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Late Quaternary Paleoceanography as Recorded by Planktonic Foraminifera in the Ulleung Basin, East Sea

GIL YOUNG KIM, DAE CHOUL KIM[1], IM CHUL SHIN[2], SOO CHUL PARK[3]
HI IL YI[4] AND JEONG CHANG KIM[5]
Department of Applied Geology, Pukyong National University, Pusan 608-737, Korea
[1]Department of Exploration Engineering, Pukyong National University, Pusan 608-737, Korea
[2]Chemical Oceanography Division, Korea Ocean Research and Development Institute, Ansan P.O. Box 29, Seoul 425-600, Korea
[3]Department of Oceanography, Chungnam National University, Taejon 305-764, Korea
[4]Marine Geology and Geophysics Division, Korea Ocean Research and Development Institute, Ansan P.O. Box 29, Seoul 425-600, Korea
[5]Department of Shipboard Training, Pukyong National University, Pusan 608-737, Korea

Paleoceanographic history of the East Sea is reconstructed based on several environmental parameters (coarse fraction content, planktonic foraminifera/benthic foraminifera ratio, fragmentation and assemblages of planktonic foraminifera, and coiling ratio of *Neogloboquadrina pachyderma*, etc,) of the late Quaternary sediments obtained from the Ulleung Basin. *N. pachyderma* and *Globigerina bulloides* are dominant species (greater than 90% in abundance) among the total planktonic foraminifera assemblages in the late Quaternary sediments. The benthic foraminifera rarely occurred throughout the cores. Sinistrally-coiled specimens of *N. pachyderma* representing cold water temperature are observed more abundantly than dextrally-coiled ones. In addition, the sinistrally-coiled *N. pachyderma* showed more the amount at the lower part of the cores than at the upper part suggesting the restriction of the Tsushima Warm Current into the East Sea during glacial period. *G. bulloides*, a species representative of upwelling condition, shows more abundant occurrence in the sediments of Core 941013 than those of Core 941006. This implies that Core 941013 is more influenced by upwelling than Core 941006. The upper part of the two cores contain more fragmentation of planktonic foraminifera suggesting significant dissolution by corrosive bottom water. Ascending CCD also played an important role for the absence of planktonic foraminifera at the upper part of the cores.

INTRODUCTION

Paleoceanographic history of the Ulleung Basin is investigated based on the planktonic foraminiferal assemblages and physical characteristics of two core sediments. Both Core 941006 (37°00'07.7N, 131°00' 07.3E water depth of 2170 m) and Core 941013 (36°45'02.8N, 131°29'82.3E water depth of 1960 m) were collected from the Ulleung Basin, the East Sea.

Various planktonic foraminiferal assemblages including species diversity indices have been used for the paleoceanographic and paleoclimatic in the deep-sea sediments (Ruddiman, 1971; Williams and Johnson; 1975; Hecht, 1973).

Planktonic foraminifer *Neogloboquadrina pachyderma* (Ehrenberg) has been the subject of paleoceanographic study over the past few decades, mainly because of the potential as a paleoclimatologic tool to assess the cold-water condition (Ericson, 1959: Bandy, 1960). They showed the relationship between the coiling direction of *N. pachyderma* and surface-water temperature; changing coiling direction with time was correlated with water temperatures in which the left-coiled species prefer the cold temperature.

The paleoenvironments of the East Sea during the late Quaternary have been studied by various micropaleontological and geochemical (mainly stable isotopes) analyses (Koizumi, 1970, 1985, 1989; Ujiie and Ichikura, 1973; Mayia *et al.*, 1980; Oba *et al.*, 1980, 1991; Ujiie *et al.*, 1983; Woo *et al.*, 1995). Ujiie and Ichikura (1973) reported that the intrusion of the present Tsushima Warm Current into the East Sea occurred at about 11 ka based on the replacement of sinistrally-coiled *N. pachyderma* by the dextral forms as well as the occurrence of a warm water planktonic foraminiferal fauna. However, these studies have not documented a variety of environmental parameters (coarse fraction, p/b ratio, planktonic foraminifera fragmentation, etc). In addition, they did not carry out the downcore analyses of core sediments in detail.

The purpose of the present study is to investigate the late Quaternary paleoceanographic history in the Ulleung Basin, East Sea based on the temporal and spatial distributional patterns of planktonic foraminifera and several environmental parameters.

PHYSIOGRAPHY AND OCEANOGRAPHIC SETTING

Physiography

The East Sea is a semi-isolated marginal sea with an average water depth of 1350 m. It is connected with the Sea of Okhotsk, the North Pacific, and the East China Sea through the four shallow straits (Fig. 1): Tatarskiy Strait, Soya Strait, Tsugaru Strait, and Korea Strait.

