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Black shale formation during the Latest Danian Event and the Paleocene–Eocene Thermal Maximum in central Egypt: Two of a kind?

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ABSTRACT

The Paleocene–Eocene Thermal Maximum (PETM; ~55.8 Ma) is considered as the most severe of a series of transient warming events ("hyperthermals") that occurred during the Early Paleogene. However, the extent and magnitude of environmental changes during the short-lived warming events pre- and post-dating the PETM are still poorly constrained. In this study, we focus on the Latest Danian Event (LDE, ~61.7 Ma) and compare it to the PETM. We present high-resolution micropaleontological, geochemical, and mineralogical data of the PETM and the LDE in two adjacent sections from the Gebel Qreiya area in Egypt. There, both events are characterized by a distinct set of event beds overlying an unconformity. They are associated with intense carbonate dissolution and substantial changes in the benthic foraminifera fauna. Moreover, both show an abrupt drop of siliciclastic input (sediment starvation) correlative to the onset of black shale formation and a strong enrichment in redox-sensitive trace elements. The evidence for enhanced detrital input during the onset of the PETM and a longer recovery phase with enhanced phosphorus-sedimentation during the PETM attests a stronger environmental impact of this event compared to the LDE.

According to Rock-Eval and elemental analysis, the PETM as well as the LDE event beds have up to 4 wt.% organic carbon, small amounts of volatile hydrocarbons, but high amounts of highly weathered and inert organic matter ("black carbon"). During pyrolysis, the extremely high temperatures for the maximum release of hydrocarbons of the PETM and LDE samples correspond to thermal heating of >170 °C, which is incompatible with the sediment burial history. Therefore, we suggest that the organic matter in both event deposits does not reflect well-preserved marine biomass but predominantly represents a mixture of heavily weathered autochthonous marine material and allochthonous combustion residues. Differences in preservation and/or type of organic matter are also likely to account for the divergent stable isotope anomalies of organic carbon: the well-known negative carbon isotope anomaly at the PETM and a positive anomaly at the LDE. Although warming, water column stratification, and enhanced nutrient input may have promoted anoxic conditions on the shelf during the LDE as well as during PETM, our results support rapid sea level rise and clastic starvation as one important mechanism for black shale formation and carbon sequestration for both events. This result underlines the similarity of both hyperthermal events in terms of environmental changes recorded on the Southern Tethyan margin, with the PETM showing an additional early phase of strong detrital input not revealed at the LDE.

1. Introduction

The early Paleogene greenhouse episode is punctuated by a series of transient warming events ("hyperthermals", Thomas and Zachos, 2000; Speijer, 2003; Bernaola et al., 2007; Nicolo et al., 2007; Quillévéré et al., 2008; Agnini et al., 2009; Bornemann et al., 2009). These hyperthermals generally show a negative carbon isotope excursion ("CIE") in marine environments, as well as enhanced sea-floor carbonate dissolution, deep- to intermediate water oxygen depletion, and pronounced (transient) changes in marine benthic faunas. These characteristics are indicative for the massive addition of ^{13}C-depleted carbon to the ocean–atmosphere system from an external carbon reservoir, leading to increasing atmospheric pCO_2 and temperature, substantial shoaling of the lysocline and calcite compensation depth (CCD), and accelerated hydrologic and weathering cycles (e.g., Zachos et al., 2005; Nicolo et al., 2007; Sluijs et al., 2007). The source and amount of the isotopically light carbon, however, are still debated (e.g., Higgins and Schrag, 2006). It may derive from the catastrophic release of gas hydrates (e.g., Dickens et al., 1995) or from large-scale venting triggered by magma intruding

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organic-rich sediments (e.g., Svensen et al., 2004). Equally discussed is the mechanism (e.g., weathering or productivity increase) and rate by which the excess carbon was sequestered from the atmosphere and oceans (see Bains et al., 2000; Torfstein et al., 2009).

