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Reconstruction of Oceanographic Changes Based on the Diatom Records of the Central Okhotsk Sea over the last 500000 Years

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ABSTRACT

This study provides insight into changes in sea ice conditions and the oceanographic environment over the past 500 kyr through analysis of the diatom record. Based on the relative abundance of 13 diatoms species in piston core MD012414, four types of environmental conditions in the central Okhotsk Sea over the last 330 ka BP have been distinguished: (1) open-ocean alternating with seasonal sea-ice cover in Stages 9, 5, and 1; (2) almost open-ocean free of sea-ice cover in Stages 7 and 3; (3) perennial sea-ice cover in Stages 6, 4, and 2; and (4) a warm ice-age dominated by open ocean assemblages in Stage 8. The littoral diatom species, *Paralia sulcata*, showed a sudden increase from the glacial period to the interglacial period over the last 330 ka BP, except during Stage 8. Such a result implies that melting sea-ice transported terrigenous materials from the north Okhotsk Sea continental shelves to the central ocean during deglaciation. From Stage 13 to Stage 10, however, cold and warm marine conditions unexpectedly occurred in the late interglacial periods and the glacial periods, respectively. One possible reason for this is a lack of age control points from Stage 13 to Stage 10, and the different sediment accumulation rates between glacial and interglacial periods. This study suggests not only the process by which oceanographic variation of sea ice occurred, but also new significance for *Paralia sulcata* as an indicator in the diatom record of the Okhotsk Sea.

Key words: Diatom indicator, Okhotsk Sea, Sea-ice, Paleoenvironment

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1. INTRODUCTION

The Okhotsk Sea is part of the Western Pacific Ocean. It plays a significant role in climatic and ocean environmental changes on both a regional and global scale. The Okhotsk Gyre is a component of the Subarctical Gyre, which has a counter-clockwise surface flow. The ocean absorbs warmth from the northwest and returns to the southeast, close to the West Kamchatka coast. The main currents in the region such as the West Kamchatkan current (WKC) to the east and the East Sakhalin current (ESC) to the west, along with others, generate a general cyclonic water movement (Stepanov 1974).

The Okhotsk Sea represents both the lowest-latitude and largest region with seasonal sea-ice in the world. Interannual variation in the maximum extent of seasonal sea-ice cover depends on ice advection by wind and air temperature conditions (Kimura and Wakatsuchi 1999). At present, Okhotsk sea ice forms in the northwestern coastal area in November (Wakabayashi et al. 1995). Its maximum elongation extends as far south as northern Hokkaido in March and disappears by June (Shimada and Hasegawa 2001).

Intermediate seawater from the Okhotsk Sea is a possible source of North Pacific Intermediate Water. The formation of Okhotsk Sea Intermediate Water (OIW) during the summer is perhaps associated with the inflow of saline water of the Tsushima Current from the Japan Sea through the Soya Strait. Okhotsk Sea Intermediate Water is formed largely through sinking of brine water, which the sea-ice rejects, along the northwest shelf of the Okhotsk Sea (Wong et al. 1998). A portion of the NPIW is formed in the Okhotsk Sea and flows out mainly through the Bussols' Strait into the North Pacific (Talley 1991; Freeland et al. 1998).

Ternois et al. (2000) reconstructed paleotemperature changes over the last 15 ka for the southern Okhotsk Sea based on alkenones. Organic geochemical and terrestrial

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biomarkers were studied in the sediments from the last 27 ka for the Okhotsk Sea (Ternois et al. 2001). They suggested that sea-ice rafting was the main transport mechanism by which continental material became Okhotsk Sea sediments during the glacial to early interglacial periods. Paleohydrographic profiles below a depth of 1000 m were reconstructed employing stable isotope data on benthic foraminifera (Gorbarenko 1996; Keigwin 1998; Gorbarenko et al. 2002, 2004).

