GLOBAL CLIMATE CHANGES AND BIOTA: EVIDENCE FROM FORAMINIFERA
DURING PALEOGENE CRITICAL INTERVALS

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Abstract
The first year of this PhD project is focused on the study of the Middle Eocene Climatic Optimum (MECO). This warming episode, centered at ca. 40 Ma, interrupted the overall cooling trend of the middle Eocene. MECO is recorded worldwide by pronounced changes of the δ¹³C and δ¹⁸O values and coeval oscillations in global CCD. This work represents the first study on benthic foraminiferal response to the MECO and aims to reconstruct sea-floor paleoenvironmental changes induced by this major climatic perturbation. Analyses were carried out on samples coming from Alano di Piave section (northeastern Italy, central-western Tethys) which provides an excellent record of the MECO. My results show that warming induced by MECO deeply affected sea-bottom environment through an enhanced export productivity which caused oxygen depletion at the sediment/water interface. A Nuttallides umbonifera-dominated assemblage is for the first time recorded in the Eocene, just above MECO and post-MECO perturbed intervals. This suggests that a long and intense event of climatic instability, as the MECO, can have profound effects over the oceanic system, affecting bottom water circulation and/or the rate of organic flux to the sea-floor.

Introduction
The early Paleogene is increasingly attracting the attention of the scientific community as it represents one of the more climatically dynamic period in the Earth history. The available paleoclimatic records (e.g. Zachos et al., 2001, 2008) indicate that the Earth climate system reached a peak of global warming during the Early Eocene Climatic Optimum (EECO, 50–52 Ma) within an extended interval of greenhouse-climate regime. EECO was followed by a long-term cooling trend through the middle–late Eocene (49 to 34 Ma) eventually leading to the establishment of Antarctic ice-sheet at the base of the Oligocene (Miller et al., 1991). Superimposed on this long-term cooling trend there are episodes of climatic instability testified by a series of transient warming events (Bohaty and Zachos, 2003; Sexton et al., 2006; Edgar et al., 2007a). In particular, the middle Eocene climatic evolution was significantly interrupted by at least one prominent transient (500 kyr) warming event: the Middle Eocene Climatic Optimum (MECO), which occurred at the top of Chron C18r at 40 Ma (Bohaty et al., 2009).

MECO is recorded worldwide by pronounced changes in δ¹³C and δ¹⁸O values and coeval oscillations in global carbonate compensation depth (CCD; Tripati et al., 2005; Bohaty et al., 2009). Previous isotopic and bio-magnetostratigraphic studies (Spofforth et al., 2010; Agnini et al., 2011) have detected the occurrence of an excellent and expanded record of the MECO within the Alano di Piave section, northeastern Italy. Associated with and following the peak-warming of MECO two organic-rich sapropel-like intervals occur (ORG1 and ORG2; Spofforth et al., 2010). The first step of this PhD project constitutes the conclusive phase of a multy-proxy study focused on MECO of the Alano di Piave section (see Luciani et al., 2010, Spofforth et al., 2010, Toffanin et al., 2011). Specifically, it aims to reconstruct the paleoenvironmental perturbations occurred at the sea-floor through the analysis of benthic foraminiferal assemblages. Since their sensitivity to environmental parameters and their extensive occurrence in marine sediments, benthic foraminifera are, indeed, widely employed tools for paleoceanographic reconstructions (e.g., Van der Zwaan et al., 1999). This study will contribute to better understand the biotic and environmental response to the MECO event as recorded in a central-western Tethys bathyal setting.

Methods
Study on Alano MECO benthic foraminiferal fauna was done in two steps:
1) Taxonomic determination of the most common species and genera. It was made in both the ≥63 and ≥125 µm size fractions, following the available literature about Tethyan Eocene benthic foraminifera (e.g.: Hagn, 1956; Braga et al., 1975; Grünig, 1985 etc.). Samples were chosen in critical levels identified during previous studies (e.g. Luciani et al., 2010). At least 200 taxa were identified and determined at specific or higher taxonomic level. The most representative specimens were picked and mounted on microslides for a permanent record. Morphological analysis through scanning electron microscope (SEM) was performed on the most representative taxa.

