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Perturbation of a Tethyan coastal environment during the Paleocene–Eocene thermal maximum in Tunisia (Sidi Nasseur and Wadi Mezaz)

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ABSTRACT

Despite the large number of studies on the Paleocene–Eocene thermal maximum (PETM), the knowledge of environmental and biotic responses in shallow marine environments remains quite poor. Benthic foraminiferal assemblages of the Sidi Nasseur and Wadi Mezaz sections in Tunisia were studied quantitatively and the paleoecologic interpretations provide new insights into the complex relationship between PETM global warming and perturbations of shallow marine settings. These sections expose upper Paleocene to lower Eocene shales and marls of the El Haria Formation up to the phosphate layers of the Chouabine Formation underlying the El Garia limestones. The Sidi Nasseur section contains a more complete and expanded Paleocene–Eocene boundary interval compared to Wadi Mezaz, although being truncated at the top. The Wadi Mezaz section contains a more complete post-PETM interval. The studied interval can be subdivided into a sequence of 4 biofacies, representing respectively a latest Paleocene biofacies, two PETM biofacies and one post-PETM Eocene biofacies.

The latest Paleocene biofacies 1 consists of numerous calcareous benthic foraminifera (e.g. *Anomalinoides midwayensis*, *Frondicularia* aff. *phosphatica* and various *Bulimina* and *Lenticulina* species), abundant non-calcareous taxa (*Haplophragmoides*) and rare planktic foraminifera, indicating a slightly hypersaline eutrophic inner neritic to coastal environment, regularly interrupted by oxygen deficiency (moderate dysoxia). During the latest Paleocene, this highly productive environment shallowed as indicated by the increasing abundances of *A. midwayensis*. The variable dominance of non-calcareous agglutinated taxa in biofacies 1 indicates post-mortem dissolution effects. The TOC $\delta^{13}C_{org}$ record reveals a sharp negative excursion, marking the base of the Eocene. In general, the absence of lithologic changes, an increasing sedimentation rate and absence of reworking indicate that the initial part of the PETM is complete and expanded in the Sidi Nasseur section. A sharp faunal turnover coincides with this negative $\delta^{13}C_{org}$ excursion and is characterized by the disappearance or diminution of common Paleocene taxa in this area. During the PETM, benthic foraminifera are less abundant and consist of opportunistic non-calcareous taxa together with deeper dwelling (middle neritic) lagenids and buliminids (biofacies 2 and 3). Planktic foraminifera, dominated by flat-spired *Acarinina* (mainly *A. multicamerata*), become more abundant, as observed in many open marine sequences worldwide. All these faunal parameters suggest more stressed probably severe dysoxic sea floor conditions within a transgressive phase during the onset of the PETM. An estimation of the total duration of the Sidi Nasseur PETM interval is difficult to establish, yet the lack of recovery carbon isotope values suggests that the preserved PETM interval reflects only a part of the CIE “core”. The top of the PETM interval is truncated due to local (?) erosion during the early Eocene. The Eocene recovery fauna is mainly composed of *Lenticulina* and *Stainforthia* species (biofacies 4), indicating restricted coastal to hyposaline lagoonal eutrophic conditions, distinctly different from earlier environmental conditions.

1. Introduction

The Paleocene–Eocene thermal maximum (PETM), ~55.8 Ma ago, was a geologically brief (~170 kyr; Röhl et al., 2007) episode of globally elevated temperatures, superimposed on the long-term late Paleocene and early Eocene warming trend that culminated in the highest ocean temperatures of the Cenozoic (EECO, Early Eocene

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climatic optimum; Kennett and Stott, 1991; Zachos et al., 2001, 2008). The PETM is characterized by a global 5–8 °C warming of Earth's surface as well as the deep oceans and the onset of the PETM is marked by a worldwide simultaneous negative excursion in $\delta^{13}C$ values (CIE — carbon isotope excursion; Kennett and Stott, 1991). Although the ultimate cause and trigger of the CIE is uncertain (for an overview see Sluijs et al., 2007), the dissociation of methane hydrates along continental margins is a plausible hypothesis to account for the injection of large amounts of ^{13}C-depleted carbon into the oceanic and atmospheric reservoirs (Dickens et al., 1997). Simultaneously with the CIE, major global biotic changes are recorded, such as a major extinction of deep-sea benthic foraminifera (e.g. Tjalsma and Lohmann, 1983; Thomas, 1998), blooms of the tropical–subtropical planktic foraminiferal genus *Acarinina* (e.g. Kelly et al., 1996), an acme of the dinoflagellate *Apectodinium* at middle and high latitudes (e.g. Crouch et al., 2001), distinctive assemblages of calcareous nannoplankton (e.g. Bralower, 2002), a turnover of larger foraminifera (e.g. Orue-Etxebarria et al., 2001; Scheibner et al., 2005), the disappearance of coral reefs (Scheibner and Speijer, 2008), changes in ostracod assemblages (e.g. Steineck and Thomas, 1996; Speijer and Morsi, 2002) and rapid dispersion of modern orders of mammals (e.g. Gingerich, 2006).