In this study, we utilize the relative abundance of sea-ice, high-productivity and open-ocean diatom assemblages to reconstruct sea ice conditions in the Okhotsk Sea over the last 500 ka. Three sets of sea-ice conditions and their corresponding diatom assemblages are defined: (1) perennial sea-ice cover is characterized by increases in sea-ice assemblages and lower amounts of diatom valves. Such a scenario describes eternal sea ice cover where only rare amounts of sea-ice diatom survive in the ice sheet; and the ice lid prevents not only diatoms but also other possible sources of biotic and abiotic material settlement that might be carried on currents or in the atmosphere. This barren phenomenon has been discussed not only in the context of diatoms (Shiga and Koizumi 2000; Koizumi et al. 2003) but also radiolarian (Matul et al. 2003; Okazaki et al. 2003); (2) open-ocean conditions free of sea ice are characterized by the dominance of open-ocean assemblages (Barash et al. 2001, 2005, 2006). In this scenario, the warm current from the north Pacific gyre frees the Okhotsk Sea of sea ice and brings with oceanic assemblages; (3) seasonal sea ice conditions are characterized by a lower proportion of sea-ice assemblages and a higher proportion of high-productivity assemblages. It is quite likely that ice floe, accompanied by cold low-salinity surface water from melted ice, suppressed total diatom production and increased sea-ice assemblages (Smith and Nelson 1985; Wilson et al. 1986; Shimada and Hasegawa 2001).

To explore possible scenarios of oceanic evolution, especially NPIW and sea ice succession, the international IMAGES VII circum-Pacific initiative (WEPAMA) conducted deep sediment-core drilling work in the central Okhotsk Ocean and successfully cored a long (ca. 53.88 m), high resolution core (MD012414), reflecting 1.8 Myrs of climate history (Lui et al. 2006).

We adopt the diatom for its robustness as a proxy to help reveal environmental fluctuations including sea ice variations and NEIW evolution throughout the last 500 ka BP in the Okhotsk Sea.The aim of this study, however, is not only to reconstruct a possible pattern of the past climate, but also to seek out other potential robust diatom indictors in this area.

2. MATERIAL AND METHODS

Figure 1 shows sediment core MD012414 retrieved from the center of the Okhotsk Sea during IMAGES VII cruise in 2001. The coring site for MD012414 is located near the mixing zone of the southward-flowing East Sakhalin Current (ESC). This zone consists of fresh-water discharged from the Amur River, and the salty Soya Warm Current originating in the Tsushima Warm Current in the Japan Sea. It has been suggested that the growth of sea-ice in the area leads to the formation of dense, saline shelf waters during the winter periods, while intermediate water formation during the summer periods might be associated with the salty Soya Warm Current (Watanabe and Wakatsuchi 1998).

In order to reconstruct what changes might have occurred in the oceanographic environment of the Okhotsk Sea, paleoceanographic analyses based on the distribution of the 13 characteristic diatom species proposed by Shiga and Koizumi (2000) and Koizumi et al. (2003), and their abundance (valves g^{-1} dry weight) were carried out.

For quantitative analysis, one gram of dry sediment was subsampled and chemically treated to clean and concentrate the diatoms. The calcium carbonate component was removed by adding concentrated HCl (10%), and the organic matter was oxidized using hydrogen peroxide (H_2O_2 30%). Fractions were diluted in 20 ml of distilled water pipetted onto a glass slide, using Pleurax as the mounting medium. Light-microscope observations were made at magnifications of 1000x, at least 400 valves were counted per sample, and specific frequencies were computed.

The previous study in this core (Lui et al. 2006) utilized

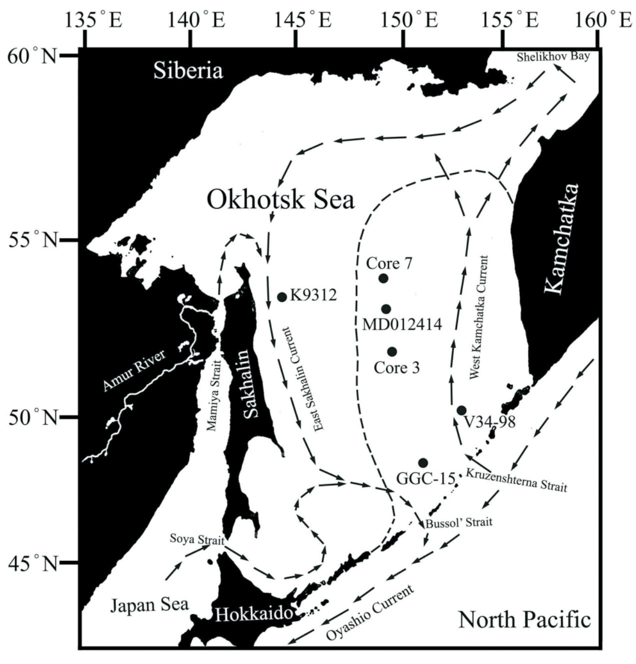

Fig. 1. Locations of MD012414 and other relative cores in the Okhotsk Sea. Arrows indicate flow of ocean surface currents in the Okhotsk Sea and surrounding areas. The present location of sea-ice from March to April is represented by a dotted line (After Koizumi et al. 2003).

color *b** analogous to MD012414 and MD012415, and built a reliable age model up. In this study, we also adopt this age model.

