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Biogenic opal production changes during the Mid-Pleistocene Transition in the Bering Sea (IODP Expedition 323 Site U1343)

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ABSTRACT

Biogenic opal content and mass accumulation rate (MAR) at IODP Expedition 323 Site U1343 were found to fluctuate consistently, generally being high under warm conditions and low under cold conditions during the last 2.4 Ma. Continuous wavelet transform analysis of the normalized biogenic opal content indicates that export production in the Bering Sea varied predominantly at 41-ka periodicity before 1.25 Ma, and shifted to 100-ka periodicity at the onset of the Mid-Pleistocene Transition (MPT; 1.25–0.7 Ma). The 100-ka cycles dominated until the Holocene. Export production in the Bering Sea decreased markedly in the Bering Sea two times during the MPT: the first occurred at the beginning of the MPT (1.25 Ma) and the second in the middle of the MPT (0.9 Ma). These decreases coincided with both increases in the relative abundance of sea-ice diatoms and decreases in the warm-water diatom species *Neodenticula seminae*, indicating that reductions in export production in the Bering Sea during the MPT were associated with climate cooling. Decreases in export production in the Bering Sea during the MPT were most likely associated with the increased influence of polar/Arctic domains on the high-latitude North Pacific.

Introduction

The Mid-Pleistocene Transition (MPT) is considered the most important global climate transition since the intensification of the Northern Hemisphere Glaciation (NHG) at 3.5 to 2.5 Ma (Mudelsee and Raymo, 2005). The MPT is characterized by the emergence of high-amplitude glacial–interglacial variability with cycle durations of ~100 ka, accompanied by ice-sheet expansion without any significant change in orbital forcing (Shackleton et al., 1988; Raymo et al., 1997; Clark et al., 2006). Although the reported timing of the MPT differed at various regions, Clark et al. (2006) proposed that the MPT spanned from 1.25 Ma to 0.7 Ma based on the global benthic oxygen isotope stack (LR-04: Lisiecki and Raymo, 2005).

Alkenone sea-surface temperatures (SSTs) decreased during the MPT at Site 846 (3°05′S, 90°49′W, 3296 m) and Site 849 (0°11′N, 110°31′W, 3851 m) in the eastern equatorial Pacific (Liu and Herbert, 2004; McClymont and Rossel-Mele, 2005) and at Site 1077 (5°10′S, 10°26′E, 2382 m) in the eastern tropical Atlantic (Schefus et al., 2004). Shallow marine sediments in Japan recorded sea levels 20–30 m lower during Marine Isotope Stage 22 (MIS 22) at ~0.9 Ma than during MIS 28 (Kitamura and Kawagoe, 2006). These results support the hypothesis that ice-sheet expansion associated with climate cooling occurred during the MPT. Based on the measurements of %$C_{37:4}$, a proxy for subarctic/subpolar water mass distribution, at Site 983 (60°24′N, 23°38′W, 1985 m) in the northern North Atlantic and at Site 882 (50°22′N, 167°36′E, 3244 m; Fig. 1) in the northwestern North Pacific, McClymont et al. (2008) suggested that polar/Arctic water masses expanded toward the equator during the MPT. Despite these pieces of clear evidence for the climate cooling and ice-volume increases during the MPT, there have been few studies at high-latitude locations where climate changes are directly linked to cryospheric processes.

The Bering Sea is located in the northern high latitudes where seasonal sea ice forms. In particular, the Beringian slope area in the Bering Sea is influenced not only by the relatively warm subarctic water masses (the Alaskan Stream) but also by the seasonal sea-ice cover. The slope area is also characterized by high surface-water productivity (e.g., Springer et al., 1996) and high sedimentation rates (>25 cm/ka) (Expedition 323 Scientists, 2009; Itaki et al., 2009; Kim et al., 2011). Surface-water productivity in the slope area is restricted by extensive sea-ice conditions and facilitated by the input of the Bering Slope Current (BSC) (Nakatsuka et al., 1995; Clement et al., 2005; Okazaki et al., 2005), an extension of the Alaskan Stream. Nutrient supply from the subsurface layer is associated with the BSC (Okkonen

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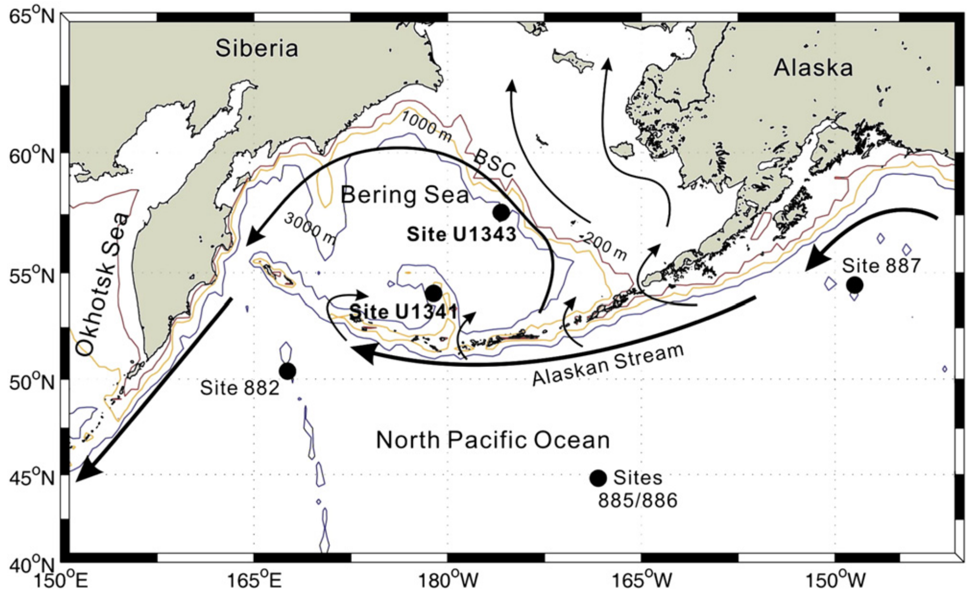

