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Anomalous shifts in tropical Pacific planktonic and benthic foraminiferal test size during the Paleocene–Eocene thermal maximum

Kunio Kaiho [a,*], Kotaro Takeda [a], Maria Rose Petrizzo [b], James C. Zachos [c]

[a] *Institute of Geology and Paleontology, Tohoku University, Sendai 980-8578, Japan*
[b] *Dipartimento di Scienze della Terra "Ardito Desio", Universita' degli Studi di Milano, via Mangiagalli 34, Milano 20133, Italy*
[c] *Earth and Ocean Sciences Departments, University of California, Santa Cruz, CA 95064, United States*

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Abstract

Paleocene–Eocene warming and changes in oceanic hydrography should have significantly impacted the ecology of marine microorganisms, both at the surface and on the seafloor. We analyzed several key characteristics of foraminifera from two Shatsky Rise (ODP Leg 198) cores spanning the P/E boundary including the maximum test diameters of the largest calcareous trochospiral benthic foraminifera and largest shallow-dwelling planktonic foraminifera, and the stable carbon and oxygen isotope ratios of benthic foraminifera and bulk samples. We also qualitatively constrained changes in bottom water dissolved oxygen concentrations by quantifying changes in benthic species abundances. We find warming synchronous with an unusual increase in the size of surface-water planktonic in contrast to deep-water benthic foraminifera which decrease in size. We suggest that a decline in bottom water dissolved oxygen is the primary mechanism responsible for the size reduction of Pacific deep-sea benthic foraminifera, whereas the contemporaneous size increase of surface-water planktonic foraminifera is attributed to an increase in thermal stratification and decrease in local nutrient supply.

Keywords: Benthic foraminifera; Planktonic foraminifera; Size; Dissolved oxygen; Nutrient; Stable isotope; Paleocene; Eocene

1. Introduction

Stable isotope investigations of Ocean Drilling Program (ODP) Site 690 (Kennett and Barker, 1990; Kennett and Stott, 1991), South Atlantic ODP Sites 525 and 527 (Thomas and Shackleton, 1996; Thomas et al., 1999), and paleoequatorial Pacific ODP 865 (Bralower et al., 1995) document a rapid, nearly contemporaneous (<6 kyr) ~5 °C warming of deep water, and a reduction of vertical and latitudinal thermal gradients. Sea surface temperatures (SST) in the Antarctic increased by as much as 10 °C (Kennett and Stott, 1991), while tropical SST increased by 5 °C (Zachos et al., 2003). Often referred to as the Paleocene–Eocene thermal maximum (PETM, a.k.a., LPTM (Late Paleocene thermal maximum) and IETM (Intial Eocene Thermal Maximum)), this event also coincides with a ~2.5–3.0‰ drop in marine $\delta^{13}C$ (CIE), presumably from massive dissociation of methane hydrate (~55.5 Ma; Dickens et al., 1995, 1997; Kaiho et al., 1996). The subsequent oxidation of

* Corresponding author. Tel.: +81 795 6615; fax: +81 795 6634.
E-mail addresses: kaiho@dges.tohoku.ac.jp (K. Kaiho), kotaro-t@mail.tains.tohoku.ac.jp (K. Takeda), mrose.petrizzo@unimi.it (M.R. Petrizzo), jzachos@emerald.ucsc.edu (J.C. Zachos).

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methane and solution into the ocean resulted in extensive dissolution of seafloor carbonate, drop in ocean pH, and carbonate ion content beneath the thermocline (Thomas et al., 1999; Zachos et al., 2005).

The Paleocene/Eocene (P/E) boundary is also marked by the largest benthic foraminiferal extinction event (BEE) of the last 90 m.y. (Kaiho, 1988, 1989, 1991, 1994b; Kaiho et al., 1993, 1996; Kennett and Stott, 1991; Miller et al., 1987; Nomura, 1991; Ortiz, 1995; Thomas, 1989, 1990; Tjalsma and Lohmann, 1983). The extinction event was relatively abrupt occurring over a few tens of thousands of years or less (Kennett and Stott, 1991; Pak and Miller, 1992; Thomas, 1992; Thomas and Shackleton, 1996). The event is marked by extinction of many intermediate- and deep-water benthic foraminiferal species (more than one third of the taxa: 33–50% per site and occasionally 65% per site) as well as some shallow dwelling (50- to 150-m water depths) benthic foraminifera (22%; Kaiho, 1994b).

