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Enhanced primary productivity and magnetotactic bacterial production in response to middle Eocene warming in the Neo-Tethys Ocean

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ABSTRACT

Earth's climate experienced a warming event known as the Middle Eocene Climatic Optimum (MECO) at ~40 Ma, which was an abrupt reversal of a long-term Eocene cooling trend. This event is characterized in the deep Southern, Atlantic, Pacific and Indian Oceans by a distinct negative $\delta^{18}O$ excursion over 500 kyr. We report results of high-resolution paleontological, geochemical, and rock magnetic investigations of the Neo-Tethyan Monte Cagnero (MCA) section (northeastern Apennines, Italy), which can be correlated on the basis of magneto- and biostratigraphic results to the MECO event recorded in deep-sea sections. In the MCA section, an interval with a relative increase in eutrophic nannofossil taxa (and decreased abundances of oligotrophic taxa) spans the culmination of the MECO warming and its aftermath and coincides with a positive carbon isotope excursion, and a peak in magnetite and hematite/goethite concentration. The magnetite peak reflects the appearance of putative magnetofossils, while the hematite/goethite apex is attributed to an enhanced detrital mineral contribution, likely as aeolian dust transported from the continent adjacent to the Neo-Tethys Ocean during a drier, more seasonal climate during the peak MECO warming. Based on our new geochemical, paleontological and magnetic records, the MECO warming peak and its immediate aftermath are interpreted as a period of high primary productivity. Sea-surface iron fertilization is inferred to have stimulated high phytoplankton productivity, increasing organic carbon export to the seafloor and promoting enhanced biomineralization of magnetotactic bacteria, which are preserved as putative magnetofossils during the warmest periods of the MECO event in the MCA section. Together with previous studies, our work reinforces the connection between hyperthermal climatic events and the occurrence (or increased abundance) of putative magnetofossils in the sedimentary record.

1. Introduction

The early part of the Cenozoic Era was characterized by greenhouse conditions through the early Eocene, followed by a ~17 Myr-long cooling trend (e.g. Zachos et al., 2008). This long-term cooling trend was interrupted by the Middle Eocene Climatic Optimum (MECO) — a warming event that peaked at ~40 Ma (base of Chron C18n.2n) (e.g. Bohaty and Zachos, 2003; Jovane et al., 2007; Bohaty et al., 2009). The MECO event has been recognized from multiple sites in the Southern, Atlantic, Pacific, Indian, and Tethyan Oceans (Fig. 1a). It was first identified in foraminiferal stable isotope records from the Atlantic and Indian sectors of the Southern Ocean (Barrera and Huber, 1993; Bohaty and Zachos, 2003) and the hallmark of the event is a distinct negative $\delta^{18}O$ excursion that spanned 500 kyr (Bohaty et al., 2009). The end of the event was marked by a prominent negative shift in benthic foraminiferal $\delta^{13}C$ of up to ~1.0‰ (e.g. Bohaty et al., 2009; Edgar et al., 2010). The long-lasting $\delta^{18}O$ excursion, with a <100 kyr warming peak (MECO warming), has been interpreted to indicate a ~4–6 °C temperature increase of both surface and intermediate deep waters (Bohaty et al., 2009; Edgar et al., 2010). Organic molecular paleothermometry in the southwest Pacific revealed absolute sea surface temperatures of 24 °C

