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Original article

Surface-water chemistry and fertility variations in the tropical Atlantic across the Paleocene/Eocene Thermal Maximum as evidenced by calcareous nannoplankton from ODP Leg 207, Hole 1259B

Variations de la chimie des eaux de surface et de la fertilité dans l'Atlantique tropical au cours du Maximum Thermique du Paléocène/Eocène : mise en évidence par l'analyse du nannoplancton calcaire sur le site 1259B (Leg ODP 207)

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Abstract

Calcareous nannoplankton assemblages at Ocean Drilling Program (ODP) Site 1259 on Demerara Rise (western equatorial Atlantic) underwent an abrupt and fundamental turnover across the Paleocene/Eocene Thermal Maximum (PETM) ~55.5 m.y. ago. The PETM is marked by a dissolution interval barren or nearly-barren of nannofossils due to the rapid acidification of the world oceans. *Toweius*, *Fasciculithus*, and *Chiasmolithus* sharply decrease at the onset, whereas *Chiasmolithus*, *Markalius* cf. *M. apertus*, and *Neochiasmolithus* thrive immediately after the event, which also signals the successive first appearances of *Discoaster araneus*, *Rhomboaster*, and *Tribrachiatus*. The environmental indications of these changes were further investigated by correspondence analysis on quantitative nannofossil counts. The PETM event has been attributed to CO_2-forced greenhouse effects. At Site 1259, the elevated pCO_2 and subsequent lowered surface-water pH values at the onset of the PETM caused intensive carbonate dissolution, producing the nannofossil-barren interval. The chemically stressed habitats may well have also induced the evolution of ephemeral nannofossil "excursion taxa", such as *Rhomboaster* and malformed discoasters (*D. araneus* and *Discoaster anartios*). Based on its sudden increase, *Markalius* cf. *M. apertus* is considered to have been a local opportunistic species that took advantage of the surface-water changes. At the same time, a presumably higher runoff from continental areas fertilized the western equatorial Atlantic as indicated by an increase in the abundance of r-mode specialists preferring high-nutrient conditions, such as *Chiasmolithus*, *Coccolithus pelagicus*, and *Hornibrookina arca*. Contrasts between the results of this study and previous work at ODP Site 690 in the Southern Ocean, the New Jersey continental margin, and the central paleoequatorial Pacific further demonstrate that the response to the PETM can be influenced by local differences in geologic setting and oceanographic conditions.

Résumé

Une analyse quantitative des assemblages du nannoplancton calcaire a été effectuée sur le site Ocean Drilling Program (ODP) 1259 (Ride de Demerara, Atlantique équatorial ouest) au passage Paléocène/Éocène. Cette étude révèle un brusque turnover du nannoplancton calcaire au cours du maximum thermique du Paléocène/Éocène, il y a 55 Ma. La limite Paléocène/Éocène est marquée par un intervalle de dissolution où les nannofossiles sont absents ou très peu abondants, événement qui peut être relié à une rapide acidification des océans. Au sein de l'assemblage, l'abondance de *Toweius, Fasciculithus* et *Chiasmolithus* diminue brusquement au début de l'événement thermique tandis que *Chiasmolithus*, *Markalius* cf. *M. apertus*, et *Neochiasmolithus* croissent rapidement après l'événement. Dans le même temps, on observe les premières appari-

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tions successives de *Discoaster araneus*, *Rhomboaster*, et *Tribrachiatus*. Les indications environnementales de ces changements floraux ont été examinées à travers une analyse des correspondances des abondances relatives des nannofossiles calcaires. L'événement thermique du Paléocène/Éocène a été attribué à un forçage climatique par effet de serre lié à une augmentation du CO_2 atmosphérique. Sur le site 1259, la pCO_2 élevée et la diminution subséquente du pH des eaux de surface qui a lieu au début de l'événement thermique ont entraîné une dissolution intense des carbonates, attestée par l'intervalle où les nannofossiles sont absents. La chimie particulière de ces eaux de surface pourrait également avoir entraîné un stress écologique donnant lieu à l'évolution éphémère de quelques taxons de nannofossiles, tels que *Rhomboaster* et des *Discoaster* malformés (*D. araneus* et *Discoaster anartios*). La soudaine augmentation de *Markalius* cf. *M. apertus* suggère que ce taxon est une espèce locale opportuniste qui a profité de ce changement soudain de la chimie des eaux de surface. Dans le même temps, une augmentation des précipitations sur les aires continentales émergées pourrait avoir fertilisé l'Atlantique équatorial ouest par un lessivage accru. Ceci est attesté par une augmentation de l'abondance des taxons spécialistes de type r préférant des eaux plus riches en nutriments, tels que *Chiasmolithus*, *Coccolithus pelagicus* et *Hornibrookina arca*. Les contrastes entre cette étude et les travaux précédents effectués sur le site ODP 690 dans l'Océan austral, sur la marge continentale du New Jersey et dans le Pacifique équatorial central démontre une fois de plus que la réponse au cours du maximum thermique du Paléocène/Éocène peut être influencée par des différences locales telles que les conditions océanographiques et l'environnement de dépôt.

