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Younger Dryas Type Climatic Oscillation in the East Sea

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The latest-Quaternary paleoceanographic history of the Ulleung Basin, the East Sea (the Sea of Japan) is reconstructed on the base of planktonic foraminifera, oxygen and carbon isotopes, and accelerator mass spectrometer radiocarbon (AMS-^{14}C) data from two cores. Sinistral populations of *Neogloboquadrina pachyderma* are dominant during the last glacial period while dextral forms of *Neogloboquadrina pachyderma* are abundant in the Holocene. An abrupt increase in $\delta^{18}O$ values in both cores that began about 11 ka B.P. may indicate the Younger Dryas cooling episode. A low-salinity event, marked by light $\delta^{18}O$ values (0−1‰), is observed before the Younger Dryas event. As previous works suggested, the low-salinity event is probably due to the freshening of surface water caused by fresh water input from Huang Ho river and/or the excess of precipitation over evaporation. The lowest salinity water in the Ulleung Basin was probably continued from approximately 18 ka B.P. to 15 ka B.P. The $\delta^{18}O$ values have gradually decreased since the Younger Dryas as a result of the continuous inflow of the warm Tsushima Current into the East Sea.

INTRODUCTION

The East Sea is a semi-isolated marginal sea connected to the adjacent marginal seas and the Pacific through four sills (Fig. 1). Paleoceanographic studies of the East Sea (Koizumi, 1970, 1985, 1989; Ujiie and Ichikura, 1973; Oba *et al.*, 1980, 1991; Gorbarenko, 1983, 1993; Woo *et al.*, 1995; Park *et al.*, 1997; Kim, 1998; Kim *et al.*, 1998) have revealed that the sea has experienced large environmental changes from glacial to interglacial due to the silled straits. The eustatic sea level lowering during the last glacial maximum severely restricted or completely blocked the inflow of the warm Tsushima Current into the East Sea, leading to a considerable drop of the sea-surface temperature (Oba *et al.*, 1991). Gorbarenko (1993), based on stable isotopic data from planktonic foraminifera, suggested the possibility of freshening of surface water mass during the last glacial period.

During the postglacial period, the opening of the Korea Strait and the inflow of the warm Tsushima Current into the East Sea led to a drastic change in oceanographic conditions in the sea. The replacement of sinistrally-coiled *Neogloboquadrina pachyderma* by dextrally coiled forms and the occurrence of warm-water planktonic foraminiferal fauna suggest that the inflow of the warm Tsushima Current began about 11 ka B.P. (Ujiie and Ichikura, 1973).

In this study, we investigate the latest Quaternary paleoceanographic history of the Ulleung Basin in the southern East Sea using stable isotopic data recorded in planktonic foraminifera.

MATERIALS AND METHODS

Two locations, Sites 941006 (37°00'07"N, 131°00' 07.3"E; water depth of 2170 m) and 941013 (36°45' 02.8"N, 131°29'82.3"E; water depth of 1960 m), were selected for sediment coring because they are located in areas generally free from significant input of terrigenous sediments (turbidity current). Cores from these sites contain sediment layers with no erosional surfaces or hiatus indicating continuous sediment deposition. Microfossils are also well preserved in these cores (Kim *et al.*, 1998).

Oxygen and carbon stable isotope analyses were performed for planktonic foraminifera specimens. Planktonic foraminifera specimens were wet-sieved using a 63 μm screen. Then, a total of 20 to 30 specimens per sample with sizes ranging from 150 to 250 μm were picked for two abundant species: *Neogloboquadrina pachyderma* (sinistral) and

