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Characterising the middle Miocene Mi-events in the Eastern North Atlantic realm: A first high-resolution marine palynological record from the Porcupine Basin

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ABSTRACT

The warm climate of the Miocene peaked during the middle Miocene Climatic Optimum (MMCO; 17–14.5 Ma). After the MMCO, global climate went through several short-lived cooling events: the Mi-events (Miocene isotope events). One of the more severe Mi-events is Mi-3, associated with East Antarctic Ice Sheet growth, species turnover in terrestrial and marine realms, Northern Hemisphere and mid-latitude aridification and Antarctic sea-surface temperature cooling. CO_2 reconstructions, as well as the aforementioned observations, suggest that a drawdown of CO_2 and/or changes in ocean circulation led to the changes surrounding Mi-3. A combination of eccentricity and obliquity amplitude modulation minima, favourable conditions for ice growth, has also been suggested as a possible triggering mechanism. However, an exact cause cannot be pinpointed yet. High-resolution records necessary to investigate the exact order of events surrounding Mi-3 and the possible role of orbital forcing, a very likely trigger, are sparse.

Integrated Ocean Drilling Program (IODP) Leg 307 recovered such a high resolution record from the middle Miocene at the Porcupine Basin (offshore south-western Ireland). Well-preserved palynomorphs, mainly organic-walled dinoflagellate cysts, acritarchs and some pollen were extracted from Site U1318, and relative and absolute abundance changes were determined. Using dinocysts and calcareous nannoplankton the age model for the record was improved. Based on the palynology, the Mi-3a, Mi-3b and Mi-4 events were successfully identified and concomitant palaeoenvironmental change was observed. These events, although different in magnitude, can be associated with a decrease in sea-surface temperature, as well as with a likely fall in sea-level. Furthermore, possible palaeoenvironmental preferences of 5 dinocyst taxa were determined, based on observations from the record and multivariate statistics.

1. Introduction

Over the last 65 million years (Ma) Earth's climate underwent a significant change: from a warm greenhouse climate in the Paleogene to a glaciated Icehouse World in modern times (e.g. Zachos et al., 2001, 2008). From the Early Eocene Climatic Optimum onwards the climate started cooling and during the Eocene–Oligocene Transition Antarctica became glaciated for the first time in Cenozoic history (e.g. Zachos et al., 2001; De Conto and Pollard, 2003). Climate remained relatively stable until the Late Oligocene warming and the Mid Miocene Climatic Optimum (MMCO; 16–14.5 Ma; Abels et al., 2005). After the MMCO climate started cooling again in gradual steps, eventually leading to the bipolar glaciated world as we know it now. A series of these brief glaciation periods, where Antarctica experienced major ice caps again (Shevenell et al., 2004; Lewis et al., 2007; Haywood et al., 2009), has been identified in several Miocene isotope zones (e.g. Miller et al., 1991, 1996). The positive increases in benthic stable oxygen isotopes ($\delta^{18}O$) in these zones, also referred to as the Miocene isotope events (Mi-events), indicate a drop in bottom water temperature and/or an increase in ice volume (see Fig. 1). Mi-1 (23.13 Ma, Abels et al., 2005) is considered the second largest climate aberration after the Eocene–Oligocene Transition and it is accompanied by accelerated turnover rates in certain groups of biota (Zachos et al., 2001). After the MMCO the Mi-3 throughout Mi-7 events carried on the pattern of stepwise cooling. Of these events Mi-3 is considered to be the strongest event and $\delta^{18}O$ values did not return to pre-event values (e.g. Zachos et al., 2001). The Mi-3 event was later split into Mi-3a (14.2 Ma) and Mi-3b (13.82; Miller et al., 1996; Abels et al., 2005), of which Mi-3a was relatively small in comparison to the second major Mi-3b event (Abels et al., 2005 and references therein). During and after Mi-3 a series of environmental changes occurred, such as species turnover in both

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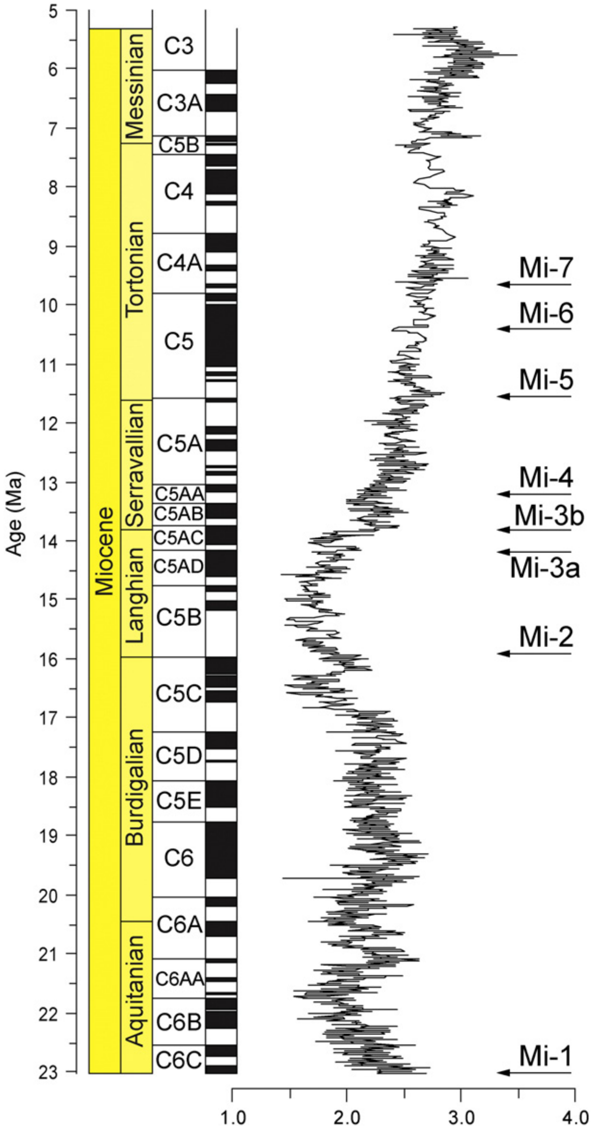

