Marine Micropaleontology 129 (2016) 24–31

Contents lists available at ScienceDirect

Marine Micropaleontology

journal homepage: www.elsevier.com/locate/marmicro

Research paper

Contrasting response of the calcareous nannoplankton communities after the Eocene hyperthermal events in the tropical Atlantic Ocean

Yuanda Lei [a], Shijun Jiang [b,*], Sherwood W. Wise Jr. [c], Ying Cui [d], Yang Wang [c]

[a] Department of Ecology, Jinan University, Guangzhou 510632, China
[b] Institute of Groundwater and Earth Sciences, Key Laboratory of Eutrophication and Red Tide Prevention of Guangdong Higher Education Institutes, Jinan University, Guangzhou 510632, China
[c] Department of Earth, Ocean and Atmospheric Science, 108 Carraway Building, Florida State University, Tallahassee, FL 32306, United States
[d] Department of Earth Sciences, Dartmouth College, 204 Fairchild Hall, Hanover, NH 03755, United States

ARTICLE INFO

Article history:
Received 10 December 2015
Received in revised form 31 October 2016
Accepted 4 November 2016
Available online 05 November 2016

Keywords:
Calcareous nannoplankton
Eocene hyperthermals
Ecosystem regime shift
Nutrient supply
Tropical Atlantic

ABSTRACT

Latest Paleocene and early Eocene hyperthermals were geologically brief, profound environmental perturbations caused by massive additions of ^{13}C-depleted carbon to the ocean-atmosphere system, and therefore provide ancient analogs to assess the impact of modern global warming on the Earth's ecosystem. We document and compare population changes in calcareous nannoplankton, the major primary producers in Paleogene oceans, across three consecutive hyperthermal episodes of differing magnitudes (i.e., the most severe Paleocene/Eocene Thermal Maximum (PETM), the relatively mild Eocene Thermal Maximum 2 (ETM2) and the least severe H2) in the tropical Atlantic. Across all three hyperthermal events, the total abundance and the abundance of the eutrophic and mesotrophic taxa decreased significantly, while oligotrophic taxa increased markedly, suggesting that oligotrophy prevailed in tropical Atlantic surface waters. A nonmetric multidimensional scaling ordination revealed that, during the peak of each hyperthermal, nannoplankton communities featured excursion taxa and assemblages substantially deviated from the pre-event composition. However, during the recovery phase, nannoplankton communities rapidly returned to quasi pre-event compositions for the ETM2 and H2 perturbations, but remained distinct from the pre-event composition for the PETM. This contrast between pre- and post-event compositions of nannoplankton communities may imply that the PETM perturbation exceeded the resilience threshold of the tropical Atlantic surface ecosystem and caused a regime shift, cautioning the possible risk of an abrupt state change in oceanic ecosystem under the present situation, which has a considerably faster and greater perturbation to the C cycle than during the PETM.

1. Introduction

Superimposed on the long-term global warming from the late Paleocene through early Eocene were a series of hyperthermal events (Thomas and Zachos, 2000), among which, in descending magnitude, are the Paleocene–Eocene Thermal Maximum (PETM; 55.93 Ma), the Eocene Thermal Maximum 2 (ETM2, 54.02 Ma) and the slightly younger H2 event (54.01 Ma). These intervals appear to have been geologically brief episodes characterized by significant Earth surface warming, massive carbon input to the ocean-atmosphere system, and pronounced environmental change (see McInerney and Wing, 2011 for a review). As such, these hyperthermals share key biogeochemical characteristics with current anthropogenic global warming caused by light-carbon release from the burning of fossil fuels (Hönisch et al., 2012), and provides a possible blueprint for assessing the future impact of modern global warming on the Earth's ecosystem.

