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Diatom, silicoflagellate and ebridian biostratigraphy and paleoceanography in IODP 323 Hole U1343E at the Bering slope site

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ABSTRACT

Integrated Ocean Drilling Program (IODP) Expedition 323 was dedicated to reconstruct the details of the Pliocene–Pleistocene paleoenvironmental conditions of the Bering Sea. In this study, fossil diatom assemblages from Hole U1343E were investigated to define diatom biostratigraphy and reveal paleoceanography of the Bering slope region throughout Pleistocene. As the results, four diatom zones with Neogene North Pacific Diatom zone codes (NPD) were determined from the *Neodenticula seminae* Zone (NPD 12) to the *N. koizumii* Zone (NPD 9). Diatom biohorizons defined in this study closely correspond with onboard data, but the distinct difference is recognized at the top of the *N. koizumii*. Additional four biostratigraphic zones estimated by three silicoflagellate and one ebridian datums suggest the core sediment age younger than 2.5 Ma. The fluctuations of several paleoenvironmental diatom indicators show that cold conditions with sea-ice existed throughout the duration of the interval studied as well as sea ice expansion occurred at ca. 1.9 Ma and ca. 0.9 Ma. Moreover, increases of neritic diatom species reveal a drop in sea level. *Neodenticula seminae* is the diatom tracer of the Aleutian Current and hence the decrease of this taxon suggests decrease in inflow of the North Pacific water mass. Although the sea levels must have been dropped during the cold time interval, the consistent occurrences of *N. seminae* indicate that the surface water circulation in the Bering Sea was significantly influenced by the Alaskan Stream at ca. 1.9 Ma. On the other hand, during the other cooling event at ca. 0.9 Ma, which corresponds to the mid-Pleistocene transition (MPT) event, an increase of neritic diatom species and decrease of *N. seminae* were observed. This suggests that coastal environmental conditions accompanied the sea level drop and that the inflow from the North Pacific was weakened. The increases of sea-ice and neritic diatom species suggest that the sea ice and coastal conditions were developed after the cooling at 0.9 Ma. The ages at remarkable changes of silicoflagellate assemblages correspond to the ages of global climate shifts at ca. 1.4 Ma, 1.25 Ma, and 0.8–0.9 Ma. The unusual alternate dominances of *Distephanus medianoctisol* in glacial and *Dictyocha* species in interglacial periods during the 1.25–0.8 Ma interval suggest the north–south migration of water masses between the Bering Sea and the Subarctic North Pacific.

1. Introduction

The rate and regional expression of recent global warming are difficult to understand and even more difficult to predict. Recent warming of the high latitudes in the Northern Hemisphere is presumably related to sea ice albedo feedback and teleconnections to other regions (Solomon et al., 2007). Of these regions, the Bering Sea has been considered as important one which significantly affects global climate changes in Pliocene–Pleistocene (Expedition 323 Scientists, 2011a; Takahashi et al., 2011). Therefore, it is pertinent to study both the behavior of sea-ice-climate interactions and the role of large-scale atmospheric and oceanic circulations during such climate changes with geologic records in hand from the Bering Sea. However, little is known about the climate history of the Bering Sea except for several piston core studies mainly focused on the last glacial–interglacial cycle (e.g., Brunelle et al., 2007; Cook et al., 2005; Gorbarenko, 1996; Katsuki and Takahashi, 2005; Nakatsuka et al., 1995; Okazaki et al., 2005; Tanaka and Takahashi, 2005; Takahashi et al., 2005).

Integrated Ocean Drilling Project (IODP) Expedition 323 was dedicated to examine the Pliocene–Pleistocene paleoenvironmental

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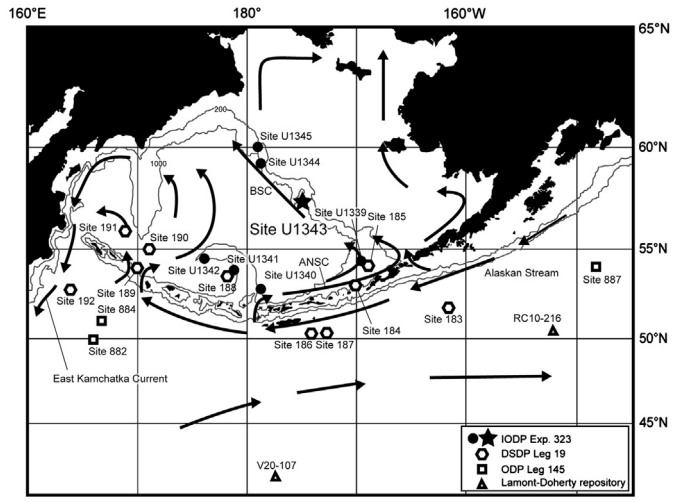

Fig. 1. Map illustrating the sites drilled during the Integrated Ocean Drilling Program (IODP) Expedition 323 (Sites U1339-U1345), Deep Sea Drilling Project (DSDP) Leg 19 (Sites 183–192), Ocean Drilling Program (ODP) Leg 145 (Sites 882, 884 and 887) and the piston cores from the Lamont–Doherty repository (V20-107, RC-216) with the surface water circulation modified after Creager et al. (1973), Expedition 323 Scientists (2011a), Haug et al. (2005), Kamikuri et al. (2007), and Stabeno et al. (1999). The Alaskan Stream, East Kamchatka Current, Bering Slope Current (BSC), and Aleutian North Slope Current (ANSC) are indicated.

conditions of the Bering Sea; the drilling cruise took place during 5 July–4 September 2009 (Takahashi et al., 2011) (Fig. 1). During the Expedition, drilling was performed at seven sites covering three different areas: Umnak Plateau (Site U1339), Bowers Ridge (Sites U1340, U1341, and U1342) and the Bering Sea shelf (Sites U1343, U1344, and U1345) regions. Site U1343, which is the main research focus of this study, is located at Bering Sea shelf region called the "Green Belt" because of its high biological productivity (Springer et al., 1996). The Green Belt is formed by the Bering Slope Current (BSC) that originates from the Alaskan Stream water that flows into the Bering Sea through the western Aleutian Islands from the North Pacific. Along the BSC, tidal currents cause strong vertical mixings of the water masses, enhancing biological productivity within the Green Belt. This site is also located close to the maximum extent of today's seasonal sea-ice cover. Thus, this site must have been affected by the fluctuation of ice cover with seasonal or perennial sea-ice during the cold periods such as glacial intervals.