The general bathymetry of the Ulleung Basin is characterized by a northeastward U-shaped gentle slope. The basin extends northeastward through the gap between Ulleung and Tok islands, forming a narrow and long interbasin plain. The Ulleung Basin floor is generally flat and progressively deeper northward, connected to the Japan Basin by the Ulleung Interplain Channel (Chough *et al.*, 1985). The Ulleung Interplain Channel is approximately 7 km wide and 35 m deep (Fig. 1). It is erosional in origin and undercuts the turbidite sequence, formed most likely by strong bottom currents flowing through the gap (Chough, 1984).

Present oceanography

In spite of deeper water depth as much as 3000 m, the East Sea water is isolated from the deep and intermediate water masses of the adjacent Pacific Ocean due to the straits (Fig. 1).

The topographic isolation of the sea, in combination with the severe winter climate in its northern part including the formation of sea ice, produces an extraordinarily cold and highly oxygenated water mass that contrasts sharply with the thermally stratified and suboxic waters of the adjacent Pacific Ocean (Worthington, 1981).

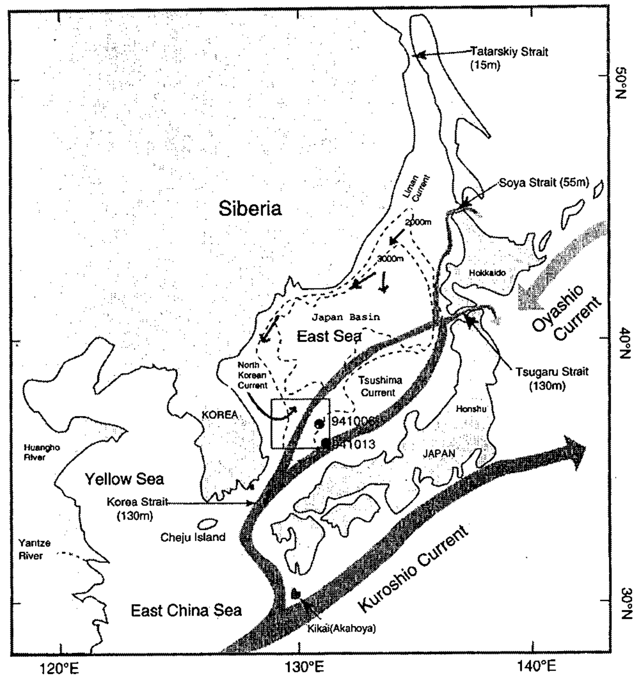

Fig. 1. Location of study area and the present current system around the Korea Peninsula and Japanese islands. The figure shows sill depth of straits, contour in meter. The study area marked in a box (modified from Oba *et al.*, 1991).

In the present East Sea, warm saline surface water derived from the Kuroshio Current enters the East Sea through the Korean Strait as the Tsushima Warm Current. The Tsushima Warm Current flows northward in the eastern East Sea and exits to the North Pacific mostly through the Tsugaru Strait and partly through the Soya Strait (Fig. 1). Colder, less saline surface waters flow southward in the western East Sea as the Liman Current and North Korean Old Current indicating the hyper-ventilated and highly oxic state of the present sea. The Liman Current travels southward and ultimately sinks at the thermal front with the water from the Tsushima Warm Current because of its high density, perhaps aided by mixing and caballing (Ingle *et al.*, 1990). The convective circulation induced by these seasonal characterizes the low-temperature (0—1°C) and well-oxygenated (5—7 ml/l) water mass the at all depths below 300 m (Hidaka, 1966; Yasui *et al.*, 1967; Matoba, 1984). Owing to the high dissolved oxygen content, bottom sediments are oxidized (Kim *et al.*, 1995), and the present-day calcite compensation depth (CCD) lies at about 2000 m (Ichikura and Ujiie, 1976), much shallower than in the adjacent Pacific Ocean.

Cold oxic deep waters have greatly influenced modern sedimentation in the East Sea and are responsible for the occurrence of carbonate-poor "red clay" sediments depleted in organic matter (Niino *et al.*, 1969; Ujiie and Ichikura, 1973). The carbonate content of the Quaternary in deep basins of the East Sea is generally less than 1% and the foraminiferal preservation is poor, consistent with deposition below the CCD (Tamaki *et al.*, 1990).

MATERIALS AND METHODS

Samples for foraminiferal study were prepared from sediment cores of the two sites located in the Ullueng Basin (Fig. 1). The cores are particularly well suited to monitor the paleoenvironmental history of the East Sea because they are collected from the location not deposited by mass flow (Fig. 2). By high resolution (Chirp Acoustic) subbottom profile, piston coring sites show thin-and evenly-layered, and a well stratified deposits (Fig. 2).