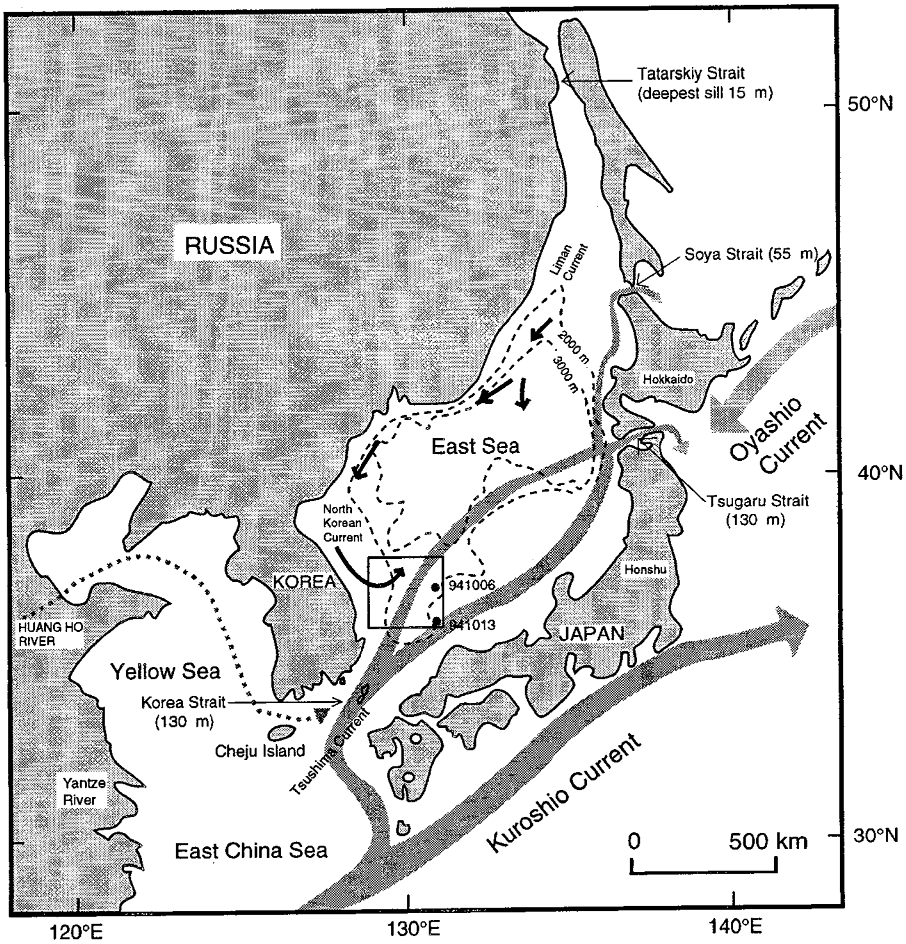

Fig. 1. The present current system in and around the East Sea. Core locations are indicated by dots. Sill depths of the straits are shown in meters. The study area marked in a box.

Globigerina bulloides. The specimens were cleaned ultrasonically, dried, and roasted under vacuum at 375°C for one hour to remove organic matter. Then, samples were reacted at 90°C with 100% phosphoric acid in an automatic carbonate preparation device (Kiel device) attached to a Finnigan MAT 252 mass spectrometer in the Department of Geology and Geophysics at the Woods Hole Oceanographic Institution, U.S.A. Analysis of four standards: the international standard (NBS-19) and three in-house standards (Carrera Marble, B-I marine carbonate, and *Atlantis* 2 deep sea coral) showed that reproducibility of measurements on the mass spectrometer is 0.07‰ for $\delta^{18}O$ and 0.03‰ for $\delta^{13}C$. All isotopic data are expressed using standard δ notation in permil relative to Pee Dee Belemnite (PDB) carbonate standard.

Accelerator mass spectrometer (AMS) radiocarbon ages were measured using 1500 specimens of *Neogloboquadrina pachyderma* and *G. bulloides*. AMS-^{14}C was analyzed at the Geochron Laboratories of Krueger Enterprises, Inc., U.S.A.

RESULTS AND DISCUSSION

Sediments in both cores are mainly composed of homogeneous and bioturbated clay and mud, well laminated mud, and bioturbated sandy mud (Kim, 1998; Kim *et al*., 1998). The cores contain a well-documented tephra layer (210−215 and 109−130 cm downcore depth at Sites 941006 and 941013, respectively) equivalent to the Ulleung-Oki eruption (*ca*. 9.3 ka B.P.). The tephra layer along with AMS ages helped estimate the sediment accumulation rate in this study.

The dominant planktonic foraminiferal species from the upper Quaternary sediment are *Neogloboquadrina pachyderma* and *G. bulloides* with a minor amount of *Neogloboquadrina dutertrei* and *Globigerinoides ruber*. Planktonic foraminifera are abundant in the lower part of the cores. Planktonic foraminifera fragmentation, which is a proxy measure of carbonate dissolution, generally increases from the lower part of the cores ($<10\%$) to the top ($>90\%$) of the cores, suggesting a shoaling calcite

Table 1. Oxygen and carbon isotopic data (permil) for sinistral *Neogloboquadrina pachyderma* and *Globigerinoides bulloides* at Site 941006

