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The demise of the early Eocene greenhouse – Decoupled deep and surface water cooling in the eastern North Atlantic

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ABSTRACT

Early Paleogene greenhouse climate culminated during the early Eocene Climatic Optimum (EECO, 50 to 53 Ma). This episode of global warmth is subsequently followed by an almost 20 million year-long cooling trend leading to the Eocene-Oligocene glaciation of Antarctica. Here we present the first detailed planktic and benthic foraminiferal isotope single site record ($\delta^{13}C$, $\delta^{18}O$) of late Paleocene to middle Eocene age from the North Atlantic (Deep Sea Drilling Project Site 401, Bay of Biscay). Good core recovery in combination with well preserved foraminifera makes this site suitable for correlations and comparison with previously published long-term records from the Pacific Ocean (e.g. Allison Guyot, Shatsky Rise), the Southern Ocean (Maud Rise) and the equatorial Atlantic (Demerara Rise). Whereas our North Atlantic benthic foraminiferal $\delta^{18}O$ and $\delta^{13}C$ data agree with the global trend showing the long-term shift toward heavier $\delta^{18}O$ values, we only observe minor surface water $\delta^{18}O$ changes during the middle Eocene (if at all) in planktic foraminiferal data. Apparently, the surface North Atlantic did not cool substantially during the middle Eocene. Thus, the North Atlantic appears to have had a different surface ocean cooling history during the middle Eocene than the southern hemisphere, whereas cooler deep-water masses were comparatively well mixed. Our results are in agreement with previously published findings from Tanzania, which also support the idea of a muted post-EECO surface-water cooling outside the southern high-latitudes.

1. Introduction

The Paleogene represents a prominent long-term climate transition in Earth history with a late Paleocene to middle Eocene interval that is characterized by a long-term global warmth (Zachos et al., 1994, 2001; Norris et al., 2013). The existence of a late Paleocene–early Eocene greenhouse is supported by numerous paleontological, isotopic and sedimentological findings suggesting temperatures in subpolar regions and ocean bottom waters that were up to 10 °C higher than today (e.g. Wolfe, 1980; Axelrod, 1984; Zachos et al., 1994; Bice et al., 1996; Zachos et al., 2001; Tripati et al., 2003; Tripati and Elderfield, 2005; Sexton et al., 2006a; Hollis et al., 2012). Polar ice-sheets were either small or did not exist (Frakes et al., 1992; Miller et al., 2005; Spielhagen and Tripati, 2009; Tripati et al., 2008). The Paleocene–Eocene warmth culminated in the Early Eocene Climatic Optimum (EECO; 50–53 Ma, Vandenberghe et al., 2012), and was subsequently followed by a long-term cooling, which finally led to the Oligocene icehouse (e.g. Miller and Curry, 1982; Miller et al., 1987; Zachos et al., 1994). Most authors have invoked high atmospheric pCO_2 levels to explain the greenhouse climate mode, while the post-EECO cooling has often been attributed to a decline of atmospheric pCO_2 concentrations (Pearson and Palmer, 2000; Demicco et al., 2003; Pagani et al., 2005; Zachos et al., 2008).

Our current view of temperature trends and prevailing paleoceanographic conditions during the early Paleogene relies on multi-site composite benthic foraminiferal $\delta^{18}O$ records (Zachos et al., 1994, 2001, 2008; Cramer et al., 2009) compiled from multiple drill sites in different ocean basins. These records provide an average signal of the deep ocean. Presently, most single site planktic foraminifera stable isotope data are of low resolution or based on poorly preserved foraminiferal calcite. High quality paleotemperature data are particularly lacking for the Eocene North Atlantic. Other than the tropical Demerara Rise records (ODP Sites 1258 and 1260) of Sexton et al. (2006a), no long-term single site benthic foraminiferal record with an adequate temporal resolution for the early to middle Eocene has been published from this region.

