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ROCK MAGNETIC SIGNATURE OF THE MIDDLE EOCENE CLIMATIC OPTIMUM (MECO) EVENT IN DIFFERENT OCEANIC BASINS

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ABSTRACT

The Middle Eocene Climatic Optimum (MECO) event at ~40 Ma was a greenhouse warming which indicates an abrupt reversal in long-term cooling through the middle Eocene. Here, we present environmental and rock magnetic data from sedimentary successions from the Indian Ocean (ODP Hole 711A) and eastern Neo-Tethys (Monte Cagnero section - MCA). The high-resolution environmental magnetism record obtained for MCA section shows an interval of increase of magnetic parameters comprising the MECO peak. A relative increase in eutrophic nannofossil 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 concentrations. The magnetite peak reflects the appearance of magnetofossils, while the hematite/goethite apex are attributed to an enhanced detrital mineral contribution, likely related to aeolian dust transported from the continent adjacent to the Neo-Tethys Ocean during a drier, more seasonal MECO climate. 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 magnetofossils during the warmest periods of the MECO event. Environmental magnetic parameters show the same behavior for ODP Hole 711A. We speculate that iron fertilization promoted by aeolian hematite during the MECO event has contributed significantly to increase the primary productivity in the oceans. The widespread occurrence of magnetofossils in other warming periods suggests a common mechanism linking climate warming and enhancement of magnetosome production and preservation.

Keywords: MECO, Magnetofossils, Monte Cagnero, ODP Hole 711A, Indian Ocean, Italy.

RESUMO

O Ótimo Climático do Eoceno Médio (OCEM) em ~40Ma foi um evento "greenhouse" que revelou uma mudança abrupta na tendência de resfriamento de longo período através do Eoceno médio. Aqui nós apresentamos dados de magnetismo ambiental e magnetismo de rochas para sucessões sedimentares do Oceano Índico (ODP Hole 711A) e Néo Tétis (Seção de Monte Cagnero - MCA). O registro de magnetismo ambiental de alta resolução obtido para a seção MCA mostra um aumento nos parâmetros magnéticos durante o evento OCEM. Um aumento relativo da taxa de nanofósseis eutróficos abrange o auge do aquecimento do OCEM, coincidindo com uma excursão positiva dos isótopos de carbono, e um pico de concentração de magnetita e hematita/goetita. O aumento da magnetita reflete a existência de magnetofósseis, enquanto o ápice da hematita/goetita é atribuído a uma contribuição mineral detritica, provavelmente relacionado à poeira eólica transportada do continente adjacente ao Neo-Tétis durante o período mais seco do OCEM. A fertilização por ferro da superfície marinha é sugerida como estimulante da alta produtividade de fictoplanctons, aumentando do sequestro de carbono orgânico no fundo marinho promovendo a biomineralização das bactérias magnetotáticas, que são preservadas como magnetofósseis no período mais quente do evento OCEM. Os parâmetros de magnetismo ambiental mostram o mesmo comportamento para o testemunho 711A da ODP. Nós especulamos que a fertilização com ferro promovida pela hematita eólica durante o evento OCEM tem contribuído significativamente para aumentar a produtividade primária nos oceanos. A ocorrência generalizada de magnetofósseis em outros períodos de aquecimento sugere um mecanismo comum de entre aquecimento global e o aumento na produção e preservação de magnetossomos.

Palavras Chave: OCEM, Magnetofósseis, Monte Cagnero, Testemunho 711A ODP, Oceano Índico, Itália.

Introduction

The Middle Eocene Climatic Optimum (MECO) is a 500-kyr warming event centered at ~40.0 Ma (base of Chron C18n.2n) well characterized by a distinct negative ~1.0-1.5‰ in δ^{18}O recognized in the Atlantic, Pacific, Southern, and Neo-Tethys Oceans (*e.g.*, Bohaty and Zachos, 2003; Jovane *et al*., 2007; Bohaty *et al*., 2009; Edgar *et al*., 2010). Beginning with a steady decrease in δ^{18}O of ~0.5‰ at ~40.6-40.5 Ma, the MECO shows a climax at ~40.0 Ma and returns to pre-event values within less than 100 kyrs (Bohaty *et al*., 2009). The whole negative δ^{18}O excursion spanning the onset of the MECO and its peak was interpreted as an increase of ~4°-6°C both at the surface and intermediate oceanic deep waters (Bohaty *et al*., 2009). Carbon isotopic records also show a distinct δ^{13}C shifts during the MECO (Bohaty *et al*., 2009).

Recent environmental magnetic analyses on sedimentary successions from different ocean basins show stratigraphic variations in magnetic mineralogy during the MECO event (Jovane *et al*., 2007; Savian *et al*., 2014). Moreover, those variations coincides with an interval with a relative increase in primary productivity during the MECO warming and its aftermath and coincides with a positive carbon isotope excursion, and a peak in magnetite and hematite/goethite concentration (Savian *et al*., 2014).

