Distribution and behavior of dissolved bioactive trace metals in the Indian Ocean

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In recent years, more attention is being paid to the importance of trace metals and their roles in biogeochemical cycling in the ocean. The Indian Ocean is the third largest of the world's oceanic divisions, covering approximately 20% of the water on the Earth's surface. In the north, the Indian Ocean has two large embayments west and east of India: the Arabian Sea and Bay of Bengal which are thoroughly contrasting oceanographic regimes. The saline Arabian Sea and its marginal seas are dominated by evaporation, while the fresher Bay of Bengal is dominated by runoff river. The ocean circulation in the northern Indian Ocean is dominated by reversing monsoonal wind forcing. The northern Indian Ocean also receives large atmospheric dust and anthropogenically derived inputs. Despite of the important role of the Indian Ocean on global elemental cycle and climate change, the data on trace metals in seawater are still very poor. Due to a low concentration of bioactive trace metals in seawater, clean techniques during sampling and preparation and analysis of seawater samples are therefore required to ensure the reliable data (Sohrin and Bruland 2011). In addition, the analytical methods with high sensitivity and accuracy are also necessary. This study reports simultaneous determination of the nine elements (Al, Mn, Fe, Co, Ni, Cu, Zn, Cd and Pb) in the Indian Ocean for the first time providing a comprehensive information on biogeochemistry of the nine elements in the Indian Ocean.

Seawater samples were collected from 0–5300 m depths at 11 stations in the Indian Ocean during the KH09-5 cruise of R/V Hakuho-Maru in November 2009-January 2010 (Fig. 1). Clean techniques were employed throughout the sampling, processing and analytical procedures. After the sampling, seawater for dissolved (D) species was filtered through a filter with a pore-size of 0.2 μm and acidified to pH 2.2 with HCl. The nine elements were preconcentrated by a one-step solid-phase extraction using a NOBIAS-Chelate PA1 resin column (Sohrin et al. 2008) and determined by high resolution inductively coupled plasma mass spectrometry (HR-ICP-MS).

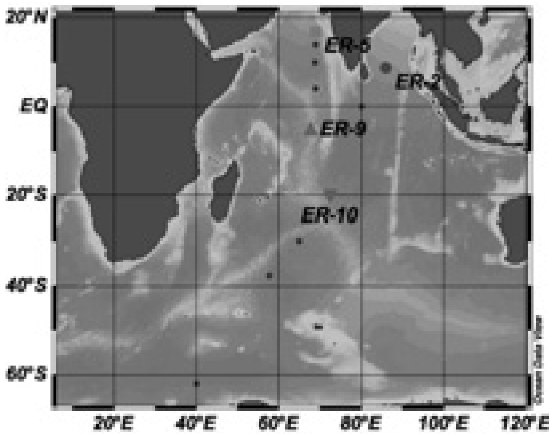

Fig. 1 Sampling locations and vertical profiles of DMn, DFe, DCo and DZn in the Indian Ocean

