**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 medianoetis* 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 (Takahashi et al., 2011; Expedition 323 Scientists, 2011a). 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., Nakatsuka et al., 1995; Gorbarenko, 1996; Cook et al., 2005; Katsuki and Takahashi, 2005; Okazaki et al., 2005; Tanaka and Takahashi, 2005; Takahashi et al., 2005; Brunelle et al., 2007).

Integrated Ocean Drilling Project (IODP) Expedition 323 was dedicated to examine the Pliocene-Pleistocene paleoenvironmental conditions of the Bering Sea; the drilling cruise took place during 5 July to 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 to 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 to 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 Koizumi (1968) and Akiba (1982, 1986) 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 to 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 hours. 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 ($\text{Na}_4\text{P}_2\text{O}_7$, 0.01N) was added to the beaker, which was allowed to stand for 5 hours. 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 ($\text{Na}_4\text{P}_2\text{O}_7$, 0.01N) 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 cover glass and heated in 50 to 60 °C for one hour 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-e, 2005a-c, 2006b-c, 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 pilus* varieties, hypovalves of *Gemellodiscus caveatus* and *G. micronodosus*, and valves of *X. hirsuta* and epivalve of *G. micronodosus*). These similarities made it difficult to identify certain species; therefore these unknown valves were not included in the species richness tally.

Diatom abundance is expressed as an approximate number of diatom valves per slide calculated using the length of scanning lines. To determine the fluctuation of diatom and resting spore assemblages, 400 vegetative valves of 'normal' diatoms and 100 *Chaetoceros* resting spores valves were counted at species level for each sample. After counting, the slides were scanned to record the presence of species missed in the original tally. The resting spore abundance is defined here as the number of spore valves encountered during a count of 400 vegetative cell valves of other diatom species.

Depending on the content of lithogenic materials, the analyzed sample volume for analyses of silicoflagellate and ebridian assemblages was adjusted from 14.9 to 50.1 dry mg (Mean = 26.5 mg, 1SD = 9 mg). The membrane filter slides for coarse grains (>20 µm size fraction) were made by the same method of Onodera et al. (in this volume). Under light microscope with ×200 and ×400 magnifications, all encountered specimens were counted and identified at species or genus level. In addition, small size fraction was also observed for the

samples around the datum event depth of tiny species.

In diatom biostratigraphic assignments, ages for diatom bioevents that define zones or characterize certain horizons are based on the western North Pacific diatom zonation by Barron and Gladenkov (1995) and Yanagisawa and Akiba (1998). Taxonomy and biostratigraphic zones for silicoflagellates and ebridians are based on Bukry (1973) and Ling (1973, 1977, 1992). The latest age model at Site U1343 provided by Asahi et al. (in this volume) is used and fitted with diatom and silicoflagellate biostratigraphy as the precise core datums in this paper.

3. Results

3.1. Diatoms

All samples from Hole U1343E that contained sufficient diatoms per slide (>400, usually nearly 1,000 valves) and *Chaetoceros* resting spores (>100, usually nearly 400 valves) were investigated in order to refine the sedimentary ages which were initially assigned onboard (Expedition 323 Scientists, 2011b) and to reconstruct the paleoceanographic conditions by diatom assemblage analysis. The preservation and abundance of fossil diatoms are good and common to abundant throughout all microslides, although abundance of *Chaetoceros* resting spores is rare to common (**Appendix tables 1, 2**). Diatom assemblages are mostly composed of useful biostratigraphic markers with continuous and abundant occurrences (**Fig. 2, Table 1**) and several paleoceanographic indicators; cold-water, temperate-water, sea-ice species as well as the taxa living in neritic, open and fresh-waters (**Figs. 3-5**).

3.1.1. Diatom biostratigraphy

Core materials from IODP Expedition 323 Hole U1343E investigated in this study correspond to four diatom zones with the Neogene North Pacific Diatom zone codes (NPD) of Yanagisawa and Akiba (1998), the *Neodenticula seminae* (NPD 12; 0.0-0.3 Ma), *Proboscica curvirostris* (NPD 11; 0.3-0.9 Ma), *Actinocyclus oculatus* (NPD 10; 0.9-(2.0-2.2) Ma) and *N. koizumii* (NPD 9; (2.0-2.2)-(2.6-2.7) Ma) Zones (**Fig. 2**). The last occurrence (LO) datums of *Proboscica curvirostris* (Jousé) Jordan et Priddle and *Thalassiosira jouseae* Akiba are recognized between Samples 323-U1343E-7H-3W, 141-143 cm and 7H-5W, 136-138 cm (61.47±1.46 m CSF-A, 70.29±1.46 m CCSF-A), giving an age of 0.3 Ma (Barron and Gladenkov, 1995; Yanagisawa and Akiba, 1998). The interval between the top of Hole

