

# Overview: Special Issue on “Paleoenvironmental Changes in the Antarctic Cryosphere: Global Climate Change Investigated in the Southern Ocean”

Minoru IKEHARA<sup>1</sup>, Hideki MIURA<sup>2</sup>, Mutsumi NAKAI<sup>3</sup>,  
Tsutomu NAKAZAWA<sup>4</sup>, Osamu SANO<sup>5</sup> and Hitoshi KOIDE<sup>4</sup>

## I. Importance of Southern Ocean and Antarctic cryosphere on the global climate system

The Antarctic cryosphere, including the Antarctic ice sheet and the Southern Ocean, plays an important role in the global climate system both at present and in the geologic past. Throughout geologic time, variations of atmospheric CO<sub>2</sub> partial pressures ( $p\text{CO}_2$ ) have been associated with global climate change. During glacial periods, increased biological pump and/or surface stratification in the Southern Ocean may have contributed to low atmospheric  $p\text{CO}_2$ . To resolve the causes and processes of atmospheric CO<sub>2</sub> change, it is important to understand the mechanisms and processes of sub-systems in the Antarctic cryosphere such as changes of biological productivity, sea-surface temperature, surface water frontal system, sea ice distribution, and Antarctic ice sheet during the glacial-interglacial climate cycle.

Because the Antarctica and the Southern Ocean are remote from Japan, not many Japanese researchers consider those areas as a research field. However, geological and geomorphological research projects on the Antarctic continent have been conducted under the program of the Japanese Antarctic Research Expedition (JARE) in recent years. The marine geological survey cruises also used the R/V Hakuho-maru in the Indian

sector of the Southern Ocean. Therefore, the contribution of Japan to Antarctic cryosphere research has been increasing. In addition, the Integrated Ocean Drilling Program (IODP) Expedition 318 explored the Wilkes Land margin, East Antarctica in 2009. Seven researchers from Japan were aboard the drilling vessel JOIDES Resolution, and participated in joint international research. Thus, research on paleoenvironmental changes in the Antarctic cryosphere has progressed through various approaches in recent years.

## II. Contents of this special issue

The special issue “Paleoenvironmental changes in the Antarctic Cryosphere” is composed of four review papers and one article covering recent results of the paleoceanographic studies in mid- to high-latitude oceans in the southern hemisphere. Research topics of two cruises (Leg 175: Benguela Current; Leg 189: Tasman Gateway) of the Ocean Drilling Program (ODP) are compiled in the two review papers (Motoyama, 2012 and Suzuki, 2012) to understand the relationship between global climate evolution and the Antarctic cryosphere during the Cenozoic. Two review papers (Ikehara, 2012 and Katsuki, 2012) also focus on ice-rafted debris (IRD) and siliceous microfossils to reveal paleoceanographic variations of sea ice distribution, polar front, and biological pump

<sup>1</sup> Center for Advanced Marine Core Research, Kochi University, Kochi, 783-8502, Japan

<sup>2</sup> National Institute of Polar Research, Research Organization of Information and Systems, Tokyo, 190-8518, Japan

<sup>3</sup> Faculty of Literature, Daito Bunka University, Tokyo, 175-8571, Japan

<sup>4</sup> National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, 305-8567, Japan

<sup>5</sup> University of Tokyo, Professor Emeritus, Tokyo, 113-0032, Japan

during the late Quaternary. Furthermore, one article presents a detailed method for studying past export fluxes of biogenic materials using radioactive nuclide, and its application (Harada *et al.*, 2012). The following is a summary of the papers in this special issue.

Motoyama (2012) reviews studies on paleoceanographic changes in the Benguela Current system in the South Atlantic based on results from ODP Leg 175. The Benguela Current is an eastern boundary current in the South Atlantic subtropical gyre, which is associated with strong coastal upwelling off Namibia, and plays a major role in heat transport from the Indian Ocean to Atlantic Ocean through the Agulhas Current and in the global carbon cycle through high biologic productivity. This paper focuses on three following paleoceanographic events: the carbonate crash, Matuyama Diatom Maximum, and Walvis Opal Paradox. This is a useful review paper for understanding an international project that aims to reveal the mysteries of paleoceanographic variations in the South Atlantic and global climate change.

Suzuki (2012) reviews studies on paleoceanographic changes and tectonic events from the uppermost Cretaceous to the Quaternary based on the results of ODP Leg 189, which drilled in the Tasmania region. The opening of the Tasmania Gateway is an important tectonic event considering ocean circulation and climate change in the world, because the Tasmania Land Bridge blocked the seawater connection between the Pacific and Indian oceans before the Eocene. Detailed changes during the opening and deepening of the Tasmanian Gateway and related climate changes are reported in this review. It also introduces how these changes relate to global climate change. This review is essential reading for paleoceanographers to understand the long-term history of paleoceanographic changes in the Southern Ocean.

Ikehara (2012) reviews the north-south migration of the oceanic frontal systems such as the Antarctic Polar Front and the winter sea ice edge in the Southern Ocean during the modern and last glacial period. In the modern Southern Ocean, it is reported that the Antarctic Circumpolar Current (ACC) warmed and migrated south

during the mid-20th century, based on a large number of float observations. In the geological time scale, sea ice expansion events occurred suddenly in the Atlantic sector of the Southern Ocean during the last glacial period. Ice-rafted debris (IRD) is an important proxy for reconstructing past iceberg discharges and sea ice expansions.