2) Quantitative study of benthic foraminiferal assemblage. It was carried out on 36 samples from a 22 m interval straddling the MECO. Samples spacing is 40 cm over the interval corresponding to the δ18O isotopic shift and on average 80 and 100 cm below and above the critical interval. Quantitative study was based on representative splits of residues on more than 300 specimens from the ≥ 63 µm fraction. Despite all problems linked with the use of the small size fraction (time-consuming, difficulties in taxonomic determination) it was preferred to avoid the loss of very small taxa, that are usually known to bloom in highly stressed environments (Giusberti et al., 2009).

For paleoecological analysis were calculated relative abundances of the more common taxa (>5%) and some faunal indexes as: Fisher-α diversity index, faunal density (number of specimens/gr sediment), infaunal-epifaunal ratio (following Corliss, 1985; Jones and Charnock, 1985; Corliss and Chen, 1988 and Kaminski and Gradstein, 2005 for morphotype allocation), agglutinated-calcareous taxa ratio, cumulative percentage of bi-triserial taxa. Paleo-environmental inferences were obtained following some benchmark papers about the use of benthic foraminiferal assemblage as paleoceanographic proxies (e.g. Jorissen et al., 1995; Van der Zwaan et al., 1999; Gooday, 2003; Jorissen et al., 2007).

Preliminary results and interpretations

This study shows that MECO had major effects on benthic foraminiferal fauna of Alano section. As seen with planktonic foraminiferal record, assemblage modifications start at the beginning of the gradual δ18O negative shift and become more streaking in the so-called post-MECO interval (see Luciani et al., 2010). Just above the perturbed interval, the assemblage changes again, but it never returns to pre-event features. In more details:

- MECO: Paleoecological indices as faunal density, faunal diversity, infaunal-epifaunal ratio, the cumulative, relative abundance of bi-triserial taxa, show a gradual increase which parallels oxygen negative isotope excursion. This indicates a mesotrophic environment which steadily shifts toward more eutrophic conditions, thus an increasing organic matter flux from surface water to the sea bottom. Samples coinciding with peak warming of the MECO and maximum depletion in CaCO3%, show peak values of agglutinated-calcareous ratio and planktonic foraminiferal fragmentation index (Luciani et al., 2010). Such peaks are associated with marked decreases of N/g and benthic foraminiferal preservation, suggesting severe carbonate dissolution. This could be interpreted as a rapid and transient shallowing of the lysocline-CCD depth, due to a strong ocean acidification, during the warmest temperatures reached in the MECO (see Bohaty et al., 2009).

Above MECO peak-warming, benthic foraminiferal assemblage dramatically changes. At Alano this interval corresponds with the deposition of a dark, organic rich, sapropel-like unit, splitted in two subunits named ORG1 and ORG2 (Luciani et al., 2010).

- ORG1: Assemblage dominated by a high-diverse, eutrophic, stress-tolerant fauna, composed mainly by: Uvigerina spp., Bolivina spp., Bulimina semicostata, Oridorsalis umbonatus, Globocassidulina subglobosa and uniserial hyalineous taxa. Infaunal stress-tolerant taxa constitute about 85% of the entire assemblage, while epifaunal/surface dwelling taxa, which typify stable meso-oligotrophic environments, almost completely disappear. This is consistent with the high
percentage of organic matter stored in the sediment (TOC; Spofforth et al., 2010) and confirms that a strongly increased flux of organic matter reached the sea-floor, causing markedly eutrophic conditions. Dominance of the aforementioned taxa could indicate also a certain degree of oxygen depletion at the sediment/water interface, probably due to the stratifications of the water column (Luciani et al., 2010) and to O$_2$ consumption by organic matter degradation at the sea floor (Spofforth et al., 2010). Despite that, both faunal density and Fisher-α diversity indices do not show a true drop in this interval, meaning that oxygen depletion occurs but it is not so severe to become limiting for deep-infaunal taxa, adapted to live in oxygen impoverished environments (~1-0.5 ml/l).

