

## Major Element Changes in the Upper Quaternary Sediment of the East Sea (Sea of Japan): Their Implications for the Onset of Holocene

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Two piston cores (94PC-2 and 95PC-4) taken from the East Sea (Sea of Japan) are studied to evaluate the paleoceanographic changes and its interaction with climatic variation. The bulk geochemistry of the non-biogenic fractions of 54 sediment samples is determined using X-ray fluorescence. Four geochemical stratigraphic units at both core sediments are recognized based on the variations in major element concentration. These chemical stratigraphic units correspond well with the sedimentological and paleontological facies. Source materials are considered as basic and/or intermediate rocks judging from silica content. A distinctive boundary around 11 kyr may correspond to Younger Dryas event. The switch of most major elements at this level and the distinctive changes in concentration of typical terrigenous elements ( $\text{TiO}_2$  and  $\text{Al}_2\text{O}_3$ ) are the strong evidence for the difference in sources of terrigenous materials. The weathering indices exhibit high degree in Core 94PC-2 and low degree in Core 95PC-4. The changes in weathering degree can be distinguished by the lowest value occurred at 11 kyr in Core 94PC-2 and by a gradual decrease from top to bottom in Core 95PC-4. The profiles of potassium and sodium exhibit specific excursions between the Holocene and the late Pleistocene. This implies that sediments of the two cores originating from different sources with different weathering degrees. The distinct two-group distributions in  $\text{K}_2\text{O}/\text{CaO}$  vs.  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  also support the difference in provenance of aluminosilicate materials at the boundary of 11 kyr. Thus, supply patterns of terrigenous materials are stable in Holocene and more complicated in the last glacial period.

### INTRODUCTION

The East Sea (Sea of Japan) is a typical inactive back-arc basin and is characterized by a semi-enclosed marginal sea with four shallow straits: Tsugaru (130 m deep), Korea (Tsushima) (130 m deep), Soya (55 m deep) and Tatarskiy (15 m deep) straits, respectively. Its oceanographic conditions were mainly affected by the glacio-eustatic sea-level changes during glacial and interglacial periods (Oba *et al.*, 1991; Tada *et al.*, 1992). Variations of sediment composition in the East Sea, especially the variations in detrital components, are in turn highly linked with oceanographic and climatic changes during the glacial/interglacial periods (*e.g.* Dersch and Stein, 1994). Thus, sediment composition and its chemical components can provide the records of climatic variation during the periods.

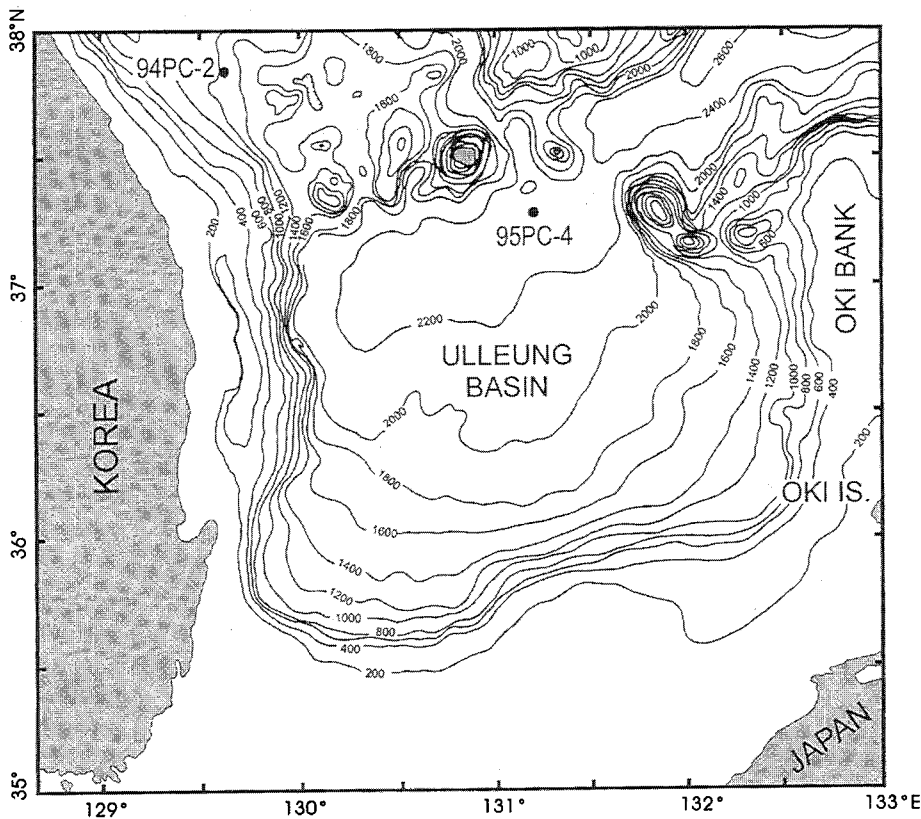
Numerous studies have been performed to understand the paleoceanographic changes in the East Sea (*e.g.*, Oba *et al.*, 1991; Minai *et al.*, 1992; Tada *et*