Keywords: Calcareous nannofossils; Paleoecology; Paleocene/Eocene Thermal Maximum; Correspondence analysis; Surface-water chemistry; Paleoproductivity

Mots clés : Nannofossiles calcaires ; Paléoécologie ; Maximum Thermique du Paléocène/Eocène ; Analyse des correspondances ; Chimie des eaux de surface ; Paléoproductivité

1. Introduction

The Paleocene/Eocene Thermal Maximum (PETM; formerly termed the Late Paleocene Thermal Maximum, or LPTM by Zachos et al., 1993) was a catastrophic, transient (<220 kyr [Norris and Röhl, 1999; Röhl et al., 2000; Farley and Eltgroth, 2003]) climate event ~55.5 m.y. ago. This global warming elevated sea-surface temperature (SST) by 5 °C in the tropics and as much as 9 °C at the high latitudes (Kennett and Stott, 1991; Zachos et al., 2003), whereas bottom water warmed by 4–5 °C (Thomas and Shackleton, 1996; Thomas et al., 2000). This event has been widely accepted as one of the best examples of deep-time, rapid greenhouse-forced warming.

The most compelling evidence for this extreme event is a coeval carbon-isotope excursion (CIE) of ~3‰ recorded in global marine and terrestrial systems, suggesting a massive perturbation to the global carbon cycle (e.g. Kennett and Stott, 1991; Koch et al., 1992; Thomas and Shackleton, 1996; Beerling and Jolley, 1998; Bains et al., 1999; Norris and Röhl, 1999). The large magnitude and pattern of rapid decrease and gradual recovery through the CIE indicate multi-pulse injections of isotopically depleted carbon into the ocean and atmosphere (Dickens et al., 1997; Bains et al., 1999; Dickens, 2000). The most plausible source of this carbon is the sudden dissociation of methane hydrates from continental shelves and slopes (Dickens et al., 1995, 1997; Katz et al., 1999), whereas thermogenic methane from hydrothermal vents (Svensen et al., 2004) and carbon dioxide from global wildfires (Kurtz et al., 2003) or an extraterrestrial comet (Kent et al., 2003) have also been suggested. Methane, or its subsequent product of oxidation, carbon dioxide, would have immediately contributed to greenhouse warming and changes in ocean chemistry.

The abrupt climatic change associated with the PETM triggered massive turnovers in oceanic benthic and planktonic organisms as well as in terrestrial vegetation and mammals, and caused a widespread rapid shoaling of the calcite compensation depth (CCD) (Zachos et al., 2005). Deep-water warming and subsequent oxygen deficiency may have led to the extinction of 30–50% of benthic foraminiferal species (Tjalsma and Lohmann, 1983; Thomas, 1990; Kennett and Stott, 1991; Thomas and Shackleton, 1996), the rising temperature to the evolutionary radiation of land mammals and vegetation (Koch et al., 1992; Clyde and Gingerich, 1998; Meng and McKenna, 1998; Wing and Harrington, 2001; Jaramillo, 2002; Gingerich, 2003) and diversification of planktonic foraminifers (Kelly et al., 1996, 1998; Berggren and Ouda, 2003), and the changes in oceanic surface-water chemistry to the evolution of ephemeral "excursion taxa" among planktonic foraminifera and nannofossils (Bybell and Self-Trail, 1995; Kelly et al., 1996; Kahn and Aubry, 2004).

The responses and/or strategies of surface-dwelling and benthic organisms to the PETM environmental changes appear to have been fundamentally different. Because of very limited high-resolution investigations using calcareous nannofossils (e.g. Angori and Monechi, 1996; Bralower, 2002; Tremolada and Bralower, 2004; Raffi et al., 2005; Gibbs et al., 2006) and their Sr/Ca ratios (Stoll and Bains, 2003), and the lack of consensus on productivity variation during the PETM from different proxies even at the same site (Bains et al., 2000; Bralower, 2002; Stoll and Bains, 2003), just how phytoplankton, the primary producers in ocean surface waters and major carbonate contributors to deep-sea sediments, reacted to the PETM, is still not well understood. Recent comparisons, however, suggest that their response were different in continental margin vs. open ocean settings (Gibbs et al., 2006).

The equatorial Atlantic Ocean has been long known to be an important repository of information for Earth's history. Sediments that have accumulated beneath the divergence-driven upwelling system provide the most continuous high-resolution archives and sensitive recorders of oceanographic change, which document a complex interplay of ocean chemistry, productivity, climate, ocean-atmospheric circulation, and plate tectonics (Van Andel et al., 1977). Because the sediments are shallowly buried, crop out on the seafloor in places, and