3. RESULTS

3.1 Distribution of the 13 Characteristic Diatom Species

There are 87 diatom taxa examined in the upper 20 m of core MD012414. Most of them are typical of present day Okhotsk, being widespread in the sediment (Sancetta 1982). However, we only adopt the 13 selected taxa in this study because of the clear environmental significance attributed to these species in previous research (Shiga and Koizumi 2000; Koizumi et al. 2003) into the Okhotsk Sea. Furthermore, the 13 diatom taxa are constitute more than 80% of the diatoms in the upper 20 m of the core and therefore well reflect environmental oceanic change.

Sea-ice assemblages included *Bacterosira bathyomphalus, Fragilariopsis cylindra*, *F. oceanica, Thalassiosira antarctica*, and *T. nordenskioldii*. The general pattern of this sea-ice group is that they became rare obviously in the interglacial stage but more evident in the glacial stage (Fig. 2). However, in Stage 8, only low amounts of sea-ice assemblages are evident and only *Thalassiosira antarctica* shows a slight increased. Some other cold events revealed by abnormal pulses in sea-ice assemblages (Fig. 3) during the warm period are worth examining in: late Stage 13, early Stage 11, early Stage 7, and early Stage 1.

High-productivity assemblages consisted of *Neodenticula seminae*, *Thalassiosira latimaginata*, and *Thalassiothrix longissima*. These assemblages displayed similar patterns to those of diatom abundance showing two peaks in early Stage 9, and one peak in late Stage 5 and early Stages 13, 11, and 1 (Fig. 3). *Thalassiosira latimaginata is* do-

