Marine Micropaleontology 139 (2018) 28–41

Contents lists available at ScienceDirect

Marine Micropaleontology

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

Research paper

Variability in diatom and silicoflagellate assemblages during mid-Pliocene glacial-interglacial cycles determined in Hole U1361A of IODP Expedition 318, Antarctic Wilkes Land Margin

Linda H. Armbrecht[a,*], Vikki Lowe[a], Carlota Escutia[b], Masao Iwai[c], Robert McKay[d], Leanne K. Armand[a,e]

[a] Department of Biological Sciences/MQMarine, Macquarie University, North Ryde, NSW 2109, Australia
[b] Instituto Andaluz de Ciencias de la Tierra, CSIC - University de Granada, 18100, Armilla (Granada), Spain
[c] Natural Science Cluster/Center for Advanced Marine Core Research, Kochi University, Akebono-cho, Kochi 780-8520, Japan
[d] Antarctic Research Centre, Victoria University of Wellington, Wellington 6140, New Zealand
[e] Research School of Earth Sciences, The Australian National University, Acton ACT 2601, Australia

ARTICLE INFO

Keywords:
Sea-surface temperature
Sea-ice
Fragilariopsis barronii
Rouxia naviculoides
Rouxia antarctica
Denticulopsis simonsenii
Chaetoceros resting spore

ABSTRACT

The Earth is currently experiencing climatic changes that will result in similar environmental conditions to those experienced during the mid-Pliocene (5.3–3.6 million years ago [Ma]), such as similar atmospheric CO_2 concentrations, elevated sea surface temperature, and higher sea-levels due to polar ice melt. Studying the temporal distribution of Antarctic diatoms and silicoflagellates from this epoch provides insights into environmental conditions and sea-ice configurations during that time, and remains the only way to realistically estimate future phytoplankton community responses and Southern Ocean sea-ice extent during large-scale transient changes of similar magnitude to that anticipated by anthropogenic causes. In this study, we identified and quantified diatoms and silicoflagellates in a sediment core section obtained from the Antarctic Wilkes Land margin (IODP Expedition 318, Hole U1361A), spanning four glacial and interglacial cycles around the Gauss/Gilbert geochron boundary (3.6 Ma) between about 3.69 and 3.56 Ma. Two major abundance peaks (around 79.66 and 76.86 mbsf; representing time intervals around 3.65 Ma and 3.58 Ma, respectively) were identified. Both peaks temporally match previously determined high productivity warm intervals (interglacials). Diatom and silicoflagellate assemblages in these two interglacial periods differed: the abundance peak in the older sediments is dominated by the pennate diatoms *Fragilariopsis barronii*, *Rouxia naviculoides* and *Rouxia antarctica*; indicative of seasonal, meltwater associated stratification. The abundance peak in the younger sediments is composed principally of *Chaetoceros* resting spores, suggesting higher productivity, strong stratification and prolonged ice-free, open water conditions. Analysing highly abundant diatoms and environmental indicator species from this IODP Site in relation to the previously determined palaeo-productivity proxy Ba/Al allowed us to refine the age model. Our study provides orbital-scale insights into the variability of Antarctic diatom and silicoflagellate assemblages during the mid-Pliocene, thereby offering a reference for future predictions of extant diatom responses to ongoing climate change.

1. Introduction

Anthropogenic greenhouse gas emissions are currently leading to rapidly increasing global temperatures and climate change. According to latest assessments, atmospheric CO_2 will double and temperatures will increase 1.5°– 4 °C by the end of this century (IPCC, 2013). Under the IPCC RCP8.5 scenario (worst case scenario representing CO_2 concentrations of 936 ppm by 2100) atmospheric CO_2 concentrations will reach the threshold expected to induce continental ice sheet melting (IPCC, 2013; DeConto and Pollard, 2016; Golledge et al., 2016). Melting of Greenland is estimated to contribute ~7.4 m to global sea-level rise (Vasskog et al., 2015) and Antarctic melting is estimated to contribute ~15 m by 2500 (DeConto and Pollard, 2016). While sea-ice in the Arctic has retreated dramatically (~4% decrease in annual mean sea-ice extent per decade, 1979–2012), trends in the Antarctic are less apparent (IPCC, 2013; Jones et al., 2016), however, climatic models simulate a strong Antarctic sea-ice retreat by 2100 (DeConto and Pollard, 2016; Hobbs et al., 2016).