This paper reviews factors and problems connected with IRD deposition on the pelagic seafloor. IRD deposition is controlled not only by the dynamics of the Antarctic ice sheet but also by surface water conditions such as sea-surface temperature and oceanic front migrations. The author emphasizes the importance of the origins of IRD in the Southern Ocean. This paper indicates that both modern continuous observations and paleoenvironmental investigations of the geological time scale are needed to understand marine environmental changes in the Southern Ocean.

Katsuki (2012) reviews paleoceanographic reconstructions of sea-ice distribution and productivity during the Last Glacial Maximum (LGM) and Holocene in the Southern Ocean based on a quantitative study of diatoms. Siliceous microfossils such as diatoms provide important information about paleoenvironmental changes in high-latitude oceans, where there is poor deposition of carbonate microfossils such as foraminifers. For example, it reports that the winter sea ice distribution in each sector differed at the LGM in the Southern Ocean, and that the summer sea-ice extent at the LGM was closed to summer sea-ice distribution except in the Weddell Sea. Abrupt variations of Holocene diatoms with 200-300 year cycle fluctuations indicate rapid climate changes in the Southern Ocean, which were very closely correlated to the solar activity cycle. This paper shows that a diatom assemblage analysis is a useful proxy for reconstructing paleoenvironmental change in the Southern Ocean.

Harada *et al.* (2012) investigate  $^{230}\text{Th}$ -normalized export flux of biogenic components as proxies for paleoproductivity in a sediment core from off the central-south Chilean coast. The mass accumulation rate (MAR) method using sedimentation rate is generally used for evaluating paleoproductivity change; however, it is pointed out that

this method overestimated the export flux by accumulated sediment supply of terrigenous material. This paper explains the  $^{230}\text{Th}$ -normalized method, revealing that primary productivity was low during the last glacial period and increased in the late deglaciation. Evaluating the biological pump in the Southern Ocean is essential to verify factors of atmospheric  $\text{CO}_2$  concentration change. It is expected that reconstruction of  $^{230}\text{Th}$ -normalized fluxes of biogenic components will provide a new data set for evaluating past biological pump activity in the Southern Ocean.

### III. Future prospects

In the Special Issue on "Paleoenvironmental changes in the Antarctic Cryosphere", we present reviews and an article explaining the circumstances of paleoenvironmental changes in the Southern Ocean. We expect these papers to provide useful information on Antarctic cryosphere evolution to researchers in the Earth sciences. We also expect the special issue will help young scientists who aim to carry out research in the Antarctica and Southern Ocean.

An outline of recent marine geological surveys in the Indian sector of the Southern Ocean is reported in the pictorial of this volume. The situations of the north-south shift of oceanic fronts, such as ACC, polar front, summer and winter sea-ice extent for Milankovitch cycles, and millennial to centennial scales are studied using piston cores taken during research cruises. Recently, knowledge about changes of various time scales in the Southern Ocean has been accumulated steadily, because many research expeditions using the Japanese research vessels Hakuho-maru, Umitakamaru, Mirai, and Shirase have systematically explored the Southern Ocean. We hope interdisciplinary studies will develop that explain the actual situation of Antarctic cryosphere change in the near future.

Recent investigations by marine geological surveys on paleoceanographic changes in the Southern Ocean form part of preparations to make a new proposal for the Integrated Ocean Drilling Program (IODP). Although the current IODP will end in September 2013, the program will be

renamed the International Ocean Discovery Program (IODP), which is planned to start in October 2013 and last for 10 years. Detailed bathymetric map and seismic reflection profiles were revealed by site surveys of the Conrad Rise during two cruises using the R/V Hakuho-maru. Based on recent results, it is planned to submit the new proposal for the Southern Ocean scientific drilling to the IODP. An international workshop will be held in United States in July 2012 to discuss future scientific drilling in the Antarctic and Southern Ocean. In the next decade, it is expected that Cenozoic paleoenvironmental studies will progress through these drilling activities in the Southern Ocean and on the Antarctic continental shelf. A new research project with drilling in the Southern Ocean led by Japan will be carried out during the next phase of IODP, and drilling science will contribute to future Antarctic cryosphere evolution research.

### References

- Harada, N., Kawakami, H., Fukuda, M., Miyashita, W. and Matsumoto, T. (2012):  $^{230}\text{Th}$ -normalized fluxes of biogenic components from the central Chilean margin during the late Quaternary. *Journal of Geography (Chigaku Zasshi)*, **121**, 555-569. (in Japanese with English abstract)
- Ikehara, M. (2012): North-south shift of oceanic fronts in the Southern Ocean: Linkage between migration of sea ice coverage, Antarctic Polar Front, Antarctic Circumpolar Current, and global climate change from the present to late Quaternary. *Journal of Geography (Chigaku Zasshi)*, **121**, 518-535. (in Japanese with English abstract)
- Katsuki, K. (2012): History of sea-ice and productivity in the Southern Ocean since the last glacial maximum based on the diatom assemblage changes. *Journal of Geography (Chigaku Zasshi)*, **121**, 536-554. (in Japanese with English abstract)
- Motoyama, I. (2012): A review of the paleoceanography of the Benguela Current system in the South Atlantic (ODP Leg 175): Evolution of coastal upwelling and response to global climate change. *Journal of Geography (Chigaku Zasshi)*, **121**, 478-492. (in Japanese with English abstract)
- Suzuki, N. (2012): The latest Cretaceous to the Quaternary paleoceanographic history in the Southern Ocean, south of Tasmania, Australia: Results of ODP Leg 189. *Journal of Geography (Chigaku Zasshi)*, **121**, 493-517. (in Japanese with English abstract)