All subsamples collected at 10 cm intervals from the core and were washed over 63 μm sieve and the sand-sized residue was dried in oven, weighed, and inspected for foraminifera. Samples with abundant planktonic foraminifera are split into several fractions by using an Otto microsplitter until 300 foraminiferal specimens are found. The planktonic foraminifera are identified into species level and counted. The benthic foraminifera are only counted.

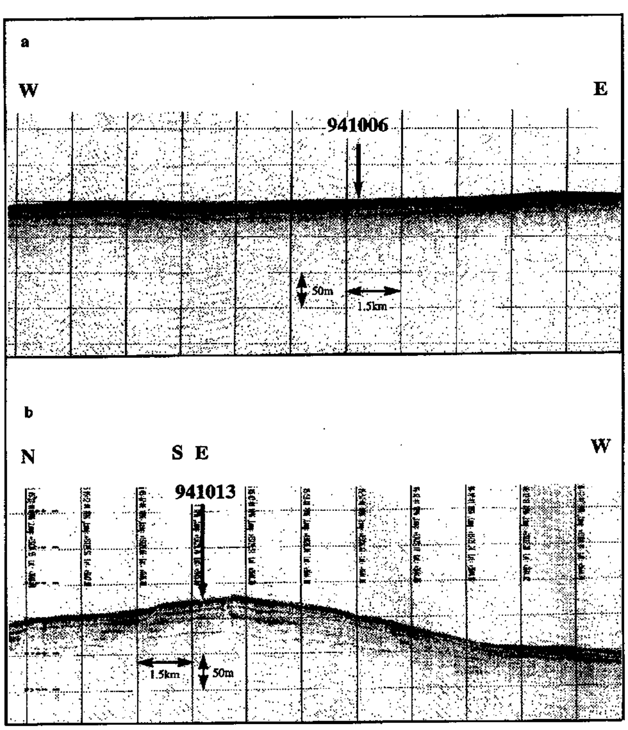

Fig. 2. Chirp Acoustic profiles around the piston coring sites. Note a well-stratified deposits.

Several paleoenvironmental parameters are measured: coarse fraction content by dry weight, the number of planktonic and benthic foraminifera, planktonic/benthic foraminifera ratio (number of planktonic foraminifera specimens/total number of foraminifera specimens), planktonic foraminifera fragmentation, the coiling ratio of *Neogloboquadrina pachyderma* (number of sinistral forms/total number of *N. pachyderma* tests).

For the calculations of the coarse fraction (greater than 63 μm) content in the sediments, each sample was oven-dried overnight at approximately 80°C and then weighed. The coarse fraction was split using microsplitter as many times as required to get a subsample of approximately 300 foraminiferal specimens.

In the cores, grain sizes of greater than 63 μm were used for countings of broken planktonic foraminifera. The fragmentation is obtained by the number of broken planktonic foraminifera among 100 planktonic foraminifera. The ratio of planktonic to benthic foraminifera (p/b) was counted from the size fraction greater than 63 μm to avoid any information loss.

RESULTS AND DISCUSSION

Both cores contain a well-known tephra layer (210—215 cm in Core 941006; 109—130 cm in Core 941013) equivalent to the Ulleung-Oki eruption (ca. 9300 yrs B.P.). According to the grain size analyses and X-radiography, the sediments are mainly composed of the homogeneous and bioturbated clay and mud, well laminated mud, and bioturbated sandy mud (Figs. 3 and 4).

The planktonic foraminifera examined from the late Quaternary sediments in the Ulleung Basin are *Neogloboquadrina pachyderma* and *Globigerina bulloides* with minor amounts of *Neogloboquadrina dutertrei* (Tables 1 and 2). Vertical variations of planktonic foraminifera show abundant occurrences at lower part (below 240 cm and 160 cm downcore in Core 941006 and Core 941013, respectively) than upper part (above 240 cm and 160 cm downcore, respectively) of core sediments in both cores (Tables 1 and 2). Core 941013 contains more plank-

