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The onset of the Paleocene–Eocene Thermal Maximum (PETM) at Sites 1209 and 1210 (Shatsky Rise, Pacific Ocean) as recorded by planktonic foraminifera

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Abstract

High-resolution biostratigraphic and quantitative studies of subtropical Pacific planktonic foraminiferal assemblages (Ocean Drilling Program, Leg 198 Shatsky Rise, Sites 1209 and 1210) are performed to analyse the faunal changes associated with the Paleocene–Eocene Thermal Maximum (PETM) at about 55.5 Ma. At Shatsky Rise, the onset of the PETM is marked by the abrupt onset of a negative carbon isotope excursion close to the contact between carbonate-rich ooze and overlying clay-rich ooze and corresponds to a level of poor foraminiferal preservation as a result of carbonate dissolution. Lithology, planktonic foraminiferal distribution and abundances, calcareous plankton and benthic events, and the negative carbon isotope excursion allow precise correlation of the two Shatsky Rise records. Results from quantitative analyses show that *Morozovella* dominates the assemblages and that its maximum relative abundance is coincident with the lowest $\delta^{13}C$ values, whereas subbotinids are absent in the interval of maximum abundance of *Morozovella*. The excursion taxa (*Acarinina africana*, *Acarinina sibaiyaensis*, and *Morozovella allisonensis*) first appear at the base of the event. Comparison between the absolute abundances of whole specimens and fragments of genera demonstrate that the increase in absolute abundance of *Morozovella* and the decrease of *Subbotina* are not an artifact of selective dissolution. Moreover, the shell fragmentation data reveal *Subbotina* to be the more dissolution-susceptible taxon. The upward decrease in abundance of *Morozovella* species and the concomitant increase in test size of *Morozovella velascoensis* are not controlled by dissolution. These changes could be attributed to the species' response to low nutrient supply in the surface waters and to concomitant changes in the physical and chemical properties of the seawater, including increased surface stratification and salinity.

Comparison of the planktonic foraminiferal changes at Shatsky Rise to those from other PETM records (Sites 865 and 690) highlights significant similarities, such as the decline of *Subbotina* at the onset of the event, and discrepancies, including the difference in abundance of the excursion taxa. The observed planktonic foraminifera species response suggests a warm–oligotrophic scenario with a high degree of complexity in the ocean structure.

Keywords: Paleocene–Eocene Thermal Maximum; Planktonic foraminifera; Carbonate dissolution; Biostratigraphy

1. Introduction

The abrupt and global warming that occurred at the Paleocene/Eocene boundary (ca. 55.5 Ma) is referred to as the Paleocene–Eocene Thermal Maximum (PETM).

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It was associated with a sharp increase in greenhouse gas concentrations and is considered by many to be analogous to modern global warming caused by industrialization.

Evidence for the warming is observed in marine and terrestrial basins around the world. Stable-isotope investigations on deep-water benthic foraminifera document a rapid increase in deep-sea temperature by 5 to 6 °C in less than 6 ka (Thomas and Shackleton, 1996; Thomas, 2003). Sea-surface temperatures obtained from planktonic foraminiferal isotope records also show an 8 °C increase at high latitudes, while tropical sea-surface temperatures increased by about 5 °C (Zachos et al., 2003). This magnitude of warming is confirmed by increased Mg/Ca ratios in planktonic (Zachos et al., 2003) and benthic (Tripati and Elderfield, 2005) foraminifera. Estimates from the terrestrial realm (e.g., Big Horn Basin in the United States), based on oxygen isotope composition of carbonate soil nodules (Koch et al., 2003) and fossil plants (Wing et al., 2005), are also in the range of 5 °C.