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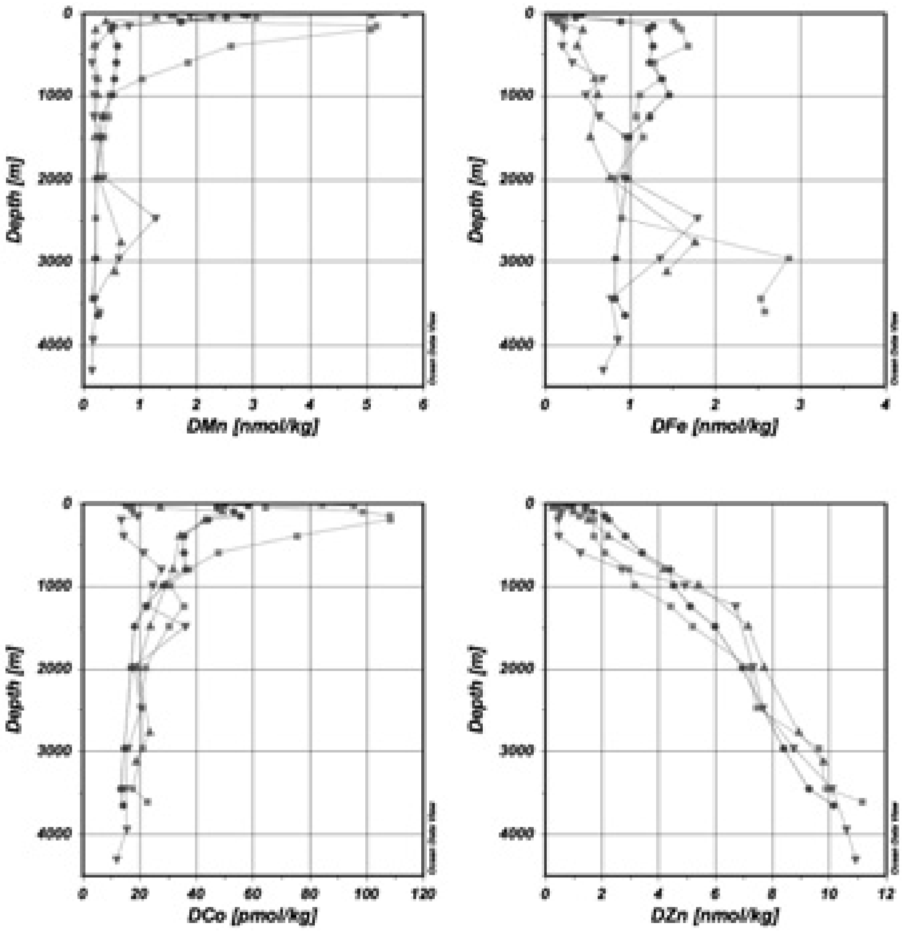
The first simultaneous distribution of the nice bioactive trace metals in the Indian Ocean was discovered. The dissolved bioactive trace metals are divided into 3 groups based on the distributions and correlations: (1) scavenged-type elements for Al, Mn, Co and Pb, (2) nutrient-type elements for Ni, Cu, Zn and Cd, and (3) recycled and scavenged-type element for Fe.

DAl, DMn, DCo and DPb showed high concentrations in surface water due to aeolian dust input. DMn and DCo showed maximums in the upper layer (< 1000 m) where oxygen was depleted, suggesting the influence of reductive dissolution from particles. However, the increase in DCo was not as high as DMn indicating biological uptake of this metal by organisms. A maximum of DMn and DFe was observed at 2500–3000 m of stations ER9 and ER10 showing the influence of the hydrothermal activity on the Central Indian Ridge. DCu, DNi, DZn and DCd increased with depth. DCd, DNi and DZn were highly correlated with macronutrients ($r > 0.78$ for DCd, DNi and $r > 0.65$ for DZn) indicating their distributions are largely controlled through uptake by microorganisms and remineralization from settling particles. DCu exhibited a weak correlation with macronutrients. DFe showed complex distributions affected by both scavenging and biogeochemical cycling.



The atmospheric dust deposition and horizontal advection cause elevated concentrations of DAl, DMn, DCo, DCu and DPb in the upper water column in the Arabian Sea and the Bay of Bengal. The South Indian Current carries DAl, DMn, and DCu eastward at ~20°S. Manganese reduction and iron reduction occur in the Oxygen Minimum Zone resulting the increase of DMn, DCo and DFe. Mid-depth enrichment of DMn and DFe above the Central Indian Ridge is influenced by hydrothermal plumes. The distribution of DNi, DCu, DZn and DCd is controlled by biogeochemical cycle. DZn would be depleted faster than DNi and DCu would be depleted faster than DNi and DZn in surface water. Although DFe does not show a linear correlation with macronutrients and nutrient-type DMs, iron will be a co-limiting factor for phytoplankton production in most of the study area. The stoichiometry of dissolved metals is generally comparable between deep waters in the northern Indian Ocean and the North Pacific Ocean, suggesting consistence of the mechanism controlling the behaviors of dissolved metals between the Indian and Pacific Oceans.