The most prominent and well-documented hyperthermal is the ~170 ky-long Paleocene–Eocene Thermal Maximum ("PETM", Fig. 1, ~55.8 Ma) that was associated with global warming of up to 10 °C and a major benthic foraminifera extinction event ("BFEE", Kennett and Stott, 1991; Thomas and Shackleton, 1996; Speijer et al., 2000; Zachos et al., 2001; Sluijs et al., 2007). Additionally proposed hyperthermals, albeit of shorter duration and lower magnitude, include (i) the early Danian Dan-C2 event (~65.2 Ma, Fig. 1, Quillévéré et al., 2008; Coccioni et al., 2010); (ii) the Latest Danian Event (~61.7 Ma, Fig. 1, Speijer, 2003; Bornemann et al., 2009); (iii) the Early-Late Paleocene Event (~58.2 Ma, Fig. 1, Bralower et al., 2002; Petrizzo, 2005; Bernaola et al., 2007), and (iv) the early Eocene Thermal Maxima 2 and 3 (~53.7 and ~53.6 Ma, respectively, Lourens et al., 2005; Nicolo et al., 2007; Agnini et al., 2009; Stap et al., 2009; Zachos et al., 2010). However, the stratigraphy and global signature of these suspected hyperthermal events pre- and post-dating the PETM are still poorly constrained, although their environmental consequences and rates of change may provide important clues to the carbon release and sequestration mechanisms.

Specifically, the Latest Danian Event (LDE) has been proposed as a transient warming event (Figs. 1 and 2). It was first recognized on the southern Tethyan margin (Egypt and Tunisia, Speijer, 2003; Guasti et al., 2006; Van Itterbeeck et al., 2007; Bornemann et al., 2009; Sprong et al., 2011, 2012), and subsequently observed in the eastern Atlantic (Zumaia, Arenillas et al., 2008), and in the Pacific (Westerhold et al., 2011) at the top of magnetochron C27n close to the planktic foraminiferal Subzone P3a/P3b boundary and within the calcareous nannofossil Zone NP4 (Steurbaut and Sztrákos, 2008; Sprong et al., 2009). Distinctive features of this event are an up to 2‰ negative carbon isotope excursion (Fig. 2, Arenillas et al., 2008; Bornemann et al., 2009; Westerhold et al., 2011), evidence for carbonate dissolution, benthic faunal changes, and sea-level changes (Speijer, 2003), as well as warming (Fig. 2, Westerhold et al., 2011). The total duration of the event has been estimated to be ~191 ky (Bornemann et al., 2009) or

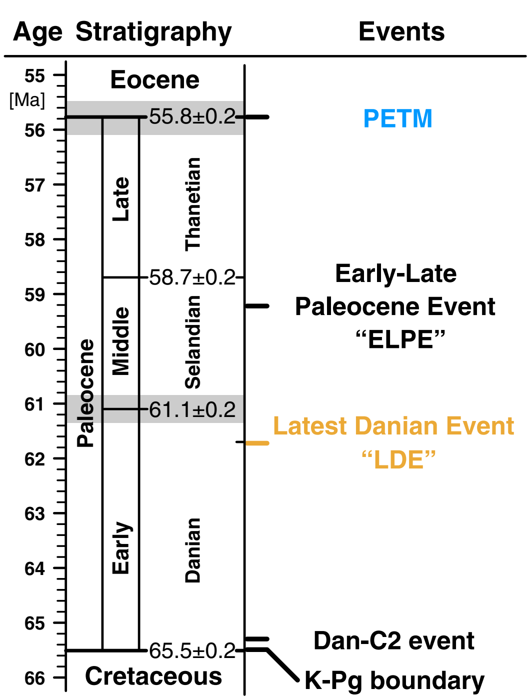

Fig. 1. Time scale of the Paleocene with important global events. Modified after Gradstein et al. (2004).

~190 to 200 ky (Westerhold et al., 2011), with the latter period being very similar to the duration of the PETM as outlined above.