Although the geologically brief episode of global warming during the PETM has been intensively studied since its breakthrough in 1991 (Kennett and Stott, 1991), debates on the onset, total duration and recovery phases still continue until today. In order to establish the exact pathways of biotic responses to climate change during the PETM, detailed analyses of faunal and floral changes are needed from a wide spectrum of different environments, from the deep ocean, through shallow basins to terrestrial settings. Despite the increasing number of studies on the PETM in oceanic environments, the knowledge of marine processes and biotic responses in neritic environments remains quite meager. Sediments deposited along the borders of the Tethys Ocean, what was once an extensive east–west subtropical seaway during the Paleogene, offers a wide variety of neritic environments (Tunisia: Aubert and Berggren, 1976; Egypt: Luger, 1985 and Speijer, 1994). High-resolution paleoecologic studies indicate that in the deeper (bathyal) marginal basins of the Tethys (Egypt, Israel, Turkmenistan) the benthic foraminiferal extinction event was equally severe as in the deep-sea (Speijer et al., 1997). Faunal changes at shallower middle neritic water depths (Egypt; Speijer et al., 1996) appear less abrupt and most disappearances of taxa were temporary since they reappeared after the PETM or are described in younger Eocene sediments elsewhere. The observed benthic foraminiferal distribution patterns are incorporated into a general repopulation model describing the collapse and recovery of the oligotrophic bathyal–outer neritic ecosystem after the onset of anoxia at the Tethyan sea floor. This anoxic phase triggered downslope migration of opportunistic taxa (e.g. *Anomalinoides aegyptiacus*) from shallower waters (Speijer et al., 1997; Speijer and Wagner, 2002). It was argued that these faunal changes resulted from upwelling of low oxygen intermediate Tethyan water into the Egyptian epicontinental basin leading to enhanced biotic productivity and basinwide sea floor anoxia.

In order to unravel the nature and spatial distribution of these temporary eutrophic and anoxic conditions in the southern Tethys, additional studies are needed. In northwest Tunisia, the clays and marls of the El Haria Formation are exposed in wide incised valleys and plains, creating excellent opportunities for high-resolution studies on early Paleogene climatic events in the southern part of the Tethys Ocean. The purpose of this study is to reconstruct the Tunisian paleoenvironmental evolution in a shallow marine setting with special attention to changes in the foraminiferal associations across the Paleocene–Eocene boundary. This will enable us to determine the biotic response to rapid global warming during the PETM in a marginal marine setting dominated by deposition of fine grained terrigenous sediments (clay). Additionally, as coastal ecosystems are very sensitive to sea level changes, the proposed link between the onset of the PETM and rapid eustatic sea level rise can be tested (Speijer and Wagner, 2002; Sluijs et al., 2008).

2. Regional setting

The Maastrichtian to lower Ypresian El Haria Formation overlies Campanian–Maastrichtian limestones of the Abiod Formation and is overlain by Ypresian phosphatic marls of the Chouabine Fm. and limestones of the El Garia Fm., both belonging to the Metlaoui Group. The El Haria Fm. consists mainly of dark gray shales and marls with thin limestone intercalations. Phosphate beds are scattered throughout the formation and represent condensed intervals corresponding to periods of maximum sediment starvation (Saint-Marc, 1992). Lateral facies and thickness variations of the El Haria Fm. are thought to be structurally controlled along basement lineaments resulting in a number of small tectonically controlled basins, surrounding the large emerged zone of the Kasserine Island (Zaïer et al., 1998). The result is a latest Cretaceous–Paleocene paleogeography characterized by subsiding troughs in the north and northeast (NW Tunisian Trough and NE Tunisian Basin) and the Gafsa Gulf in the southwest (Aubert and Berggren, 1976; Zaïer et al., 1998). During the Paleocene, the studied region was situated in the southern proximal part of the subsiding Tunisian Trough and in the vicinity of the emerged Kasserine Island (Fig. 1). Prolonged marine sedimentation took place in a shelf setting with high subsidence rate, high sediment input and with reduced sediment thickness towards the Kasserine Island (Bensalem, 2002).

The paleoecologic aspects of the El Haria Formation have been the subject of several studies because of its relative richness in microfossils and it offers expanded and nearly continuous stratigraphic records of the Paleocene (e.g. Aubert and Berggren, 1976). Outcrops near El Kef are well known and distribution patterns of ostracodes (Peypouquet et al., 1986), benthic foraminifera (Kouwenhoven et al., 1997) and dinoflagellates (Guasti et al., 2005) have been studied intensively. These studies indicate that the lower and middle Paleocene part of the El Haria Formation is transgressive (zones P2 and P3), extending over large parts of Tunisia and, in the Tunisian Trough, is followed by a general shallowing trend during the late Paleocene (zones P4 and P5; Aubert and Berggren, 1976; Kouwenhoven et al., 1997; Guasti et al., 2005). The sections in this study (Sidi Nasseur and Wadi Mezaz) form the top part of an expanded and well exposed sequence of the El Haria Formation in the Kalaat Senan region (50 km to the southwest of El Kef). Studying the Paleocene–Eocene boundary in this area is complicated because of the few good exposures and the occurrence of small faults. The Sidi Nasseur and Wadi Mezaz sections expose the most expanded and complete Paleocene–Eocene boundary sequences.

3. Material and methods

The Sidi Nasseur (N35°48′18.48″ and E08°26′48.36″) and Wadi Mezaz (N35°47′52.12″ and E08°26′31.95″) sections are located around the Sidi Nasseur hill, close to Kalaat Senan. The Sidi Nasseur section is well exposed from the lowermost phosphate beds up to whitish limestones with a phosphatic basal layer. The section terminates where the dip of the slope decreases and the surface is covered by debris from overlying Eocene limestones. The Sidi Nasseur section has been sampled twice, a low-resolution sampling in 1999 (Nas'99) and a new high-resolution sampling in 2006 (Nas'06) with a special focus on the Paleocene–Eocene boundary. Both sample sets are converted to comparable Sidi Nasseur heights and described as the NAS samples (Fig. 2). The nearby Wadi Mezaz section (900 m to the south of Sidi Nasseur) is exposed in two trenches, the Mzg'06 and Mzh'06 sections, both sampled in 2006. The base of the Mzg'06