Palaeogeography, Palaeoclimatology, Palaeoecology 393 (2014) 45–60

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

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

Sea-level changes across the Paleocene–Eocene interval in the Spanish Pyrenees, and their possible relationship with North Atlantic magmatism

Victoriano Pujalte [a,*], Birger Schmitz [b], Juan Ignacio Baceta [a]

[a] *Department of Stratigraphy and Palaeontology, Faculty of Science and Technology, University of the Basque Country UPV/EHU, Ap. 644, 48080 Bilbao, Spain*
[b] *Division of Nuclear Physics, Department of Physics, University of Lund, P.O. Box 118, SE-221 00 Lund, Sweden*

ARTICLE INFO

Article history:
Received 11 October 2012
Received in revised form 23 October 2013
Accepted 31 October 2013
Available online 9 November 2013

Keywords:
Sea-level changes
Paleocene–Eocene interval
PETM
Pyrenees
N Atlantic magmatism

ABSTRACT

The issue of whether major and rapid global sea-level changes existed on a preglacial Earth can be resolved by the detailed study of the Paleocene–Eocene (P–E) interval, where a large and rapid carbon isotope excursion linked to an important global warming event, the Paleocene Eocene Thermal Maximum, allows for high-resolution correlation between terrestrial, coastal and marine settings. Based primarily on outcrop and borehole information from the Tremp-Graus Basin in the southern Spanish Pyrenees, it is shown that a sea-level fall of at least 20 m occurred less than 75 kyr prior to the PETM. This forced a seaward displacement of the shoreline of ca. 20 km, a widespread incision of valleys in the alluvial plains and the subaerial exposure and excavation of the adjacent marine carbonate platform. The subsequent sea-level rise caused the infilling of the incised valleys, a process completed before the onset of the PETM, and continued rising during and after the event, leading to the aggradation of the alluvial plain and eventually to the transgression of the whole Tremp-Graus Basin. However, the sea level did not regain its pre-fall position until near the end of the PETM. Therefore, although rising, the sea level was comparatively low in the southern Pyrenean area during most of the PETM. The pre-PETM sea-level fall has been reported in other basins of the southern Pyrenees, in the North Sea area, the Austrian Alps and in Egypt, and the subsequent sea-level rise has been documented in widely separated sites around the Earth, an evidence of their global (eustatic) scope. The causal mechanism(s) of the pre-PETM sea-level fall is (are) unresolved, although glacioeustasy may have played a role. The subsequent sea-level rise was most likely caused by tectonomagmatic activity in the North Atlantic.

1. Introduction

The Paleocene Eocene Thermal Maximum (PETM) was the most prominent of several geologically brief episodes (< 200 kyr) of extremely high temperatures which interspersed the warm early Paleogene greenhouse climate. It is well documented that during the PETM, which occurred ca. 56 Ma ago, global temperatures rose by about 5–9 °C, causing a significant biotic impact (e.g., Thomas, 1998; Crouch et al., 2001; Gingerich, 2003). The fingerprint of the PETM is a 2–6‰ negative carbon isotopic excursion (CIE), identified in many ocean sediment cores and land-based sections (e.g., Zachos et al., 2003; Aubry et al., 2007). The CIE developed in less than 20 kyr (McInerney and Wing, 2011) requiring the rapid addition of massive quantities of isotopically light carbon to the atmosphere-ocean reservoir.

Yet, the trigger of the PETM remains controversial. Alternative hypotheses include, among others, destabilisation of oceanic methane hydrates (Dickens et al., 1995), thermogenic CO2 and CH4 production in the North Atlantic (Svensen et al., 2004), orbitally triggered carbon release from the thawing of circum-Arctic and Antarctic terrestrial permafrost (DeConto et al., 2012) and the oxidation of organic matter after the desiccation of a large epicontinental seaway (Higgins and Schrag, 2006). The latter hypothesis required a “relative sea-level fall prior to the onset of the CIE”, a possibility that Higgins and Schrag (2006, p. 531) supported with literature data, including a study by Schmitz et al. (2001). Indeed, Schmitz et al. (2001), and later Schmitz and Pujalte (2003) inferred from their studies in the Pyrenees that the PETM might have occurred during an interval of low sea level. Some authors, however, have challenged a pre-PETM sea-level drop (e.g., Sluijs et al., 2008).