- **ORG2**: Assemblage dominated again by stress-tolerant, highly eutrophic, infaunal taxa associated with a significant drop in faunal density and Fisher-α diversity index. Taxa which show peaks (*Bolivina* spp., *Oridorsalis umbonatus*, *Osangularia* spp., *Bulimina alazanensis*), are know to peak today in severely oxygen deplete environments as the Oxygen Minimum Zones. These data could be interpreted as indicative of an interval of more severe, eutrophy-induced, hypoxic conditions at the sea-floor.

Above the end of MECO and post-MECO organic-rich intervals, geochemical and isotopic conditions rapidly return to background values, similar to those of the pre-isotope excursion interval (Spofforth et al., 2010). Benthic foraminiferal assemblage changes again, and becomes strongly dominated by small-sized *Nuttallides umbonifera* (ca. 50-60%). The present work highlights for the first time very high abundance of *N. umbonifera* in the Eocene. This is a cosmopolitan, living species which dominates (although with lower abundances) the abyssal plains of deep oceans basins, also below 4000 m water depth. Most of the authors consider *N. umbonifera* as adapted to highly oligotrophic, carbonate undersaturated bottom water (e.g. Gooday, 2003). However, findings of *Nuttallides umbonifera*-dominated assemblages in areas with strong seasonal pytodetrital pulses (Gooday, 1993; Kurbjeweit et al., 2000) indicate that the ecology of this important species is far to be fully understood. Apart from that, the *Nuttallides umbonifera* bloom at Alano just above the top of the ORG2 interval, certainly points out to deeply changed bottom water conditions if compared with those characterizing the pre-MECO interval.

**Preliminary conclusion**

MECO does represent a global warming event which deeply perturbed sea-bottom environment in the central-western Tethys. Data from benthic foraminiferal fauna indicate a progressive eutrophication of sea-bottom, with higher rate of marine organic matter burial immediately following MECO maximum warming. This could be interpreted, at least in a marginal setting, as a mechanism to draw down atmospheric CO$_2$ and return to cooler temperatures (Spofforth et al., 2010). Higher input rate of CO$_2$ into the atmosphere is, indeed, currently believed the most probable cause of MECO warming (Bohaty et al., 2009). These data further confirm the key role of oceanic system in climatic control, 40 Ma ago, as well as today. *Nuttallides umbonifera*-dominated assemblage above the perturbed interval, indicates that sea-bottom changes were not only transitional and strictly linked to seawater warming: MECO could have induced, in this portion of Tethys, long-term variations in sea-bottom circulation and/or in the flux of export productivity from surface water to the sea-floor.

**Next step**

In order to discriminate local from global signals in the response of benthic foraminifera to MECO (e.g. *Nuttallides umbonifera* bloom), the next step of this PhD project will be the study of the MECO in an oceanic deep-sea record. Specifically, samples from the ODP Site 1263 (Walvis Ridge, South Atlantic) were ordered. This site was chosen because of its relatively shallow paleobathymetry, comparable with that of Alano di Piave section, in order to allow detailed comparisons of benthic foraminiferal response to the MECO in two different settings.
References


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**SUMMARY OF LAST YEAR ACTIVITY**

**Courses:**


MICHAEL A. KAMINSKI, RODOLFO COCCIONI, MALCOLM HART, ISABELLA PREMOLI SILVA, FABRIZIO FRONTALINI, CLAUDIA CETEAN. International School on Foraminifera, 4th Course, Università degli Studi di Urbino, Urbino, 13-22 Luglio, 2011.


**Oral communications:**


**Posters:**