U1343E and the LO of *P. curvirostris* is assigned to the *N. seminae* Zone (NPD 12) of Yanagisawa and Akiba (1998). The LO datum of *Actinocyclus oculatus* Jousé (0.9 Ma) is observed between Samples 323-U1343E-33H-5W, 146-148 cm and 34H-3W, 146-148 cm (282.65 ± 3.97 m CSF-A, 318.27 ± 3.97 m CCSF-A). The interval between this datum level and the LO of *P. curvirostris* is assigned to *P. curvirostris* Zone (NPD 11). The interval below this datum and above the LO of *N. koizumii* Akiba et Yanagisawa is *A. oculatus* Zone (NPD 10). In addition, the first occurrence (FO) of *P. curvirostris* (1.7 Ma) is defined between Samples 323-U1343E-55X-3W, 146-148 cm and 55X-5W, 132-134 cm (471.60 ± 1.44 m CSF-A, 507.22 ± 1.44 m CCSF-A), and the LO of *Stephanopyxis horridus* Koizumi (1.9 Ma) is also observed between Samples 323-U1343E-60X-5W, 130-133 cm and 61X-3W, 146-148 cm (524.39 ± 3.39 m CSF-A, 560.01 ± 3.39 m CCSF-A) in the interval of the *A. oculatus* Zone (NPD 10). In the deeper Hole U1343E, the LO of *N. koizumii* is estimated between Samples 323-U1343E-71X-5W, 128-130 cm and 72X-3W, 132-134 cm (630.01 ± 3.33 m CSF-A, 665.63 ± 3.33 m CCSF-A), assigning an age of 2.1 Ma (Yanagisawa and Akiba, 1998). The absence of a biostratigraphic marker species *N. kamtschatica* indicates that the interval between this datum and the bottom of Hole U1343E can be assigned to the *N. koizumii* Zone (NPD 9).

With respect to the shipboard age data (Expedition 323 Scientists, 2011b), the diatom biohorizons defined by several diatom zones in this study correspond closely to those of the shipboard results, however a distinct difference is recognized at the top of the *N. koizumii* Zone. Although the LO of *N. koizumii* was observed at 680.8 m CSF-A ($=714.42$ m CCSF-A) at the onboard data, the biohorizon is recognized in the upper part (633.33 m CSF-A, 668.95 m CCSF-A) in this study. Compare to the age model provided by Asahi et al. (in this volume), the LO of *A. oculatus* and the FO of *P. curvirostris* were recognized in lower and upper parts, respectively.

3.1.2. Diatom paleoenvironmental indicators

In this study, 110 species of vegetative cell valves of 'normal' diatoms are observed. Figure 3 shows the relative abundance (%) of selected paleoenvironmental indicators in diatom assemblages from Hole U1343E. Most diatom species observed in this study are marine planktonic ones, but a few fresh water species are observed sporadically: *Achnanthes inflata* (Kützing) Grunow, *A. lanceolata* (Brébisson ex Kützing) Grunow in Cleve et Grunow, *A. lineariformis* Lange-Bertalot, *Amphora ovalis* var. *libyca* (Ehrenberg) Cleve, *Aulacoseira granulata* (Ehrenberg) Simonsen, *Caloneis westii* (W. Smith) Hendey, *Cyclotella meneghiniana* Kützing, *Cymbella cistula* (Hemprich in Hemprich et Ehrenberg) Kirchner, *C.*

subaequalis Grunow in Van Heurck, *Eunotia pectinalis* var. *minor* (Kützing) Rabenhorst, *E. praerupta* var. *praerupta* Ehrenberg, *Fragilaria construens* (Ehrenberg) Grunow, *Navicula elginensis* (Gregory) Ralfs in Pritchard, *N. menisculus* Schumann, *N. salinarum* Grunow, and *Reimeria sinuata* (Gregory) Kociolek et Stoermer.

Marine diatoms are divided into five groups: cold-water, temperate-water, sea-ice related, neritic and open-ocean species. Figure 3 shows relative abundances (%) of these paleoceanographic indicators in total occurrences of vegetative cells as well as occurred valve numbers of *Chaetoceros* resting spores. Several indicators are included as follows:

Cold-water species: *Actinocyclus ochotensis* Jousé, *Bacterosira bathyomphala* (P.T. Cleve) Syvertsen et Hasle in Hasle et Syvertsen, *Coscinodiscus oculus-iridis* Ehrenberg, *Neodenticula seminae* (Simonsen et Kanaya) Akiba et Yanagisawa, *Porosira gracialis* (Grunow) E. Jørgensen, *Rhizosolenia hebetata* J.W. Bailey, *Shionodiscus trifultus* (G. Fryxell) Alverson et al. (= *Thalassiosira trifulta* G. Fryxell in Fryxell et Hasle), *Thalassiosira hyalina* (Grunow in Cleve et Grunow) Gran, *T. nordenskiöldii* Cleve and *T. sancettae* Akiba (after Sancetta, 1982; Medlin and Priddle, 1990).

Sea-ice related species: *B. bathyomphala*, *Fragilariopsis cylindrus* (Grunow) Frenguelli, *T. hyalina*, and resting spores of *Thalassiosira antarctica* Comber (after Expedition 323 Scientists, 2011b).

Temperate-water species: *Thalassiothrix* spp. and *Stephanopyxis* spp. (after Sancetta, 1982; Hasle and Syvertsen, 1996).

Neritic species: *B. bathyomphala*, *Paralia sulcata* (Ehrenberg) Cleve, *Porosira gracialis* (Grunow) Cleve and *T. hyalina* (after Sancetta, 1982; Medlin and Priddle, 1990).

Open-ocean species: *A. ochotensis*, *R. hebetata* and *S. trifultus* (after Sancetta, 1982).

