MIDDLE EOCENE TO EARLY OLIGOCENE CLIMATE: PRELIMINARY MAGNETOBIOSTRATIGRAPHIC DATA FROM MONTE CAGNERO SECTION, CENTRAL ITALY

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Abstract

Deep-sea foraminiferal stable isotope records ($\delta^{18}O$) indicate a long-term cooling trend that culminated in the Oi-1 glaciation near the Eocene/Oligocene transition at ~34 Ma. In the late middle Eocene, this trend was interrupted by a strong, transient warming event at ~40 Ma, known as Middle Eocene Climatic Optimum (MECO). The Monte Cagnero sedimentary section, located in the northeastern Apennines near Urbania (Italy), in the Umbria-Marche Basin, is an important middle Eocene to lower Oligocene section. We use magnetobiostratigraphy to study the impact of the closure of the Neo-Tethyan gateway on subtropical Eocene circulation to better understand global climate changes during the switch from greenhouse to icehouse conditions. The studied sediments consist of alternating reddish and greenish limestones and marlstones. We undertook high-resolution paleomagnetic, foraminiferal and calcareous plankton biostratigraphic analyses to construct an integrated age model. The magnetic mineralogy is dominated by a mixture of high- and low-coercivity minerals (probably hematite and magnetite). Environmental magnetic data indicate long-term trends in the concentration, grain-size and composition of magnetic minerals. These new biostratigraphy and magnetic results from Monte Cagnero suggest that the section provides a continuous and well-preserved interval for analyzing middle Eocene to early Oligocene climate variability.

Resumo

Registros de isótopos estáveis ($\delta^{18}O$) de foraminíferos do fundo marinho indicam uma tendência de resfriamento de longo período que culmina na glaciação Oi-1 próxima à transição entre o Eoceno/Oligoceno há ~34 Ma. No Eoceno médio inferior, esta tendência foi interrompida por um intenso evento de aquecimento há ~40 Ma atrás, conhecido como o ótimo climático do Eoceno médio (MECO). A seção sedimentar de Monte Cagnero, localizada ao nordeste dos Apeninos próximo a Urbania (Itália), na Bacia de Umbria-Marche, é uma importante seção para o Eoceno médio e para o Oligoceno inferior. Nós usamos a magnetoestratigrafia para estudar o impacto do fechamento do Neo-

Tétis sobre a circulação oceânica subtropical no Eoceno, de modo a melhor compreender as mudanças climáticas durante a transição “greenhouse” para “icehouse”. Os sedimentos estudados consistem calcários avermelhados e esverdeados e margas. Nós realizamos paleomagnetismo de alta resolução, análises biostratigráficas em foraminíferos e plânctons calcários para construir um modelo de idade integrado. A mineralogia magnética é constituída por minerais de alta e baixa coercividade (provavelmente hematita e magnetita). Os dados de magnetismo ambiental indicam uma tendência de longo período na concentração, tamanho de grão e composição dos minerais magnéticos. Estes novos resultados biostratigráficos e magnéticos de Monte Cagnero sugerem que a seção fornece um intervalo contínuo e bem preservado para analisar a variabilidade climática no Eoceno médio e do Oligoceno inferior.

Introduction

Deep-sea foraminiferal oxygen isotope records ($\delta^{18}O$) indicate a general high-latitude cooling trend over the last 50 Ma, since the Early Eocene climatic optimum (EECO) (e.g. Zachos et al., 2008). The late Eocene to early Oligocene was a key interval for Earth’s transition from the warm, ice-free climate of the early Cenozoic to the icehouse conditions that operated in the Oligocene (e.g. Zachos et al., 2008). The first major glaciation of Antarctica (Oi-1, ~34Ma; Miller et al., 1991) near the Eocene/Oligocene (E/O) boundary was an important climate step from a greenhouse to an icehouse conditions. The Oi-1 transition reveals an abrupt cooling (~4°C) and rapid expansion of Antarctic continental ice-sheets. Moreover, the E/O transition also shows a marked increasing in ocean fertility, a major drop in the calcite compensation depth (CCD), and the onset of the Antarctic thermohaline circulation in classic Deep Sea Drilling Project (DSDP) records (e.g. Coxall et al., 2005). The main hypotheses for the cause for these dramatic climatic changes include the opening of Southern Ocean gateways (e.g. Lyle et al., 2007), the decreasing in the amount of greenhouse gases in the atmosphere (e.g., DeConto and Pollard, 2003), and the closure of the Neo-Tethys gateway (e.g. Jovane et al., 2007a). Concerning the last hypothesis, new data from the Tethyan Ocean are necessary to better assess the effects of the gradual closure of the Neo-Tethys gateway, which was driven by the collision between Arabia and Eurasia (Jovane et al., 2007a; Allen and Armstrong, 2008). The gradual nature of the closure resulted in paleoceanographic oscillations, particularly clear evidence in magnetic properties, in the Neo-Tethys during the run up to the Oi-1 event (Jovane et al., 2007a), probably as a result of variations in the subtropical Eocene Neothethys (STENT) current.