Although changes in deep-sea benthic foraminiferal test size and an oxygen index have been established at low resolution for the past 120 m.y. (Kaiho, 1994b, 1998, 1999a), these indices have yet to be applied at high-resolution to the P/E boundary. One exception is the section at Tawanui, New Zealand (Kaiho et al., 1996), where application of the benthic foraminiferal oxygen index (BFOI; Kaiho, 1994a) documented near anoxia of intermediate water at the onset of the event. A similar record has yet to be developed for the deeper pelagic sections of the Pacific or Atlantic Oceans.

In contrast, planktonic foraminifera suffer no extinction (Kelly et al., 1996). Instead, there are significant changes in both the distribution and diversification of foraminifera virtually in all regions. In the tropics, thermocline dwellers such as *Subbotina* disappear while *Morozovella* diversify with the appearance of exotic taxa (Kelly et al., 1996). In the polar regions, cooler water species are displaced by warmer water taxa (Kelly, 2002; Stott et al., 1991).

A number of parameters control the composition and size range of benthic foraminiferal assemblages. Food resources and algal symbiosis are probably the main controlling factors of test size of shallow-water benthic foraminifera (Hallock, 1985). Test size of the deep-sea benthic foraminifera, on the other hand, may be affected by factors such as dissolved oxygen levels and food supply (Perez-Cruz and Machain-Castillo, 1990; Phleger and Soutar, 1973; Kaiho, 1994a, 1998, 1999a; Koutsoukos et al., 1990). Planktonic foraminifera abundances and size are influenced by several factors including nutrient fluxes and productivity. In highly oligotrophic settings, for example, the populations tend to be diverse and dominated by species bearing algal symbionts (Hallock et al., 1991; Hemleben et al., 1989). Reduced surface productivity during the PETM has been inferred from assemblage shifts of calcareous nannoplankton at Site 690 (Bralower, 2002) and Site 865 (Bralower et al., 1995; Tremolada and Bralower, 2004), and by the proliferation of photosymbiotic planktonic foraminifera at Site 865 (Kelly, 2002; Kelly et al., 1998), which seem to thrive under oligotrophic conditions.

Cores recovered from Shatsky Rise during ODP Leg 198 provide a unique opportunity to establish detailed records of changes in water column chemistry during the PETM in the low latitude Pacific Ocean. This includes the carbon isotope and dissolved oxygen (BFOI) chemistry. The objective of this paper is to (1) document variations in the test size of deep-water (1500–1700 m water depth) calcareous trochospiral benthic and mixed-layer planktonic foraminifera spanning the PETM, and (2) evaluate potential causes of the variations on the basis of the comparison of the test size with the benthic foraminiferal oxygen index (BFOI; Kaiho, 1994a), $\delta^{18}O$ and $\delta^{13}C$ data. We show here that minima in benthic foraminiferal test size and maxima in mixed-layer planktonic foraminiferal test size coincident with the PETM and low BFOI values.

2. Materials and methods

We analyzed latest Paleocene to earliest Eocene calcareous trochospiral benthic and planktonic foraminifera in 61 samples from two ODP Holes 1209B (Core 22H, Secton 1, Interval 100–141 cm; 32°30.1081′N, 158°30.3564′E, water depth 2387 m) and 1210B (Core 20H, Secton 3, Interval 90–120 cm; 32°13.4202′N, 158°15.5623′E, water depth 2573 m) (Bralower et al., 2002). Paleodepths of 2000 and 2160 m, respectively, were estimated using a simple thermal subsidence model (Berger and Winterer, 1974; Sclater et al., 1971). Lithologically, the Paleocene/Eocene boundary is represented by a sharp contact with light (pale yellowish brown) calcareous ooze overlain by a thin (~2 mm) dark (dusky yellowish brown) calcareous ooze (199.55 mbsf in Hole 1209B and 184.31 mbsf in Hole 1210B; Figs. 1 and 2). Carbonate content declines from 95% to 80% across this contact (Zachos et al., 2003).

A roughly one-meter long continuous U-channel was collected across the Paleocene/Eocene boundary from each core and continuously sampled at 1 cm intervals. Each sample was freeze dried and soaked in a 3 : 1 solution of calgon and buffered water, and then sieved through a 32 μm meshes with buffered deionized water. The >63 μm fraction was used for the benthic