In Expedition 323 Scientists (2011b), *Bacterosira bathyomphala* which showed the characteristic changes at 0.8 and 1.1 Ma were contained as sea-ice related species, and these transitions were predicted to be affected by the mid-Pleistocene transition (MPT). In this study, higher resolution samples than those used in onboard study were used to reveal the effect of the MPT in more detail. Therefore, *Bacterosira bathyomphala* were classified to sea-ice related species. Moreover, *Stephanopyxis* spp. may be strongly affected by the sea surface temperate water (Sancetta, 1982) although they are also mentioned dwelling taxa that are transported to deeper waters. Therefore, *Stephanopyxis* spp. were not treated as neritic nor open-water species in this study.

Cold-water and sea-ice related species occur at high-abundances throughout the hole. Increased abundances of cold-water species are observed at ca. 1.9 Ma and ca. 1.2 Ma and those of sea-ice related species are recognized at ca. 1.9 Ma and ca 0.9 Ma (**Fig. 3**). The temporal decrease of cold-water species is observed after ca. 1.1 Ma. After the de-

crease, the relative abundance of cold-water species remains at nearly the same level, but the abundance of sea-ice related species shows a gradual increasing trend. On the other hand, the drastic decrease of temperate-water species is recognized at ca. 1.9 Ma with the periodic changes in abundance before the decreasing event. Occurrences of neritic and open-ocean species show gradual increases from the bottom to the top.

3.1.3. Abundance of *Chaetoceros* resting spores and species diversity

Figure 3 also shows the stratigraphic abundance changes of *Chaetoceros* resting spores as observed valve numbers during counting routine of 400 vegetative cell valves. Abundances of *Chaetoceros* resting spores in most samples are common and the valve numbers exceed from 100 to 300, although some samples show low abundances.

Species diversity of resting spores shows slight variation, but rapid decrease of *Gemellodiscus cingulus* var. *longus* Suto and drastic increase of *G. cingulus* var. *cingulus* Suto are recognized in Sample 323-U1343E-53X-3W, 146-148 cm (450.87 m CSF-A, 486.49 m CCSF-A). Although no distinct change in the morpho-generic level was observed, the abundance of *Dispinodiscus* spp. appears to increase gradually towards the upper section. The ecology of fossil and extant resting spores is unclear except for some species (e.g., Oku and Kamatani, 1999), however, the fluctuation of *Chaetoceros* has been interpreted as a measure of diatom productivity and indicator of the extent of upwelling with high nutrient supply (Sancetta, 1982; Suto, 2006a). Therefore, the fluctuation of *Chaetoceros* assemblages and abundance likely shows environmental conditions regarding nutrients.

3.2. Skeleton contents of silicoflagellate and ebridian

Total silicoflagellate and ebridian contents are usually very low throughout the hole (**Figs. 4, 6, Appendix table 3**). The silicoflagellate contents ranged from 0 to 256.8×10^3 skeletons dry g^{-1} (mean = 8.4×10^3 , 1SD = 29.6×10^3 , median = 1.3×10^3 skeletons dry g^{-1} , N = 154). The large fluctuation of silicoflagellate contents essentially corresponds to glacial-interglacial cycles; with minimal members of silicoflagellate contents usually observed in glacial periods. Their low contents are mainly due to a dilution effect by abundant lithogenic materials. The ebridians are usually observed in the lower part of this hole. The ebridian contents ranged from 0 to 7.3×10^3 skeletons dry g^{-1} (mean = 0.3×10^3 , 1SD = 0.8×10^3 , median = 0 skeletons dry g^{-1} , N = 154).

The encountered silicoflagellates and ebridians were categorized to 12 and 5 taxa, respectively (**Appendix table 3**). Silicoflagellates found in this study are similar to those in

previous studies on DSDP Leg 19 cores (Bukry, 1973; Ling, 1973). Ebridian specimens of genus *Ammodoichium* in this study are probably composed of several subspecies. However, they are here treated as *Ammodoichium rectangulare* group for the comparison with previous studies.

3.2.1. Silicoflagellate-Ebridian biostratigraphy

Based on the silicoflagellate and ebridian biostratigraphic zone by Ling (1973), Hole U1343E cores can be categorized into four zones as followed (**Fig. 2**).

Distephanus octangulatus Zone

The LO of *Distephanus octonarius* is located between Samples 323-U1343E-5H-3, 146-148 cm and 6H-3, 146-148 cm (45.92 ± 4.67 m CSF-A, 52.82 ± 6.28 m CCSF-A).

The upper interval above this datum is assigned to *Distephanus octangulatus* Zone.

Distephanus octonarius Zone

As the bottom of this zone, the LO of *Dictyocha subarctios* is estimated between Samples 323-U1343E-23H-3, 140-142 cm and 23H-5, 53-55 cm (188.39 ± 1.07 m CSF-A, 215.60 ± 1.07 m CCSF-A). This datum is usually observed just above the Brunhes/Matuyama magnetic boundary (Ling, 1992). However, the depth of LO of *Dc. subarctios* recognized in this study is deeper than the Brunhes/Matuyama boundary at 181.37 m CSF-A (207.73 m CCSF-A). The LO of *Distephanus crux stauracanthus* is also observed between Samples 323-U1343E-19H-5, 96-98 cm and 20H-3, 121-123 cm (157.58 ± 2.55 m CSF, 180.89 ± 3.84 m CCSF).