*al.*, 1992; Dersch and Stein, 1994). However, there have been relatively few reports concerning the variations of chemical composition of sediments related to climatic changes.

In this paper, major element data, chemical index of weathering (CIW) and chemical index of alteration (CIA) are used to reconstruct interrelation between chemical sediment composition and climatic variations in the East Sea during the Holocene and the glacial periods. Variations of chemical composition of sediment are also discussed in terms of the change of sediment provenance.

### METHOD AND MATERIALS

Two piston cores (94PC-2 and 95PC-4) studied here were collected during the '94 and '95 cruises by the R/V *Onnuri* of Korea Ocean Research and Development Institute. The cores were taken from the Korea Plateau (Core 94PC-2, water depth of 1302 m) and the northern part of the Ulleung Basin



**Fig. 1.** Map of core locations and bathymetry of the study area. Contours are in meters.

(Core 95PC-4, water depth of 2197 m) (Fig. 1). Piston core sediments were bisected and a half of the core sediment was analyzed for the water content and then dried at 105°C for more than 24 hr. After drying, all samples were powdered using *retsch* for more than five minutes and analyzed using X-ray fluorescence (XRF-Philips/PW 1480) to determine ten major elements ( $\text{SiO}_2$ ,  $\text{TiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{MnO}$ ,  $\text{CaO}$ ,  $\text{Na}_2\text{O}$ ,  $\text{MgO}$ ,  $\text{K}_2\text{O}$  and  $\text{P}_2\text{O}_5$ ) at the Korea Basic Science Institute. The major element data are considered accurate within 5% for MgO and 2% for other elements. All of major elements exhibit errors of < 3% for representative duplicate experimental results. The calculation of CIW is quoted from Harnouis (1988) as follow:

$$\text{CIW} = \left[ \frac{\text{Al}_2\text{O}_3 (\%)}{\{\text{Al}_2\text{O}_3 (\%) + \text{CaO} (\%) + \text{Na}_2\text{O} (\%)\}} \right] \times 100.$$

