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Evidence from phosphorus speciation for changing nutrient status in the Southern Ocean since the last glacial period

SHIMODE, Naoyuki[1*] ; YAMAGUCHI, Kosei E.[2] ; IKEHARA, Minoru[3]

[1]Department of Chemistry, Toho University, Japan, [2]Toho University & NASA Astrobiology Institute, [3]Center for Advanced Marine Core Research, Kochi University, Japan

The Southern Ocean, a high-nutrient, low-chlorophyll region, plays an important role in regulating global climate system. The Southern Ocean became anoxic during the last glacial period (˜70 to 10 kyr ago), with its maximum at the Last Glacial Maximum (LGM). In order to elucidate changes in the redox state and nutrient status of the seawater caused by sea ice and/or shelf ice, we performed phosphorus speciation analysis of the marine sediments (COR-1bPC) recovered at the Conrad Rise in the Southern Ocean by 2010 KH10-07 cruise. Selected, freeze-dried and powdered 37 samples were used for sequential extraction of phosphorus-bearing phases (loosely sorbed P (P_{abs}), iron-bound P (P_{Fe}), authigenic apatite P + biogenic apatite + $CaCO_3$-associated P (P_{auth}), detrital apatite P (P_{det}), organic P (P_{org})) by modified SEDEX method of Ruttenberg (1992). Phosphorus concentrations of each sample solution were measured by molybdenum blue method. Average contents of P_{auth}, P_{det}, P_{org}, and P_{tot} in the dark colored sediments (corresponding to the last glacial period) was 0.020 wt.%, 0.004 wt.%, 0.008 wt.%, and 0.059 wt.%, respectively. Conversely, those in the light colored sediment (the interglacial period) were 0.005 wt.%, 0.002 wt.%, 0.004 wt.%, and 0.022 wt.%, respectively. During the last glacial period, where the Southern Ocean was covered by sea ice, suppressed interactions between atmosphere and ocean would have decreased dissolved oxygen concentration and gradually created anoxic condition. Such anoxic condition would have occasionally but repeatedly expanded to include the Conrad Rise and affected P_{Fe} abundance in sediment. In the LGM, abundance of P_{auth}, P_{det}, P_{org}, P_{Fe}, and P_{tot} suddenly increased to the maximum value. Sources of phosphorus to the ocean are either or combination of wind-driven dust, glacier-scored debris, or regeneration from sediments upon reductive dissolution of P-absorbed Fe (oxy)hydroxide. Wind-driven dust is unlikely because the surface of Antarctic Continent was covered by ice sheet. Therefore, the latter two processes would have increased P and Fe nutrient supply to the ocean, enhanced primary production, induced anoxic condition by consumption of dissolved oxygen upon degradation of organic matter, and decreased pCO_2. Analysis of phosphorus speciation is useful in reconstructing redox and nutrient states in the ocean.