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Middle to late Miocene oxygen isotope stratigraphy of ODP site 1085 (SE Atlantic): new constrains on Miocene climate variability and sea-level fluctuations

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Abstract

The middle Miocene $\delta^{18}O$ increase represents a fundamental change in earth's climate system due to a major expansion and permanent establishment of the East Antarctic Ice Sheet accompanied by some effect of deepwater cooling. The long-term cooling trend in the middle to late Miocene was superimposed by several punctuated periods of glaciations (Mi-Events) characterized by oxygen isotopic shifts that have been related to the waxing and waning of the Antarctic ice-sheet and bottom water cooling.

Here, we present a high-resolution benthic stable oxygen isotope record from ODP Site 1085 located at the southwestern African continental margin that provides a detailed chronology for the middle to late Miocene (13.9–7.3 Ma) climate transition in the eastern South Atlantic. A composite Fe intensity record obtained by XRF core scanning ODP Sites 1085 and 1087 was used to construct an astronomically calibrated chronology based on orbital tuning. The oxygen isotope data exhibit four distinct $\delta^{18}O$ excursions, which have astronomical ages of 13.8, 13.2, 11.7, and 10.4 Ma and correspond to the Mi3, Mi4, Mi5, and Mi6 events. A global climate record was extracted from the oxygen isotopic composition. Both long- and short-term variabilities in the climate record are discussed in terms of sea-level and deep-water temperature changes. The oxygen isotope data support a causal link between sequence boundaries traced from the shelf and glacioeustatic changes due to ice-sheet growth.

Spectral analysis of the benthic $\delta^{18}O$ record shows strong power in the 400-kyr and 100-kyr bands documenting a paleoceanographic response to eccentricity-modulated variations in precession. A spectral peak around 180-kyr might be related to the asymmetry of the obliquity cycle indicating that the response of the dominantly unipolar Antarctic ice-sheet to obliquity-induced variations probably controlled the middle to late Miocene climate system. Maxima in the $\delta^{18}O$ record, interpreted as glacial periods, correspond to minima in 100-kyr eccentricity cycle and minima in the 174-kyr obliquity modulation. Strong middle to late Miocene glacial events are associated with 400-kyr eccentricity minima and obliquity modulation minima. Thus, fluctuations in the amplitude of obliquity and eccentricity seem to be the driving force for the middle to late Miocene climate variability.

Keywords: ODP Site 1085; Miocene; Oxygen isotopes; Astrochronology; Mi events; Sea-level

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1. Introduction

The Neogene period comprises a major change in climate state from relatively global warmth of the early Miocene to colder climates at the end of the Pliocene. As inferred from co-varying $\delta^{18}O$ values of planktonic and benthic foraminifers, the general cooling trend in the middle to late Miocene was superimposed by several punctuated periods of intensive glaciations (Mi-Events) which supposedly reflect continental ice sheet growth and/or bottom water cooling (Miller et al., 1991; Lear et al., 2000; Turco et al., 2001; Billups and Schrag, 2002). Due to the scarcity of continuous marine records spanning the middle to late Miocene, a period of widespread erosion in the deep sea (Keller and Barron, 1987), the characteristics of and the control on the Miocene glacial events is controversial. Recently, astronomically calibrated ages for the Mi5 and Mi6 event showed (Turco et al., 2001) that these coincide with periods of low-amplitude variations in obliquity related to the ~1.2 Ma cycle as proposed by Lourens and Hilgen (1997).

ODP Site 1085 is one of the most expanded and complete middle to late Miocene marine records retrieved from the Southwest African continental margin during ODP Leg 175. In this paper we present a unique high-resolution benthic oxygen isotope record spanning the middle to late Miocene (13.8–7.3 Ma). In addition, an astronomically calibrated time scale based on tuning of a composite Iron (Fe) intensity record from ODP Sites 1085 and 1087 has been constructed. For the first time, this high-resolution $\delta^{18}O$ record enables us to decipher the driving mechanisms of the middle to late Miocene climate system in detail. Therefore, this study focuses on the characterization and timing of the Mi-events, the orbital control of $\delta^{18}O$ variability, and inferences on sea-level fluctuation during the middle to late Miocene.

2. Material and methods

ODP Holes 1085A and 1087C were drilled in the Cape Basin during Leg 175. ODP Site 1085 is located at the southwestern African continental margin (Fig. 1) (29°22.47′ S, 13°59.41′ E, 1713 m water depth) off the mouth of the Orange River, a perennial river discharging into the South Atlantic (Wefer et al., 1998). A continuous hemipelagic sedimentary section composed of nannofossils ooze, diluted by various amounts silt and clay, was recovered from Site 1085 reaching down to the middle Miocene (14 Ma). The studied interval (350–600 mbsf) spanning the Middle to the Late Miocene has no composite section, but shows a mean recovery of over 100% with an average sedimentation rate of 3–5 cm/kyr (Wefer et al., 1998). Today, Site 1085 is bathed primarily in the Upper Circumpolar Deep Water (UCDW) near the mixing zone with the North Atlantic Deep Water (NADW) (Wefer et al., 1998). ODP Site 1087 is located further south at the continental margin (31°27.91′ S, 15°18.65′ E, 1372 m water depth). Sediments recovered from Site 1087 down to 430 mbsf span the last 10 Ma with sedimentation rates ranging from 2 to 7 cm/kyr and represent a relatively continuous pelagic section, rich in carbonate and poor in organic carbon (Wefer et al., 1998). The lowermost 70 m contain middle Miocene to early Oligocene sediment layers interrupted by at least two major discontinuities.

Continuous measurements of the elemental composition of sediments at ODP Sites 1085A and 1087C were performed at the Bremen ODP Core Repository (BCR) using the X-ray fluorescence (XRF) core scanner (Röhl and Abrams, 2000), which allows high-resolution, nearly continuous, non-destructive analyses of major and minor elements at the surface of split cores (Jansen et al., 1998). The XRF core scanner at the BCR is equipped with a molybdenum X-ray source (3–50 kV), a Peltier-cooled PSI detector (Kevex™) with a 125-μm beryllium window and a multi channel analyzer with a 20-eV spectral resolution. This system configuration allows the analysis of elements from potassium (K, atomic number 19) through strontium (Sr, atomic number 38; at 20 kV X-ray voltage). XRF data were collected every 4 cm downcore over a 1 cm^2 area using 30-s count time and an X-ray current of 0.087 mA to obtain the elemental concentration of Fe. More than 240 m of core from Site 1085A (42X through 63X, 382–594 mbsf) were analyzed. The data from 353.4 to 392.45 mbsf (39X through 41X) are taken from Vidal et al. (2002). The entire record represents the time period from about 6.5 to 13.9 Ma. From Site 1087C, approximately 144 m (30X through 44X, 261–405 mbsf) were scanned,