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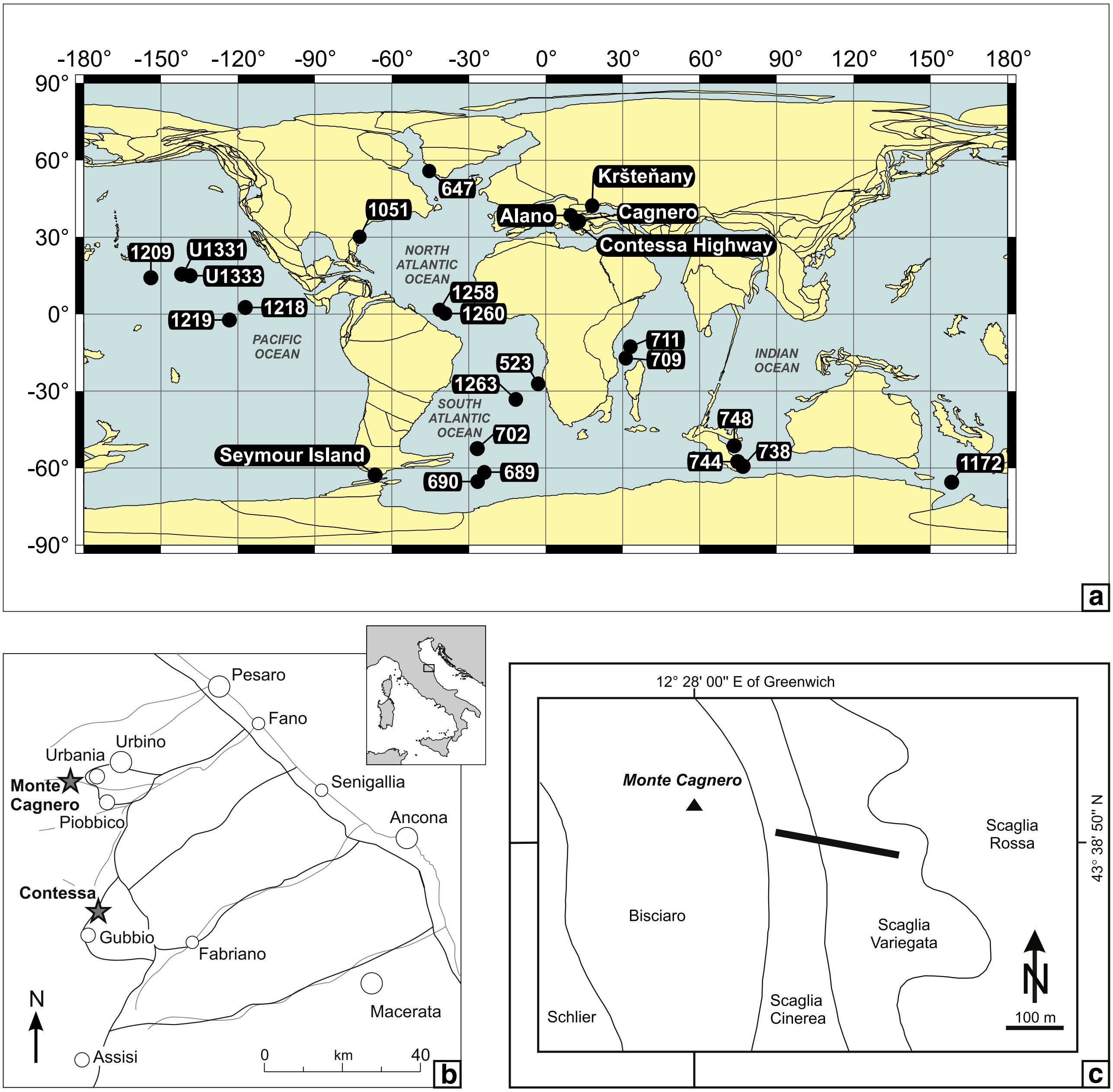

Fig. 1. (a) Paleogeographic reconstruction at 40 Ma and global distribution of sites from which the MECO event has been studied. The sites include: Kerguelen Plateau (ODP Leg 119, Sites 738, 744; ODP Leg 120, Site 748), Weddell Sea (ODP Leg 113, Sites 689, 690), Angola Basin (DSDP Leg 73, Site 523), Islas Orcadas Rise (ODP Leg 114, Site 702), Blake Nose (ODP Leg 171, Site 1051), Shatsky Rise (ODP Leg 198, Site 1209), Equatorial Pacific (ODP Leg 199, Sites 1218, 1219; IODP Legs 320–321, Sites U1331–U1333), Mascarene Plateau (ODP Leg 115, Sites 709, 711), Walvis Ridge (ODP Leg 208, Site 1263), Demerara Rise (ODP Leg 207, Sites 1258, 1260), East Tasmanian Plateau (ODP Leg 189, Site 1172), Labrador Sea (ODP Leg 105, Site 647) and the onshore Monte Cagnero (MCA), Contessa Highway (CHW), Alano, Kršteňany, and Seymour Island sections. The reconstruction was made with web-based software available at http://www.odsn.de/odsn/services/paleomap/paleomap.html. (b) Location of the MCA and CHW sections. (c) Simplified geological map of the MCA section (Lat. 43°38′50″N, Long. 12°28′05″ E, 727 m above sea level) with formation names and boundaries indicated (Coccioni et al., 2013).

to 26 °C just below the onset of MECO, and MECO peak temperatures exceeding 28 °C (Bijl et al., 2010). The temperature increase corresponded to a concomitant pCO_2 increase by a factor of 2 to 3 (Bijl et al., 2010). An atmospheric pCO_2 rise has also been inferred at other sites by changes in deep ocean chemistry as revealed by the net decline in carbonate accumulation that reflects widespread calcite compensation depth (CCD) shoaling (Bohaty et al., 2009). The abrupt pCO_2 increase during the MECO event has been tentatively ascribed to massive decarbonation during subduction of Tethyan Ocean pelagic carbonates under Asia as India drifted northward (Bohaty and Zachos, 2003; Bijl et al., 2010).

The Contessa Highway (CHW) section in Central Italy represents the first outcrop section of marine sediments in which MECO was documented (Fig. 1a, b; Jovane et al., 2007). More recently, the MECO event has also been recognized at the Alano di Piave section, northeast Italy (Fig. 1a; Luciani et al., 2010). In the Alano section the MECO event is followed by deposition of two organic-rich intervals (ORG1 and ORG2; Spofforth et al., 2010), which are thought to represent rapid organic carbon burial contemporaneous with the global pCO_2 drawdown during the post-MECO recovery interval. Significant paleoredox, foraminifera and calcareous nannofossil assemblage changes have been documented in the same section that point to a shift toward more eutrophic waters and a lowering of oxygen availability at the end of MECO during deposition of organic-rich beds (Luciani et al., 2010; Spofforth et al., 2010; Toffanin et al., 2011). Deposition of organic-rich sediments after the transient warming event has been associated