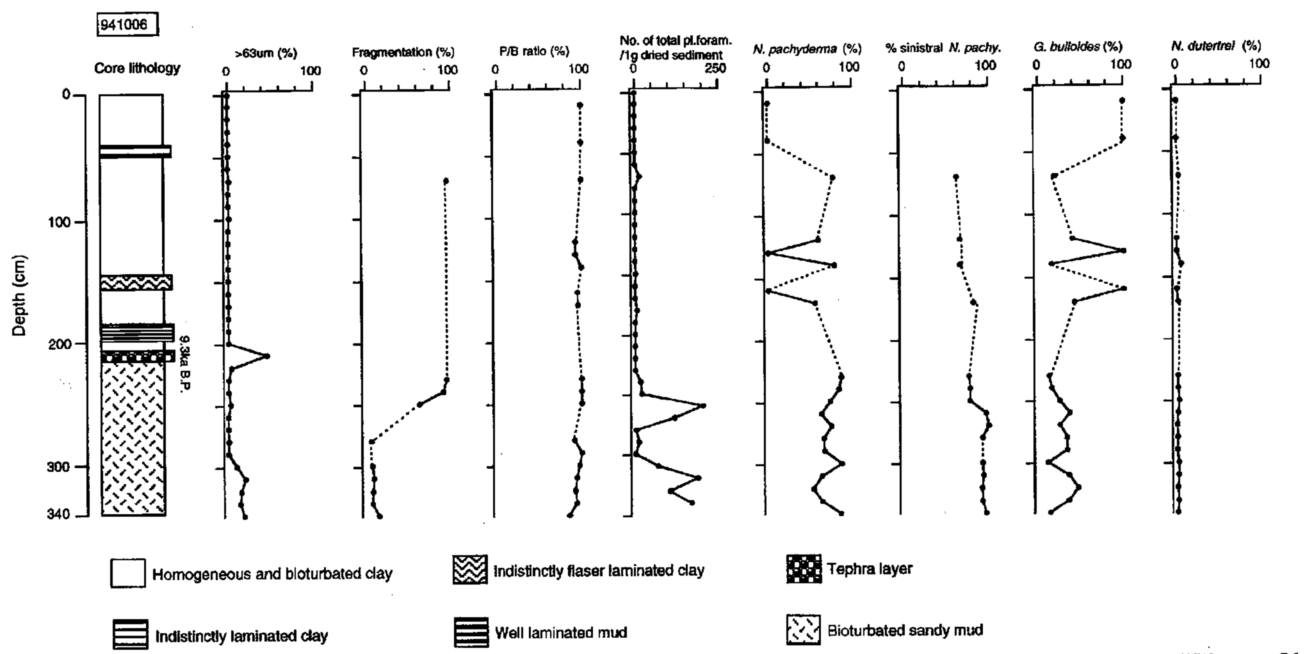

Fig. 3. Lithologic and foraminiferal characteristics of the Core 941006. Tephra layer is originated from the Ulleung-Oki eruption (*ca.* 9300 yrs B.P.). Dotted line is foraminiferal barren zone. The relative frequency of *N. pachyderma* and *G. bulloides* shows a mirror image.

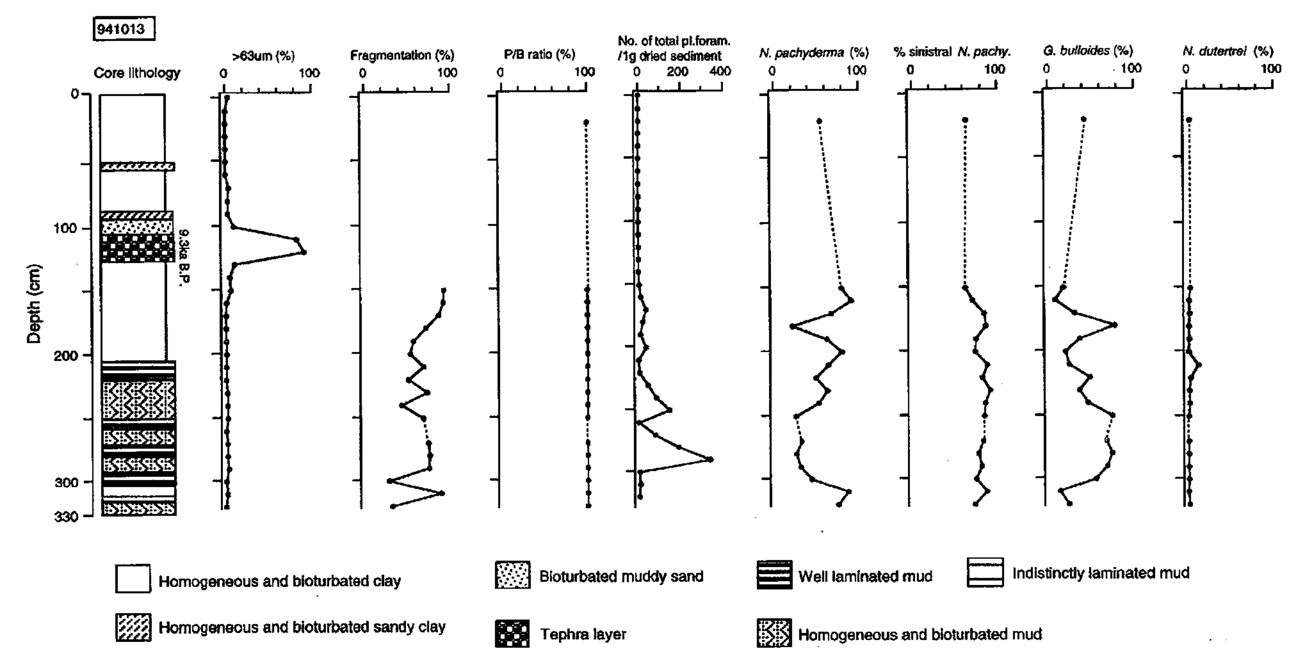

Fig. 4. Lithologic and foraminiferal characteristics of the Core 941013. Legends are same as Fig. 3.