The purpose of this paper is to reassess sea-level changes across the Paleocene–Eocene (P–E) interval based primarily on evidence from the South Pyrenean Tremp-Graus Basin, but also with data from a selection of other basins. It is shown that in the Tremp-Graus Basin: 1) there is clear proof that a sea-level fall occurred shortly before the onset of the PETM; 2) the subsequent sea-level rise was initiated before the onset of the PETM and continued during and after the event; and 3) although rising, the sea level stayed relatively low during most of the PETM. The published results from other basins in the Pyrenees and elsewhere seem to confirm that the range of the reported sea-level changes was at least

---

* Corresponding author. Tel.: +34 946012606; fax: +34 6013500.
E-mail address: victoriano.pujalte@ehu.es (V. Pujalte).

0031-0182/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.palaeo.2013.10.016

supra-regional if not global. Finally, a possible link between North Atlantic tectonomagmatic activity in the North Atlantic and the sea-level rise across the P–E interval is discussed.

2. Geological setting

The Pyrenean orogen resulted from the Late Cretaceous to Early Miocene collision between the Iberian and European plates (Roest and Srivastava, 1991). Its axial zone, formed mostly of Palaeozoic basement, is flanked to the north and south by thrust sheets of Mesozoic and Cenozoic sedimentary rocks with low-angle basal detachments (Muñoz, 1992). Three of these sheets are recognised in or near the study area, emplaced during the Santonian–late Maastrichtian, the Ypresian, and the Lutetian–early Miocene (Fig. 1; Fernández et al., 2012).

Tectonic quiescence prevailed during the latest Maastrichtian–earliest Ypresian, as demonstrated by slow and near homogeneous subsidence and the absence of angular unconformities or growth structures within the coeval succession. The studied succession was accumulated towards the end of this interval (Fig. 1), during which the main allocyclic controls of the sedimentation were climate and eustasy-dominated sea-level changes. The Ypresian Stage is, however, very long (8.2 Ma), and the local Ilerdian Stage is used here to allow for greater stratigraphic precision and because this stage name is used in most of the literature on Pyrenean stratigraphy. It should be noted that the bases of the Ilerdian and Ypresian Stages are coeval (Pujalte et al., 2009a; Vandenberghe et al., 2012).

