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Paleoceanographic changes in the Northeast Indian Ocean during middle Miocene inferred from carbon and oxygen isotopes of foraminiferal fossil shells

Barnita Banerjee [a], Syed Masood Ahmad [a,*], Waseem Raza [b], Tabish Raza [b]

[a] Academy of Scientific and Innovative Research (AcSIR), CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad 500 007, India
[b] CSIR- National Geophysical Research Institute, Uppal Road, Hyderabad 500 007, India

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ABSTRACT

The middle Miocene transition witnessed rapid fluctuations in oceanographic and climatic systems. However, very limited work has been attempted in Miocene sediments of the Northern Indian Ocean to identify these changes. Here we present the first detailed $\delta^{13}C$ and $\delta^{18}O$ records of surface and deep dwelling foraminifera from ODP site 758 in the Northeast Indian Ocean, located atop the Ninetyeast Ridge. Carbon and oxygen isotopic data on *Globigerinoides quadrilobatus* (planktonic) and *Cibicidoides wuellerstorfi* (benthic foraminifera) indicated various global and local successions of oceanographic and climatic importance. The climatic events recorded at ODP 758 are; (a) Mid Miocene climatic Optimum (17–15 Ma), (b) Monterey excursion (17–14 Ma), (c) East Antarctica Ice sheet formation (13.8 Ma), (d) Initiation of Indian Summer Monsoon with waning of Antarctica Ice sheet (12.3–10.4 Ma), and (e) evidence of a cooling event (10.2–9.6 Ma).
Our benthic foraminifera $\delta^{18}O$ record showed almost identical deep water evolution to that of the Indo Pacific for 13.9–11.5 Ma interval. A significant decrease in $\delta^{13}C_{ben}$ at ~10.2 Ma was indicative of a complete re-adjustment of the carbon cycle after the Monterey excursion and export of the North Atlantic Deep Water (NADW) towards the southern Ocean to give rise to the Circumpolar Deep Water (CDW), with a $\delta^{13}C$ value of ~0.4‰. The formation of the NADW had given rise to modern deep water like conditions at ~10 Ma ago. A comparison of our record with previously published isotopic records from other regions suggested a good correlation between the South Pacific, Indo Pacific and Northeast Indian Ocean during the studied time interval. It appears that a strong westerly Indian Ocean current (MIOjet) may have linked these Oceans from 14 to 9 Ma.

1. Introduction

The Miocene epoch marks the most salient interval in the Cenozoic era, characterized by several major events, such as the continental drifting, mountain building and other tectonic processes, which in turn engendered climatic and oceanographic changes like waxing and waning of Antarctica ice sheets, strengthening of the Antarctic Circumpolar Current (ACC) resulting into sudden increase in deep sea hiatuses, development of deep water masses and vertical temperature stratification and evolution of global climate and ecosystems (Srinivasan and Gupta, 1990). Stable carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotopic records of carbonate pelagic sections have become important tools to unlock these events. There is a scarcity of isotopic data on Miocene sediments from the Northern Indian Ocean to reconstruct surface and deep water characteristics in this region. The integration of our result with published records from other parts of the world oceans will enable us to gain better understanding regarding global and regional climatic and oceanographic changes. Another important aspect is related to a better understanding of the initiation and intensification of Indian summer monsoon (ISM), which is believed to have occurred during Miocene epoch. While most researchers agree that the Asian monsoon systems intensified at around 8 Ma (Prell and Kutzbach, 1992; Chen et al., 2003; Wan et al., 2007), however this view has been challenged by Jia et al. (2003) and Licht et al. (2014), who suggested that the intensification occurred during the early Miocene and the late Eocene respectively. Therefore, in order to better understand the timing of ISM initiation we focused our attention to reconstruct the paleoceanography of the Northeast Indian Ocean.