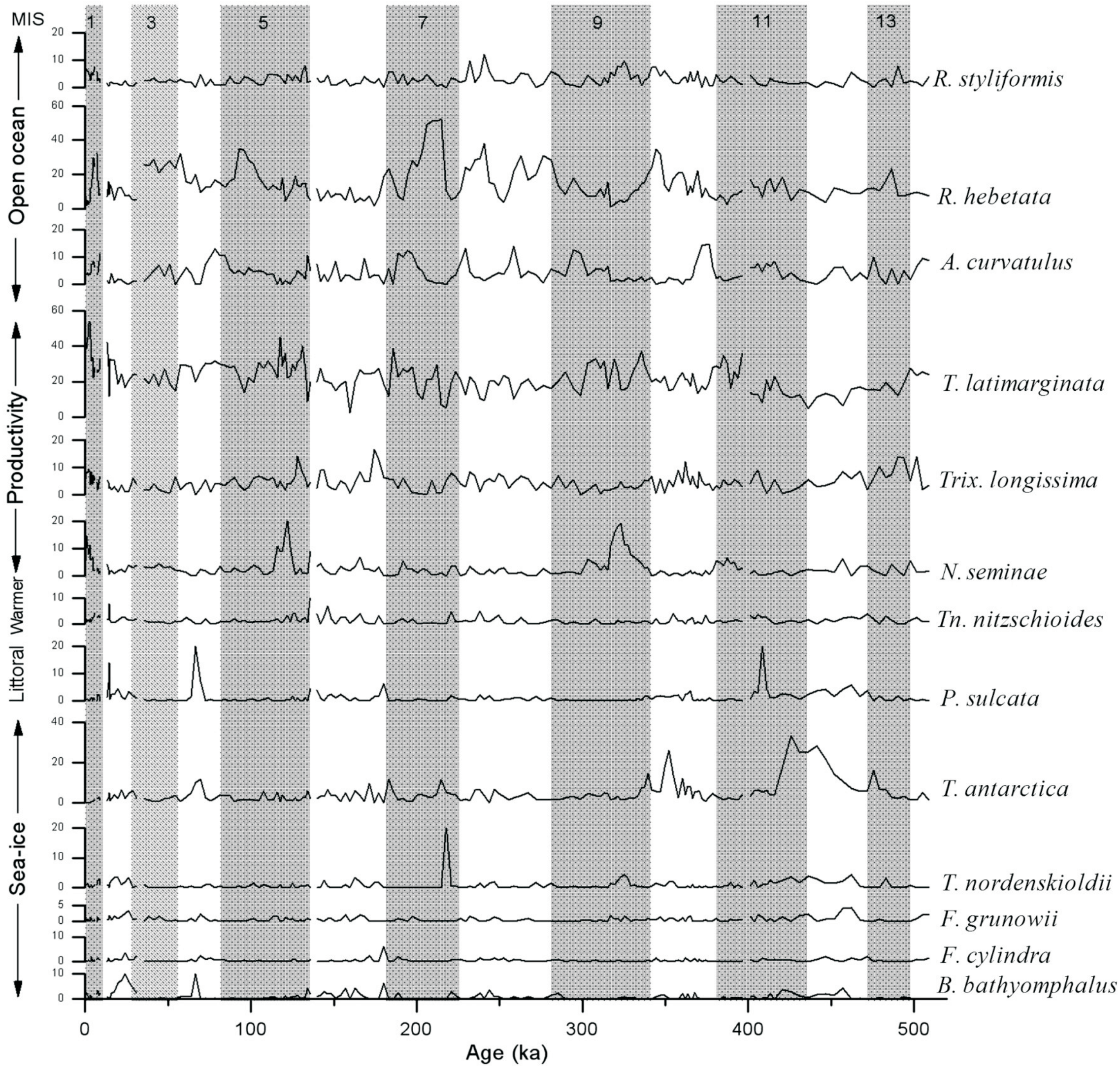

Fig. 2. Chronology of relative abundance (%) of 13 characteristic diatom species belonging to five different assemblages in core MD012414.

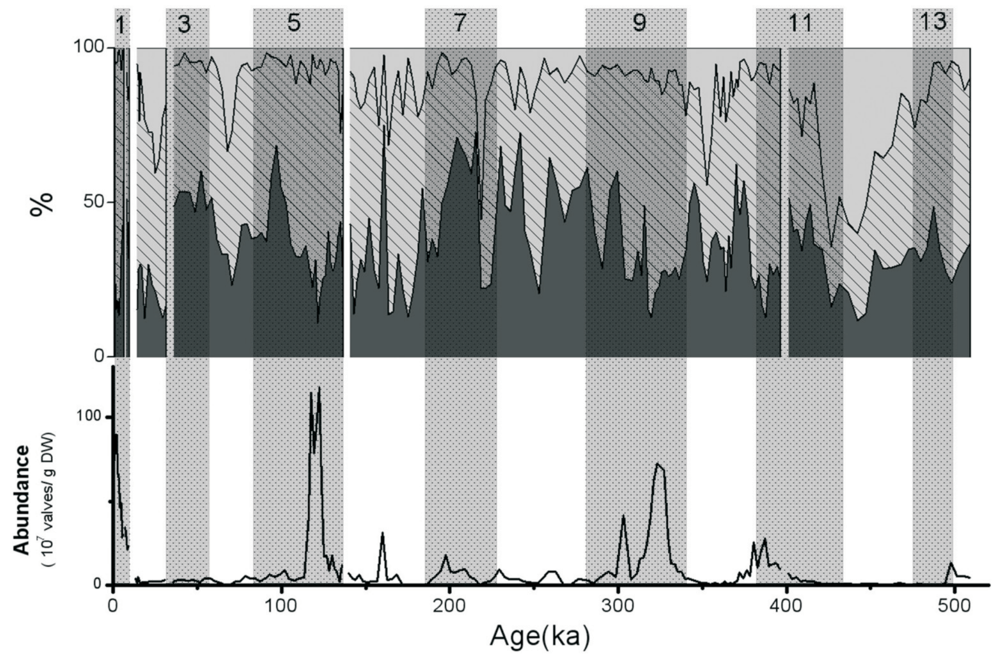

Fig. 3. Chronology of sea-ice (gray), high productivity (striated) and open-ocean (black) assemblages and diatom abundance in core MD012414. The existence of both dominant high productivity assemblages and large amounts of diatom valves indicates seasonal sea ice cover. Dominant open-ocean and sea-ice assemblages refer to ice-free and eternal sea-ice cover scenarios, respectively.

minant with *Thalassiothrix longissima* having a minor presence. Anomalous increases of *N. seminae* occurred in early and late Stage 6 (Fig. 2).

Open-ocean species included *Rhizosolenia hebetata*, *Rhizosolenia styliformis*, and *Actinocyclus curvatulus*. *Rhizosolenia hebetata* is dominant with *Rhizosolenia styliformis* having a minor presence. Open-ocean assemblages contributed much less in the cold stages than the warmer ones, but abnormally high abundance phenomena could be found in cold Stages 10 and 8 (Fig. 3).