tonic foraminifera compared to Core 941006. This is probably due to the effect of CCD by difference of water depth. Core 941013 is also located in higher productivity zone than Core 941006 (Fig. 5). Especially, planktonic foraminifera are abundantly found below tephra layer (Figs. 3 and 4). Furthermore, the occurrence of the planktonic foraminifera is sporadic with many gaps within two cores. This probably is due to the fluctuations of CCD during the past in the Ulleung Basin, East Sea.

Fluctuations of CCD in the East Sea during the latest Quaternary are reported by Kitazato (1984)

Table 1. Listing of data including percent sand-sized material by weight (> 63 μm), planktonic foraminifera fragmentation, planktonic/benthic foraminifera ratio, weight (split) of sample examined for foraminifera, number of *N. pachyderma* (sinistral and dextral), coiling ratio of *N. pachyderma*, and relative frequency taxa of planktonic foraminifera in Core 941006

Depth (cm)	> 63 μm (%)	Planktonic fragmen. (%)	P/B ratio (%)	Dry sedi. (> 63 μm) (g)	No. of total pl. foram./1 g dried sediment	No. of *N. pachyderma* (left coiled)	No. of *N. pachyderma* (right coiled)	% sinistral *N. pachyderma*	No. of *G. bulloides*	No. of *N. dutertrei*
0—2	0.2			0.02	0.0					
9—11	0.2		100	0.02	0.1				1	
19—21	0.1			0.02	0.0					
29—31	0.2			0.03	0.0					
39—41	0.5		100	0.09	0.1				1	
49—51	0.3			0.04	0.0					
59—61	0.1			0.03	0.0					
69—71	1.4	96	100	0.18	14.5	89	53	62.6	35	5
79—81	0.3			0.05	0.0					
89—91	0.3			0.03	0.0					
99—101	1.6			0.20	0.0					
109—111	0.4			0.05	0.0					
119—121	0.2		93	0.04	0.3	2	1	66.6	2	
129—131	0.3		100	0.04	0.0		1		1	
139—141	0.2		100	0.02	1.6	10	5	66.6	3	1
149—151	0.2			0.03	0.0					
159—161	0.5		100	0.06	0.0				1	
169—171	0.8		96	0.10	5.6	33	7	82.5	30	1
179—181	0.3			0.04	0.0					
189—191	0.2			0.03	0.0					
199—201	0.7			0.09	0.0					
209—211	45.2			8.60	0.0					
219—221	3.6			0.34	0.0					
229—231	0.6	95	100	0.08	16.1	156	47	76.8	28	3
239—241	0.7	91	100	0.11	18.9	199	55	78.3	46	3
249—251	2.9	63	100	0.05	201.8	201	57	77.9	85	9
259—261	0.1		100	0.01	117.1	62	2	96.8	37	1
269—271	0.1		100	0.02	1.8	3		100	1	
279—281	0.6	6	91	0.17	10.3	166	13	92.7	90	2
289—291	0.2		100	0.03	0.2	2			1	
299—301	9.6	7	97	0.36	68.0	204	16	92.7	27	5
309—311	19.8	9	94	0.34	187.3	191	13	93.6	112	5
319—321	15.1	8	92	0.48	102.9	159	14	91.9	148	3
329—331	13.8	7	94	0.25	167.4	180	15	92.3	106	4
339—341	18.8	15	85	0.37	138.6	227	8	96.6	36	2

and Oba *et al.* (1991). They documented a fluctuations of CCD in the East Sea during the last 28 kyr based on the presence or absence of calcareous foraminiferal tests in six piston cores around the Oki Ridge. They suggested the CCD existed deeper than 2500 m during the last glacial period (28—18 ka) and gradually ascended to the depth of 1500 m between 18 ka and 11 ka. Between 10 ka and 6 ka the CCD is remarkably rised shallower than 1000 m. After 6 ka the CCD deepened again to about 2000 m, which is nearly same as that of the present East Sea. Their results suggest that the CCD was deepest during the last glacial lowstand of sea level, shallowest during the transition from glacial lowstand to interglacial highstand. This trend can be supported by the present study. Sedimentation rate in the East Sea was calculated as 10—12 cm/1000 yr (Ingle *et al.*, 1990). The accelerator mass spectrometry (AMS) C-14 dates in the Ulleung Basin at 110 cm downcore was 11.7 ka and at 250 cm was 20.1 ka (KORDI, 1996). If we apply these data to two core sediments, the abundant occurrence of planktonic foraminifera at the lower part of the cores suggest that the CCD was deeper than 2000 m during glacial period. Whereas, the upper part of both cores are barren (or very rare) of foraminifera due to shallow CCD (< 1000 m) during interglacial period.