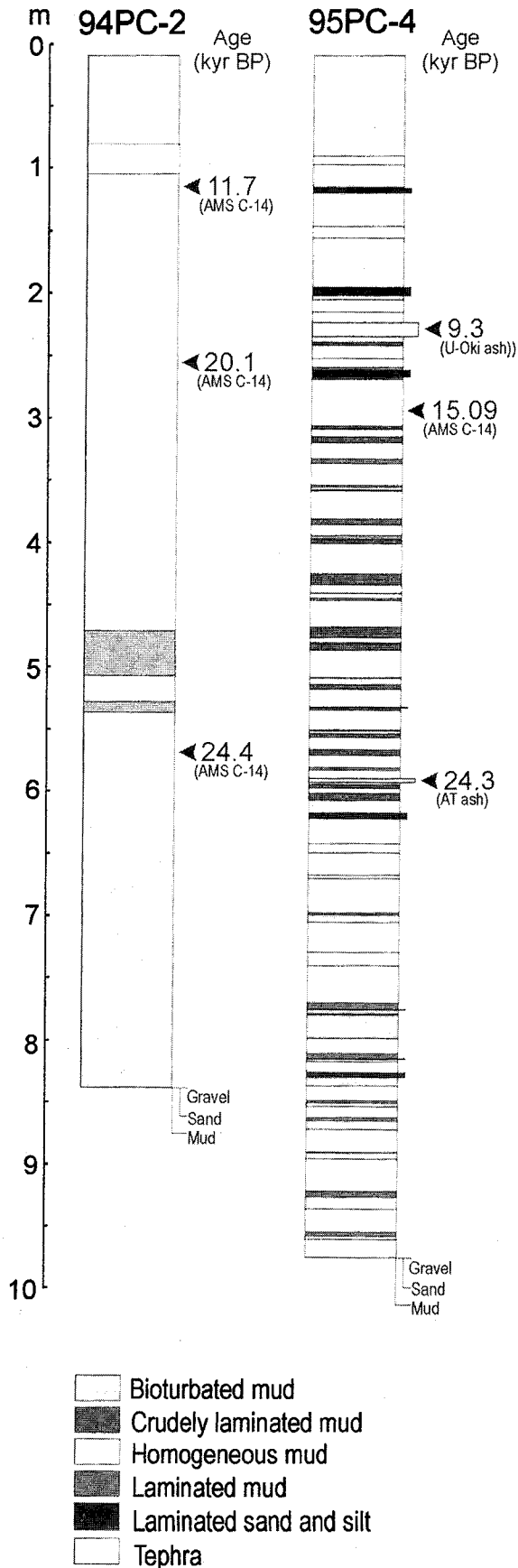
The CIA (Nesbitt and Young, 1982) is defined as a combination of several mobile and immobile elements as follow:

$$\text{CIA} = \left[ \frac{\text{Al}_2\text{O}_3 (\%)}{\{\text{Al}_2\text{O}_3 (\%) + \text{CaO} (\%) + \text{Na}_2\text{O} (\%) + \text{K}_2\text{O} (\%)\}} \right] \times 100.$$

### GENERAL LITHOSTRATIGRAPHY AND AGE CONTROL POINTS

The preliminary report illustrated that the sediment of the two cores comprises mud (homogenous, bioturbated or thinly laminated), sandy mud, lapilli and ash with several changing boundaries of sedimentary facies (Han *et al.*, 1996). The large fluctuations of carbonate content, organic matter and grain texture (sand, silt and clay) and the repeated occurrence of thinly laminated mud layers support that the sediment has been exposed to complicated sedimentary and oceanographic conditions. It is considered that the occurrence of various types of mud (bioturbated, laminated or homogenous) from both cores can provide detailed information on paleoceanographic changes as far as their deposition was related with climate changes. Sediment in Core 94PC-2 can be classified into four intervals in accordance with grain size, and its lithology can be discriminated into three sedimentary facies in terms of the variation of sedimentary structure (Youn *et al.* 1996). The lithology of Core 95PC-4 TS described in detail by Bahk *et al.* (1997) and simplified lithology of the two cores is shown in Fig. 2.

The accelerator mass spectrometry (AMS)  $^{14}\text{C}$  age of the core 94PC-2 show that the age at the depth 110 cm is 11700 yr BP and that at 250 cm is 20100 yr BP (Park *et al.*, 1997). In Core 95PC-4, AMS  $^{14}\text{C}$



**Table 1.** The age control points and sedimentation rates of the studied cores

	Depth (cm)	<sup>1</sup> Age (kyr)	<sup>2</sup> S.R. (cm/kyr)
	0	0	9.4
	110	11.7 ± 50	16.67
94PC-2	250	20.1 ± 95	74.42
	570	24.4 ± 110	23.5
	847	<sup>3</sup> 36.2	
	0	0	24.19
	225	9.3	
95PC-4	250	14.86	11.23
	290	15.09	32.57
	590	24.3	24.28
	980	<sup>3</sup> 40.36	

<sup>1</sup>Ages of Core 94PC-2 are from Park *et al.* (1997) and those of Core 95PC-4 are from Han *et al.* (1996).

<sup>2</sup>Sedimentation rate.