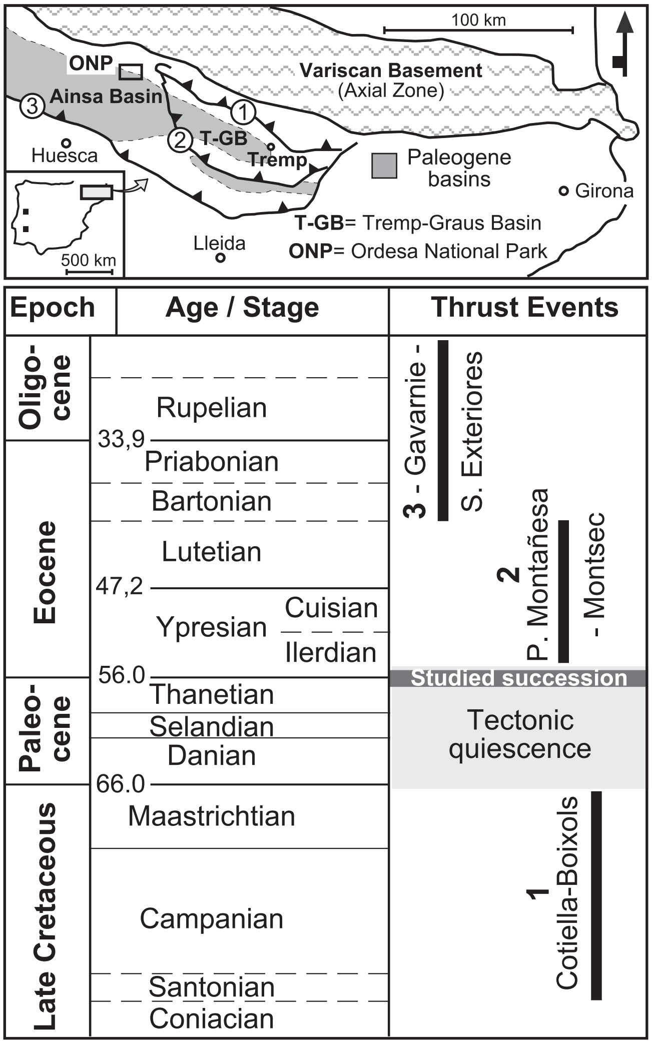

Fig. 1. Simplified geological map of the southern Pyrenees showing the position of the Tremp-Graus and Ainsa basins, and chronostratigraphic chart with indication of thrusting (i.e., tectonically active) and quiescent intervals (modified from Fernández et al., 2012).

Throughout the P–E interval the Pyrenean domain was a deep-water embayment, opened westwards into the Bay of Biscay and flanked by shallow marine carbonate shelves. The shelves were surrounded by coastal alluvial plains that were particularly well-developed in the Tremp-Graus Basin due to an abundant clastic input from nearby mountains created during the Santonian–late Maastrichtian thrusting phase (Figs. 1, 2A).

3. Data set and methods

This paper partly draws on information from earlier studies, but mainly on new field and laboratory data. Earlier information includes several δ^{13}C isotope profiles across the P–E interval from soil carbonate nodules, which for the first time allowed the delineation of the PETM in continental sections of Spain (Schmitz and Pujalte, 2003, 2007; Supplementary Fig. 1). Isotope profiles based on dispersed organic matter ($\delta^{13}C_{TOC}$) of Domingo et al. (2009) have also been taken into account, as well as palaeontological information from marine Thanetian and Ilerdian deposits of Robador et al. (1990), Scheibner et al. (2007), Robador (2008) and Baceta et al. (2011).

Key new data include high-resolution maps across the P–E interval of three sectors of the Tremp-Graus Basin (Fig. 2B). The Esplugafreda sector is situated in the northern margin of the basin and was the last to be reached by the Ilerdian Sea. The Claret sector corresponds to the basin axis, the part of the basin showing the highest subsidence rate. The Esplugafreda and Claret sectors were situated in a coastal alluvial plain during Paleocene times, and were flooded by the sea after the PETM. In contrast, the Campo sector was in a marine setting during most of the Thanetian and Ilerdian times. The map of the Esplugafreda sector was included in a field guide of restricted circulation (Fig. 3.2 in Baceta et al., 2006). The maps of the other two sectors are published in this paper for the first time. New interpretations of borehole data across the P–E interval are also provided.

Also new are: 1) Field and $\delta^{13}C_{TOC}$ isotope data from a new section, the Ferrera ridge (longitude: 0° 19′ 59″ latitude 42° 25′28″); 2) thin-section and polished-slab data from the Ferrera and Campo sections; and 3) micropalaeontological data from non-marine deposits across the P–E interval. Carbon isotopic analyses were performed with an Isoprime mass spectrometer with a dual inlet system, following standard procedures, at the Department of Geography and Geology at the University of Copenhagen. The results are listed in Table 1.

The micropalaeontological data were obtained by examining under a binocular microscope wet sieving residues of mudstone samples of several sections. In about half of the samples a scant assemblage (10–20 specimens) was found. Specimens with abraded and reddened tests, obviously resedimented, were ignored, but those with better-preserved tests and of colours similar to their host rocks were considered autochthonous or para-autochthonous. They are listed in Table 2, their environmental significance being discussed in the appropriate sections below.

4. Stratigraphy

Danian–lower Ilerdian successions of the Tremp-Graus Basin comprise two major facies, shallow marine and continental, which interfinger laterally and alternate vertically (Figs. 2B, C, 3). Shallow marine deposits mainly consist of carbonates that are rich in larger foraminifera (nummulitids, alveolinids and soritids), calcareous algae, molluscs and corals. Continental deposits, traditionally referred to in geological literature as “Garumnian” or “Garumnian facies”, are now included in the formally defined Tremp Group (Cuevas, 1992; Pujalte and Schmitz, 2005). This Group comprises several formations, of which only the upper two are relevant to this study (Fig. 2C). The