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Micropalaeontological evidence for the late Oligocene Oi-2b global glaciation event at the Zarabanda section, Spain

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ABSTRACT

We present an integrated micropalaeontological study (using smaller and larger benthic foraminifera, planktonic foraminifera and calcareous nannofossils) of the late Oligocene from the Zarabanda section (western Tethys), in order to reconstruct the palaeoenvironmental turnover and to precisely establish the chronology of the palaeoclimatic events. Planktonic foraminifera show that the Zarabanda section is apparently continuous and spans the planktonic foraminiferal zones O5 (upper part), O6 and O7, and the calcareous nannofossil zones CP19b and CN1a (lower part). The quantitative analysis of smaller benthic foraminiferal assemblages enabled us to determine a middle–lower bathyal depth of deposition for most part of the section. The smaller benthic foraminifera show a bloom of neritic species, an increase in the percentages of cool-water species, a decrease of the Planktonic/Benthic ratio, generic richness, heterogeneity and diversity all around a 10 m thick succession of calcarenites, in the lower part of the planktonic foraminifera O6 Zone and the middle part of the calcareous nannofossil CP19b Zone. These changes coincide with the major turnover in the larger benthic foraminiferal assemblages; the last occurrence of *Eulepidina dilatata* and the first occurrence of *Nephrolepidina morgani*. These variations in the smaller and larger benthic foraminiferal assemblages may be associated with the major expansion of the Antarctic Ice Sheet at approximately 26.7 Ma, which is known as the Oi-2b global glaciation event.

1. Introduction

The Oligocene climate was variable, with several cooling events (formerly known as Oi-events; Miller et al., 1991; Miller et al., 2008; Miller et al., 2009) caused by large fluctuations in the Antarctic Ice Sheet and the formation of cold deep water in the Southern Ocean (Zachos et al., 2001; Lawyer and Gahagan, 2003). The first and largest Oxygen isotope ($\delta^{18}O$) shift of the Oligocene is the Oi-1 glaciation event at approximately 33.5–33.7 Ma (Miller et al., 1998; Zachos et al., 2001; Eldrett et al., 2009). This event marks a profound global change from Paleocene–Eocene greenhouse to Oligocene icehouse climatic conditions, with development of the Antarctic ice sheet (Zachos et al., 2001; Coxall et al., 2005). The Oi-1 was followed by a second large $\delta^{18}O$ excursion at approximately 26.7 Ma, which is the Oi-2b glaciation event (Miller et al., 1998; Wade and Pälike, 2004; Flower and Chisholm, 2006; Pekar et al., 2006), also sometimes referred to as the "Oligocene Glacial Maximum" (e.g., Van Simaeys et al., 2005). Additionally, Haq et al. (1987) recognised a sea-level fall at approximately 30 Ma which may correspond to the Oi-2 glaciation event (e.g., Pekar and Miller, 1996; Miller et al., 1998; Wade and Pälike, 2004; Pekar et al., 2006; Coccioni et al., 2008). One additional increase in $\delta^{18}O$ values is recognised in the late Oligocene, e.g., the Oi-2c glaciation event (~25.1 Ma) (e.g., Pekar et al., 2006). Proposed driving mechanisms for the global climate change include Antarctica ice build-up and large reduction in atmospheric CO_2 from the high Eocene levels to low levels in the Oligocene (Coxall et al., 2005; Pagani et al., 2005). Development of the Antarctic ice sheet and the CO_2 atmospheric concentrations exerted a profound influence in global climate. Within these scenarios, the Oi-2b glaciation and warming events during the late Oligocene become important to understand the forcing mechanisms and for accurate climate reconstructions.

Previously a warming event was thought to have occurred in the late Oligocene, which was attributed to a combination of Antarctic ice volume decrease and deep-sea warming (Zachos et al., 2001). However, this was later recognised as an artefact caused by combining records from different locations (Cramer et al., 2009). De Man and Van Simaeys (2004) argued that warming occurred in the North Sea Basin directly after the Rupelian/Chattian boundary, e.g., considerably earlier than the late Oligocene warming events seen in Southern Ocean records. The extent, timing and even the existence of a warming event in the late Oligocene are therefore not well defined at present.