Dictyocha subarctios Zone

The LO of ebridian *Ammodoichium rectangulare* is located between Samples 323-U1343E-63X-5, 83-85 cm and 64X-3, 146-148 cm (552.55 ± 4.12 m CSF-A, 558.17 ± 4.12 m CCSF-A), which is the base of this zone. Although the Sample 323-U1343E-63X-5, 83-85 cm includes one specimen of ebridian *Am. rectangulare*, it is probably rework component because one specimen of old ebridian *Ebriopsis antiqua* (LO: 2.5 Ma) is also observed in the sample. *Dictyocha subarctios* in this hole mainly occurred in the upper part of this zone. The FO of this taxon in the North Pacific nearly corresponds to that of radiolarian *Eucyrtidium matuyamai* (Ling, 1976). However, the deepest occurrence of *Dc. subarctios* in this study is observed at 470.17 m CSF-A (505.79 m CCSF-A) whereas the FO of *Eu. matuyamai* is estimated at 612.5 m CSF-A (648.1 m CCSF-A) (Expedition 323 Scientists, 2011b).

Ammodoichium rectangulare Zone

Because the LO of *Ebriopsis antiqua* is not found in this hole, the interval between

the LO of *Ammodoichium* spp. and Sample 323-U1343E-82X-5, 146-148 cm (732.47 m CSF-A, 768.09 m CCSF-A) is assigned to this zone. Silicoflagellates in this zone are mainly composed of *Distephanus speculum*. Biostratigraphic zone for Core 83X is not specified due to barren of age indicator species.

3.2.3. Silicoflagellates paleoenvironmental indicators

Silicoflagellates older than ca. 1.38 Ma are usually dominated by *Distephanus speculum*, which is common in cold waters (Poelchau, 1976). The dominant taxon in the assemblages frequently changed in the interval younger than 1.38 Ma (**Fig. 6**). The high dominance (> about 70-80%) of *Ds. medianoctisol* probably suggests significantly cold condition with sea-ice (Takahashi et al., 2009). The gradual increase of *Ds. medianoctisol* (%) since ca. 1.2 Ma suggests the colder sea surface condition in glacial periods. On the other hand, the temporal dominance of *Dictyocha subarctios* and *Dc. spp.* (*Dc. aff. mandrai* ?) in interglacial periods between 1.25 Ma and 0.9 Ma may reflect temperate condition based on the biogeographic studies (Ling, 1976; Poelchau 1976).

4. Discussion

4.1. Diatom-based paleoceanographic discussion at Hole U1343E

The abundant and steady occurrences of cold-water and sea-ice related diatom species encountered throughout Hole U1343E indicate that the existence of seasonal sea-ice cover with fairly low sea surface temperatures was present during the interval between ca. 2.2 Ma and the present (**Fig. 3**). The changes in relative abundances of these groups may be related with cyclic climate changes of warm-cold intervals which initially developed since the intensification of the Northern Hemisphere glaciations at 2.7 Ma (Haug et al., 2005).

The drastic decrease of temperate-water species and increase of cold-water and sea-ice related species at ca. 1.9 Ma indicate that the Bering slopes region around Hole U1343E became cooler and covered sea-ice expanded in a short interval. The increase of neritic species observed coincides with the expansion of sea-ice and may suggest that the basin around this hole became shallower and/or more typical of coastal environmental conditions corresponding with a sea level regression coinciding with global cooling. Katsuki et al. (2004) mentioned that the continental shelf was exposed to the air when the sea level dropped the 50 m. Therefore, the emergence of the continental shelves may be happened

at the cooling of ca. 1.9 Ma.

The relative abundance of *Neodenticula seminae*, which is considered as a good tracer for the relative warm Alaskan stream from the North Pacific (Sancetta, 1982), remained at higher levels throughout the hole. This coincided with a decrease of temperate-water species at 1.9 Ma and increases of cold-water, sea-ice related and neritic species during several intervals (**Fig. 3**). When the eastern passes in the Aleutian Arc became closed during the low sea-level stands, the abundance of *N. seminae* must have decreased due to weakening of the entry of the Alaskan Stream water mass. Therefore, the consistent occurrences of *N. seminae* suggest that the oceanic circulation in the Bering Sea was at times strongly influenced by the Alaskan Stream, which entered the Bering Sea through the passes in the Aleutian Arc (Stabeno et al., 1999), similar to the circulation occurring during the last glaciation (Katsuki and Takahashi, 2005) (**Fig. 1**). It also indicates that waters above the Bering slope site became cooler and shallower while the North Pacific water was supplied from the Aleutian passes.

The increases of cold-water and sea-ice related species observed at 0.9 Ma correspond to the middle Pleistocene transition (MPT) which is characterized by a severe increase of glaciations starting at 1.25 Ma (Clark et al., 2006). The transition to glacial period was also well-known to change from 41-kyr cycle to 100-kyr cycle in ocean temperature around the age. Lisiecki and Raymo (2005) also showed it as the cyclic changes of the Marine Isotope Stages (MISs) constructed stacked by the benthic foraminiferal $\delta^{18}\text{O}$ records conducted by averaging 57 globally distributed sites. The maximum glaciation was established at ca. 0.7 Ma with the dominant 100-kyr cycles and the minimum value of the sea surface temperature (SST) was observed at 0.9 Ma in the North Atlantic from DSDP Leg 94 Site 607 (Clark et al., 2006). On the other hand, the minimum SST was not observed from ODP Leg 145 Site 882 in the North Pacific region (McClymont et al., 2008). Moreover, Sancetta and Silvestri (1986) showed by the cluster analysis of diatom assemblages that much of the low temperature and salinity waters which consisted of the Okhotsk water. The increase of cold-water species and peak of sea-ice related taxa at ca. 1.25 to 0.9 Ma recognized in this study might be affected by the global cooling of the MPT. The continuous increase of sea-ice related species, gradual increase of neritic taxa and relatively low abundance of *N. seminae* observed after the MPT indicate that the cooling and restricted pelagic water entry with regression were caused by closure of the Aleutian Arc passes. Therefore, the extent of the Bering surface water mass circulation appears to have become weaker after the MPT.