Depth (cm)	Oxygen Isotope	Carbon Isotope	Species used
69–71	2.46	−0.85	*G. bulloides*
139–141	2.98	−0.52	*G. bulloides*
169–171	1.33	0.34	*N. pachyderma*
229–231	3.60	−0.52	*G. bulloides*
239–241	3.24	−0.64	*G. bulloides*
249–251	3.06	−0.66	*G. bulloides*
259–261	0.71	0.20	*N. pachyderma*
279–281	1.48	−1.34	*N. pachyderma*
299–301	0.43	0.10	*N. pachyderma*
309–311	0.94	0.50	*N. pachyderma*
319–321	0.43	0.13	*N. pachyderma*
329–331	1.25	0.13	*N. pachyderma*
339–341	0.52	0.05	*N. pachyderma*

Table 2. Oxygen and carbon isotopic data (permil) for sinistral *Neogloboquadrina pachyderma* and AMS-^{14}C ages at Site 941013

Depth (cm)	Oxygen Isotope	Carbon Isotope	Age (yr)
21–23	2.63	−0.08	
151–153	3.52	−0.10	
161–163	2.49	0.06	
171–173	2.31	0.16	13,220± 60
181–183	1.92	−0.31	
191–193	2.07	−0.57	
201–203	2.01	−0.82	
211–213	1.64	−0.37	
221–223	0.09	0.03	
231–233	0.64	−0.03	
241–243	0.61	0.05	
251–253	0.26	0.19	
271–273	0.05	0.32	
281–283	0.10	0.04	
291–293	0.20	0.35	
301–303	−0.07	0.13	
311–313	1.81	0.26	18,940±100
321–323	1.04	0.18	

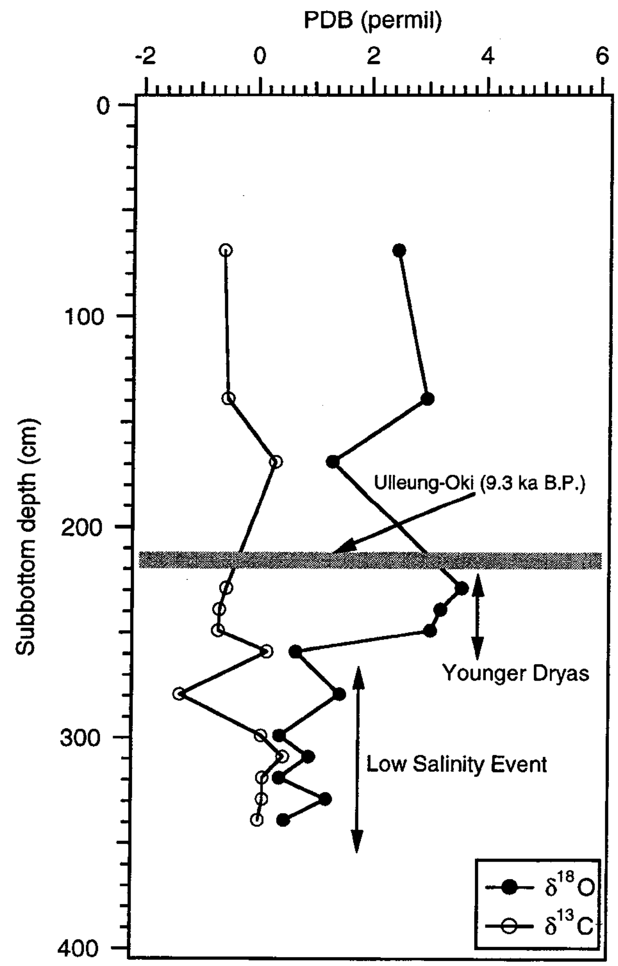

Fig. 2. Stratigraphic variations of oxygen and carbon isotopic values of planktonic foraminifera from Site 941006. Tephra layer (Ulleung-Oki eruption, 9.3 ka B.P.) is marked around 215 cm depth.

compensation depth (CCD) since the latest Quaternary (Kim *et al.*, 1998).

Planktonic foraminifera oxygen and carbon isotopic values for the two cores are listed in Tables 1 and 2 and shown in Figs. 2 and 3, respectively. The stable isotopic data are not available from surface to the depth of 68 cm at Site 941006 and from surface to the depth of 20 cm at Site 941013 due to the absence of planktonic foraminifera.

Oxygen isotopic values for the interval of 229−251 cm at Site 941006 are heavier than those of the above (69−171 cm) and below (259−341 cm) (Fig. 2), suggesting a short cooling event. Studies in the North Atlantic suggested that the deglacial warming proceeded in two steps (Termination 1a and Termination 1b), separated by a major cooling and a southward migration of the polar front between 11.5 ka and 10.5 ka B.P. (Duplessy *et al.*, 1981; Ruddiman and McIntyre, 1981; Bard *et al.*, 1987). This strong cooling is also observed on the European continent and referred to as the Younger Dryas event. The heavy $\delta^{18}O$ values found in the core may represent the Younger Dryas event. The Younger Dryas event in the East Sea was first reported by Park *et al.* (1997). The relatively low values of $\delta^{18}O$ (259−341 cm) below the Younger Dryas event probably correspond to a decrease in salinity caused by fresh water input from the continent (Oba, 1983, 1984; Oba *et al.*, 1991). The $\delta^{13}C$ values of planktonic foraminifera fluctuate between approximately −1.3 and 0.5‰.