The littoral species, *Paralia sulcata*, was very rare throughout the core, spiking briefly in each deglacial period, except in Stage 8 (Fig. 2).

3.2 Diatom Abundance (valves g^{-1} DW) in Core MD012414

The number of diatom valves varied from 0.04×10^7 valves g^{-1} DW (dry weight) at 227 ka BP to 117.8×10^7 valves g^{-1} DW at 119 ka BP, the maximum value (Fig. 3). The mean diatom abundance was 12.7×10^7 valves g^{-1} DW. Across the period of the study, diatom abundance was lower than average in all ice-ages, except for one spike at 155 ka BP. The abundance of diatoms in high-productivity assemblages showed a similar pattern. During warmer periods when high-productivity species were dominant, diatom abundance was almost always above average. However, when open-ocean species predominated or sea-ice species increased, diatom abundance showed clear identifiable decreases falling below average levels.

4. DISCUSSION

4.1 Changes in Sea-Ice Recorded in MD012414

According to Shiga and Koizumi (2000), sea-ice free waters contracted to the present extent at 7 ka BP, and the location of the sea-ice margin was very similar to that of the present day from March to April. Core MD012414 was taken from a location close to the current mean ice extent from February to April (Fig. 1). Variations in centennial time scales since 7 ka BP can be documented by analyzing diatom assemblages in the western part of the Okhotsk Sea. While small time-scale studies of the LGM and the Holocene have been performed, we still lack large time-scale studies of the glacial-interglacial cycles. This study attempts to reconstruct sea-ice patterns during the glacial and interglacial periods from 500 ka BP to the present, and determine the composition of sea-ice for all seven interglacial and the six glacial periods during this time.

In Stage 13, high productivity assemblages are dominant and alternate with open-ocean assemblages. Moreover, about 450 ka sea ice assemblages increase and rare diatom valves accumulate (Fig 3). This response suggests that open-ocean conditions consequently change to perennial sea-ice cover in Stage 12. All three types of sea ice conditions are evident in Stage 11. They are sequentially perennial sea-ice, ice-free and seasonal sea-ice cover, and company with the gradually increased abundance. A quite different scenario is found out in Stage 10. During this stage, perennial sea-ice is formed during the middle period but the environment abruptly changes back to open ocean conditions.

This phenomenon may infer a relatively warmer climate or more input from the North Pacific current.

In Stage 9, high productivity assemblages are dominant and diatom abundance is always above average, with the exception of a period 310 ka BP, when the open-ocean assemblages show an increase with large fluctuations. Two short open ocean events between 300 - 340 ka were examined in recent research on the central Okhotsk Sea (Barash et al. 2006). Four cooling events were evidenced by corresponding increases in sea-ice assemblages and smaller numbers of diatom valves. In Stage 6, the ocean is almost entirely covered by ice, as identified by extremely rare amounts of diatoms and increased sea-ice assemblages. Four peaks in open-ocean assemblages indicate ice-free open ocean.

In early Stage 5, between 129 and 107 ka BP, a high proportion of high-productivity assemblages and a great increase in diatom abundance indicate seasonal sea-ice conditions. From 107 to 73 ka BP, the open-ocean assemblages become abundant, suggesting that seasonal sea-ice gave way to ice-free conditions.

A relatively high proportion of sea-ice assemblages and lower productivity and oceanic assemblages, along with smaller numbers of diatom valves, suggest that the area has perennial ice-cover in Stages 4 and 2. Throughout Stage 3, both the sea-ice and high-productivity assemblages are found in lower proportions, while the open-ocean assemblage becomes abundant, indicating ice-free conditions.

In early Stage 1, from 9 to 7 ka BP, sea-ice assemblages continually decrease, while the proportion of open-ocean assemblages rises, indicating ice-free conditions. From 6 ka BP on, a high proportion of high-productivity assemblages and increasing numbers of diatom valves indicate seasonal sea-ice.

4.2 Comparing the Climate of Different Stages

The climate history of the Okhotsk Sea for the past 500 ka was reconstructed based on sea ice conditions. Open-ocean conditions indicate a warm climate, while seasonal or perennial sea ice is attributed to both cool and cold climates (Koizumi et al. 2003). According to this hypothesis, high diatom-abundant stages, i.e., Stages 13, 11, 9, 5, and 1, have relative warm climates that alternate with cold events. The warmer stages, indicated by having a high proportion of open-ocean assemblages, are Stages 7 and 3.

