record has provided essential constraints for understanding climate dynamics and a baseline for predicting future responses to carbon input. However, this information can only offer limited insight into the Earth's possible response to rapid, massive input of carbon gases. Ancient greenhouse periods, in which atmospheric carbon gas content was either much higher than today or increased abruptly, may be closer analogues. The Early–Middle Eocene was one such period, as it was characterized by high concentrations of greenhouse gases and the warmest global temperature of the last 100 million years (Zachos et al., 2001). Superimposed

---

* Corresponding author. Fax: +34 946 013 500.
E-mail address: a.payros@ehu.es (A. Payros).

0037-0738/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.sedgeo.2010.04.010

on this generally warm climate, several short-lived, transient climatic perturbations called hyperthermal events occurred. These extreme global warming events were caused by the sudden release of large volumes of carbon gases to the atmosphere. For all these reasons, the Early–Middle Eocene has been regarded as an analogue to predict the long-term effects of the present-day anthropogenic carbon input to the atmosphere (Zachos et al., 2001, 2008; Jansen et al., 2007).

Based on these assumptions, the aim of this study is to provide a comparative insight into the characteristics of future shallow-marine carbonate systems by the analysis of deposits accumulated on a Middle Eocene carbonate ramp, namely the Urbasa–Andia limestone Formation (Fm) from the western Pyrenees (Fig. 1A; Payros, 1997). Its facies and evolution fit in with the characteristics and behaviour of future tropical seas subject to foreseeably warmer conditions (Meehl et al., 2007; Christensen et al., 2007). Furthermore, a comparison with other Eocene and older shallow-marine carbonate systems shows that such characteristics may not be an exception, but rather are common to greenhouse climates.

2. Geological setting

The Pyrenees are a collision mountain belt created by the Santonian–Miocene N–S convergence of the European and Iberian plates (Muñoz, 1992). During Eocene times foreland basins developed on both sides of the orogenic belt (Fig. 1B), each one composed of a deep-water foredeep flanked by ESE-trending (c. 110°) shallow-marine bioclastic ramps (Plaziat, 1981; Pujalte et al., 2002). Both foreland basins opened northwestwards into the Atlantic Ocean at approximately 35ºN paleolatitude. In the study area, located in the western part of the south Pyrenean foreland basin, the geometry and behaviour of the carbonate ramp was influenced by the synsedimentary activity of the Pamplona fault. This is a NE-trending deep fracture that in Eocene time caused rapid subsidence of the eastern fault block, whereas the western block remained uplifted and under shallow-marine waters (Payros, 1997; Pujalte et al., 2002; Larrasoaña et al., 2003; Payros et al., 2007). Consequently, a hinge zone developed on top of the Pamplona fault and produced an eastward-facing local slope. The Urbasa–Andia Fm was located on the western block of the Pamplona fault, whereas deep-water deposits (Erize Marl Fm of Payros, 1997) accumulated on the downthrown fault block.

3. Sedimentary units: stratigraphy and evolution

The shallow-marine Urbasa–Andia limestone Fm crops out in the core of the E–W trending syncline that makes up the so-called plateaus (Fig. 1A). In addition, other isolated outcrops occur in the neighbouring Lizarra depression as a consequence of localized fault tilting and halokinetic deformation. In the Andia plateau (Dorrokoteka and Goñi sections) the Urbasa–Andia limestones grade northeastwards into deep-water marls of the Erize Fm. Nummulitid and planktonic foraminiferal biostratigraphy allowed attribution of the Urbasa–Andia and Erize Fms to the Middle Eocene (upper Lutetian to lower Bartonian; Table 1).