However, the long-term climatic cooling did not occur as a single gradual change. Superimposed on this cooling trend, a series of distinct cool and warm events have been observed (e.g. Bohaty and Zachos, 2003; Tripati et al., 2005; Edgar et al., 2007; Jovane et al., 2007b; Villa et al., 2008; Zachos et al., 2008; Bohaty et al., 2009; Edgar et al., 2010). The Middle Eocene Climatic Optimum (MECO) was an important global warming event, characterized by a large negative $\delta^{18}O$ excursion at ~40 Ma (Bohaty et al., 2009; Edgar et al., 2010). Benthic foraminiferal $\delta^{13}C$ records also display several prominent changes between ~40 and 39.2 Ma, with benthic $\delta^{13}C$ peaks up to ~1.6‰ (Bohaty et al., 2009).

Development of high-resolution age models is fundamental for the reliable determination of sequences of climatic change events in the geological record. In order to obtain a high-quality age model, the interpretation of the magnetic polarity pattern obtained along key sections in correlation with the geomagnetic polarity time scale (GPTS) and biostratigraphy provides calibrated of age-models onto which the climate proxies can be accessed.

The Monte Cagnero section (Urbania, Italy) represents a continuous and undisturbed sedimentary sequence to study the climatic events during Eocene and Oligocene interval. In this paper, we present a preliminary magnetobiostratigraphic study of the Monte Cagnero section from the middle Eocene to the early Oligocene interval.

Materials and Methods

The Monte Cagnero section (43°38’50”N, 12°28’05”E) is situated on the Umbria-Marche Basin, northeastern Apennines, Italy (Fig. 1). The studied portion of the Monte Cagnero section is 70-m thick. Our paleomagnetic sampling consisted of 241 oriented block samples for magnetostratigraphic analysis at approximately 30 cm resolution. Measurements were carried out in the paleomagnetic laboratory of the National Oceanography Centre Southampton (NOCS), University of Southampton. All measurements were made using a 2G–Enterprises superconducting quantum interference device (SQUID) magnetometer (model 755R). In addition, a total of seven hundred bulk rock samples were collected at ~10 cm intervals from the Monte Cagnero section for calcareous plankton stratigraphy. All the materials are housed in the laboratory of the Dipartimento di Scienze della Terra, della Vita e dell’ Ambiente, Università di Urbino, Italy.

In order to separate the rock magnetic components, we demagnetized the 241 cubic samples using alternating field (AF) and thermal demagnetizations. We proceeded using progressive stepwise AF demagnetization (5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80 mT), and stepwise heating (25, 100, 150, 200, 250, 300, 350, 400, 450, 500, 540, 560, 580, 600, 620, 640, 660, 680, 700 °C). Magnetic components were identified using stereographic projections, orthogonal and demagnetizing intensity plots. The characteristic remanent magnetization (ChRM) directions were calculated using principal component analysis (Kirschvink, 1980) with paleomagnetic data software package REMASOFT 3.0.

Thermomagnetic curves were performed in a CS-3 Kappabridge apparatus at the paleomagnetic laboratory of the IAG – University of São Paulo, São Paulo (Brasil). Thermomagnetic curves are produced by heating samples and then measuring susceptibility as a function of temperature that shows features typical of individual magnetic minerals or groups of minerals (Hrouda, 2003). The thermomagnetic curves were interpreted and evaluated using the software package CUREVAL, AGICO.

Biostratigraphic investigations were performed for all samples. Calcareous nannoplankton samples were prepared from unprocessed material as smear slides and were examined using a light microscope at 1150x magnification. The calcareous nannofossil standard zonation of Martini (1971) and Okada and Bukry (1980) were applied. Samples for planktonic foraminifera were treated following the cold acetolyse technique for Lirer (2000) by sieving trough a 32 µm mesh and drying at 50°C. The tropical planktonic foraminiferal standard zonations of Berggren and Pearson (2005) and Wade et al. (2011) were followed making additional reference to the previous zonation of Berggren et al. (1995).