The PETM is characterized by a >3.5‰ negative carbon isotope excursion (CIE) in global marine and continental records (e.g., McInerney and Wing, 2011). This CIE implies a massive introduction of over 3×10^{18} g ^{13}C-depleted carbon and a fundamental perturbation to the atmosphere and ocean systems (Dickens et al., 1997; Panchuk et al., 2008; Zeebe et al., 2009). The resulting abrupt global warming heated the surface ocean by ~5–9 °C and the deep sea by ~4–5 °C at all latitudes (Kennett and Stott, 1991; Zachos et al., 2003; Tripati and Elderfield, 2004; Sluijs et al., 2006; Aze et al., 2014; Hollis et al., 2015), and triggered significant changes in marine and terrestrial ecosystems (e.g., Kennett and Stott, 1991; Kelly et al., 1996; Wing and Harrington, 2001; Penman et al., 2014; Stassen et al., 2015). The relatively mild ETM2 and H2 events involved smaller amounts of carbon release and consequently resulted in less severe environmental changes associated with 3–5 °C and 2 °C of warming, respectively (Lourens et al., 2005; Sluijs et al., 2009; Stap et al., 2010). The PETM perturbation caused significant population changes in calcareous nannoplankton communities in both deep ocean and nearshore settings (e.g., Bralower, 2002; Gibbs et al., 2006; Jiang and Wise, 2006; Bown and Pearson, 2009; Raffi et

* Corresponding author.
E-mail addresses: sjiang@jnu.edu.cn, ssj0047@my.fsu.edu (S. Jiang).

http://dx.doi.org/10.1016/j.marmicro.2016.11.001
0377-8398/

al., 2009). Previous studies have discovered that there existed a scaled biotic response (e.g., extinction and calcification) of marine calcifiers to the amount of carbon released during various-magnitude hyperthermal events (Gibbs et al., 2012; Foster et al., 2013). This suggests that biotic response can be used to predict how ecosystems respond to larger perturbations and highlights the need to further explore the population change across each environmental perturbation (Norris et al., 2013). In particular, these successive environmental perturbations of varying magnitude provide a unique opportunity to gauge the resilience of the marine ecosystem regarding light carbon tolerance.

Here we quantitatively document and compare temporal population changes in calcareous nannofossil assemblages from one of the most complete and expanded, low-latitude PETM, ETM2 and H2 sections in the tropical Atlantic (Fig. 1). We attempt to 1) demonstrate in detail how marine primary producers responded to global warming in a tropical setting; and 2) explore the response of the tropical surface marine ecosystem under varying-magnitude warming events. This study provides ancient analogs for assessing the ecological consequences of modern ongoing global warming.

2. Materials and methods

The ETM2 and H2 records were obtained from Ocean Drilling Program (ODP) Site 1258 (paleodepth ~2000 m), and the PETM records from adjacent Sites 1259 and 1260 (paleodepth ~1500 and 1700 m, respectively). These three sites, drilled during ODP Leg 207 in 2003, lie in 3192.2 m, 2354 m and 2549 m of water depth, respectively, in the western equatorial Atlantic (Fig. 1). The PETM, ETM2 and H2 intervals were identified based on the magnitude and stratigraphic position of the CIE as universally accepted.

Fifty-four samples bracketing the ETM2 and H2 events were taken from Core 1258B-14R. Each sample was assigned an orbital age via interpolation based on the high-resolution Fe cyclostratigraphy by Westerhold and Röhl (2009). Sample spacing varied depending on sample availability and proximity to the magnetic susceptibility spike that approximates the CIE; it was generally ~10 cm close to the events and 20–30 cm farther away, temporally equivalent to about 4–10 ka. Calcareous nannofossils were prepared following the modified "glass beads" method (Okada, 1992; Jiang and Wise, 2009) that allows random counts to be converted into absolute coccolith numbers per g of sediments, and their identification followed the commonly used taxonomy in Perch-Nielsen (1985) and Bown (1998). No mechanical settling or concentration was applied and two slides were made for each sample to ensure better representation of the original fossil assemblages. Specimens representing more than half of a complete fossil were identified and counted under a Zeiss Axiophot II microscope (Florida State University, Tallahassee, USA) at 1000× magnification from fields of view with materials evenly distributed. Counting continued until the following three thresholds were reached: 1) >400 specimens were tallied; 2) >150 glass beads were counted; and 3) specimens were counted from within ≥20 fields of view randomly selected from the two slides. The preservation state of a fossil assemblage was quantified using the ratio of indeterminate to identifiable *Toweius* specimens following Gibbs et al. (2006), with smaller values indicating better preservation. The PETM nannofossil records from Sites 1259 and 1260 were previously studied following the same or similar methodology (Jiang and Wise, 2006; Mutterlose et al., 2007).