Among the glacial periods, Stage 12 exhibits the coldest conditions throughout the 500 ka. During the other ice ages, the study area was perennially ice-covered, but some warm events did occur. Stage 8 was a very warm ice age, quite distinct from the other glacial periods. In support of our observations, this anomalous stage was previously examined by Barash et al. (2006) and Lui et al. (2006). In addition, previously determined alkenone-SST in the PC2 (Seki et al. 2004a, b) suggest a warm event in Stage 5a and a cold period in early Stage 3; both these events are recognized in this study.

4.3 The NIPW Supply from the Okhotsk Sea

The NPIW, defined as the salinity minimum at depth 300 - 500 m, is formed somewhere in the northwestern (NW) Pacific. Its source has been identified as the Okhotsk Sea (Yasuda 1997). Okhotsk intermediate water is produced by brine rejection during the formation of the sea ice on the continental shelf in winter. It is exported by vertical change in the Bussols' Strait to ventilate the subpolar gyre of the North Pacific Ocean. Okhotsk Sea seasonal sea ice formation is the key process driving NPIW production at present.

Pacific intermediate circulation may have changed significantly during glacial periods. The ventilation of the intermediate water from glacial higher oxygen conditions to Holocene low oxygen conditions has been observed in the Santa Barbara Basin, in the northeastern (NP) Pacific (Kennett and Ingram 1995; Behl and Kennett 1996), and better ventilation has been found at depths shallower than 2 km in the glacial Okhotsk Sea of the NW Pacific (Keigwin 1998).

The glacial distribution of the NPIW radiolarian indicator, *Cycladophora davisiana,* dominates in the North Pacific and the Bering Sea, but is barren in the Okhotsk Sea (Okazaki et al. 2003), which suggests that the intermediate water is derived from the Bering Sea rather than the Okhotsk Sea (Ohkushi et al. 2003). During LGM, the sea ice cover is heavy and there is no formation of winter sea ice in the shelf region where the intermediate water is currently produced. This suggests that the existence of seasonal sea ice is the key condition for NPIW supply from the Okhotsk Sea. On the basis of the correlation between the NPIW and sea ice conditions, we suggest that NPIW products in the Okhotsk Sea increase in volume during periods of seasonal sea ice cover, rather than during periods of perennial sea ice cover. By the same token, periods of open ocean in the study area indicate a more limited southern extension of winter sea ice, which indicates that the NPIW supply probably mediates all three types of sea ice conditions.

4.4 *Paralia sulcata* as An Indicator of Continental Detritus Input in the Okhotsk Sea

Paralia sulcata (Ehrenberg) Cleve is a brackish to marine diatom found in benthic microphyte communities in temperate coastal waters. The thick walls of *P. sulcata* sink readily and are relatively resistant to dissolution, and both these factors contribute to its abundance in coastal sediment records. The most common interpretation of *P. sulcata* is as an indicator of coastal upwelling situations which result in high primary production (Abrantes 1988a, b, 1991). *Paralia sulcata* does not typically form large blooms in plankton, but high proportions can be found in the water column during winter (Sancetta 1989; Hobson and McQuoid 1997). Since *P. sulcata* grows primarily in benthic habitats, physical forces such as strong winds (Haggart 1988; Cullingford et al. 1989) and tidal mixing (Oh and Koh 1995) may be primary mechanisms for the transport of cells into the plankton. The diameter of *P. sulcata* usually ranges between 8 and 29 μm. However, cells up to 130 μm have been recorded (Hasle and Syvertsen 1996). There is growing evidence that environmental conditions can regulate changes in valve diameter. Small cells are more numerous in highly productive waters (Roelofs 1984), and larger valve diameters are most abundant in moderately low salinities (Sherrod 1999) or when nutrient availability is patchy (Abrantes 1988a). In this study, the valves of *P. sulcata* are almost all small, suggesting high productivity conditions.

