Identification and characterization of early Eocene hyperthermals in shallow marine sequences

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In less than 20 years, the PETM has grown into a text-book example of rapid global warming in deep time. Simultaneously, observations on deep-sea cores resulted into the proposal of a series of additional early Paleogene transient paleoclimatic events, such as Dan-C2, ELPE, ETM-2 (“h1”), ETM-3 (“X-event” or “k”). These were discovered through anomalies in lithology, color changes, isotopic excursions, elemental distributions, and anomalous microfaunas. Another hyperthermal proposed, the Latest Danian Event (LDE; Bornemann et al., 2009 – *Jour. Geol. Soc. Lond.*) was first identified in shallow sequences in Egypt, bearing strong similarities with the regional expression of the PETM: laminated black shales with anomalous benthic and planktic microfaunas; Speijer, 2000 – *GFF*; Schulte et al. this volume; Stassen et al. this volume). Besides the LDE, studies of continental margin records remain highly challenging with respect to identifying the secondary hyperthermals.

In theory, numerous lower Eocene sequences worldwide should yield coverage of ETM-2 or ETM-3, but thus far these events have largely been documented from outcrops of deep water deposits (New-Zealand, Italy; e.g. Nicolo et al. 2007 – *Geology*; Agnini et al. 2009 – *Paleoceanography*). It has not yet been convincingly demonstrated that these events left a distinct signature in shallow continental margin records. In order for these proposed hyperthermals to become established as significant events affecting the global biosphere, they also need to be identified and analyzed in shallow margin (and terrestrial) sequences. However, this is not an easy task. Shallow marine marly sequences and especially those in outcrops provide several extra challenges compared to (most) open ocean drill cores, such as discontinuous exposure, weathering, faulting, and unconformities. Additionally, the stratigraphy of outcrop sequences is not constrained from the start by physical properties such as paleomagnetic data, which leaves the initial stratigraphic constraints usually based on low-resolution biostratigraphy from general stratigraphic surveys. On the other hand, potentially thick continental margin sequences provide one major benefit: the possibility to dissect in high-resolution the full sequence and development of a hyperthermal event.

We have conducted studies in Belgium, Egypt and France towards identification and characterization of early Eocene hyperthermals and find anomalous faunal patterns and isotopic excursions which seem to relate to ETM-2 (Pirkenseer et al. this volume; Stassen et al. this volume) or ETM-3. Our study on the new Kallo core (Belgium), drilled through ~100 m of Ypresian clays which were deposited in the mid-latitude shallow North Sea Basin, reveals a 5 m-thick interval which appears to correlate closely with ETM-3. It is characterized by a temporary influx of planktic foraminifera and *Asterigerina kaasschieteri*, a benthic foraminiferal species that is considered indicative of deposition in a shallow and warm sea. After the brief microfaunal incursion, the fauna that was present prior to this event became more or less re-established. Further constraints on the relation with ETM-3 should come from stable isotopic studies on well-preserved planktic and benthic foraminifera. Early Eocene hyperthermals prove difficult to track in shallow water sequences, but our results seem to indicate that also these lesser hyperthermal events had short- and long-term impacts on the development of shallow marine ecosystems.

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