Another subset of samples from the same depths was pretreated with 10% hydrogen peroxide for 24 h to remove organic matter prior to bulk-isotopic analysis. The freeze-dried samples were then homogenized, and a suitable aliquot weighed for isotopic analysis. The stable C- and O-isotopic ratios were measured on a Gas Bench II Auto-Carbonate device interfaced to a Finnigan Mat Delta plus XP mass-spectrometer housed at the National High Magnetic Field Laboratory of Florida State University in Tallahassee, USA. All results were calibrated against international and internal laboratory standards, and reported in delta notation relative to the Peedee Belemnite (PDB) standard. Analytical precision is better than ±0.03‰ for C isotopes and ±0.04‰ for O isotopes.

Nonmetric multidimensional scaling (NMS) was used to analyze and compare temporal changes in the nannofossil assemblage (Jiang and Wise, 2006; Mutterlose et al., 2007) across the PETM, ETM2 and H2 events. NMS is an ordination technique that makes no assumptions about the distribution of the underlying data and is one of the most robust unconstrained ordination methods in community ecology (Minchin, 1987). During the analyses the Bray-Curtis distance measure was used and 100 random initial starting configurations chosen to avoid

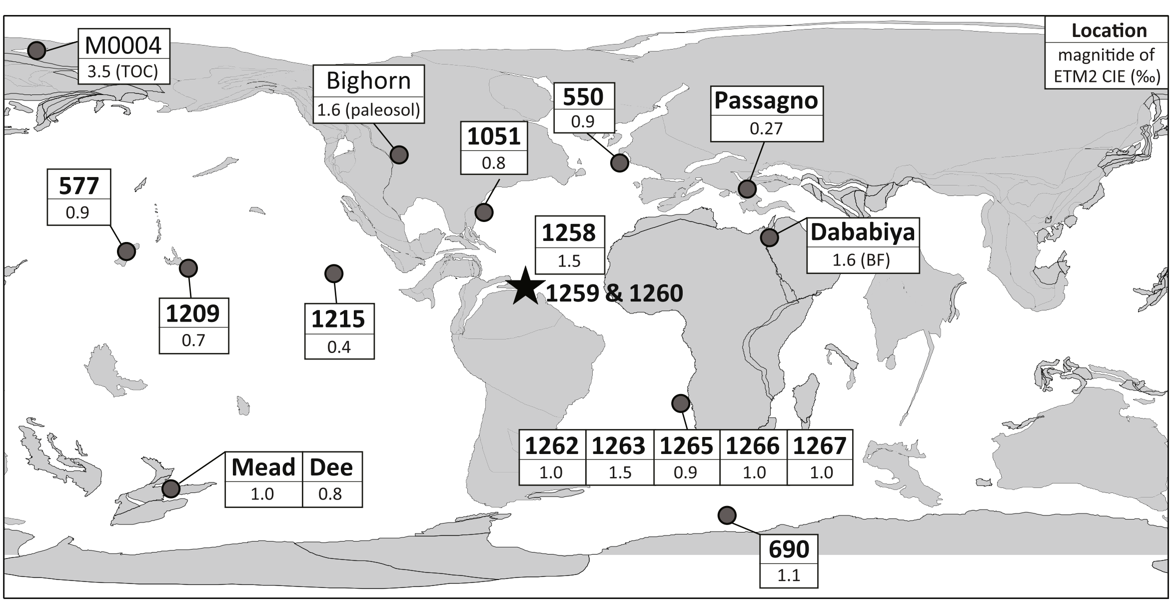

Fig. 1. Location of ETM2 records at studied (filled star) and reference sites (solid circle) on a 53-Ma paleogeography map (www.odsn.de). Reference sites include the land section at Bighorn Basin (Koch et al., 2003), and oceanic sections at Mead and Dee Streams (Nicolo et al., 2007), Passago (Agnini et al., 2007b), Dabiya (Stassen et al., 2012), DSDP Sites 550 & 577, ODP Sites 690, 1051 (Cramer et al., 2003), 1209 (Gibbs et al., 2012) and 1215 (Leon-Rodriguez and Dickens, 2010), and IODP Site M0004 (Sluijs et al., 2009). CIE based on bulk carbonate unless otherwise stated. BF = benthic foraminifer.