A sudden increase in *P. sulcata* occurs at the end and beginning of glacial periods, except in Stages 11 and 8 (Fig. 2). Two explanations for this phenomenon have been proposed in this study. In the first, changes in the local physical environment, such as upwellings or nutrient input increases, stimulate *P. sulcata* production. However, there are no reports of upwellings in the central Okhotsk Sea, or periods of nutrient input increases (Ternois et al. 2001). Further, high productivity periods, indicated by diatom records, are not concurrent with *P. sulcata* increases. Alternatively, *P. sulcata* may be reworking species transported from other places. Where is the possible source of *P. sulcata* in the Okhotsk Sea? According to satellite remote sensing data (SeawiFS 1986), the north shelf area exhibits upwelling and has the highest productivity in the Okhotsk Sea (Nezlin et al. 1997; Nimmergut and Abelmann 2002). In the sediment record, *P. sulcata* is also dominant in this area (Sancetta 1982). This data suggests that the continental shelf is the likely source of *P. sulcata*.

Atmospheric circulation, fluvial input, and sea-ice constantly erode the north continental shelves and transport the reworking *P. sulcata* to the central Okhotsk Sea. The atmospheric transport of materials to the marginal sediments is a key process, and enhanced terrigenous inputs in the glacial period has been observed from the Equatorial Pacific (Ohkouchi et al. 1997a, b), the Northwest Pacific (Gorbarenko 1996), and the Japan Sea (Ishiwatari et al. 1994). Those have been explained by an enhancement of atmospheric circulation, eolian dust transport, or the dust scavenging rate. However, the enhancement of atmospheric circulation during glacial periods is continual, and this mechanism can hardly explain the drastic increase of continental supply in the short intervals. Dust transport by atmospheric circulation accumulates in the glacial periods, when the sea is perennially ice-covered. The dust sinks to the bottom sediments when the ocean condition changes to seasonal ice cover or ice free, and the perennial sea-ice melts. However, intervals of sea-ice melting are not simultaneous with *P. sulcata* increase events.

Fluvial inputs, mostly from the Amur River, and detrital inputs from continental shelf erosion are two important processes for the transport of continental materials to the marginal ocean. However, the former mechanism can hardly explain the drastic increase in continental supply observed in the Okhotsk Sea during the glacial period, since much dryer conditions, which probably prevailed over the Asian continent at that time (Hovan et al. 1991), would have reduced the water inflow from the Amur River to the Okhotsk Sea.

Several lines of evidence suggest that continental shelf erosion caused by sea-level rise has occurred in the North Pacific Ocean. Increased shelf weathering associated with sea-ice transport of the eroded material has been proposed to intensify continental detrital accumulation in glacial sediments (Conolly and Ewing 1970; Keigwin et al. 1992). During such periods, strong winter storm and moderate summer conditions enhance the generation of sea-ice near the coast, which may induce an uptake of eroded continental materials into the bottom of the sea-ice by freezing processes. Enhanced oceanic circulation probably promotes long-distance transport of sea-ice. Then, far from its source region, it melts in the summer, allowing the vertical transport of the sea-ice-entrapped shelf materials to the ocean floor (COHMAP 1988).

Relative abundance of *P. sulcata* in the central area of the Okhotsk Sea (this study) and the terrigenous biomarkers in southern areas, (Ternois et al. 2000) increased simultaneously (Fig. 4), reflecting the vertical transport of the sea-ice-entrapped shelf materials to the ocean floor. The results indicate that enhanced erosion of the shelves due to sea-level rise, coupled with ice rafting processes, is the mechanism responsible for the supply of a significant amount of continental materials to the Okhotsk Sea sedi-

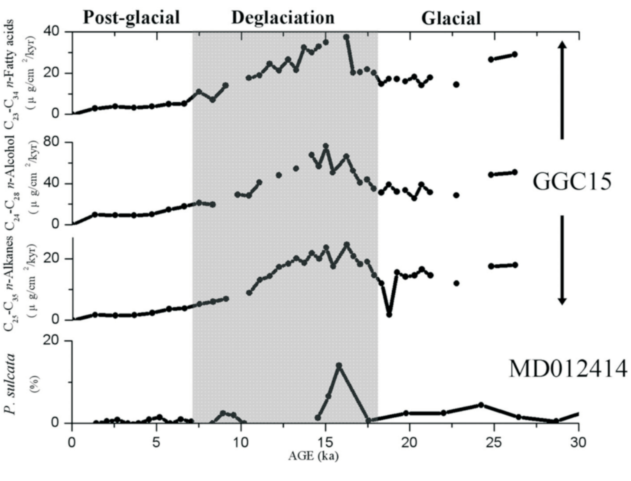

Fig. 4. Downcore profiles of the terrigenous biomarker accumulation rate [(in μg cm^{-2}) kyr^{-1}] and *Paralia sulcata* relative abundance (%) in the south (GGC15, after Ternois et al. 2001) and central (MD012414, this study) Okhotsk sediment cores, respectively. The shaded area represents the deglaciation periods.

ments (Ternois et al. 2001). That there was no *P. sulcata* increase event in Stage 8, the ice-free glacial period, also suggests that this event was sea-ice-dependent. Moreover, the abnormal pulse in sea-ice assemblages in 410 ka also indicates a heavy sea-ice cover scenario (Fig. 3), and the phase lag for the ice melting should be a reliable cause.

