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Was the late Paleocene thermal maximum a unique event?

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Deep-sea benthic foraminiferal faunas were decimated by a massive extinction during an episode of rapid warming, the late Paleocene thermal maximum (LPTM), with a duration of between 50 and 200 k.y. (e.g., Thomas 1989, 1990; Kennett & Stott 1991). During the LPTM carbon isotope values of the atmospheric and oceanic carbon reservoir decreased by 2–3‰, a sign of major upset in the global carbon cycle (e.g., Kennett & Stott 1991; Koch et al. 1995; Thomas & Shackleton 1996; Beerling & Jolley 1998). A large carbon isotope excursion on such short time scales could be explained by dissociation of methane hydrates (Dickens et al. 1995, 1997; Matsumoto 1995; Kaiho et al. 1996). Possibly, the long-term warming trend of the middle Paleocene, which might have been caused by increased CO_2 emissions by the North Atlantic flood basalts during the opening of the North Atlantic, was a primary cause (Eldholm & Thomas 1993). This warming was more pronounced at high latitudes and could have caused the formation of warm, thus low-density surface waters close to the poles, preventing these waters from sinking and contributing to the deep and intermediate ocean waters (Dickens et al. 1995, 1997). The low density could have been exacerbated by the increased precipitation at high latitudes during warm climates, as expected in climate models which produce deep-intermediate waters at low latitudes (Bice et al. 1997) and indicated by increased kaolinite abundance in high latitude sediments (Robert & Kennett 1994). The trigger for methane dissociation, however, is not clear and several possibilities have been explored, including surface water cooling at low latitudes as a result of volcanic eruptions (Bralower et al. 1997) and seismic disturbance of continental margins (e.g., Bains et al. 1999). Methane dissociation in combination with changes in ocean circulation offers a possible mechanism for climatic instability in the absence of polar ice caps (Thomas et al. 1999). Presently, we lack the high-resolution, stratigraphically complete biostratigraphical and isotope data sets necessary to evaluate whether the early Eocene climate was unstable overall (e.g., Aubry 1995).

The high average global temperatures in the early Eocene could reflect a warm background climate with superimposed 'hyperthermals': intervals of extremely high temperatures and very low latitudinal sea surface temperature gradients, during which the deep to intermediate oceans were dominated by waters derived from subtropical latitudes (Thomas et al. 1999). Such episodes are difficult to trace using benthic foraminiferal faunas, because the post extinction faunas were unstable, showing large, rapid fluctuations in species abundance. Such instability might not be linked to direct environmental triggers, but result from factors within the faunas in the aftermath of an extinction, with various opportunistic species blooming alternately, thus showing a typical post-extinction behavior.

The species *Aragonia aragonensis* has been interpreted as such an opportunistic species by comparison of its abundance patterns with that of opportunistic ostracods (Steineck & Thomas 1996). This species shows a clear, short-term peak just after the LPTM extinction at many studied sites. There is, however, a second, coeval peak in its relative abundance at Sites 690 (Weddell Sea) and 865 (equatorial Pacific), at some time between 51.7 and 52.4 Ma (paleomagnetic Chron C23r, planktonic foraminiferal zone P7, nannoplankton Zone NP12). Preliminary isotopic evidence (Fig. 1) suggests that this interval might indeed be characterized by warming of deep to intermediate waters, surface waters, and low carbon isotopic values. The precise timing and the magnitude of the event still need to be clarified, because this interval of the record is, like the LPTM interval, characterized by the common occurrence of short unconformities. The preliminary data strongly suggest, however, that 'LPTM-like'