Oligocene benthic foraminiferal successions from various water depths have been analysed for the Atlantic Ocean (Katz et al., 2003),

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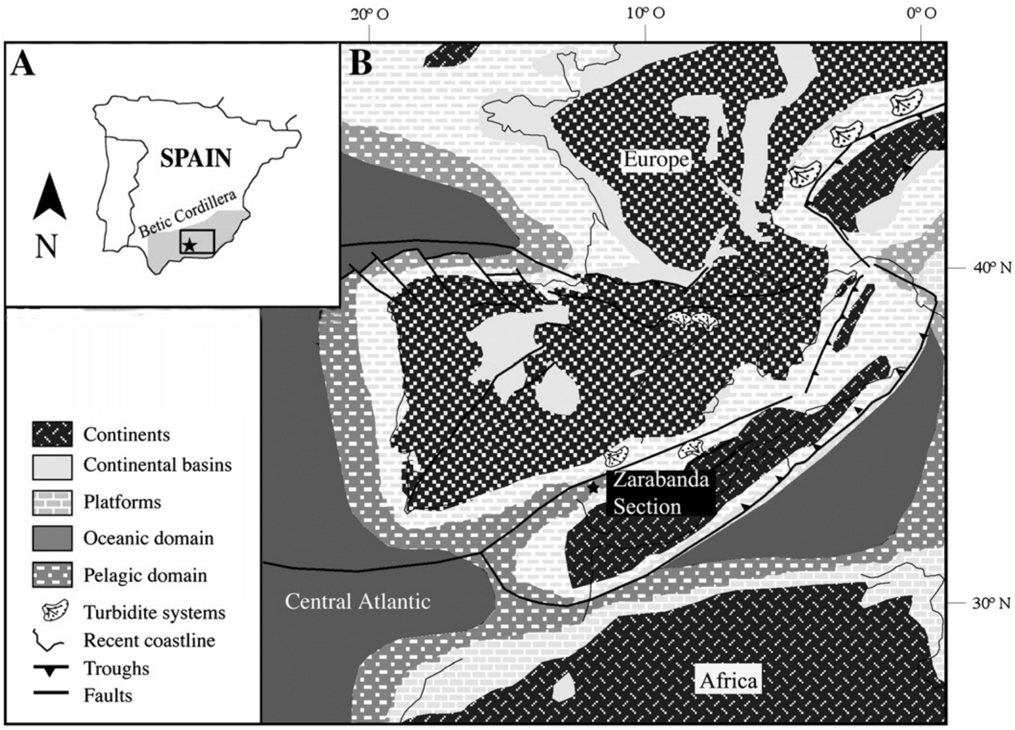

Fig. 1. A. Position of the Fuente Caldera section relative to modern geography. B. Palaeogeographic reconstruction of the European continent during the Eocene–Oligocene Transition, and location of the Zarabanda section (Betic Cordillera, southern Spain).
Modified from Andeweg (2002).

the Indian Ocean (Nomura, 1995), the eastern Equatorial Pacific Ocean (Takata and Nomura, 2005) and Weddell Sea (Thomas, 1992). Despite this, our knowledge of short-term fluctuations in the late Oligocene benthic foraminiferal assemblages remains limited, particularly within the western Tethyan region. The Zarabanda section of southern Spain therefore provides an ideal succession for studying this interval. This region is highly relevant due to its palaeogeographic location in the western Tethys, situated between the North Sea basin where there are several investigations about the late Oligocene palaeoclimatic events (e.g., Van Simaeys, 2004; Van Simaeys et al., 2004, 2005; Nielsen et al., 2007) and the Aquitanian Global Boundary Stratotype Section and Point (GSSP) at the Italian Lemme-Carrosio section (e.g., Coccioni et al., 2008). The section is extremely rich in micro-fossils and continuously spans ~1.7 Ma of the Upper Oligocene in a middle to lower bathyal setting.