The PETM is marked by a 3.0‰ negative carbon isotope excursion (CIE) in marine inorganic carbon and a 5.0‰ excursion in the terrestrial carbon reservoir (Kennett and Stott, 1991; Zachos et al., 2001), followed by a stable interval of low values and a subsequent exponential recovery. The CIE is thought to reflect the rapid release of massive quantities of isotopically depleted carbon into the ocean–atmosphere system (2000–4500 Gt) (Dickens et al., 1995, 1997; Zachos et al., 2005). Other possible causes that could have contributed to the CIE and the global warming include increased out-gassing of CO_2 due to accelerated production of oceanic crust (Rea et al., 1990; Eldholm and Thomas, 1993), bolide impact (Kent et al., 2003; Cramer and Kent, 2005), circum-Caribbean explosive volcanism (Bralower et al., 1997), and intrusion-forced injection of thermogenic methane in carbon-rich sedimentary strata during the northeast Atlantic spreading (Svensen et al., 2004).

Despite the question of what caused the PETM, all marine pelagic sections are characterized by a decline of the $CaCO_3$ content attributed to the dissolution of calcareous sediments on the seafloor in response to the rapid release of vast quantities of carbon (Dickens et al., 1997; Dickens, 2000). Dissolution layers are present in the central (Site 865; Thomas, 1998; Mort et al., 2003) and northwest (Leg 198, Bralower et al., 2002) Pacific, in the southeastern Atlantic (ODP Leg 208, Zachos et al., 2004), and in the Tethys (Coccioni et al., 1994). These findings indicate that the calcite compensation depth (CCD) and the lysocline shoaled significantly and rapidly during the PETM in all oceanic regions. Moreover, as the thickness of the clay layer varies from a few millimetres (Shatsky Rise, Pacific Ocean; Bralower et al., 2002) to several centimetres (Walvis Ridge, Atlantic Ocean; Zachos et al., 2004), the degree of carbonate dissolution was not uniform across the ocean. In each locality it is likely influenced by paleodepth and latitude and is possibly linked to the position of the carbon source, as well as to the patterns of thermohaline circulation and to the shift in deep-ocean circulation (Nunes and Norris, 2006).

The duration of the PETM and CIE, as defined by the negative carbon isotope excursion and subsequent recovery, is debated. The onset of the event in the terrestrial and marine records is easily identified at the abrupt shift of the carbon isotope record, but the exact termination of the CIE often lacks a clear inflection point of the $\delta^{13}C$. Moreover, different approaches have resulted from differences in estimates of the total duration of the event, of the duration of its peak and recovery phase, and of the amount of time involved in its onset. Two age models derived from ODP Site 690, which is characterized by a relatively expanded section, estimate a duration for the entire CIE of 120 ka, based on the extraterrestrial ^3He record (Farley and Eltgroth, 2003), and a duration of 220 ka, based on the number of precession cycles derived from the Fe and Ca records (Röhl et al., 2000).

In spite of the uncertainty in the duration of the PETM, the age models are in agreement that it was a geologically brief event associated with large-scale biotic turnover including the appearance of several land mammal groups in North America (Koch et al., 1992; Maas et al., 1995), migration of terrestrial mammals (Bowen et al., 2002), large coastal blooms of the tropical shallow-water dinoflagellate genus *Apectodinium* (Crouch et al., 2001), and a brief turnover in nannoplankton assemblages (Bralower, 2002; Tremolada and Bralower, 2004; Raffi et al., 2005).

The PETM is also marked by the largest benthic foraminiferal extinction event (BFE) in the last 90 Ma, mainly affecting intermediate and deep-water species (i.e. Tjalsma and Lohmann, 1983; Miller et al., 1987; Thomas, 1990, 2003; Kaiho, 1994; Kaiho et al., 1996). By contrast, in the tropical area (equatorial Pacific, ODP Site 865) planktonic foraminifera suffered no extinction and diversified, with the appearance of short-lived exotic taxa (*Acarinina africana*, *Acarinina sibaiyaensis*, and *Morozovella allisonensis*) that reached peak abundance (~16%) within the $\delta^{13}C$ excursion and were therefore called "excursion taxa" by Kelly et al. (1996, 1998). This diversification involved increased dominance by