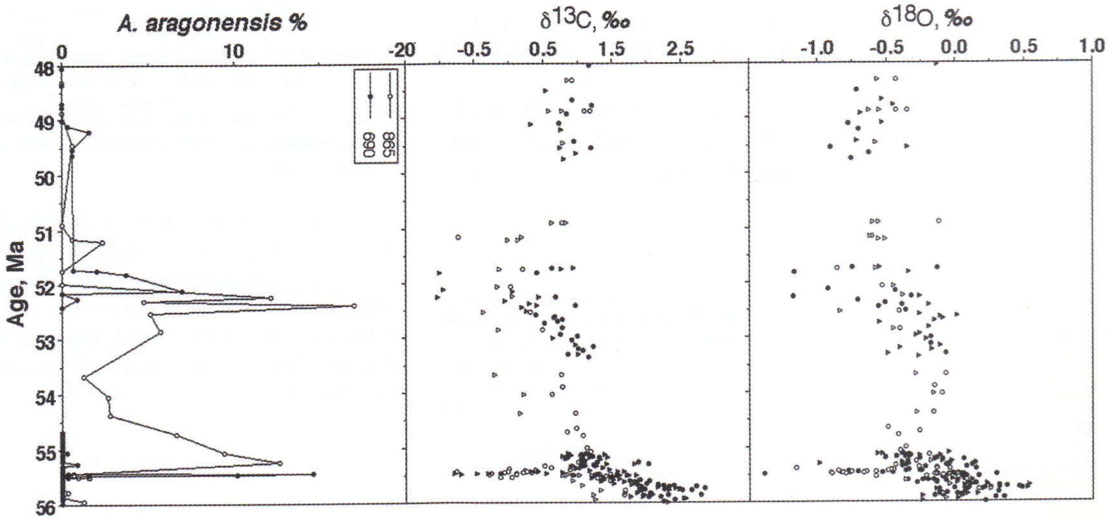

Fig. 1. Relative abundance of *Aragonia aragonensis* at Site 690, Maud Rise, Weddell Sea (Thomas 1990) and Site 865 (Thomas 1998; unpubl. data); benthic foraminiferal oxygen and carbon isotope data for Site 690 (closed symbols) after Kennett & Stott (1990); Thomas & Shackleton (1996); Thomas et al. (1999); Zachos & Thomas, unpubl. data) and for Site 865 (after Bralower et al. 1995*a*, 1995*b*; Thomas et al. 1999; Thomas & Zachos, unpubl. data).

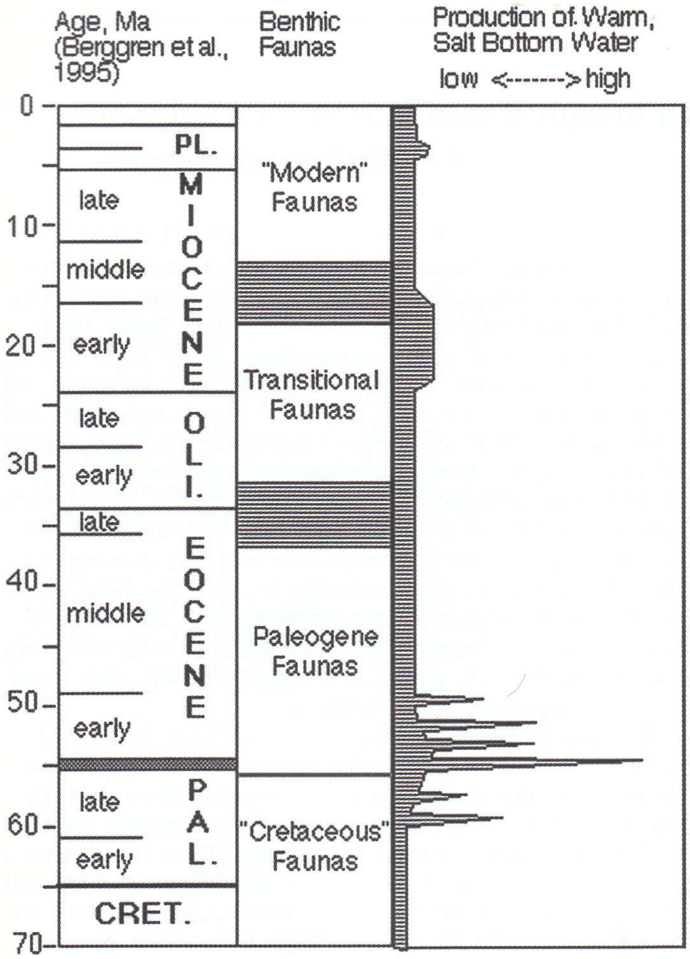

Fig. 2. Possible occurrence of 'LPTM-like' events of hyperthermals in the late Paleocene and early Eocene. Modified after Thomas et al. (1999).

events (or hyperthermals) did occur more than once. Investigation of published benthic foraminiferal and bulk carbon isotope records suggests that such events were limited to the late Paleocene and early Eocene, and that possible events may have occurred at around 49 Ma, 52.3 Ma, 54.8 Ma, 55.5 Ma, 58.0 Ma, and 60.5 Ma according to the time scale of Berggren et al. 1995 (Fig. 2). High resolution studies of late Paleocene and early Eocene studies similar to these by Bains et al. (1999) are needed if we want to understand the occurrence, triggering, and duration of such hypterthermal episodes. Such understanding is necessary if we are to gain understanding of climate on a 'Greenhouse Earth'.

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