Figure 1. Schematic bathymetry of the Bering Sea and the subarctic North Pacific, illustrating the drilling locations including Site U1343. Arrows show the direction of major surface currents. The Bering Slope Current is labeled as BSC.

et al., 2004) together with tidal mixing which brings continental shelf water into the slope area (Springer et al., 1996). Thus, changes in surface-water productivity in the slope area of the Bering Sea provide crucial information regarding climate changes in the northern high latitudes during the MPT.

Export production significantly decreased during the intensification of the NHG, but was relatively low and constant through the MPT, at Site 882 in the northwestern subarctic North Pacific and at Sites 885/886 (44°41′N, 168°16′W, 5700 m; 44°41′N, 168°14′W, 5700 m, respectively; Fig. 1) in the central subarctic North Pacific (e.g., Haug et al., 1995; Snoeckx et al., 1995). However, the response of surface-water productivity to climate cooling during the MPT in the high-latitude North Pacific has not yet been determined. In this study, we reconstructed surface-water productivity variations using continuous wavelet transform analysis of the biogenic opal content and mass accumulation rate (MAR) at IODP Expedition 323 Site U1343 in the Bering Sea. Our results reveal paleoceanographic/paleoclimatic changes of the high-latitude North Pacific during the MPT.

Materials and methods

Site U1343 (57°33′N, 175°49′E, 1950 m; Fig. 1) was drilled with five holes (Sites U1343A through U1343E). A total of 1187 sediment samples from the following four holes were used in this study: Holes U1343A (205 samples from 20 to 200 m below sea floor (m bsf)), U1343C (237 samples from 0 to 235 m bsf), and U1343E (51 samples from 0 to 140 m bsf and 694 samples from 185 to 745 m bsf). The Site U1343 sediments are primarily composed of silt with varying amounts of clay and diatoms and minor amounts of sand, ash, foraminifers, calcareous nannofossils, and sponge spicules (Expedition 323 Scientists, 2009). In order to exclude the effects of core expansion and incomplete core recovery, all sediment depths are reported as the corrected core composite depth below seafloor (CCSF).

According to the sampling policy of IODP Exp. 323, Kanematsu et al. (2013) and Kim et al. (2010) undertook the biogenic opal analyses for the upper half (0–330 m bsf) and for the lower half (320–745 m bsf), respectively, at Site U1343. Kanematsu et al. (2013) compared the biogenic opal data between Site U1343 (the Bering Slope area) and Site U1341 (Bowers Ridge) and came to the conclusion that the biogenic opal contents at Bowers Ridge were significantly higher than those at the Bering Slope area. Such difference is primarily attributed to the fact that the sediments at Site U1343 were more diluted by lithogenic matter derived from the Alaskan continent as well as being more affected by sea-ice cover than those at Site U1341. Kim et al. (2010) reported that biogenic opal content and its MAR show the obvious orbital-scale glacial–interglacial variations from Late Pliocene to early Pleistocene at Site U1343. Distinct decrease of these properties occurred from 2.02 Ma to 1.8 Ma, when overall $\delta^{15}N$ values increased by nearly 2‰, which marks a transition toward low concentrations of nutrients in surface water after 1.8 Ma, leading to depressed export production and high $\delta^{15}N$ values.

This study compiles all biogenic opal data of Site U1343, although the above mentioned studies reported part of the data. However, this study is an exclusive synthesis using all biogenic opal data at Site U1343, focusing on the independent and totally different theme from those of the other studies. Here we first reveal the MPT in the Bering Sea in terms of export production based on the biogenic opal data.

Age model of Site U1343

In order to constrain the age model for Site U1343, a benthic foraminiferal oxygen isotope stratigraphy was used in this study (Fig. 2). Detailed age model construction is presented in Asahi et al. (2011). The established oxygen isotope stratigraphy of Site U1343 is mostly consistent with biostratigraphic datums and isochron ages reported in Takahashi et al. (2011) (Table 1, Fig. 2). The benthic oxygen isotope record is based on a sampling interval above 365 m CCSF of ~2 ka, whereas in the interval below 365 m CCSF it is ~11 ka. In general, sedimentation rates were high before the MPT and low after the MPT, with an average sedimentation rate of ~33 cm/ka (Fig. 2).

In order to avoid distortions in the continuous wavelet transform analysis, presumably caused by inaccurate ages of Site U1343 resulting from low-resolution oxygen isotope measurements, the ages below 370 m CCSF were recalculated by correlating very high-resolution natural gamma ray (NGR) values (Expedition 323 Scientists, 2009) with the LR-04 stack (Lisiecki and Raymo, 2005) because there is a strong relationship between NGR and benthic foraminiferal oxygen isotope values at Site U1343 (Asahi et al., 2011).