Samples recovered from Hole U1343E (57°33.3814′N, 175° 48.9974′W, water depth 1956.0 m, total core length 700.27 m) were investigated to define the biostratigraphic datums and acquire the basic data for the paleoceanographic changes in the Bering Sea from the Pliocene to Pleistocene. The analyses were conducted for 'normal' diatom (i.e., diatoms except for *Chaetoceros* resting spores) and shallow-marine diatom genus *Chaetoceros* resting spore assemblages as well as silicoflagellate and ebridian group in this study.

2. Materials and methods

A duplicate pair of one hundred fifty-four microslides prepared for diatom, silicoflagellate and ebridian analyses contained abundant and well-preserved fossil diatom, resting spore, silicoflagellate and ebridian assemblages. To prepare the microslides, silty to clayey sediments containing diatoms were selected ranging from Hole U1343E Cores 323-U1343E-1H-3W, 146–148 cm (top depth: 4.46 m, uncompressed core depth below seafloor (CSF-A), 7.95 m uncompressed core composite depth (CCSF-A)) and 83X-5W, 146–148 cm (741.71 m CSF-A, 777.34 m CCSF-A). Samples were picked every 3 or 6.5 m (11 and 25 kyr temporal resolution on average) for the 0–1.6 Ma, interval which had earlier been defined onboard and every 3 or 6.5 m (5 and 11 kyr resolution) for the 1.6–2.2 Ma interval (Takahashi et al., 2011), respectively.

For standard diatom analysis, ca. 0.5 g of each wet sample was processed, and the methods of sample preparation, counting, and other procedures that we followed are basically the same as those of Akiba (1982, 1986) and Koizumi (1968) with a minor modification. The detailed methods for slide preparations and diatom observation are as followed.

Broken materials into powder and approximately 0.5 g were separated for treatment and dropped in the boiling hydrogen peroxide solution (H_2O_2, 10–15%) already made in 200 ml beaker; the aggregates were decomposed and the organic matter oxidized. Upon cooling, hydrochloric acid (HCl, 25%) was added to make an acid solution that was then boiled to dissolve the calcium salts in the sample. Afterwards, the beaker was filled with distilled water and allowed to stand for 24 h. Then, the residue was separated by decanting off the acid water in the beaker. This process was repeated 3 times. In order to remove clay fractions, 50 ml of distilled water was stirred into residue and a solution on peptizer ($Na_4P_2O_7$, 0.01 N) was added to the beaker, which was allowed to stand for 5 h. Heavy fractions that contained diatoms deposited and suspension that contained clay grains became white in this process. The residue was separated with decanting off the water in the beaker. The beaker was filled with water solution of peptizer ($Na_4P_2O_7$, 0.01 N) again. This process was repeated until the supernatant liquid became clean. This decantation separates diatoms, other siliceous fossils including silicoflagellates and ebridians, and unbroken coarser fractions in the suspensions. The remaining residue contained diatoms, other siliceous fossils and unbroken coarser mudstone fragments.

Slides for LM examination were prepared from the cleared sample in the following way. 100 ml of boiling distilled water was added to the cleaned sample and 0.7 ml of the suspension in the beaker was settled by 0.7 ml pipet for some seconds on an 18×18 mm^2 cover glass and heated in 50–60 °C for 1 h and then mounted on a slide glass using Pleurax.

Counting methods for vegetative cell valves of 'normal' diatom and *Chaetoceros* resting spores were followed after Akiba (1986) and Suto (2006a), respectively. A single vegetative cell valve is counted as one when greater than a half of a valve is observed. Other criteria for identification of specific genera are used following after Akiba (1986) and Akiba and Yanagisawa (1986). Broken specimens of pennales species are counted as one valve when two apices are observed.

Since the relationship between fossil resting spores and extant vegetative cells is not known, the concept of the morpho-species and -generic names are used for fossil *Chaetoceros* resting spores according to Article 3.3 of the International Code of Botanical Nomenclature (McNeill et al., 2006) in this study. *Chaetoceros* resting spores possess the characteristic feature of a single ring of puncta at the base of their hypovalve mantles (Suto, 2003), therefore we can easily differentiate hypovalves from epivalves both in extant and fossil material. The methods of *Chaetoceros* resting spore morpho-species and -genera identification follow those of Suto (2003, 2004a, 2004b, 2004c, 2004d, 2004e, 2005e, 2005a, 2005b, 2005c, 2006b, 2006c, 2007). However, some *Chaetoceros* species have common characteristics on the valve surfaces such as knobs and short spines (i.e. *Xanthiopyxis* type A (knobbly type); *X.* type B (short spiny type); *X.* type C (long spiny type); hyaline epi/hypovalves; hyaline, knobby and spiny type central vaulted epi/hypovalves). Moreover, several species possess undistinguishable valves (i.e., epivalves of *Dispinodiscus pilusus* varieties, hypovalves of *Gemellodiscus caveatus* and *G. micronodosus*, and valves of *X. hirsuta* and epivalve of *G. micronodosus*).