The reasons for these limitations are due to the lack of deep-sea sites which provide both: (1) good core recovery of sediments spanning the study interval; existing North Atlantic records are typically punctuated

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by frequent occurrences of chert layers, condensation and major hiatuses covering up to 2 million years particularly across the early-middle Eocene transition (e.g. Aubry, 1995; Norris et al., 2001a; Muttoni and Kent, 2007), (2) suitable microfossil preservation that allows for reliable geochemical proxy data, particularly for planktic foraminifera.

Here we present new long-term stable isotope records ($\delta^{13}C$, $\delta^{18}O$) of foraminiferal calcite from the North Atlantic (Deep-Sea Drilling Project (DSDP) Site 401, Bay of Biscay) covering the latest Paleocene to middle Eocene interval (~57–40 Ma). Key features of this time interval include a number of transient warming events (of 100–200 kyr duration) such as the well known Paleocene–Eocene Thermal Maximum (PETM, 56 Ma; e.g. Kennett and Stott, 1991; Sluijs et al., 2007; McInerney and Wing, 2011) and Eocene Thermal Maximum 2 (ETM2, 54.1 Ma; e.g. Lourens et al., 2005; Stap et al., 2009; 2010; D'haenens et al., 2014), but also numerous similar, less pronounced events of early Eocene age (Cramer et al., 2003; Sexton et al., 2011; Kirtland Turner et al., 2014). On a multi-million year timescale, secular variations in the carbon cycle are reflected in the $\delta^{13}C$ of biogenic carbonates showing the long-term $\delta^{13}C$ decline across the Paleocene–Eocene transition. This decrease resulted in a Paleogene $\delta^{13}C$ minimum period between 52 and 54 Ma which marks the onset of the long-term warmth of the EECO. While previous recent studies from the Paleocene–Eocene interval of Site 401 are exclusively focused on the PETM and ETM2 (Bornemann et al., 2014; D'haenens et al., 2012, 2014), this paper discusses the long-term evolution of the North Atlantic during the latest Paleocene to middle Eocene across the EECO interval of peak warmth.

The new long-term stable isotope records from DSDP Site 401 comprise not only benthic foraminifera representing bottom water conditions. We also present stable isotope data for planktic foraminifera as a measure of subsurface–thermocline and surface mixed-layer conditions. Until now no detailed information on the upper ocean structure and the surface water temperature trends are available for the EECO and middle Eocene from the northeastern Atlantic, thus, our records allow us to unravel the response of the entire water column and to compare our North Atlantic records of this globally warm period to previously published ones from the Pacific (Bralower et al., 1995; Dutton et al., 2005, 2006; Zachos et al., 2003; Westerhold et al., 2011), the equatorial and South Atlantic (Sexton et al., 2006a; Bice and Norris, 2005; Littler et al., 2014) and the Southern Ocean (Kennett and Stott, 1990; Stott and Kennett, 1990) for different water masses. We further examine inter-ocean basin $\delta^{13}C$ bottom water gradients as a proxy of deep-water circulation patterns and discrepancies in surface water response to the long-term middle Eocene bottom water cooling trend (Pearson et al., 2007; Inglis et al., 2015).

2. Material and methods

2.1. Location and lithology

DSDP Site 401 (47°25.65′N, 8°48.62′W) is located on the Meriadzek Terrace on the northern margin of the Bay of Biscay, eastern North Atlantic (Montadert et al., 1979)(Fig. 1). During the PETM (56 Ma) this site was located at ~42°32′N and 10°25′W (McInerney and Wing, 2011), making it (along with DSDP Site 550) one of the most northern scientific drill sites to provide pelagic carbonates of Paleogene age. Site 401 was drilled at a water depth of 2495 m (Montadert et al., 1979), the paleo-water depth for the early Eocene is estimated at 1.8 to 2 km based on benthic foraminifera (D'haenens et al., 2012).

Core recovery of the ~95-m-thick sequence is nearly complete for the latest Paleocene to early middle Eocene (c. 90%; cores 7–14), whereas the two uppermost cores 5 and 6 have only been partly recovered (Fig. 2). We took samples at a resolution of four samples per core section from cores 15 to 5 (depth interval ~212–110 mbsf), whereas core 14 (PETM) and core 13 (ETM2) were sampled at a much higher resolution (D'haenens et al., 2012; D'haenens et al., 2014; Bornemann et al., 2014).