As *Chaetoceros* resting spores are severely affected by environmental fluctuations, such as nutrient supplied by upwelling in the coastal region, their abundances must have

been changed by environmental changes such as alternation of eutrophication and oligotrophication or the variations of the clastic grain and microelements supplies from the land (Sancetta, 1982; Suto, 2006a). The continuous and abundant occurrence of *Chaetoceros* resting spores from Hole U1343E indicate that the region around this hole retained high-nutrient and/or active upwelling environmental conditions during low-nutrient seasons when *Chaetoceros* produced resting spores throughout the Pleistocene. Some peaks of the neritic and fresh water species in some samples may indicate that this hole was affected by some input of river water flowing into the Bering Sea coinciding with sea-level fall. But during these peaks, no drastic changes were observed in other species, suggesting that the effect of river water might be very weak.

4.2. Silicoflagellate-based paleoceanographic discussion at Hole U1343E

The most unusual characteristic of silicoflagellate assemblages in this study is the common occurrence of *Dictyocha* spp. at 1.085 Ma (**Fig. 6**), because *Dictyocha* species are mainly observed in subtropical-temperate waters (e.g., Poelchau, 1976). Even in the modern Bering Sea, the relative abundance of *Dictyocha* spp. in the total silicoflagellate assemblage is less than 1% during August 1990-June 1994 (Onodera and Takahashi, 2012). On the other hand, the modern silicoflagellates in the eastern subarctic North Pacific show seasonal dominance of *Dictyocha mandrai* (Takahashi, 1987). In addition, the relative abundance of *Dictyocha* in the modern Western Subarctic Gyre is less than 15% (Onodera and Takahashi, 2005). Thus, the eastern subarctic Pacific waters are considered as the possible origin of water mass with abundant *Dictyocha* at 1.085 Ma in this study. This age corresponds with deglacial conditions from MIS32 to MIS31. The “super-interglacial” event at MIS31 has been suggested by core study (Scherer et al., 2008; Naish et al., 2009) and model study (Pollard and DeConto, 2009) in the Antarctic. The global sea-level in MIS31 might be >5 m higher than today’s level due to the large collapse of the West Antarctic Ice Sheet (Pollard and DeConto, 2009). The unique warming trend from MIS32 to MIS31 might be the factor for the northward input of *Dictyocha* species.

The occurrence pattern of *Dictyocha subarctios* in this study may also reflect the water mass advection from the south of this site. This taxon has been commonly reported from the subarctic Pacific, Bering Sea, and Japan Sea (Ling, 1976), however, their limited common occurrences in interglacial periods from ca. 1.25 Ma to ca. 0.9 Ma (**Fig. 6**) suggest that the main habitat of *Dc. subarctios* was in the subarctic Pacific rather than in the northern Bering Sea. The northern limit latitude of *Dc. subarctios* distribution appears to be lower than that of *Neodenticula seminae*, because that *N. seminae* in this study is observed even

in glacial periods. The temporal northern excursion of *Dc. subarctios* to the Bering Sea at 1.25 Ma is also supported by the first occurrence of *N. seminae* in the Iceland Sea via the Bering Strait at the same timing (Koç and Scherer, 1996).

However, the dominances of *Distephanus medianoetis* in glacial periods from about 1.2 Ma to 0.5 Ma suggest the presence of sea-ice at this site or vicinal shelf during the productive seasons of silicoflagellates. The relative abundance of modern *Ds. medianoetis* in dense sea-ice area of the summer Arctic Ocean is >70% in total silicoflagellates (Takahashi et al., 2009), whereas relative abundance of *Ds. medianoetis* in the modern southern Bering Sea is less than 10% (Onodera and Takahashi, 2012). The northward shift of temperate silicoflagellates in glacial periods was limited under the colder condition.

5. Conclusions

A pair of one hundred fifty-four slides from IODP Expedition Hole U1343E, containing greater than 100 species of fossil diatom and resting spore assemblages and several silicoflagellate and ebridian groups, were investigated to define the biostratigraphic datums. They were also employed to acquire the basic data for the paleoceanographic changes in the Bering Sea from the Pliocene to Pleistocene.

As a result, four diatom zones were defined; the *Neodenticula seminae* (NPD 12: 0.0-0.3 Ma), *Proboscia curvirostris* (NPD 11: 0.3-0.9 Ma), *Actinocyclus oculatus* (NPD 10: 0.9-(2.0-2.2) Ma) and *N. koizumii* (NPD 9: (2.0-2.2)-(2.6-2.7) Ma) Zones as well as the LO datums of *Proboscia curvirostris* and *Thalassiosira jouseae* (0.3 Ma), the FO of *P. curvirostris* (1.7 Ma) and the LO of *Stephanopyxis horridus* (1.9 Ma). Moreover, four silicoflagellate and ebridian zones are also found, the *Distephanus octangulatus* Zone (0-0.2 Ma as defined/nominal), *Ds. octonarius* Zone (0.2-0.74 Ma), *Dictyocha subarctios* Zone (0.74-(1.8-2.0) Ma), and *Ammodoichium rectangulare* Zone ((1.8-2.0)-2.5 Ma).