* Corresponding author.
E-mail address: linda.armbrecht@mq.edu.au (L.H. Armbrecht).

https://doi.org/10.1016/j.marmicro.2017.10.008
Received 14 April 2017; Received in revised form 25 October 2017; Accepted 28 October 2017
Available online 18 January 2018
0377-8398/

Studying warmer than present periods, and learning from the physical, chemical and palaeontological data defining such periods, is important to estimate biological and ice sheet responses to the predicted climate conditions (Armand et al., 2017; Golledge et al., 2015, 2017). Today's CO_2 concentrations were last encountered during the warm (early and middle) Pliocene, 5–3.5 Ma, when atmospheric CO_2 was between 330 and 415 ppm (Pagani et al., 2009; Seki et al., 2010). Modelling studies suggest global sea-surface temperatures (SSTs) were between ~1.6–3.6 °C (average ~2.7 °C) warmer than pre-industrial observations (Haywood et al., 2013), with Arctic and Southern Ocean SSTs being about 8 °C and 1–3 °C warmer than today, respectively (Dowsett et al., 2011). Northern hemisphere ice sheets were not fully developed (Zachos et al., 2008) and sea-level changes were driven by fluctuations of the Antarctic ice sheet (Bamber and Aspinall, 2013; Dutton et al., 2015). Sea-level during the Pliocene is estimated to have been 10–30 m higher than today (DeConto and Pollard, 2016).

ANtarctic geological DRILLing (ANDRILL) program and Integrated Ocean Drilling Program (IODP) findings suggest that the marine-based sectors of the West Antarctic Ice Sheet (WAIS) periodically collapsed (Naish et al., 2009; Pollard and DeConto, 2009) and that a substantial retreat of the marine-margin of the East Antarctic Ice Sheet (EAIS) into the Wilkes Land subglacial basins occurred (Cook et al., 2013; Reinardy et al., 2015). The presence of repeated warm periods during the early Pliocene has been demonstrated using silicoflagellate and/or diatom data from around Antarctica (Whitehead and Bohaty, 2003; Grützner et al., 2005; Escutia et al., 2009; Bart and Iwai, 2012; McKay et al., 2012; Winter et al., 2010, 2012a). Based on studies from the Antarctic Wilkes Land margin (Sites U1359 and U1361) successive advances and retreats of the EAIS during the Pliocene have been revealed (Cook et al., 2013; Reinardy et al., 2015).

Marine diatom frustules (siliceous shells, each consisting of two valves) preserved in seafloor sediments are useful proxies for the reconstruction of palaeo-environments and -climate due to the living diatom's high sensitivity to small changes in physical and chemical properties such as temperature, sea-ice cover and salinity (Armand and Leventer, 2010; Armand et al., 2017). Based on Pliocene diatom assemblages in the ANDRILL's McMurdo Ice Shelf project AND-1B drill core from the southwestern Ross Sea, Winter et al. (2010) established a summary of relationships between abundant Southern Ocean/Antarctic sea-ice species and environmental conditions (sea-ice/cold; warm; heavy/wind-mixed; mixed; neritic/stratified). The latter study is the most comprehensive and exhaustive in high southern latitudes to date inferring environmental preferences of extinct species from co-occurrence with modern species, for which preferences are better understood.