The uppermost Paleocene to middle Eocene sedimentary succession consists of yellowish-brown to orange-brown nannofossil marls and marly chalks (Fig. 2). Sediment color cyclicity is apparent for the studied Eocene sequence reflecting changes in $CaCO_3$ and clay content. The PETM and ETM2 beds are darker, with less carbonate and a higher clay content (Fig. 2) than the rest of the section (D'haenens et al., 2012; Bornemann et al., 2014).

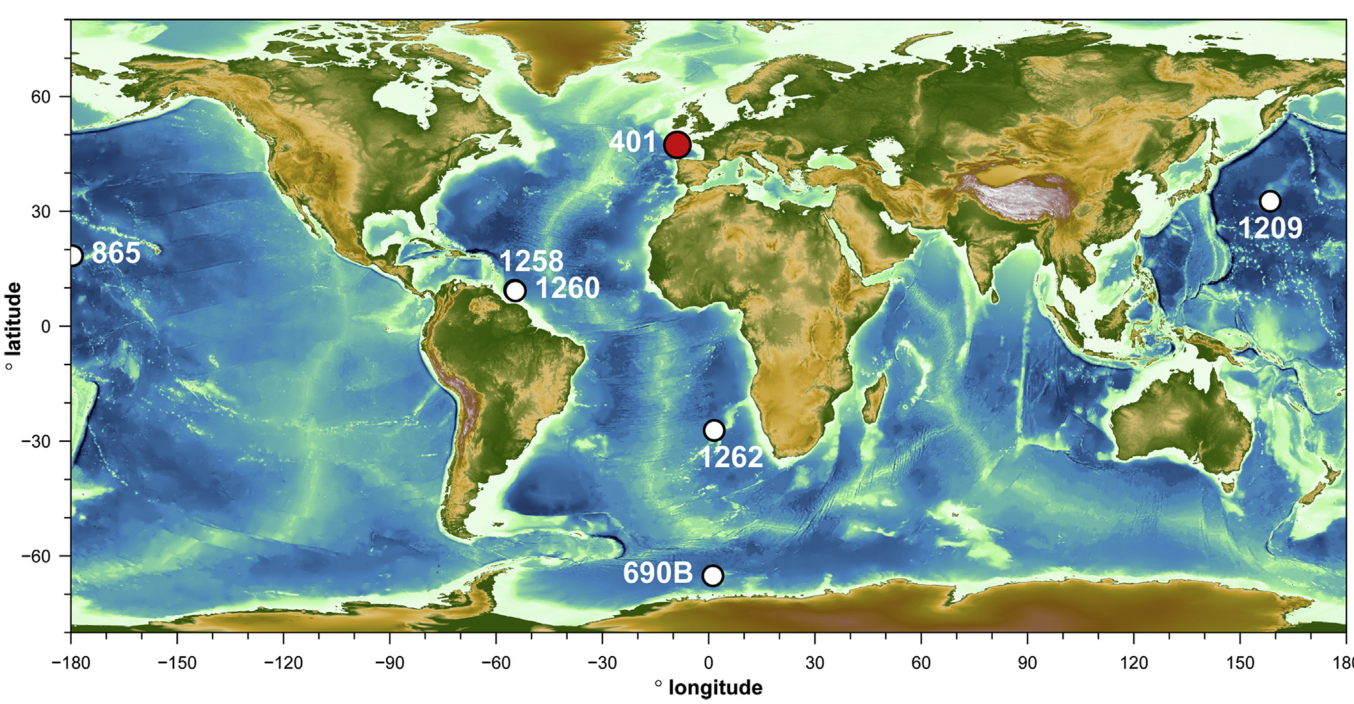

Fig. 1. Global geographic map. Sites shown are of scientific importance for the study interval and are included in the intersite comparison.