The diatom sea-ice indicators remained at high-abundances throughout the interval investigated from the hole, with the consistent occurrence of cold-water and sea-ice related species corresponding to that of ice rafted debris. On the other hand, an abrupt decrease in temperate-water diatom species is recorded at ca. 1.9 Ma. These fluctuations indicate that the existence of seasonal sea-ice during the interval from ca. 2.2 Ma to the present, and that the Bering slopes became cooler and sea-ice expanded in a short interval. After the expansion of sea-ice, the basin became shallower and/or more coastal environment with regression as the result of the global cooling.

The increases of cold-water and sea-ice related diatom species observed at ca. 0.9 Ma might be affected by onset of the MPT. The continuous increase of sea-ice related species, gradual increase of neritic taxa and relatively low abundance of *N. seminae* observed

after the MPT show that the cooling with global regression caused the closure of the Aleutian Arc passes.

Resting spores of *Chaetoceros* indicating upwelling and high-nutrient condition show consistent abundance, with the numbers of resting spores exceeding from 100 to 300 in 400 vegetative valves of other “normal” diatoms. The region around this hole, therefore, retained high-nutrient and/or upwelling conditions during low-nutrient season when *Chaetoceros* produce resting spores throughout the Pleistocene.

Silicoflagellates are usually commonly observed in interglacial periods. Relatively stable sea-surface condition suggested by constant dominance of *Ds. speculum* terminated around 1.4 Ma. The next remarkable change is marked between 1.25 Ma and 0.9 Ma by the alternate dominances of *Ds. medianotisol* in glacial and *Dictyocha* species in interglacial periods. These assemblage changes suggest north-south migration of surface waters between the Bering Sea and the subarctic North Pacific and/or larger fluctuation of sea-surface temperature. However, the sampled interval in this study is still coarse for deciphering paleoceanography in detail. The palaeoceanographic studies in higher resolution are needed for some significant intervals in the future.

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Legends

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), Stabeno et al. (1999), Haug et al. (2005), Kamikuri et al. (2007) and Expedition 323 Scientists (2011a). The Alaskan Stream, East Kamchatka Current, Bering Slope Current (BSC), and Aleutian North Slope Current (ANSC) are indicated.

Fig. 2. Relative abundance (%) of diatom, silicoflagellate and ebridian biostratigraphic markers from the IODP Expedition 323 Hole U1343E. Diatom zones and NPD codes are from Yanagisawa and Akiba (1998). Silicoflagellate and ebridian zones are from Ling (1973).

Fig. 3. Selected paleoenvironmental diatom indicators in total diatom assemblages from the IODP Expedition 323 Hole U1343E as well as changes of fossil *Chaetoceros* resting spores valve numbers per 400 valves of other diatoms with fluctuations of resting spore assemblages in morpho-generic level. Solid and dashed lines in the diatom fluctuations show the relative abundance (%) and the running means at 5 point, respectively. The age model is Asahi et al. (in this volume). The boundary age of marine isotope stages (Lisiecki and Raymo, 2005) are from http://lorraine-lisiecki.com/LR04_MISboundaries.txt.

Fig. 4. Selected biostratigraphic useful diatoms (1-6) and silicoflagellates (7-10) from IODP Expedition 323 Hole U1343E. Scale bar = 10 μ m. **1.** *Actinocyclus ochotensis* Jousé, Sample 323-U1343E-81X-5W, 146-148 cm. **2.** *Neodenticula koizumii* Akiba et Yanagisawa, Sample 323-U1343E-72X-3W, 132-134 cm. **3.** *Neodenticula seminae* (Simonsen et Kanaya) Akiba et Yanagisawa, Sample 323-U1343E-1H-3W, 146-148 cm. **4.** *Proboscia curvirostris* (Jousé) Jordan et Priddle, Sample 323-U1343E-17H-3W. 146-148 cm. **5.** *Stephanopyxis horridus* Koizumi, Sample 323-U1343E-64X-3W, 146-148 cm. **6.** *Thalassiosira jouseae* Akiba, Sample 323-U1343E-8H-3W, 137-139 cm. **7.** *Dictyocha subarctios* Ling, Sample 323-U1343E-29H-3W, 144-146 cm. **8, 9.** *Dictyocha* spp., Sample 323-U1343E-32H-5W, 146-148 cm. **10.** *Distephanus medianoctisol* Takahashi et al., Sample 323-U1343E-29H-3W, 144-146 cm.

