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Paleoceanography of the last 500 kyrs in the central Okhotsk Sea based on geochemistry

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ABSTRACT

Analyses of geochemical constituents (organic carbon, nitrogen, calcium carbonate, and biogenic opal) on Core YK07-12 PC3B (Core PC3B) provided detailed and useful information in biological productivity and paleoceanographic changes, which occurred in the central Okhotsk Sea during the last 500 kyrs. An age model for Core PC3B was established based on changes in benthic foraminiferal $\delta^{18}O$. The trend in organic carbon (OC) content represented the temporal change that can be correlated with the $\delta^{18}O$ curve in Core PC3B: high during the interglacial periods: MIS 1, 5, 9, 11, and 13. The trend in $CaCO_3$ content represented is similar to the trend seen in the OC content. The high correlation between OC and $CaCO_3$ contents indicates an increase in coccolithophorid productivity during the early deglaciations. The comparison between the changes in $CaCO_3$ and biogenic opal indicates that the dominant phytoplankton group was coccolithophorids during the early deglaciations, which was subsequently replaced by diatoms during the late deglaciations. It appears that such a temporal phytoplankton succession was caused by an increase in dissolved silicon supply to the euphotic layer, possibly associated with a change in surface hydrography that subsequently caused an upward expansion of the intermediate layer. Such ecological changes probably played an important role in the uptake of atmospheric CO_2.

1. Introduction

Marine sediments contain the material that recorded the history of marine environmental changes from the past to the present. Therefore, a sediment section collected by a piston core is an important clue to reconstruct paleoceanography. Such sediments typically include biogenic particle such as calcium carbonate ($CaCO_3$), biogenic opal, and organic matter. Organic carbon and $CaCO_3$ are of special interest because that they are directly linked to the carbon cycle. Biogenic opal, however, is indirectly linked to the carbon cycle since siliceous shells do not contain carbon within skeletal material while cytoplasm produced by siliceous plankton is directly involved. On the other hand, biogenic opal contents are considered to be a potentially important paleoproductivity proxy. In several previous studies, use of this proxy has been questioned because of remineralization in sediment (Berger and Herguera, 1992; Kumar et al., 1995; Nelson et al., 1995; Boyle, 1998; Anderson et al., 1998). However, Narita et al. (2002) suggested that production of biogenic opal and its sedimentation in the Okhotsk Sea largely reflected the biogenic opal concentrations in the sediments. Thus, in our study, we interpret that biogenic opal contents reflect mainly biological productivity in the surface layer.

The Okhotsk Sea is a marginal sea located in the northwestern region of the Pacific Ocean, surrounded by Siberia, Kamchatka Peninsula, Kuril Islands, Sakhalin, and Hokkaido Islands (Fig. 1). The Okhotsk Sea is characterized by three major factors. First, sea-ice formation that takes place today is one of the most important characteristics of the Okhotsk Sea since it influences the density of waters below the surface layer (e.g., brine water is rejected when sea-ice is formed) and hence affects the density driven global water circulation. Seasonally formed sea-ice is annually distributed over a vast area of the Okhotsk Sea and its extent varies significantly with time (e.g., Lisitzin, 1972). Second, the Intermediate Water of the Okhotsk Sea is considered a plausible source for the North Pacific Intermediate Water (NPIW) (Talley, 1991; Freeland et al., 1998; Wong et al., 1998; You et al., 2000). Third, high productivity and an efficient biological pump are also major characteristics of the subarctic Pacific and its marginal seas, including the Okhotsk Sea. Thus, they are important to the global carbon cycle (Honda et al., 1997; Takahashi, 1998).