In order to investigate the rock magnetic properties of pelagic marine carbonate during the MECO event, we present new results from sections of different basins; Monte Cagnero (MCA) section from central Italy, and ODP Hole 711A from Indian Ocean.

Geological setting, materials and methods

The MCA section is exposed on the southeastern slope of Monte Cagnero (Lat. 43°38’50”N, Long. 12°28’05”E, 727 m above sea level) near the town of Urbania, northeastern Apennines (Italy) (Fig. 1). The 14-m thick belongs to the Scaglia Variegata Formation that consists of bundles of limestone-marl couplets (Guerrera *et al*., 1988; Parisi *et al*., 1988). The studied interval comprises the top of Chron C18r (40.79 Ma, 58.00 msl) until the base of Chron C18n (39.13 Ma, 72.00 msl) (Jovane *et al*., 2013). ODP Hole 711A is located in the western equatorial Indian Ocean (Lat. 2°44.56′S; Long. 61°09.78′E), near the Seychelles Archipelago, between Madingley Rise and Carlsberg Ridge at a water depth of 4430 m (Fig. 1). The studied strata recovered within Hole 711A (cores 711A-19X to 20X) primarily consist of clay-bearing nannofossil oozes/chalks, radiolarian-bearing nannofossil oozes, and radiolarian oozes (*e.g.*, Savian *et al*., 2013).

High-resolution rock magnetic analyses were performed. Environmental and rock magnetism analyses were carried out at the National Oceanography Centre Southampton (NOCS), UK. Environmental magnetic

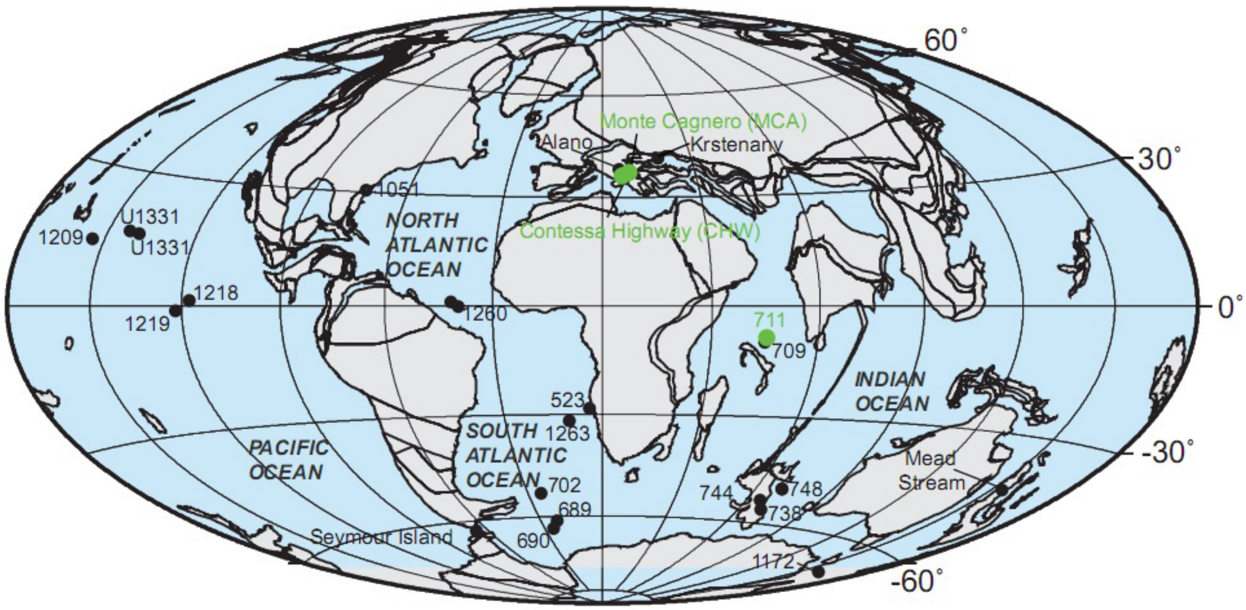

Figure 1 - Global paleogeographic reconstruction with the approximate position of Monte Cagnero (MCA), Contessa Highway (CHW), and ODP Hole 711A at 40 Ma and other sites from which the MECO event has been recognized.

measurements were performed using a three-axis 2-G Enterprises cryogenic magnetometer (model 755R), housed in a magnetically shielded room, in order to obtain a quantitative inference of variation of the composition, concentration and grain-size of the magnetic minerals (*e.g*., Evans and Heller, 2003). To identify magnetic minerals, their domain state(s), and magnetic interactions among magnetic particles, we measured IRM acquisition curves, hysteresis loops, and first-order reversal curves (FORCs) at room temperature using a vibrating sample magnetometer (VSM MicroMagTM 3900). For Italian sections the measurements were carried out at National Oceanography Centre Southampton (NOCS), UK, and for ODP Hole 711A sediments at the Laboratório de Geoprocessamento of the Oceanographic Institute of the University of São Paulo, Brazil.

