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Enhanced paleoproductivity across the Oligocene/Miocene boundary as evidenced by benthic foraminiferal accumulation rates ☆

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ABSTRACT

The Oligocene to Miocene boundary (23 Ma) marks one of the major Cenozoic cooling steps. A corresponding but slightly lagging $\delta^{13}C$ maximum in benthic foraminifer calcite of globally distributed sediment cores has been attributed to increased organic matter burial, either on land or in the oceans. To test this idea we reconstruct the organic carbon flux to the sea floor at three Atlantic Ocean Drilling Program (ODP) Sites using benthic foraminiferal accumulation rates (BFAR) and compare them with the stable isotope records. Our data show that the $\delta^{18}O$ and $\delta^{13}C$ maximum that characterizes the Oligocene/Miocene boundary is accompanied by a pronounced maximum in BFAR derived paleoproductivity at two of the sites. At tropical Atlantic Site 926 the paleoproductivity increase at the Oligocene/Miocene boundary is smaller than at the higher latitude sites, but high resolution sampling of a 2 million year interval (22–24 Ma) reveals that on eccentricity time scales productivity and stable isotope records are significantly correlated. The productivity records are in phase with the $\delta^{18}O$ and $\delta^{13}C$ records at the short-term (~125 ky) component of eccentricity. At the long-term eccentricity period (~400 ky) productivity is in phase with $\delta^{18}O$ but leads the $\delta^{13}C$ record by an amount that is consistent with published phase lags between the $\delta^{18}O$ and $\delta^{13}C$ records. These results imply that there was enhanced flux of organic matter to the ocean floor during the O/M climate transition and support that marine primary productivity may have played a role in the carbon cycle and atmospheric CO_2 draw-down at this time.

1. Introduction

The Oligocene to Miocene climate transition offers an opportunity to study potential relationships between orbital forcing of glaciations and the global carbon cycle (e.g., Zachos et al., 1997, 2001a; Pälike et al., 2006a,b). Climate reconstructions based on deep sea benthic foraminiferal oxygen isotope records indicate that massive Antarctic ice sheets first developed during the Eocene to Oligocene climate transition 33.5 my ago and remained a substantial feature of the global climate system until the early Miocene (Miller et al., 1991; Zachos et al., 2001b). At that time, ice sheets waned as climate warmed, a trend that was interrupted by the second major expansion of Antarctic ice sheets during the middle Miocene (Flower and Kennett, 1993; Shevenell and Kennett, 2007). Early Miocene warmth was punctuated, however, by several brief glacial events characterized by distinct maxima in deep sea $\delta^{18}O$ records (Miller et al., 1991). The largest of these glacial events is associated with the Oligocene/Miocene boundary at 23.0 Ma. A corresponding but slightly lagging $\delta^{13}C$ maximum suggests that a shift in global carbon reservoirs and/or transfer between these reservoirs took place or was initiated during this event, possibly in the form of increased organic carbon burial in response to global climate cooling (Zachos et al., 1997, 2001a; Pälike et al., 2006a,b).

Here we test the hypothesis that Oligocene to Miocene climate cooling was associated with the transfer of carbon from the atmosphere to the deep marine reservoir via surface ocean primary productivity by reconstructing the flux of organic carbon to the sea floor. The organic carbon flux to the sea floor depends on the amount of organic carbon produced at the sea surface by primary producers, the amount subsequently transferred out of the photic zone (export production), and the amount reaching the sea floor. The amount of organic carbon reaching the sea floor can be reconstructed using accumulation rates of benthic foraminiferal tests (BFAR) because it provides a food source for benthic communities (Berger and Wefer, 1990; Herguera, 2000). Comparing BFAR records to benthic foraminiferal stable isotope records allows us to asses to what degree climate records ($\delta^{18}O$ values) and the marine carbon cycle ($\delta^{13}C$ values) are linked to bottom water organic carbon fluxes and, presumably, primary productivity. To avoid biasing interpretation of global climate changes based on data from a single site, we investigate a number of

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sites from the Atlantic, Indian, and Pacific Oceans. Here we report results from three sites located in the Atlantic Ocean that sample different hydrographic and productivity regimes.

2. Approach

2.1. Site specifics and modern ocean productivity

Sites selected for this study come from the Atlantic Ocean spanning tropical to subantarctic latitudes (Fig. 1). We sample Site 926 on Ceara Rise in the northwestern tropical Atlantic (4°N, 43°W, 3598 m water depth), Site 1265 in the southeastern subtropical Atlantic on the Walvis Ridge (29°S, 3°E, 3083 m water depth) and Site 1090 in the subantarctic Southern Ocean on Agulhas Ridge (43°S, 30°W, 3699 m water depth). As best as can be assessed, the paleodepth of these sites was similar to today (Curry et al., 1995; Shipboard Scientific Party, 1999, 2004, respectively).