Today, a branch of the northward-flowing Tsushima Warm Current enters the East Sea through the Korea Strait and is geostrophically forced eastward to the western coast of Japan (Figs. 1 and 5). This affects salinity and temperature of the eastern and southeastern East Sea, producing warmer and higher salinity than the northern East Sea. From the north,

Table 2. Listing of data including percent sand-sized material by weight (> 63 μm), planktonic foraminifera fragmentation, planktonic/benthic foraminifera ratio, weight (split) of sample examined for foraminifera, number of *N. pachyderma* (sinistral and dextral), coiling ratio of *N. pachyderma*, and relative frequency taxa of planktonic foraminifera in Core 941013

Depth (cm)	> 63 μm (%)	Planktonic fragmen. (%)	P/B ratio (%)	Dry sedi. (> 63 μm) (g)	No. of total pl. foram./1 g dried sediment	No. of *N. pachyderma* (left coiled)	No. of *N. pachyderma* (right coiled)	% sinistral *N. pachyderma*	No. of *G. bulloides*	No. of *N. dutertrei*
0—2	3.3			0.36	0.0					
11—13	0.2			0.06	0.0					
21—23	0.2		100	0.05	1.7	14	8	63.6	17	1
31—33	0.3			0.07	0.0					
41—43	0.6			0.12	0.0					
51—53	0.2			0.04	0.0					
61—63	0.5			0.11	0.0					
71—73	3.9			0.78	0.0					
81—83	2.9			0.58	0.0					
91—93	3.0			0.61	0.0					
101—103	10.2			1.97	0.0					
111—113	82.8			16.33	0.0					
121—123	91.5			15.84	0.0					
131—133	10.9			2.84	0.0					
141—143	5.4			1.24	0.0					
151—152	6.4	93	100	1.87	3.7	53	32	62.4	1	3
161—163	1.4	92	100	0.43	10.2	195	81	70.7	24	5
171—173	0.9	87	100	0.08	34.7	174	33	84.1	93	6
181—183	0.8	72	100	0.17	19.2	75	12	86.2	317	4
191—193	1.3	57	100	0.46	8.6	141	48	74.6	111	4
201—203	1.4	53	100	0.13	34.2	185	66	73.7	63	2
211—213	1.0	69	100	0.35	0.7	14	2	87.5	6	3
221—223	0.7	51	100	0.21	4.4	55	12	82.1	65	4
231—233	2.1	73	100	0.18	43.0	193	19	91.0	122	5
241—243	2.3	43	100	0.09	83.6	153	26	85.5	158	6
251—253	2.8	68	100	0.06	145.3	69	13	84.1	244	2
261—263	0.8			0.25	0.0					
271—273	2.1	74	100	0.10	77.6	92	19	82.9	239	2
281—283	2.3	76	100	0.05	188.7	83	24	77.6	313	3
291—293	3.5	75	100	0.04	337.2	105	16	81.4	290	3
301—303	0.7	28	100	0.28	3.4	44	15	74.6	74	1
311—313	2.0	89	100	0.85	5.7	178	27	86.8	31	1
321—323	0.3	32	100	0.11	2.0	35	13	72.9	15	1

cold and low-salinity current enter the East Sea, therefore, the northern part and half of western part of the sea are covered by colder and less saline surface water (Muza, 1992). A distinct water mass boundary and oceanographic front along the 38°—40°N exist where these two surface-water masses converge and mix (Fig. 5). The convergence zone between these two surface water masses can be identified in satellite imagery which measures the phytoplankton pigment concentration in the ocean. Muza (1992) reported that pytoplankton pigment concentration within the convergence zone is 2—3 times greater (0.5—0.7 mg/m^3) than that of the pelagic environment (0.25—0.35 mg/m^3). Such high productivity zone also coincides with the 4—8°C average February sea surface isotherms. Although two core sites is located in the southern part of convergence zone, the study area is situated nearby high productivity zone (Fig. 5). Therefore, abundant planktonic foraminifera were occurred at core sediments except the upper part of each core which is influenced by CCD (Figs. 3 and 4).