The low field mass-specific magnetic susceptibility (χ) was measured with a Kappabridge KLY-4, AGICO magnetic susceptibility meter. An anhysteretic remanent magnetization (ARM) was imparted in a 100 mT AF with a superimposed 0.05 mT direct current (DC) bias field. An isothermal remanent magnetization (IRM) was imparted to the samples by applying a 900 mT direct field (IRM_{900mT}). Then, it was imparted a backfield isothermal remanent magnetization (BIRM) at 100 mT ($BIRM_{-100mT}$) and 300 mT ($BIRM_{-300mT}$). From these measurements, we calculated S-ratios ($S_{300mT} = [BIRM_{300mT}/IRM_{900T}]$) and hard isothermal remanent magnetization ($HIRM_{300mT} = [IRM_{900mT} + BIRM_{300mT}]/2$), in order to investigate the coercivity of the magnetic minerals.

Magnetic mineralogy also was investigated through acquisition of isothermal remanent magnetization (IRM). IRM acquisition curves were separated into different coercivity components (Robertson and France, 1994) and were obtained at fields up to 1 T for representative samples and analyzed by cumulative log-Gauss function (CLG) using the software developed by Kruiver *et al*. (2001). The CLG function is described by three optimal parameters (SIRM, $B_{1/2}$ and dispersion parameter, DP) that characterize each magnetic carrier of the sample (Robertson and France, 1994; Kruiver *et al*., 2001). In order to determine the Curie or Néel temperature of the magnetic minerals were used high-thermomagnetic curves (susceptibility *vs*. temperature). For selected samples, thermomagnetic curves during heating to 700 °C were obtained using a KLY-3 magnetic susceptibility meter (AGICO) at the Paleomagnetic Laboratory, USP. Hysteresis loops were measured in a maximum field of 1 T with an averaging time of 500 ms. For First-Order Reversal Curves (FORCs) measurements, 297 FORCs were measured with an averaging time of 150 ms. FORC diagrams were produced with a smoothing factor (SF) of 5 (Roberts *et al*., 2000) using the software of Heslop and Roberts (2012). The measurement parameters specified by Egli *et al*. (2010) for resolving central ridge features were used (H_{c1} = 0mT, H_{c2} = 110 mT; H_{u1} = −15 mT, H_{u2} = +15 mT; δH = 0.63 mT).

Results and Analysis

The MECO event is recognized by its distinct oxygen isotopic excursion of 1.0-1.5‰ for bulk and fine carbonate fractions at MCA section. Two discrete intervals (63-63.55 msl and 64.15-65.30 msl) containing higher environmental magnetic (χ, ARM, IRM, $HIRM_{300T}$, and S-ratio) values were recognized. The same behavior is observed during the MECO event at ODP Hole 711A.

Isothermal remanent magnetization acquisition curves were obtained at fields up to 1 T for representative samples for the three sections and analyzed by cumulative log-Gauss functions (CLG). For the representative samples, the CLG models were fitted with two, three and four components for each sample, suggesting maximum of four magnetic carriers. SIRM, $B_{1/2}$ and DP values indicate low- to medium-coercivity magnetic carriers for the component 1 (Robertson and France, 1994). The lowest coercivity component 1 is interpreted to detrital magnetite. The intermediate components were interpreted as “biogenic soft” (BS) magnetite “biogenic hard” (BH) magnetite (Egli, 2004). The highest coercivity component (component 4), is dominated by a magnetic mineral with high coercivity (*e.g*. Hematite). The low-coercivity magnetic mineral is dominant in all studied samples along the interval.

FORC distributions for all samples are similar during the MECO event. The sediments are characterized by closed concentric contours around a central peak at 30 mT. These FORC diagrams have a sharp horizontal ridge at Bu = 0 that indicates a dominance of non-interacting SD particles (Roberts *et al*., 2000). These features are statistically significant at the 0.05 level (Heslop and Roberts, 2012), and define a signature that is typical of intact magnetosome chains (Egli *et al*., 2010; Roberts *et al*., 2011, 2012, 2013). The detrital magnetic component, which is dominated by coarser-grained magnetite, is likely to be responsible for the vertical spreading of the FORC distributions at low coercivities.

Discussion and Conclusions

Our objective, in this work, is present new results from MCA and ODP Hole 711A sections. We determined the position of the MECO interval from the age model of and correlate them with three different sections in different ocean basins. We present new combined datasets of sediment magnetic analyses. The aim of this study is to identify biogenic magnetic signatures during the MECO event to improve understanding of sedimentary magnetofossil concentrations that reflect ancient variations in marine primary productivity during this significant global warming event.

Rock magnetic data from MCA and ODP Hole 711A sections provide a first detailed magnetic record of the MECO event from different ocean bases. The MECO interval at this site is characterized by changes in sediment magnetic properties that indicate increased magnetotactic bacterial productivity and suggest a major shift to eutrophic conditions. We infer an increased iron and organic carbon supply and decreased surface sediment oxygenation associated with major rearrangements of surface ocean conditions. These sedimentary diagenetic conditions provided essential iron for magnetite biomineralization, which gave rise to enhanced populations of magnetotactic bacteria at and below the sediment–water interface.

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