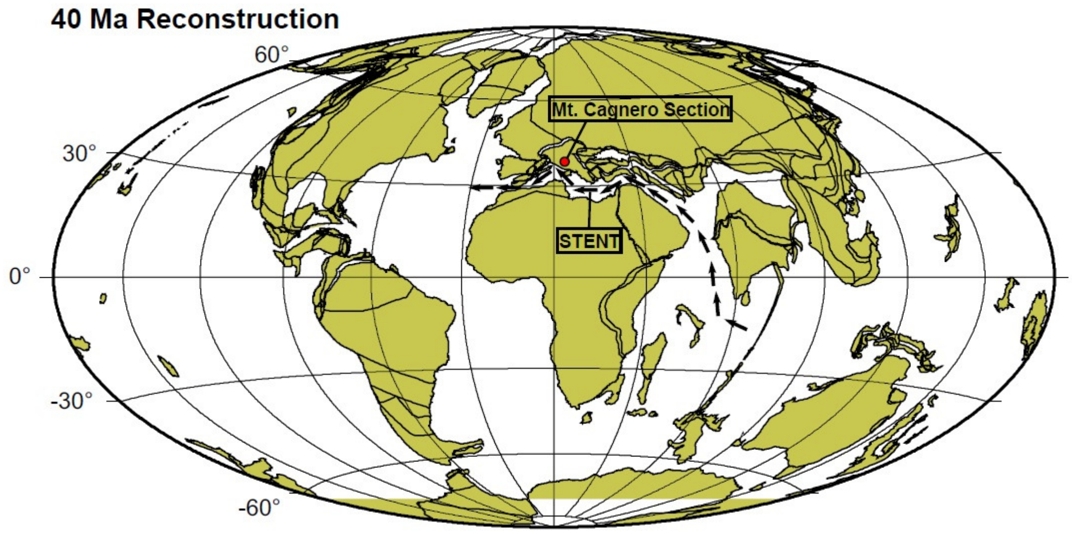

Figure 1 *– Palaeogeographic reconstruction of the late Eocene (late Lutetian 40-46 Ma) illustrating the location of the Monte Cagnero section. Palaeogeographic reconstruction from the Ocean Drilling Stratigraphic Network (GEOMAR, Germany). Black arrows show the circulation of the subtropical Eocene Neothethys (STENT) current.*

Results

The natural remanent magnetization (NRM) of sediments at Monte Cagnero section ranges from 4.27×10^{-10} Am^2/kg to 4.71×10^{-7} Am^2/kg, with a mean of 3.49×10^{-8} Am^2/kg. The intensities are significant lower in the interval between 78 to 104 msl and, consequently, the behavior of these samples during demagnetization is complex. In others intervals, most samples displayed stable paleomagnetic behavior upon stepwise AF and thermal demagnetization. AF demagnetization was more effective in removing the secondary magnetization than thermal demagnetization. A low-coercivity component can be generally removed after AF demagnetization at 10-80 mT and after thermal demagnetization at 200-540°C. These unblocking temperatures, coercivity fields and the decay of magnetic susceptibility at 580°C in thermomagnetic curves suggest that the main magnetic carrier in our samples is low-Ti titanomagnetite. Stable paleomagnetic behavior (MAD $\leq$ 15°) was obtained for 170 samples (70.53%), where the ChRM component could be isolated for both normal and reverse polarity.

We integrate our new studied polarity record of the Monte Cagnero section with the GPTS of Gee and Kent (2007). The resulting polarity pattern provided a correlation with the GPTS between chrons C18r and C12r. Resulting sedimentation rates for the Monte Cagnero section are relatively constant, varying from 5.34 m/Myr to 14.06 m/Myr, with a mean sedimentation rate of 8.66 m/Myr.

In order to calibrate the magnetostratigraphy we used the lowest occurrence (LO) and highest occurrence (HO) of the calcareous nannofossils and planktonic foraminiferal events. We have identified the LO and HO of the *Orbulinoides beckmanni* at 63.20 and 65.50 msl, respectively. The LO and HO of *O. Beckmanni* occur in the uppermost part of C18r and the lowermost part of C18n.2n, respectively. This species is restricted to tropical and warm mid-latitudes. The planktonic foraminiferal *O. beckmanni* is closely associated with the MECO event, the warmest event during the Eocene period (Bohaty et al., 2009; Edgar et al., 2010).

Preliminary data of carbon and oxygen stable isotope and $CaCO_3$ data on the same section were obtained. Carbon isotope values range between +1.6‰ and +2.1‰, with a long positive peak between 63 and 65 msl. On the other hand, $\delta^{18}O$ values range between -1.8‰ and -1.1‰. The $CaCO_3$ values range between 61.5% and 91.8%, with the negative peak at 63.35 msl. These values combined with environmental magnetism data in the interval between 63 and 65 msl is most likely related to carbonate dissolution during the MECO event.

Our new results from the Monte Cagnero section provide a new age model that is able to understand the timing of climatic events, particularly the MECO event. In future works we will provide a detailed comparison of geochemical and rock magnetic variations in the studied section. Isotopic, microfossil, rock magnetic and geochemical components will focus on understanding the nature and timing of climate and oceanic primary productivity changes prior to and during the Oi-1 glaciation. These relationships will provide new data for testing hypotheses concerning the driving forces of global E/O boundary climate changes.

Conclusions

We present new preliminary magnetostratigraphic and biostratigraphic records from Monte Cagnero section for the middle Eocene to early Oligocene. New magnetostratigraphic results can be directly correlated to the GPTS from chron C18r to chron C12r, corresponding the time interval between 40.13 and 30.93 Ma. This period spans several important climatic events, including the Oi-1 cooling event and the MECO warming event. The lowest and highest occurrence of the *O. beckmanni* are associated with the MECO event, as previously published by Edgar et al. (2010). During the conference, we will present the integrated magnetostratigraphy and biostratigraphy that permitted obtaining an accurate age model. Moreover, we will present the environmental magnetism and isotope data in order to study the climatic events in this section and interpret the result of variation of the STENT current in the global system.

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