At Site 941013, $\delta^{18}O$ values increase from 221 to 151 cm of the core (Fig. 3), probably reflecting the Younger Dryas. The $\delta^{13}C$ values compared to Site 941006 become significantly enriched throughout the core, ranging from −0.9 to 0.3‰. The decrease

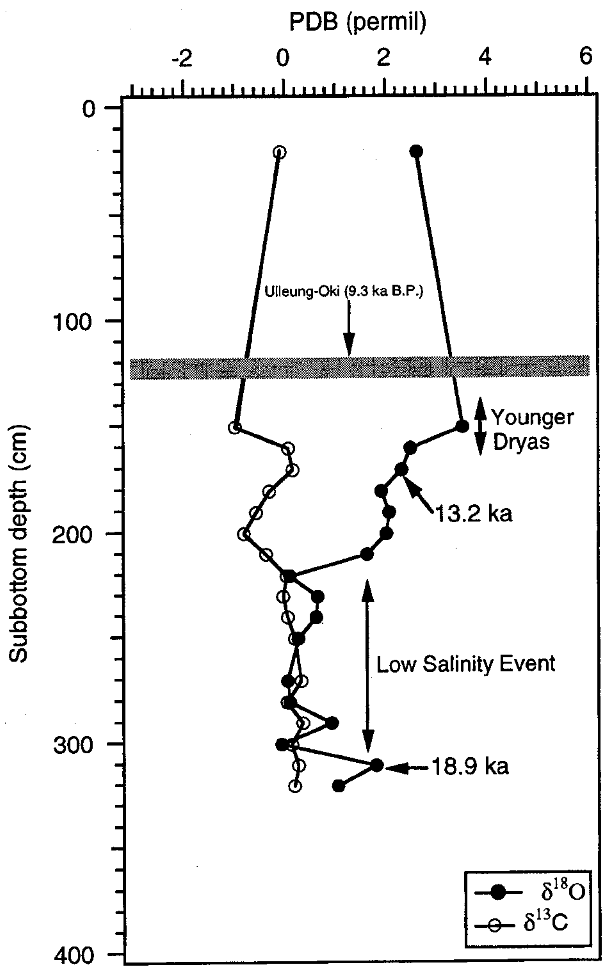

Fig. 3. Stratigraphic variations of oxygen and carbon isotopic values of planktonic foraminifera from Site 941013. Two AMS radiocarbon ages (in ka) are shown.

in $\delta^{13}C$ values from about 160 cm to 200 may be due to an increased input of terrigenous organic matter during a sea level fall (below 200 cm downcore depth).

The low $\delta^{18}O$ values found in the lower parts of both cores (Figs. 2 and 3), appear to correspond to the last glacial period. Similar isotopic curves have been reported in other parts of the East Sea (Oba *et al.*, 1991; Keigwin and Gorbarenko, 1992; Gorbarenko, 1993; Park *et al.*, 1997; Kim, 1998). These low $\delta^{18}O$ values during the glacial period may be related to the freshening of surface water caused by fresh water input from the continent (Oba *et al.*, 1991; Keigwin and Gorbarenko, 1992) and/or precipitation over evaporation (Keigwin and Gorbarenko, 1992; Gorbarenko, 1993). Keigwin and Gorbarenko (1992) suggested that the lowest salinity in the East Sea may have occurred as recently as 15 ka B.P. to 20 ka B.P. when the sea level was the lowest. In this study, the lowest $\delta^{18}O$ values occurred at intervals from approximately 18 ka B.P. to 15 ka B.P. based on the AMS-^{14}C ages and oxygen isotopic data of Site 941013 (Fig. 3).

The probable fresh water source to the Ulleung Basin is the Huang Ho River in China (Oba, 1983, 1984; Oba *et al.*, 1991). The mouth of the Huang Ho River advanced with the glacial lowering of sea level and shifted from the west side of the Cheju Island (Fig. 1) to the east side of the island when sea level dropped deeper than the present sea level (Chang and Cheong, 1987). The shift of the river mouth may have resulted in the inflow of low-salinity water, causing the abrupt decrease of $\delta^{18}O$ values in the Ulleung Basin (Figs. 2 and 3). Kim (1998) using the isotopic data of the cores obtained from the Ulleung Basin also proposed the inflow of the Huang Ho River into the Ulleung Basin. The decrease in the surface water salinity during the glacial period is also confirmed by diatom species indicating a low salinity and fresh water (Koizumi, 1973).