Fig. 5. Selected paleoenvironmental indicator diatoms from IODP Expedition 323 Hole

U1343E. Scale bars = 10 μm for figs. 1-5, 7-18 and 100 μm for fig. 6. **1.** *Actinocyclus curvatulus* Janisch in Schmidt et al., Sample 323-U1343E-11H-3W, 146-148 cm. **2.** *A. ochotensis* Jousé, Sample 323-U1343E-81X-5W, 146-148 cm. **3, 4.** *Bacterosira bathyomphala* (Cleve) Syvertsen et Hasle in Hasle et Syvertsen, Sample 323-U1343E-1H-3W, 146-148 cm. **5.** *Coscinodiscus marginatus* Ehrenberg, Sample 323-U1343E-64X-3W, 146-148 cm. **6.** *C. oculus-iridis* Ehrenberg, Sample 323-U1343E-26H-3W, 146-148 cm. **7.** *Fragilariopsis cylindrus* (Grunow) Frenguelli, Sample 323-U1343E-24H-3W, 120-122 cm. **8.** *F. oceanica* (Cleve) Hasle, Sample 323-U1343E-2H-5W, 146-148 cm. **9.** *Paralia sulcata* (Ehrenberg) Cleve, Sample 323-U1343E-1H-3W, 146-148 cm. **10.** *Porosira glacialis* (Grunow) E. Jørgensen, Sample 323-U1343E-17H-3W, 146-148 cm. **11.** *Rhizosolenia hebetata* J.W. Bailey, Sample 323-U1343E-9H-4W, 124-126 cm. **12.** *Shionodiscus trifultus* (G. Fryxell) A.J. Alverson et al., Sample 323-U1343E-2H-5W, 146-148 cm. **13.** *Stephanopyxis turris* (Greville et Arnott) Ralfs in Pritchard, Sample 323-U1343E-82X-5W, 146-148 cm. **14.** *Thalassiosira antarctica* Comber, Sample 323-U1343E-2H-5W, 146-148 cm. **15.** *T. hyalina* (Grunow in Cleve et Grunow) Gran, Sample 323-U1343E-1H-3W, 146-148 cm. **16.** *T. nordenskioeldii* Cleve, Sample 323-U1343E-73X-3W, 146-148 cm. **17.** *Gemellodiscus cingulus* var. *cingulus* Suto, Sample 323-U1343E-53X-3W, 106-108cm. **18.** *G. cingulus* var. *longus* Suto, Sample 323-U1343E-28H-3W, 145-147 cm.

Fig. 6. Time-series variation of silicoflagellates from the IODP Expedition 323 Hole U1343E. The age model is Asahi et al. (in this volume). The black dot represents the taxon presence instead of relative abundance, due to trace amount of encountered skeletons (<10 skeletons in total). The boundary age of marine isotope stages (Lisiecki and Raymo, 2005) are from http://lorraine-lisiecki.com/LR04_MISboundaries.txt.

Table 1. Datum events of diatoms, silicoflagellates and ebridian from IODP Expedition 323 Hole U1343E.

Appendix table 1. Stratigraphic occurrences of diatoms from IODP Expedition 323 Hole U1343E.

Appendix table 2. Stratigraphic occurrences of *Chaetoceros* resting spores from IODP Expedition 323 Hole U1343E.

Appendix table 3. Silicoflagellate and ebridian at Hole U1343E. The highlight with gray

color represents that the % value is meaningless due to the trace amount of encountered skeletons.

Appendix table 4. Taxonomy list of diatoms, silicoflagellates and ebridians from the IODP Expedition 323 Hole U1343E.

Teraishi et al. (Fig. 1)

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), Stabenho et al. (1999), Haug et al. (2005), Kamikuri et al. (2007) and Expedition 323 Scientists (2011a). The Alaskan Stream, East Kamchatka Current, Bering Slope Current (BSC), and Aleutian North Slope Current (ANSC) are indicated.

Teraishi et al. (Fig. 2)

Figure 2. Relative abundance (%) of diatom, silicoflagellate and ebridian biostratigraphic markers from the ODP Leg 201 Site U1343E. Diatom zones and age codes are from Taniguchi and Aiba (1998). Silicoflagellate and ebridian zones are from Ling (1973).

Teraishi et al. (Fig. 3)

Figure 3. Selected paleoenvironmental diatom indicators in total diatom assemblages from the IODP Expedition 323 Hole U1343E, as well as changes of fossil *Chaetoceros* resting spores valve numbers in 400 valves of other diatoms with fluctuations of resting spore assemblages in morpho-generic level. Solid and dashed lines in the diatom fluctuations show the relative abundance (%) and the running means at 5 point, respectively. The age model is Asahi et al. (this volume). The boundary age of marine isotope stages (Lisiecki and Raymo, 2005) are from http://lorraine-lisiecki.com/LR04_MISboundaries.txt.

Teraishi et al. (Figure 4)

Fig. 4
 Selected biostratigraphic useful diatoms (1-6) and silicoflagellates (7-10) from IODP Expedition 323 Hole U1343E. Scale bar = 10 µm. **1.** *Actinocyclus oculatus* Jousé, Sample 323-U1343E-81X-5W, 146-148 cm. **2.** *Neodenticula koizumii* Akiba et Yanagisawa, Sample 323-U1343E-72X-3W, 132-134 cm. **3.** *Neodenticula seminae* (Simonsen et Kanaya) Akiba et Yanagisawa, Sample 323-U1343E-1H-3W, 146-148 cm. **4.** *Proboscica curvirostris* (Jousé) Jordan et Priddle, Sample 323-U1343E-17H-3W, 146-148 cm. **5.** *Stephanopyxis horridus* Koizumi, Sample 323-U1343E-64X-3W, 146-148 cm. **6.** *Thalassiosira jouseae* Akiba, Sample 323-U1343E-8H-3W, 137-139 cm. **7.** *Dictyocha subarctios* Ling, Sample 323-U1343E-29H-3W, 144-146 cm. **8, 9.** *Dictyocha* spp., Sample 323-U1343E-32H-5W, 146-148 cm. **10.** *Distephanus medianoctisol* Takahashi et al., Sample 323-U1343E-29H-3W, 144-146 cm.