At Site 926 modern day surface hydrography is characterized by a seasonally deep mixed layer, convergence and downwelling (Peterson and Stramma, 1991). Modern ocean productivity ranges from a seasonal minimum of ~23 gC cm^{-2} (over a three month period) to a seasonal maximum of ~30 gC cm^{-2} (over a three month period) (Antoine et al., 1996). During the late Oligocene through early Miocene, surface hydrography may not have been very different from today because Ceara Rise remained in a similar position with respect to the South American continent and was thus not likely to have been affected by an open Central American Seaway. A marked influence of the Amazon River did not begin until about 15 Ma (Dobson et al., 1997).

Site 1265 was drilled on Walvis Ridge presently located underneath the western reaches of the northward flowing Benguela Current (Shipboard Scientific Party, 2004). Modern ocean productivity at this site remains relatively low throughout the year with a seasonal minimum of ~13 gC cm^{-2} (averaged over 3 months) and maximum of ~23 gC cm^{-2} (averaged over 3 months) (Antoine et al., 1996). Surface hydrography during the Oligocene through Miocene may have been somewhat similar because the site's location with respect to the continent has not changed, although wind driven changes and associated surface ocean currents may have been different because of the asymmetry in polar ice sheets.

Site 1090 is situated underneath Subantarctic Surface Waters north of the Polar Frontal Zone. Modern ocean productivity displays a relatively large seasonal range from a minimum of ~13 gC cm^{-2} (averaged over 3 months) to a seasonal maximum of ~30 gC cm^{-2} (averaged over 3 months) (Antoine et al., 1996). Surface water hydrography at this site may have been very different during the late Oligocene through early Miocene because of a less well developed Antarctic Circumpolar Current perhaps due to a narrower Drake Passage and Tasman Seaway (Cande and Stock, 2004; Anderson and Delaney, 2005).

2.2. Age control

Because the paleoproductivity proxy used here is ultimately based on sediment accumulation rates, age models become crucial controls.

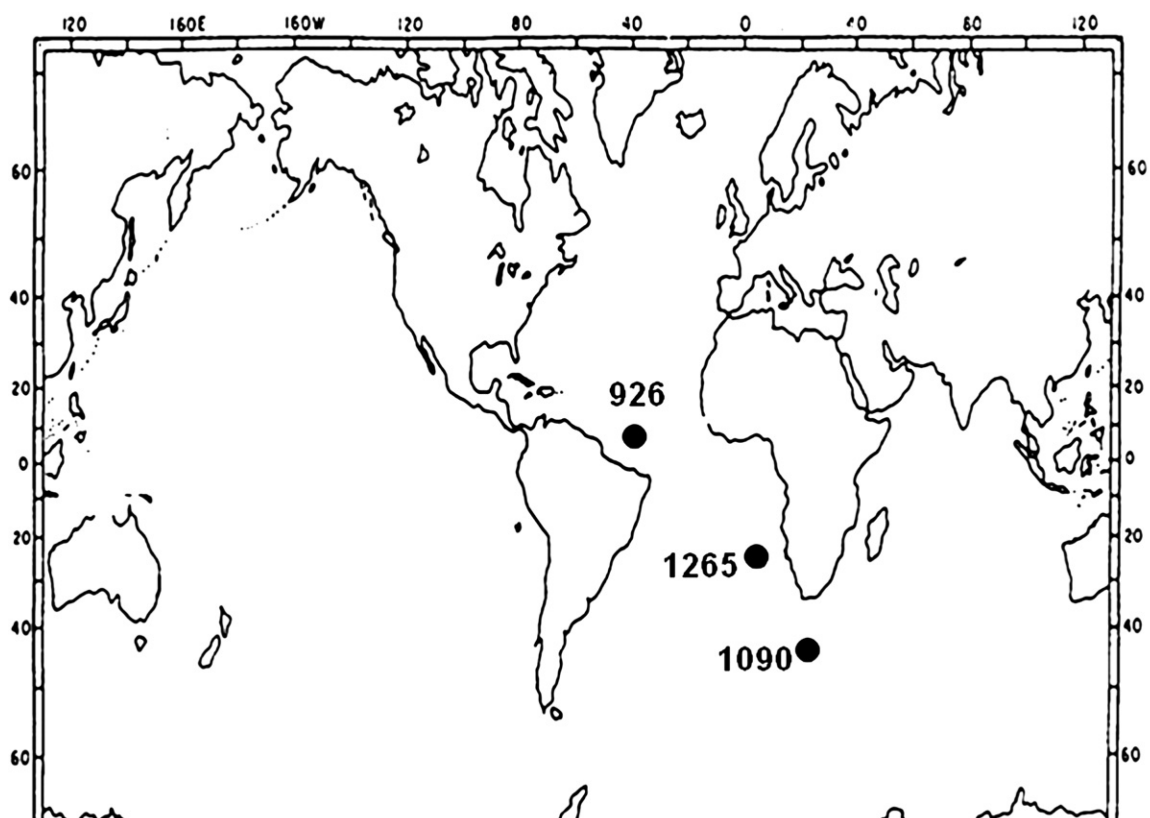

Fig. 1. Location of investigated Ocean Drilling Program Sites. Site 926 is located on Ceara Rise (4°N, 43°W, 3598 m water depth), Site 1265 is on Walvis Ridge (29°S, 3°E, 3083 m water depth), and Site 1090 lies on Agulhas Ridge (43S, 30°W, 3699 m water depth).