The East Sea is located in the southern part of the northern high-latitude belt where the quantity of precipitation predominates over evaporation (Gorbarenko, 1993). Assuming restricted exchange between the East Sea and the open ocean, the modern excess of precipitation over evaporation in the East Sea may be sufficient to account for glacial lowering of sea-surface salinity (Keigwin and Gorbarenko, 1992). Thus, the excess precipitation may be also responsible for the decrease of $\delta^{18}O$ values during the last galcial period.

Sediment accumulation rates estimated from AMS data and the tephra layer (*ca.* 9.3 ka B.P.) are 12.8 cm/ka and 24.5 cm/ka, at 120−170 cm and 170−320 cm subbottom depth in the two cores, respectively (Fig. 4). Therefore, we suggest that the beginning of the Younger Dryas in the Ulleung Basin is approximately 11 ka B.P. The duration of the Younger Dryas event, however, cannot be estimated due to the absence of calcareous microfossils above 150 cm subbottom depth (Kim *et al.*, 1998). Oxygen isotopic value ($\delta^{18}O$) gradually decreases since the Younger Dryas event as a result of a continuous inflow of the warm Tsushima Current (Figs. 2 and 3).

CONCLUSIONS

The last glacial period was dominated by sinistral populations of *Neogloboquadrina pachyderma*

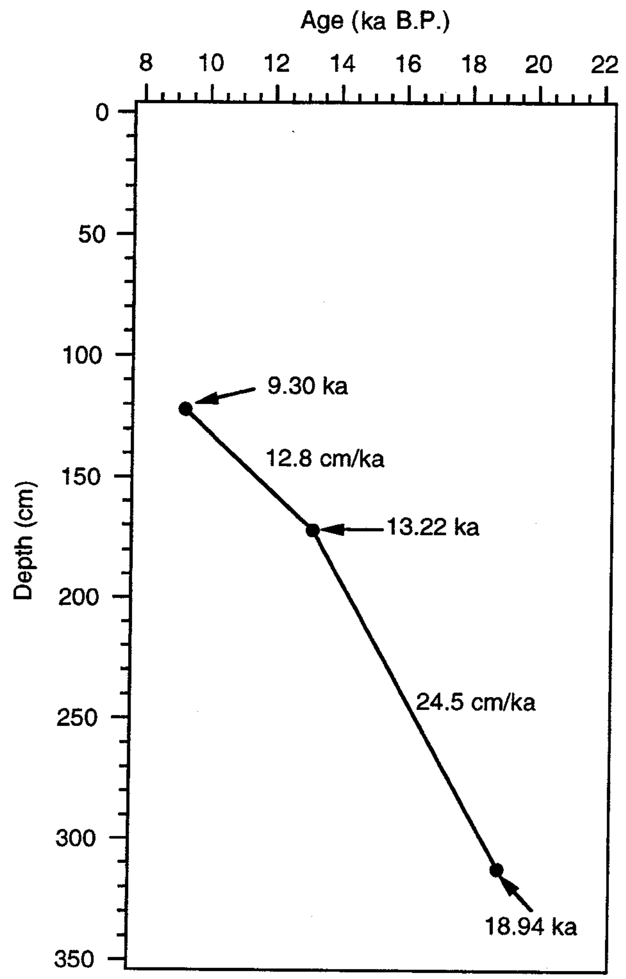

Fig. 4. Sediment accumulation rates at Site 941013 estimated from AMS ages and Ulleung-Oki tephra layer.

representing cold water. On the other hand, dextral forms of *Neogloboquadrina pachyderma* indicating relatively warm water became abundant at the beginning of the Holocene. Latest-Quaternary, pre-Holocene paleoceanographic history of the Ulleung Basin is characterized by two distinct events: low salinity event and the Younger Dryas event. The low salinity event observed below the Younger Dryas event (δ^{18}O values more than 3‰) is marked by the light δ^{18}O values (0−1‰), indicating the low surface salinity caused probably by the fresh water input from the Hunag Ho river and/or the excess precipitation over evaporation. AMS-^{14}C data and estimated sediment accumulation rates suggest that the Younger Dryas began approximately 11 ka B.P. Oxygen isotopic (δ^{18}O) values have gradually decreased since the Younger Dryas event as a result of the continuous inflow of the warm Tsushima Current into the East Sea.

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