In this study, we investigate diatom and silicoflagellate assemblages from IODP Site U1361A (Antarctic Wilkes Land margin) between ~3.69 and 3.56 Ma within the Pliocene, a time period including the Gauss/Gilbert boundary at 3.6 Ma. Being located upstream of the AND-1B site with respect to modern Antarctic Circumpolar Current flow, our results are directly comparable to microfossil assemblages from the latter core discussed in Winter et al. (2010) while providing an intermediate location between the AND-1B site and another site with mid-Pliocene records (Site 1165, Prydz Bay; Whitehead and Bohaty, 2003; Escutia et al., 2009), along a zonal transect of the easterly Antarctic slope current. Previous studies of Pliocene core sections from Site U1361A have shown that EAIS retreats (advances) were associated with high productivity, diatom-rich (low productivity, diatom-poor) sediments (Escutia et al., 2011; Cook et al., 2013; Reinardy et al., 2015). High and low productivity intervals (interglacials and glacials, respectively) were, in addition to diatom counts, determined using the palaeoproductivity proxy Ba/Al (Cook et al., 2013). Our focus is on a well-constrained series of glacial-interglacial (GI) cycles of variable amplitude across the Gauss/Gilbert boundary (Lisiecki and Raymo, 2005) at IODP Site U1361A. These cycles are characterised by a high-amplitude glacial to interglacial cycle (Marine Isotope Stages Gi4-Gi3) that reverts to a high amplitude Gi2 glacial (an ~0.45‰ positive $\delta^{18}O$ excursion), before transitioning into a period when glacial to interglacial variability is muted (e.g., Marine Isotope Stage Gi1 and Mg11), which are separated by a lower amplitude glacial (Mg12; a ~0.25‰ positive $\delta^{18}O$ excursion) coinciding with the Gauss/Gilbert boundary (Lisiecki and Raymo, 2005). We here provide high-resolution insights into the composition of the diatom and silicoflagellate assemblages across these cycles. Our specific objectives are to:

(i) investigate whether peaks in total microfossil abundances coincide with interglacial periods and times of increased productivity as described (using diatom valve concentrations and Ba/Al ratios) in Cook et al. (2013);
(ii) determine the most abundant species across glacial and interglacial periods;
(iii) determine 'environmental indicator species' also found by Winter et al. (2010) in AND-1B, which can be used to establish a constrained age model for the investigated time period.

The question is explored whether phytoplankton communities during such productive interglacial periods were highly similar or differ widely.

2. Methods

2.1. Samples and study site

Cores at the Antarctic Wilkes Land rise Site U1361 (Hole U1361A), East Antarctica, were obtained during IODP Expedition 318 (3 January – 8 March 2010) (Fig. 1). Details specific to the expedition and the investigated core, U1361A-9H (64°24.5728′S, 143°53.1992′E), can be found in Escutia et al. (2011). Subsamples of 2 cm^3 were taken at 20 cm intervals from core sections 1 W–4 W (27 samples, Supplementary Material A) and processed and analysed as detailed in Sections 2.2–2.4.

To provide environmental context to our core data visually, modelled "warm Antarctica" Pliocene conditions over East Antarctica were added to our site map (Fig. 1). Mid-Pliocene orbital forcing was dominated by decreasing variability in obliquity, minimal summer insolation variations at 75°S and low variability around mean annual insolation (Naish et al., 2009; Patterson et al., 2014). Near-surface winds over the Antarctic during the mid-Pliocene have been reported as mainly katabatic. Models suggest that in the Wilkes Land region katabatic winds blew partly over but mostly away from the Transantarctic Mountains towards the open ocean with wind speeds of up to ~12 m s^{-1} (Scherer et al., 2016; Fig. 1).

2.2. Slide preparation

Permanent and cleaned slides for identification and enumeration of diatoms were prepared from all samples following modified methods from Koizumi and Tanimura (1985) (Table 1). Approximately 1 cm^3 of each sediment sample was dried in an oven at 60 °C for 24 h. After cooling to room temperature, 50 mg subsamples were weighed, mixed with 2 mL of 15% H_2O_2 in a 14 mL polypropylene centrifugation tube and placed in a water bath at 60 °C to boil for ~30 min. Subsequently, the tubes were filled up to 10 mL with Milli-Q water, homogenised by gentle shaking, and left to settle overnight. The supernatant was removed by pipetting until the settled material and ~1 mL liquid was left in the tube. This decanting procedure was repeated 5 times, using Milli-Q to resuspend the settled 1 mL residue in runs 1 and 3–5, while in run 2 a solution of 0.01 N sodium diphosphate decahydrate ($Na_4P_2O_7 * 10H_2O$, FW: 446.06) was used for an improved dispersion of clay minerals. After run 5, the tube was filled with Milli-Q to exactly 10 mL and gently mixed. It should be noted that centrifugation was avoided to prevent any breakage of diatoms (Koizumi and Tanimura, 1985).