Water temperature has been considered as the most important factor controlling the abundance of planktonic foraminifera rather than other factors such as salinity, density, dissolved oxygen, nutrients and so on (Be, 1977). Generally, *Globigerina bulloides* is a solution susceptible species that is commonly found in subpolar and upwelling environments. In the Ulleung Basin, *G. bulloides* is abundantly occurred at the lower part of each cores (Figs. 3 and 4). Especially, Core 941013 shows more abundant occurrence of *G. bulloides* than Core 941006. This probably indicates that Core 941013 is more influenced from high production (Fig. 5) by upwelling than Core 941006.

Coarse fraction in the sediment can be used as an indicator of carbonate dissolution (Keir, 1980; Wil-

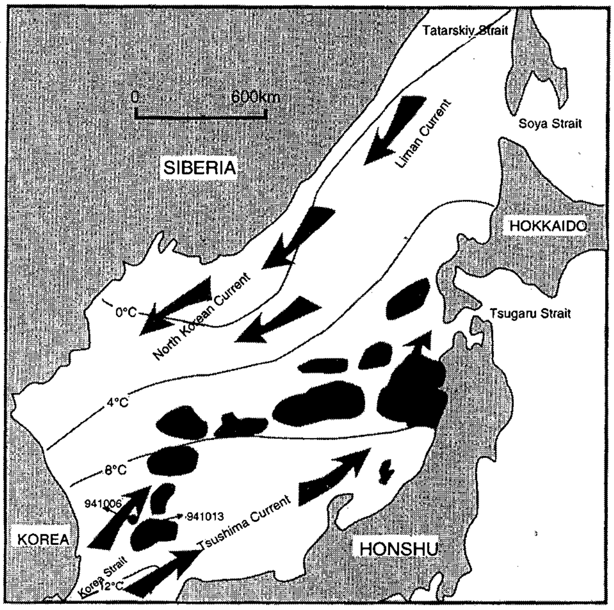

Fig. 5. Location of the East Sea oceanographic frontal zone and associated region of high productivity (mottled black) measured by phytoplankton pigment concentration (0.5—0.7 mg/m^3) derived from satellite imagery. Cold water currents (Liman and North Korea Currents) flowing southward converge and mix with the northward-flowing Tsushima Warm Current creating the oceanographic front. The region between the 4°C and 8°C average February isotherms approximates the oceanographic frontal zone. The location of piston coring sites is indicated by solid circles and are located nearby high productivity zone (modified from Muza, 1992).

liams *et al.*, 1985). Lower percentage of coarse fraction indicates periods of calcium carbonate dissolution (Williams *et al.*, 1985). Coarse fraction (%) is sensitive to dissolution because the chemical process decreases test strength and leads to fragmentation of foraminifer tests into smaller sized particles, transferring a greater percentage of the sample weight to the < 150 μm sized-fraction (Peterson and Prell, 1985). Coarse fraction also can be used as an indicator for the depositional patterns of sediments. Large percentages of coarse fractions generally occur in sediments transported from land (Douglas, 1973; Yamashiro, 1975).

Our result shows the low content of coarse fraction from the entire core depth except for the tephra layer which contains a large amount (10—91%) of coarse fraction (Figs. 3 and 4). At 230—250 cm of Core 941006, coarse fraction consists of most of foraminifera. At the depth intervals of 160—200 cm, 230—250 cm, and 270—290 cm of Core 941013, coarse fraction contains the large amount of (greater than 90%) planktonic foraminifera. Core 941013 considerably contains sand-sized gypsum (formed secondarily) from 200 cm of core depth to the bottom. Weight of dry sediments (> 63 μm) used for examination of planktonic foraminifera is less than 1 g at interval in addition to tephra layer of two cores (Tables 1 and 2). It may be inferred that the bottom current was weak and no terrigeneous input of sand-sized material (coarse particles) from the adjacent land to the Ulleung Basin during the late Quaternary.

Fragmentation of planktonic foraminifera has been also used as a reliable index for the degree of dissolution (Thunell, 1976; Le and Shackleton, 1992) and a very sensitive index for the early stages of dissolution (Vincent and Berger, 1981). Percentage of broken planktonic foraminifera generally increases with water depth. The percentage of broken specimens primarily reflects the degree of calcium carbonate dissolution due to weakening of the tests (Phleger, 1953; Berger, 1970) and secondarily reflects mechanical factors (Phlerger, 1953). Therefore, an increase in fragmentation indicates the higher dissolution. Berger (1970) also pointed out that increased fragmentation was directly related to enhanced dissolution. The planktonic foraminifera fragmentation is not sensitive to terrigenous sediment influx (Balsam, 1982).