Teraishi et al. (Figure 5)

Fig. 5.

Selected paleoenvironmental indicator diatoms from IODP Expedition 323 Hole U1343E. Scale bars = 10 µm for figs. 1-5, 7-18 and 100 µm for fig. 6. 1. *Actinocyclus curvatulus* Janisch in Schmidt et al., Sample 323-U1343E-11H-3W, 146-148 cm. 2. *A. ochotensis* Jousé, Sample 323-U1343E-81X-5W, 146-148 cm. 3, 4. *Bacterosira bathyomphala* (Cleve) Syvertsen et Hasle in Hasle et Syvertsen, Sample 323-U1343E-1H-3W, 146-148 cm. 5. *Coscinodiscus marginatus* Ehrenberg, Sample 323-U1343E-64X-3W, 146-148 cm. 6. *C. oculus-iris* Ehrenberg, Sample 323-U1343E-26H-3W, 146-148 cm. 7. *Fragilariopsis cylindrus* (Grunow) Frenguelli, Sample 323-U1343E-24H-3W, 120-122 cm. 8. *F. oceanica* (Cleve) Hasle, Sample 323-U1343E-2H-5W, 146-148 cm. 9. *Paralia sulcata* (Ehrenberg) Cleve, Sample 323-U1343E-1H-3W, 146-148 cm. 10. *Porosira glacialis* (Grunow) E. Jørgensen, Sample 323-U1343E-17H-3W, 146-148 cm. 11. *Rhizosolenia hebetata* J.W. Bailey, Sample 323-U1343E-9H-4W, 124-126 cm. 12. *Shionodiscus trifultus* (G. Fryxell) A.J. Alverson et al., Sample 323-U1343E-2H-5W, 146-148 cm. 13. *Stephanopyxis turris* (Greville et Arnott) Ralfs in Pritchard, Sample 323-U1343E-82X-5W, 146-148 cm. 14. *Thalassiosira antarctica* Comber, Sample 323-U1343E-2H-5W, 146-148 cm. 15. *T. hyalina* (Grunow in Cleve et Grunow) Gran, Sample 323-U1343E-1H-3W, 146-148 cm. 16. *T. nordenskiöldii* Cleve, Sample 323-U1343E-73X-3W, 146-148 cm. 17. *Gemellodiscus cingulus* var. *cingulus* Suto, Sample 323-U1343E-53X-3W, 106-108 cm. 18. *G. cingulus* var. *longus* Suto, Sample 323-U1343E-28H-3W, 145-147 cm.

Teraishi et al. (Fig. 6)

Figure 6. Time-series variation of silicoflagellates from the IODP Expedition 323 Hole U1343E. The age model is Asahi et al. (in this volume). The black dot represents the taxon presence instead of relative abundance, due to trace amount of encountered skeletons (<10 skeletons in total). The boundary ages of main isotope stages (Lisiecki and Raymo, 2005) are from http://foraine-lisiecki.com/ER04_MISboundaries.txt.

Table 1. Datum events of diatoms, silicoflagellates and ebridian from the IODP Expedition 323 Hole U1343E.

Datum events	Ages (Ma)	Core, section, interval (cm)		Depth CSF-A (m)			Depth CCSF-A (m)		
		Top	Bottom	Top	Bottom	Median	Top	Bottom	Median
LO <i>Distephanus octonarius</i> (s)	0.2	5H-3W, 146-148	6H-3W, 146-148	41.17	50.67	45.92	46.54	59.09	52.815
LO <i>Thalassiosira jouseae</i> (d)	0.3	7H-3W, 141-143	7H-5W, 136-138	60.01	62.93	61.47	68.83	71.75	70.29
LO <i>Proboscia curvirostris</i> (d)	0.3	7H-3W, 141-143	7H-5W, 136-138	60.01	62.93	61.47	68.83	71.75	70.29
LO <i>Ds. crux stauracanthus</i> (s)	0.69	19H-5W, 96-98	20H-3W, 121-123	155.03	160.13	157.58	177.05	184.72	180.89
LO <i>Dictyochoa subarctios</i> (s)	0.74	23H-3W, 140-142	23H-5W, 53-55	187.32	189.45	188.39	214.53	216.66	215.6
LCO <i>Actinocyclus oculatus</i> (d)	0.9	33H-5W, 146-148	34H-3W, 146-148	278.68	286.61	282.65	314.3	322.23	318.27
FO <i>Proboscia curvirostris</i> (d)	1.7	55H-3X, 146-148	55X-5W, 132-134	470.16	473.04	471.6	505.78	508.66	507.22
LO <i>Stephanopyxis horridus</i> (d)	1.9	60X-5W, 130-133	61X-3W, 146-148	521	527.78	524.39	556.62	563.4	560.01
LO <i>Am. rectangulare</i> (e)	1.8-2.0	63X-3W, 146-148	63X-5W, 146-148	548.43	556.67	552.55	584.05	592.29	588.17
LO <i>Neodenticula koizumii</i> (d)	2.0-2.2	71H-5W, 128-130	72X-3W, 132-134	626.68	633.34	630.01	662.3	668.96	665.63

Note: FO = first occurrence LO = last occurrence, LCO = last common occurrence, (d) = diatom, (s) = silicoflagellate, (e) = ebridian