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Distribution of Zirconium, Hafnium, Niobium and Tantalum in the North Atlantic Ocean, northeastern Indian Ocean and its adjacent seas

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ABSTRACT

The two pairs of geochemical twins, Zr–Hf and Nb–Ta, have similar chemical properties, leading to their limited fractionation throughout the igneous processes and thus useful and widely used to elucidate rock and mineral formation. In contrast to the analysis of solid samples (e.g. igneous rocks), however, reports of these elements from aquatic samples (e.g. seawater) are very limited due to difficulties in analyzing their very low concentrations in seawater compared to those in solid samples (up to 6 orders of magnitude different). Recent developments of clean sampling techniques coupled with pre-concentration and ICP-MS determination have made trace elements analysis in seawater reliable. Here we report the first vertical distribution of dissolved Zr, Hf, Nb and Ta in the Indian Ocean in addition to those in the Atlantic Ocean, Andaman Sea and Gulf of Thailand. In the Atlantic and northeastern Indian Ocean, Zr, Hf, Nb and Ta show surface depletion and deep water enrichment. The average deepwater Zr/Hf molar ratios in the western North Atlantic, eastern North Atlantic and northeastern Indian Ocean were 270, 315 and 280, respectively. Compared to North Pacific Ocean Zr/Hf ratios of ~500, strong intra- and inter-ocean fractionation, a term that describe a difference between concentration of trace metals in deep Atlantic and deep Pacific seawater, is observed to occur in the global ocean. However, the inter-ocean fractionation of Nb/Ta is weaker due to a more uniform distribution of Nb and Ta in seawater. In contrast to open ocean seawater, Zr, Hf, Nb and Ta concentration at stations close to the continent in the Andaman Sea and Gulf of Thailand were highest in surface water decreasing through deep water, with Zr/Hf and Nb/Ta closer to continental crust ratios indicating significant terrestrial inputs of these elements to seawater. Results suggest that, in spite of the similar chemical properties of these geochemical twin pairs generating coherent