Comparison of levels of *P. sulcata* in MD012414 and four other cores from the Okhotsk Sea at the 20 ka mark (Table 1), shows that sudden increase events of *P. sulcata* have been observed not only in MD012414, but in two other cores, cores 7 and 3, in the central area (Fig. 5, Shiga and Koizumi 2000). Sea-ice transport has been observed in four cores (cores 7, 3, MD012414, and GGC15), and *P. sulcata* and terrigenous biomarkers are found in cores from the center and south Okhotsk Sea, respectively. However, *P. sulcata* is rare in the cores from offshore Kamachata (V34-98) and Sakhalin (K9312). The distribution of those cores implies sea rafting transport from the north continental shelf to the south basin, though limited in the Okhotsk Gyre.

5. CONCLUSIONS

This fossil diatom study of central Okhotsk Sea sediment core MD012414 enables us to reconstruct sea ice conditions over the past 500 ka. The existence of alternating high proportion high-productivity and open-ocean assemblages indicates alternating cold and warm climates in Stages 9, 5, and 1. The dominance of open-ocean assemblages indicates a warm climate in Stages 7 and 3. In the glacial periods, Stages 6, 4, and 2, have very cold climates described by sudden increases in littoral diatoms transported by melting sea-ice from the northeast reefs in the colder stages. Littoral species, *P. sulcata*, and the terrigenous biomarker share a variation peak in continental supply at 15 ka BP. This sudden increase in ice-rafted detrital materials may involve materials from the continental shelves of the northern Okhotsk Sea. Melting of perennial sea-ice cover and changes in the sea-level are the primary forces responsible for eroding the northern reefs of the Okhotsk Sea during the deglacial periods, resulting in the transport of not only terrigenous materials, but reworked littoral diatoms present in the littoral sediments.

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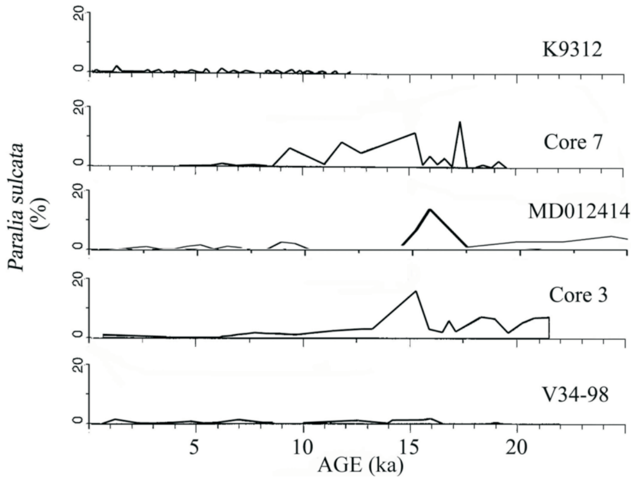

Fig. 5. Downcore profiles of *Paralia sulcata* relative abundance in different locations, K9312, Core 7, 3, V34-98 (after Shiga and Koizumi 2000) and MD012414 (this study), in the Okhotsk Sea. A *Paralia sulcata* sudden increase event happened simultaneously in the central Okhotsk Sea about 15 ka.

Table 1. Core information of MD012414 and relative cores collected from the Okhotsk Sea.

Core ID	Latitude	Longitude	Water depth (m)	Core lengh (cm)	Bottom age (ka)	Reference
Diatom						
MD012414	53°11'N	149°34'E	1123	5388	1771.4	This study
V34-98	50°07'N	153°12'E	1175	330	19.8	Shiga and Koizumi 2000
core 3	15°57'N	149°48'E	974	97	21.5	Shiga and Koizumi 2000
core 7	53°59'N	149°13'E	910	113	19.6	Shiga and Koizumi 2000
K9312	53°32'N	144°03'E	1005	687	12.4	Shiga and Koizumi 2000
Biomarker						
GGC-15	48°10'N	151°20'E	1980	325	26.2	Ternois et al. 2001

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