Fig. 1. Overview of Mi-events 1–7 plotted versus age (Ma; ATNTS 2012) and benthic $\delta^{18}O$. Benthic $\delta^{18}O$ curve is a 5 pt. running average from the Zachos et al. (2008) benthic isotope stack, positioning of the Mi-events according to Miller et al. (1991, 1996).

terrestrial and marine biota (Flower and Kennett, 1994), Northern Hemisphere and mid-latitude aridification (Flower and Kennett, 1994; Eronen et al., 2012; Pound et al., 2012), a carbonate crash in the Caribbean (Roth et al., 2000) and a shift towards heavier $\delta^{13}C$ values as measured in benthic foraminifers (Woodruff and Savin, 1991). Furthermore, in the Southern Hemisphere surface waters surrounding Antarctica cooled ca. 6–7 °C and possibly also freshened (Shevenell et al., 2004), and the tundra vegetation on Antarctica went extinct except for a few isolated communities (Pound et al., 2012). Moran et al. (2006) even suggested local presence of sea ice in the Arctic Ocean, implying the first signs of bipolar glaciation. These findings, along with various CO_2 reconstructions, suggest that a drawdown of CO_2 and/or changes in ocean circulation (e.g. Shevenell et al., 2004; Pagani et al., 2005; Kürschner et al., 2008; Badger et al., 2013) led to the changes surrounding Mi-3. However, most of the oceanic records that define and characterise the Mi-events have a relatively low resolution; an order of events and possible causal relationships is therefore hard to determine. The few available high-resolution records of the late middle Miocene suggest that the Mi-3b event (13.82 Ma ± 0.03; Abels et al., 2005) coincides with minima nodes in eccentricity and obliquity amplitude modulation (Shevenell et al., 2004; Abels et al., 2005), a specific configuration that has previously been shown to be favourable for ice growth (Coxall et al., 2005).

To assess whether orbital forcing truly has been a trigger for the Mi-events it is important to gather more high-resolution records, assessing factors such as surface water cooling, terrestrial-marine coupling, productivity changes, sea-level responses and changes in ocean circulation. Especially the biotic response is an important factor since it links the carbon cycle to climatic processes. Preserved remains of dinoflagellates, an important group of predominantly photosynthetic aquatic micro-organisms (Taylor, 1987), can provide insight into surface water properties during the middle and late Miocene cooling. Dinoflagellates are single-celled protists that live in both freshwater and marine surface waters. Together with diatoms and coccolithophorids they form the largest marine phytoplankton group and are important as primary producers. Some dinoflagellates build a strongly resistant resting cyst (dinocyst)–which consists of organic, siliceous or calcareous material–as part of their life cycle (Evitt, 1985). It has become clear from a variety of studies that dinocysts are preserved very well, and that they record climatic and environmental change in the past and present through the environmental preferences of the living dinoflagellate (e.g. Marret and Zonneveld, 2003; Rochon and Marret, 2004; Pross and Brinkhuis, 2005; Sluijs et al., 2005; Zonneveld et al., 2012). Dinocysts are excellent proxies for the reconstruction of sea surface temperature (SST), salinity (SSS), productivity and upwelling intensity (SSP) and relative sea-level (e.g. Mertens et al., 2009a,b; Verleye and Louwye, 2010; De Schepper et al., 2011). Changes in these properties can be deduced from either changes in the dinocyst assemblage composition or physiology (shape) of dinocysts.

No high-resolution dinocyst records across the Mi-3 and Mi-4 events are available and their potential for assessing the timing and mode of the Mi-events still has to be proved. Donders et al. (2009) have already suggested water mass changes and relative SST decreases based on a.o. a dinocyst record, concurrent with terrestrial cooling (based on pollen and organic biomarker evidence) for several of the Mi-events. However, that record from a continental borehole in the Netherlands is not continuously cored and thus not suited for future high resolution analysis.

A low-resolution study by Louwye et al. (2008) on organic-walled dinocysts for the biostratigraphy and deposition history of the Porcupine Basin (offshore South-western Ireland; see Fig. 2) at Site U1318, IODP Leg 307 revealed drastic dinocyst assemblage changes during the late middle Miocene, possibly in relation to the Mi-events. The dinocyst assemblage shifted to a cooler, less productive and more oceanic environment after the MMCO. Based on sedimentation rates and the environmental response in the Louwye et al. (2008) study, we consider sediments from Site U1318 to be well-suited for a high resolution dinocysts study to reconstruct the detailed environmental succession across the short-lived Mi-events.

Here we report high-resolution quantitative dinocyst and palynofacies records of environmental conditions at Site U1318 between 14.4 Ma and 12 Ma. We investigate assemblage shifts, changes in species diversity and turnover and their environmental interpretation across this time interval, and compare their timing to existing records and interpretations of the Mi-events.

2. Material and methods

2.1. Material

2.1.1. Geological setting and stratigraphic framework

The Porcupine Basin is especially famous for its deep-water habitats (Thomson, 1873; Le Danois, 1948) and harbours several large carbonate mounds (De Mol et al., 2002). These mounds are deep-water coral banks (De Mol et al., 2002; Foubert et al., 2005) and can be separated into three distinct provinces: 1) the Belgica mounds in the east, 2) the Hovland mounds in the north (De Mol et al., 2002) and 3) the buried