3.1. Basal unconformity and onlap

The Urbasa–Andia Fm systematically overlies a major angular unconformity. The deposits below the unconformity range in age from Cenomanian to Middle Eocene, being older towards the west and south of the study area (Fig. 1A). The extent of the hiatus at the unconformity is enhanced by the southwestward onlapping geometry of the Urbasa–Andia Fm. This relationship is visible in aerial views of the northern ridge of the Andia plateau, where field mapping and stratigraphic thickness measurements allow a quantitative estimate of the basal onlap (Fig. 2). The thickness of the Urbasa–Andia Fm differs by 80 m in two sections (Lizarraga and Dorrokoteka in Fig. 1A) which are approximately 6 km apart in E–W direction, yielding an apparent eastward dip of 0.8º for the basal unconformity (also see Payros et al., 2001). A westward onlap was also described by Payros and Pujalte (1998) for the Urbasa–Andia Fm exposed in the northwestern part of the Urbasa plateau (Legaire area). Furthermore, nummulitid biostratigraphic information demonstrates the southwestward onlap of the Urbasa–Andia Fm on a larger scale. The lowermost deposits of the northern part of the Andia plateau (Lizarraga section) belong to the lowermost part of the SBZ15 biozone of Serra-Kiel et al. (1998) (upper Lutetian), whereas the upper part of SBZ15 was found in the northwestern and southern outcrops of the Urbasa plateau (Legaire and Urederra), SBZ16 (uppermost Lutetian) in the southern part of the Andia plateau (Lezaun), and SBZ17 (lower Bartonian) in the Lizarra depression (Abartzuza, Bearin, Eraul and Lerate) (Table 1).

All these features demonstrate the transgressive character of the Urbasa–Andia Fm. In fact, in some locations its basal unconformity shows evidence of having been formed under subaerial conditions (Payros, 1997). In the southern part of the Urbasa plateau (Urederra area) the underlying well-stratified Paleocene micritic limestones and dolostones are affected by several vertical brecciated zones, up to 50 m high and 25 m wide, towards which the Paleocene beds downwarp and eventually become fragmented in heterometric angular clasts (Fig. 3A). Although the plan geometry of the brecciated zones is not visible, their cross-section resembles breccia pipes produced by the gravitational collapse of sinkholes and caves in karstic terrains (Sando, 1988; Sangster, 1988; Baceta et al., 2001). On a smaller scale the uppermost Paleocene limestones encase an irregular intercalation of horizontally laminated calcarenites, several metres wide and 10–15 cm thick (Fig. 3B). This intercalation is sub-parallel to the Paleocene bedding, has a wavy but generally flat top and its base is highly irregular, with downward-narrowing sub-vertical ramifications that cut across each other. These characteristics suggest the occurrence of irregular cavities in previously indurated Paleocene limestones, through which the currents that carried the calcarenitic sediment flowed eventually filling the cavities. Both the breccia pipes and the calcarenitic intercalation can best be explained by the downward circulation of meteroric water through the Paleocene limestones, most likely occurring in subaerial conditions. Although the age of the emersion of the Paleocene limestones cannot be established, the occurrence of nummulitids and *Fabiania* sp. within the calcarenitic intercalation indicates that the area remained exposed until it was re-flooded in Lutetian times.

In most locations, however, the basal unconformity of the Urbasa–Andia Fm only shows evidence of marine transgressive erosion, which probably removed any record of the former subaerial exposure. In the Lizarra depression and in the northern part of the Andia plateau the base of the Urbasa–Andia Fm is characterized by a conglomeratic bed, generally just 1 m thick, composed of varied Cretaceous and Paleogene disc-shaped sandstone and limestone pebbles and cobbles, shark's teeth and iron-oxide clasts embedded within a glauconite-rich bioclastic matrix (Fig. 2C–D). These deposits are interpreted as transgressive ravinement lags (sensu Posamentier and Allen, 1999; Catuneanu, 2006). In addition, in the northern part of the Andia plateau (between Lizarraga and Dorrokoteka) the basal unconformity shows a terraced geometry, ascending westwards in the direction of the Urbasa–Andia Fm onlap (Payros, 1997). At least five terraces, each 0.5–1 km in length from east to west, were observed along a 3.8 km long outcrop (Fig. 2). They have a brecciated planar surface with angular clasts that range from 1 to approximately 25 cm. These terraces are separated by spoon-shaped risers, 2–5 m high, that dip 20–25º towards the east (Fig. 2B). Two of the risers (1 and 5 in Fig. 2) are compound, as each is formed by two smaller escarpments that give the main risers their scalloped shape. The composite vertical height of the