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Deep-sea faunal provinces and their inferred environments in the Indian Ocean based on distribution of Recent benthic foraminifera

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ABSTRACT

Multivariate analysis was performed on percentages of 46 species of unstained deep-sea benthic foraminifera from 131 core-top to near-core-top samples (322–5013 m) from across the Indian Ocean. Faunal data are combined with GEOSECS geochemical data to investigate any relationship between benthic foraminifera (assemblages and species) and deep-sea properties. In general, benthic foraminifera show a good correlation to surface productivity, organic carbon flux to the sea floor, deep-sea oxygenation and, to a lesser extent, to bottom temperature, without correlation with the water depths. The foraminiferal census data combined with geochemical data has enabled the division of the Indian Ocean into two faunal provinces. Province A occupies the northwestern Indian Ocean (Arabian Sea region) where surface primary production has a major maximum during the summer monsoon season and a secondary maximum during winter monsoon season that leads to high organic flux to the seafloor, making the deep-sea one of the most oxygen-deficient regions in the world ocean, with a pronounced oxygen minimum zone (OMZ). This province is dominated by benthic foraminifera characteristic of low oxygen and high organic food flux including *Uvigerina peregrina*, *Robulus nicobarensis*, *Bolivinita pseudopunctata*, *Bolivinita* sp., *Bulimina aculeata*, *Bulimina alazanensis*, *Ehrenbergina carinata* and *Cassidulina carinata*. Province B covers southern, southeastern and eastern parts of the Indian Ocean and is dominated by *Nuttallides umbonifera*, *Epistominella exigua*, *Globocassidulina subglobosa*, *Uvigerina proboscidea*, *Cibicides wuellerstorfi*, *Cassidulina laevigata*, *Pullenia bulloides*, *Pullenia osloensis*, *Pyrgo murrhina*, *Oridorsalis umbonatus*, *Gyroidinoides* (= *Gyroidina*) *soldanii* and *Gyroidinoides* cf. *gemma* suggesting well-oxygenated, cold deep water with low (oligotrophic) and pulsed food supply.

1. Introduction

Benthic foraminifera are an important constituent of marine environments occurring in all oceanic environments and showing wide ecological adaptability. They live in both oxygen-depleted and oxygen-rich environments, oligotrophic and eutrophic settings, cold and warm spheres, and high and low energy conditions, having both epibenthic and endobenthic microhabitats. Because of their good fossilization potential and recent advances in the knowledge of their ecology, benthic foraminifera have been widely used to infer marine environmental changes through time, and in the reconstruction of Quaternary climate variability and ocean circulation changes in different ocean basins (e.g., Schmiedl and Mackensen, 1997; Gupta and Thomas, 1999; den Dulk et al., 2000; Hayward, 2001; Gupta and Thomas, 2003; Singh and Gupta, 2004; Kawagata et al., 2006).

A strong correlation has been observed between benthic foraminiferal population dynamics and oxygen content of ambient water and organic matter reaching the seafloor in different ocean basins (e.g., Loubere and Fariduddin, 1999; van der Zwaan et al., 1999; den Dulk et al., 2000; Heinz and Hemleben, 2003; Smart et al., 2007). Significant studies on deep-sea benthic foraminifera in the eastern and southeastern Indian Ocean are those of Peterson (1984) and Corliss (1979), respectively. These authors found a relationship between benthic foraminiferal assemblages and bottom water masses. Murgese and De Deckker (2005) made a detailed study of benthic foraminifera in the eastern Indian Ocean, offshore western Australia, Java and Sumatra. Gupta (1994) analyzed taxonomy and bathymetric distribution of Holocene deep-sea benthic foraminifera from the Indian Ocean and the Red Sea, and observed distinct benthic foraminiferal assemblages associated with different water masses. Important studies on Recent benthic foraminifera from the northwest Indian Ocean (Arabian Sea) are those of Hermelin and Shimmield (1990), Jannink et al. (1998), Heinz and Hemleben (2003, 2006), Schumacher et al. (2007), Larkin and Gooday (2009), da Silva and Gooday (2009) and Gooday et al. (2009). Benthic foraminifera in the Arabian Sea are distinct from those in the southern Indian Ocean, because the former is a climatically and oceanographically distinct region, marked by monsoon-driven high organic production and

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seasonal fluxes to the sea floor causing a pronounced oxygen minimum zone (OMZ) at depths ~200–1200 m (Hermelin and Shimmield, 1990; Gupta, 1994; den Dulk et al., 2000; Reid, 2003). In this study, near-core-top to core-top samples collected during various Ocean Drilling Program (ODP) Legs from different parts of the Indian Ocean, have been analyzed and combined with published benthic foraminiferal data from the eastern Indian Ocean (Peterson, 1984), the southwestern Indian Ocean (Corliss, 1983) and the Arabian Sea (Hermelin and Shimmield, 1990) (Fig. 1; Table 1s), enabling us to identify benthic foraminiferal faunal provinces. The benthic faunal data was combined with GEOSECS (1983) geochemical data to investigate any relation between physicochemical properties of deep water masses and different species of benthic foraminifera. This has helped us to infer environments of each biofacies and faunal province. Results of this study are expected to help paleoceanographers reconstruct a basin-wide paleoceanographic and paleoclimatic perspective of different ocean basins during the past.