Major ice sheet growth on East Antarctica resulted in increased production of deep and intermediate water masses and enhanced vertical thermal gradient (Shackleton and Kennett, 1975; Savin et al., 1975; Kennett, 1986). Carbon and oxygen isotope records of benthic foraminifera have proved to be excellent proxies for identifying changes in chemical characteristic of deep water masses in the Northern Indian Ocean during Quaternary (Raza and Ahmad, 2013 and references

* Corresponding author.
E-mail address: smasoodahmad@rediffmail.com (S.M. Ahmad).

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therein). Here we present the first detailed $\delta^{13}C$ and $\delta^{18}O$ records of benthic foraminifera from ODP site 758. Our focus is to reconstruct paleoceanographic changes for the middle Miocene period, which includes major events, such as transition from relatively warm conditions (Miocene climatic optimum) into a colder phase characterized by the Antarctic ice sheet expansion and global cooling event at 13.9 Ma (Flower and Kennett, 1993, 1995; Holbourn et al., 2005, 2007), initiation of ISM, Monterey excursion and formation of Miocene Indian Ocean Equatorial jet (MIOjet) and the NADW.

2. Materials and methods

ODP site 758 is located atop the Ninetyeast Ridge in the Northeast Indian Ocean (Lat. 5°23′N, Long. 90°21′E; water depth 2925 m) (Fig. 1). This site is located half-way between Deep Sea Drilling Project (DSDP) sites 216 and 217. The sediments at this site consist mainly of biogenic pelagic calcium carbonate ($CaCO_3$) with minor amount of terrigenous silt, clay and volcanic tephra (Farrell and Janecek, 1991). Middle Miocene sediments are made of predominantly nannofossils, forming 60–72% of the total sediment. Foraminiferal content ranges from 1% to 10% generally decreasing down section. For this study, subsamples were taken at 10 cm interval, soaked in 3% H_2O_2 overnight, and washed through a 150 μm sieve. The retained fractions were then dried at 60 °C and set aside for microscopic examination. Isotopic ratios were determined on planktonic foraminifera (*G. quadrilobatus*) and benthic foraminifera (*C. wuellerstorfi*). About 4–5 tests of planktonic and 2–3 tests of benthic foraminifera, in the size range of 250–315 μm were handpicked under the binocular microscope for isotopic measurement. Only well preserved tests of the desired foraminifera were picked under microscopic examination. All tests were cleaned ultrasonically in methanol to remove adhering fine clay particles. The $\delta^{18}O$ and $\delta^{13}C$ measurements were performed on a Mat 253 Isotope Ratio Mass Spectrometer (IRMS) equipped with Kiel-IV automatic carbonate device at the CSIR-National Geophysical Research Institute, Hyderabad, India (Ahmad et al., 2012). The tests were reacted with saturated H_3PO_4 at ~70 °C in a vacuum system and evolved CO_2 was then analyzed by IRMS. Isotopic compositions are reported in δ notation as per mil deviation from VPDB standard. Analytical precision was better than 0.07‰ for $\delta^{18}O$ and 0.04‰ for $\delta^{13}C$. Calibration to the VPDB standard was performed by repeated measurements of international reference standards NBS-19 and NBS-18. *C. wuellerstorfi* oxygen isotope data was corrected by adding 0.64‰ (Mix et al., 1991).

The chemostratigraphy age model of site ODP 758 displayed in Fig. 2 was based on best fit trend of $^{87}Sr/^{86}Sr$ with time (Ahmad et al., 2005) by using polynomial regression of Hodell et al. (1991) and Miller et al. (1991). The stratigraphic resolution of samples varies from 20 ka in the lower section to 8 ka in the upper section. The biostratigraphic age model of this site showed a reasonably good agreement with strontium isotope derived chemostratigraphy (<± 1.48 Ma). The biostratigraphic age model was based on calcareous and siliceous fossil events (nannofossils, foraminifera and diatoms) and interpolated numerical ages (Peirce et al., 1989; Klootwijk et al., 1992). Marker species used in calcareous nannofossils zonation scheme (Okada and Bukry, 1980) and different planktonic and benthic foraminifera assemblages were used to decipher biostratigraphy of the Miocene segment. Sedimentation rate for late Miocene is highest (0.5 cm/ka) for 10.8–9.6 Ma,