In this study, we investigate the LDE and PETM from the extensive outcrops of the Paleocene–Eocene succession at Gebel Qreiya in Central Egypt (Fig. 3). There, as well as in other Egyptian sections (e.g., Gebel Aweina, Gebel Nezzi; Fig. 3), the LDE has similar features as the PETM record in terms of lithological and biotic changes and both are correlated to a distinct set of event beds (Speijer and Wagner, 2002; Speijer, 2003). This provides an excellent opportunity to test the hypothesis that the LDE represents a hyperthermal event by comparing the signature of both the LDE and PETM event through a high-resolution, micropaleontological, mineralogical, and organic–inorganic geochemical study. Specifically, we aim to investigate the mechanisms of black shale formation that characterize both the LDE as well as the PETM event beds in Central Egypt (Speijer and Wagner, 2002; Speijer, 2003). A lowering of oxygen availability, commonly associated with black shale formation, has been recorded during the PETM at several deep marine sites (Bralower et al., 1997; Chun et al., 2010; Nicolo et al., 2010) and in shelf sections (Speijer et al., 1997; Speijer and Wagner, 2002; Gavrilov et al., 2003). Oxygen depletion controlled benthic faunal changes (e.g., the BFEE at the PETM) but may also triggered an increased carbon preservation and burial, which may have acted as a feedback mechanism for excess carbon sequestration during the recovery phase of these transient warming events (e.g., Speijer and Wagner, 2002).

2. Materials and methods

2.1. The Gebel Qreiya sections

The sections studied are located in the Eastern Desert, close to the Nile Valley at Gebel Qreiya (Fig. 3). The Qreiya 2 and 3 sections are situated east of the southern entrance of Wadi Qena, about 50 km north-east of Qena City. The Q3 LDE section is in the eastern end of Gebel Qreiya (26°N 27.702', 33°E 1.905'; altitude 380 m a.s.l., Sprong et al., 2011). The Q2 PETM section is located on the southeastern nose of Gebel Qreiya (26°N 27.192', 33°E 2.233'; altitude 437 m a.s.l.), about 1000 m southeast of Q3.

In the Qreiya 3 section, the LDE beds are intercalated within the marls of the Dakhla Formation close to the P3a–P3b planktonic foraminiferal subzonal boundary (Fig. 4, Sprong et al., 2009). The uppermost 15 cm of the marls below the event deposit are dark grey, contain few fish remains, and are bioturbated at the top. The lower contact of the LDE deposit with the Dakhla Formation is undulatory and possibly erosive (Sprong et al., 2009). The LDE deposit consists of two distinct beds (1 and 2). Bed 1 (8.2 to 8.3 m) is a dark purplish-brown, organic-rich laminated marl containing fish remains, P-nodules and abundant planktonic foraminifers. The upper 7 cm of bed 1 contains dark grey clay lenses parallel to the lamination. These represent downward penetrating bioturbations from bed 2 (8.3 to 8.45 m), which is dark grey marly shale and contains hematitic or limonitic bivalve and gastropod moulds. Grey shaley marls conformably overlie the LDE beds. About 10 m south of the Q3 section, a several-meter wide and ~20 cm thick calcarenite channel fill is present and cuts into the LDE beds. The channel fill shows upward-fining and is extremely rich in planktic and benthic foraminifera.

In the Qreiya 2 PETM section, the "Dababiya Quarry Beds" (hereafter PETM beds) that characterize the PETM event in Central Egypt (Dupuis et al., 2003) are intercalated within the lower part of the Esna Formation, overlying the Esna 1 unit (Knox et al., 2003; Ouda, 2003). The base of the PETM beds correlates with the BFEE and to the P5a/E1 foraminiferal subzone delineating the base of the Eocene (Fig. 4, Dupuis et al., 2003; Berggren and Pearson, 2005; Aubry et al., 2007). Above the P-E boundary, five PETM beds can be distinguished lithologically: Bed 1 (7.9 to 8.1 m): dark grey, non-calcareous laminated shale with few P-nodules in its upper centimeters. Bed 2 (8.1 to 8.3 m): brown to dark grey, laminated shale with some fish remains and P-nodules. The