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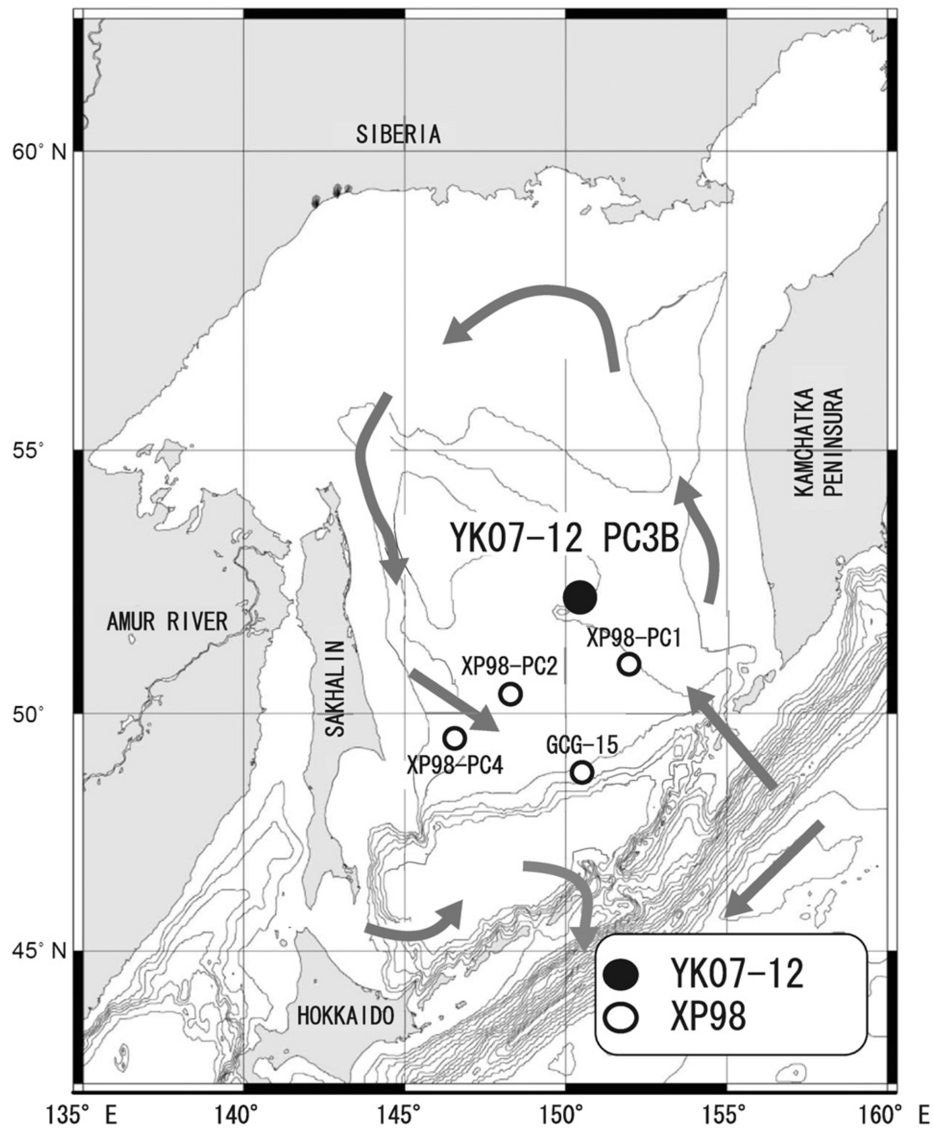

Fig. 1. Topographic map showing the location of Core YK07-12 PC3B in the central Okhotsk Sea together with the locations of Cores XP98-PC1, PC2, PC4, and GCG-15. Arrows show the direction of the major surface current (the map drawn by "Online Map Creation").

There have been various paleoceanographic studies based on geochemical analyses in the Okhotsk Sea. Gorbarenko et al. (2002), for example, deciphered the changes in environmental conditions and productivity in the southeastern Okhotsk Sea during the last 20 kyrs. Ono et al. (2005) showed geochemical results that reflected the Dansgaard–Oeschger cycles during the last 115 kyrs in the southwestern Okhotsk Sea. The clear documentation of the Dansgaard–Oeschger cycles in the upstream source region of the NPIW was performed for the first time by Ono et al. (2005). They illustrated that the Dansgaard–Oeschger cycles, which were observed in the Santa Barbara basin (Hendy and Kennet, 2003) due to expansion of the NPIW, were in part governed by the climatic variations occurred in the Okhotsk Sea. This indicates that the Okhotsk Sea sits in a globally important region in terms of climate change. Later, Harada et al. (2006, 2008) showed the results in alkenone temperature, which corresponded to the Dansgaard–Oeschger cycles, and suggested that the changes in the sea surface temperature in the southwestern Okhotsk Sea are related to the atmosphere—ocean circulation regime of the northern hemisphere. Furthermore, Seki et al. (2004) showed the past change in surface productivity during the last 30 kyrs based on geochemical analyses, suggesting that primary productivity abruptly increased during the global Meltwater Pulse event 1A (ca. 14 ka) and 1B (ca. 11 ka). In addition, Seki et al. (2004) indicated that the dominant phytoplankton taxa during the deglaciation were coccolithophorids, which were replaced by diatoms in the late Holocene. They further speculated that such a phytoplankton succession was probably caused by an increase in dissolved silicone supply in the surface layer by upwelling of the intermediate water. Furthermore, Nürnberg and Tiedemann (2004) reported the chemical analyses of sediment core samples, which covered a long period of time (over 500 kyrs) in the central Okhotsk Sea, for the first time. Soon after this, Liu et al. (2006) reported the chemical analyses of sediment core samples that dated back to 500 ka. However, sufficiently long piston cores with paleoceanographic data sets going back to 500 ka is still meager up-to-date. Thus, Core YK07-12 PC3B is valuable since it contains long term records depicting marine environmental changes. Therefore, the purposes of this study are to determine the changes in biological productivity, paleoenvironmental conditions, and water mass