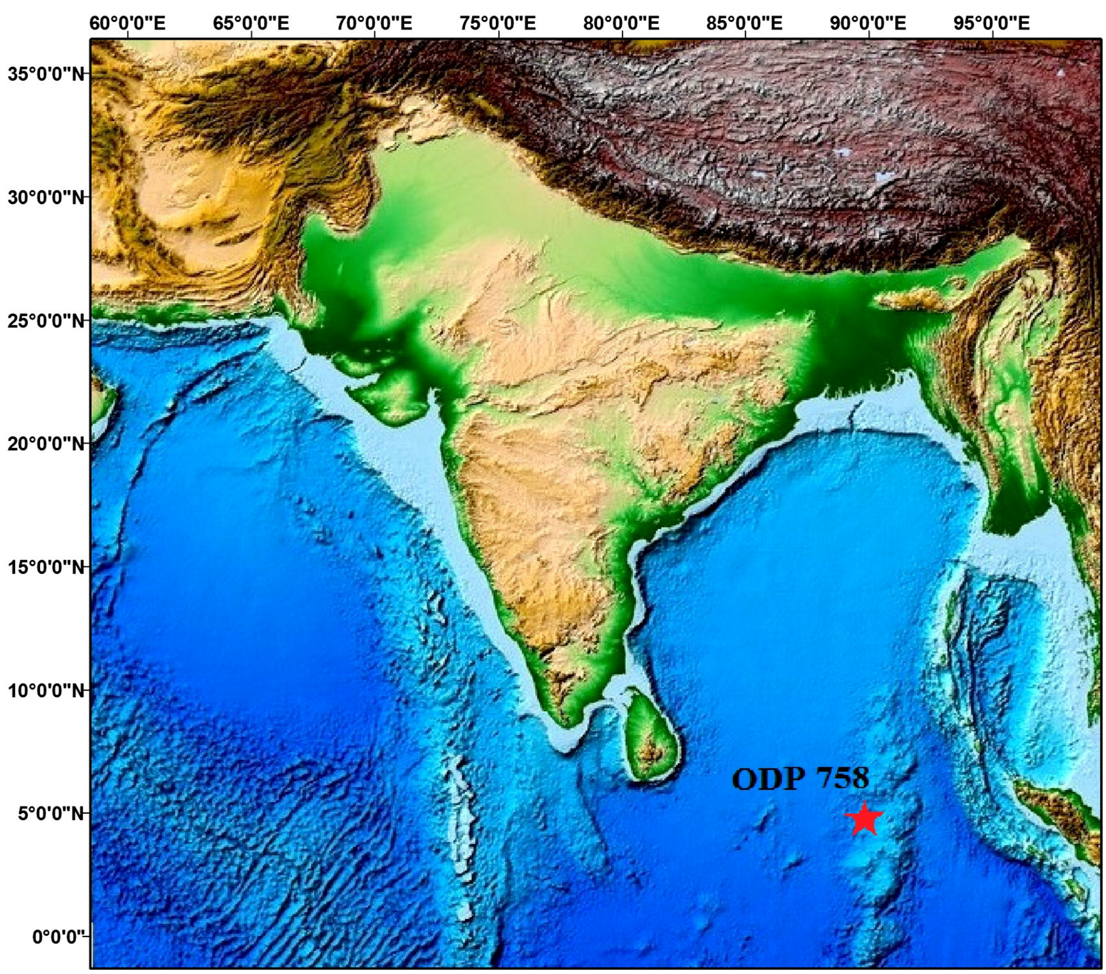

Fig. 1. Location map of ODP site 758 A. (Lat. 5°23′N, Long. 90°21′E; water depth 2925 m)