This enables a detailed integrated micropalaeontological study (smaller and larger benthic foraminifera, planktonic foraminifera and calcareous nannofossils) from the Oligocene and across the Oi-2b global cooling event to be carried out. Marine organisms, such as foraminifera, are often sensitive to such climatic events and often show changes in abundance and/or distribution (e.g., Takata and Nomura, 2005). They are therefore exceptionally useful tools in studying the cooling events of the Oligocene. The combination of micro-fossils allows for a detailed calibration of benthic foraminiferal assemblage changes to both planktonic foraminiferal and nannofossil biostratigraphy. Additionally, the presence of larger benthic foraminifera allows the response of the carbonate platform to be studied. This research reconstructs the palaeoenvironmental changes across an interval which is crucial in the understanding of the evolution of Earth's climate from an important, previously unstudied, region within the western Tethys.

2. Materials and methods

The Zarabanda section is located in the northern of Granada province, southern Spain. The section lies in the Subbetic realm of the external zones of the Betic Cordillera (Fig. 1). The coordinates of the points delimiting the section are: 37°31′23.96″N–3°22′29.06 W (base) and 37°31′20.70″N–3°22′26.04 W (top). During the late Oligocene the site had a palaeolatitude of approximately 30°N and in a temperate region (Andeweg, 2002). The Zarabanda section was studied by Molina (1979) who sampled on both sides of the old road, identifying the upper Oligocene (*Globigerina angulisuturalis* Zone), and the lower Miocene (*Globigerinoides primordius* Zone) on the southeast and northeast flanks of the road, respectively. More recently a parallel road was built eastward of the old one, exposing a better outcrop on the northeast flank and allowing for further investigation.

The Zarabanda section consists of an 82 m thick sequence of hemipelagic marls with interbedded limestone and turbiditic sandstone layers, which appear to continuously span ~1.7 Ma within the late Oligocene. The hemipelagic marls contain abundant planktonic foraminifera and calcareous nannofossils, common small benthic foraminifera and rare ostracods. The smaller foraminifera and calcareous nannofossils studied herein are from the autochthonous marls. The calcareous sandstone strata contain abundant larger foraminifera and small benthic foraminifera resedimented from the shelf, which appear to have been

Plate 1. Most significant late Oligocene small benthic foraminiferal species from the Zarabanda section. Scale-bars represent 100 μm. 1a–b. *Angulogerina angulosa* (Williamson, 1858), sample Zr-116-77; 2a–b. *Bolivina plicatella* Cushman, 1930, sample Zr-116-41; 3a–b. *Bolivina plicatella* Cushman, 1930, sample Zr-116-42; 4a–b. *Bolivinoides crenulata* (Cushman, 1936), sample Zr-116-14; 5. *Bulimina alazanensis* Cushman, 1927, sample Zr-116-36; 6a–b. *Cassidulina havanensis* Cushman and Bermúdez, 1936, sample Zr-116-8; 7a–b–c. *Cibicides lobatulus* (Walker and Jacob, 1798), sample Zr-116-14; 8a–b–c. *Cibicidoides mundulus* (Brady, Parker and Jones, 1888), sample Zr-116-63; 9a–b–c. *Cibicidoides eocaenus* (Gümbel, 1868), sample Zr-116-26; 10. *Globocassidulina subglobosa* (Brady, 1881), sample Zr-116-57; 11. *Globocassidulina subglobosa* (Brady, 1881), sample Zr-116-61; 12a–b–c. *Neoconorbina terquemi* (Rzehak, 1888), sample Zr-116-11; 13a–b. *Rosalina globularis* D'Orbigny, 1826, sample Zr-116-16; 14a–b. *Trifarina bradyi* Cushman, 1923, sample Zr-116-14.