Planktonic foraminifera fragmentation in study area (Figs. 3 and 4) generally increases from core bottom (< 10%) to top of core (> 90%). The increasing fragmentation may be associated with a rise of the CCD from the late Pleistocene to Holocene in the Ulleung Basin, East Sea. Degree of fragmentation is different from two cores. Core 941006 shows abrupt increase of fragmentation from the 250 cm downcore. Whereas, fragmentation in Core 941013 fluctuates from core bottom to 200 cm downcore, then it shows slight increase to the 150 cm downcore (Figs. 3 and 4). It may be considered due to the effects of CCD by difference of water depth between Core 941006 (2170 m) and Core 941013 (1960 m).

Planktonic/benthic foraminifera ratio can be used for paleobathymetric interpretation. The p/b ratio generally increases from shallow water to deeper water (Parker and Berger, 1971). Planktonic/benthic foraminifera ratio also is a function of preservation and is strongly affected by selective dissolution of foraminiferal tests during sedimentation (Berger, 1973). Benthic foraminifera are four times more resistant to calcium carbonate dissolution than planktonic foraminifera. Holtedahl (1959) also noted that a low percentage of planktonic foraminifera may indicate the rapid influx of clastic material. High abundance of planktonic foraminifera also suggest slow and continuous sedimentation rate. Therefore, high p/b ratio in the study area indicates the slow and continuous influx of clastic materials into the Ulleung Basin, East Sea.

Benthic foraminifera in Core 941006 are nearly less than 10%. Especially, Core 941013 shows the barren zone throughout the core. In Core 941006, the p/b ratio increases slightly towards the upper part of the core. However, significant variations do not show in this study area (Figs. 3 and 4). It may be interpreted as not being good conditions (e.g. oxic environment) for the survival of benthic foraminifera during the glacial period. During interglacial period benthic foraminifera as well as planktonic foraminifera might be dissolved due to the effect of CCD. This is compared to the previous results (Woo *et al.*, 1995) occurred abundantly in western part of the East Sea.

The coiling ratio of *N. pachyderma* can be used as a proxy measure of paleotemperature of surface waters (Be, 1960). In the Ulleung Basin, the coiling direction of *N. pachyderma* are dominated (80—90%) by sinistral *N. pachyderma* representing cold water temperature at lower part of two cores, whereas, the upper part of two cores decreases less than 70% (Figs. 3 and 4). Therefore, it can be interpreted as increased inflow of Tsushima Warm Current from the glacial to interglacial periods. This is similar to the result (> 80%) reported by Brunner (1992) in other part of the East Sea.

Be (1960) reported that dextrally-coiled specimens of *N. pachyderma* occur between 9°C and 15°C. Ericson (1959) and Be and Hamlin (1967) referred that the boundary between dextral and sinistral populations approximates the 7.2°C isotherm.

Both Core 941006 and Core 941013 are situated in oceanographic zone showing cold and high productivity (reflecting the abundances of planktonic foraminifera) between 8°C and 12°C (Fig. 5). As the result, the study area is characterized by dominant occurrence of sinistral *N. pachyderma* throughout the two cores.

CONCLUSIONS

Quantitative analyses of the late Quaternary planktonic foraminifera from two piston cores in the Ulleung Basin reveal the following.

More than 90% of the late Quaternary planktonic foraminifera assemblages in the Ulleung Basin are dominated by *Neogloboquadrina pachyderma* and *Globigerina bulloides* with minor amount of *Neogloboquadrina dutertrei*. The benthic foraminifera rarely occurred throughout the cores.

Overall sinistrally-coiled specimens of *N. pachyderma* representing cold water temperature occurred more abundantly than dextrally-coiled *N. pachyderma* in two cores. Moreover, the sinistrally coiled assemblages are common at lower part of both cores suggesting the restriction of the Tsushima Warm Current into the East Sea during the glacial period when the sea level stood lower.

G. bulloides, a species representative of upwelling conditions, shows more abundant occurrence at Core 941013 than Core 941006. This implies that Core 941013 is more influenced by upwelling than Core 941006. Especially, Site 941013 is situated at the high productivity zone as evidenced by abundant occurrences of *G. bulloides*.

Upper parts (above 240 cm and 160 cm downcore in Core 941006 and Core 941013, respectively) of the two cores are characterized by rare and barren zone of planktonic foraminifera. This interval is interpreted as evidence of severe dissolution by fluctuation of CCD. In addition, fragmentation of planktonic foraminifera shows higher percentage at upper part than at lower part of two core due to a rise of CCD from the late Pleistocene to Holocene. Therefore, the downcore variation of foraminiferal assemblages suggest paleoceanographic change in the Ulleung Basin, East Sea during the late Quaternary.

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