2. Oceanographic setting of the Indian Ocean

Oceanographically, the Indian Ocean is complex because it is landlocked in the north; in the south it meets water masses of the Southern Hemisphere whereas in the eastern Indian Ocean, Pacific water influences the surface (upper 500 m) hydrography (Tchernia, 1980). The northern Indian Ocean is marked by the seasonal reversals in the surface currents due to monsoon winds, bringing significant changes in the surface productivity and deep-sea oxygenation unlike the southern Indian Ocean. The surface primary productivity throughout the northern Indian Ocean increases during the summer or southwest (SW) Indian monsoon and decreases during the winter or northeast

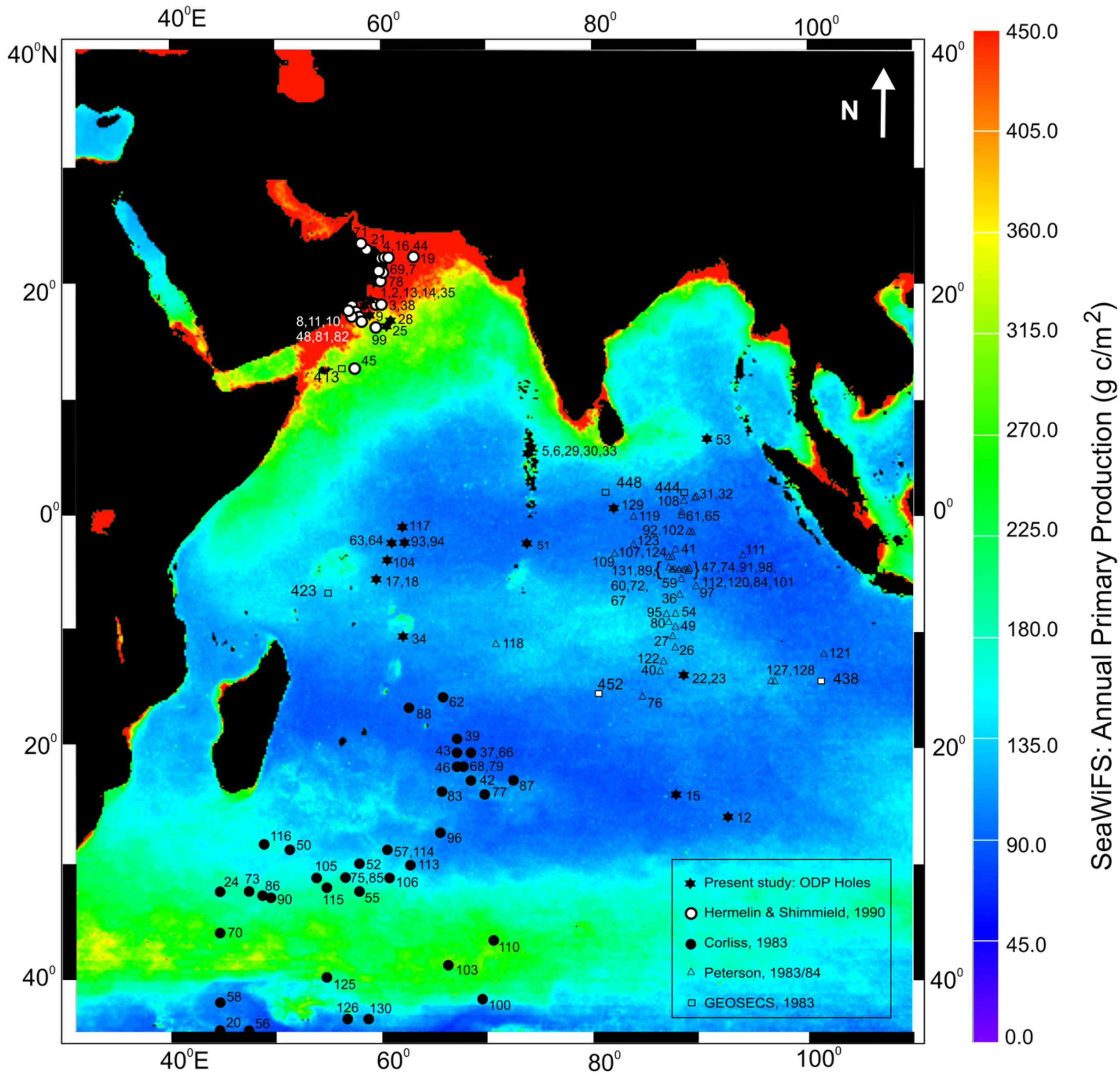

Fig. 1. Annual primary production map of the Indian Ocean based on SeaWiFS chlorophyll data along with location map (averaged over September 1998–August 1999, modified from: http://marine.rutgers.edu/opp/swf/Production/results/all2_swf.html).