<sup>3</sup>Ages at the bottom of the cores are determined using the average sedimentation rates from top to 570 and 590 cm, respectively.

age of the depth 250 cm is 14860 yr BP and 310 cm is 15090 yr BP (Han *et al.*, 1996). A distinctive volcanic-ash layer occurs at the depth 570 cm in Core 94PC-2 and at 590 cm in Core 95PC-4. These ash layers are considered as AT (Aira-Tn ash) tuff (Chun *et al.*, 1997), of which the age is considered about 22000 to 24000 yr BP (Murayama *et al.*, 1993; Chun *et al.*, 1997). In this study, we used the age of the AT tuff as 24000 yr BP. The ages at the bottoms of the two cores are determined using average sedimentation rates of each core. Sedimentation rates vary between 9.4 and 74.4 cm/kyr. The age control points and average sedimentation rates of both cores are illustrated in Table 1.

## RESULTS AND DISCUSSIONS

### *Geochemical stratigraphy based on major elements*

Total 28 sediment samples from Core 94PC-2 and 26 sediment samples from Core 95PC-4 were measured on major element contents using XRF.

**Fig. 2.** Columnar logs of the two cores with AMS and tephra ages.

**Table 2.** Relative concentrations (wt. %) of major elements in Core 94PC-2

Depth (cm)	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	TiO <sub>2</sub>	MnO	CaO	MgO	K <sub>2</sub> O	Na <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>	<sup>1</sup> LOI	Total
21	55.03	14.32	5.44	0.60	0.04	0.89	2.61	3.02	3.07	0.12	14.32	99.46
45	55.80	13.97	5.35	0.58	0.04	1.01	2.52	2.92	2.99	0.11	14.45	99.74
67	55.51	13.87	5.28	0.59	0.04	1.20	2.52	2.94	3.17	0.11	14.22	99.45
89	53.05	14.22	5.54	0.63	0.04	0.67	2.44	2.97	3.06	0.12	16.44	99.18
110	50.02	13.62	5.11	0.61	0.05	7.62	2.65	2.49	2.29	0.13	13.77	98.36
138	55.04	15.98	6.29	0.75	0.05	1.11	3.04	3.58	2.40	0.12	11.09	99.45
158	55.43	15.78	6.15	0.75	0.06	1.01	3.03	3.52	2.47	0.12	11.09	99.41
177	54.79	14.42	5.39	0.67	0.05	0.82	2.61	3.04	2.81	0.12	14.90	99.62
206	55.69	15.78	5.71	0.76	0.06	1.20	3.11	3.37	2.41	0.12	11.39	99.60
236	54.55	16.10	5.84	0.76	0.05	0.86	2.96	3.40	2.50	0.13	12.46	99.61
269	53.66	15.70	5.13	0.72	0.05	0.76	2.66	3.25	2.70	0.11	14.65	99.39
315	54.31	15.27	5.83	0.73	0.05	0.79	2.75	3.21	2.55	0.12	13.95	99.56
367	54.88	15.13	5.39	0.70	0.04	0.79	2.59	3.19	2.58	0.11	13.61	99.01
397	55.68	14.90	5.16	0.68	0.04	0.71	2.51	3.14	2.64	0.11	13.72	99.29
417	53.52	14.98	5.53	0.67	0.04	0.99	2.52	3.10	2.70	0.12	15.43	99.60
456	55.28	15.37	5.90	0.71	0.05	2.67	2.84	3.30	2.34	0.12	10.85	99.43
488	54.29	14.59	5.58	0.72	0.05	2.46	2.80	3.20	2.18	0.11	13.50	99.48
519	54.14	15.10	5.51	0.70	0.05	3.74	2.65	3.15	2.46	0.12	10.23	97.84
560	55.06	15.20	5.35	0.74	0.05	1.24	2.73	3.23	2.45	0.12	13.04	99.21
588	54.95	15.27	5.11	0.72	0.04	0.84	2.67	3.19	2.60	0.12	13.94	99.45
629	55.89	14.60	4.88	0.68	0.04	0.84	2.42	3.00	2.65	0.11	14.54	99.65
669	55.24	15.23	5.29	0.69	0.04	0.80	2.49	3.13	2.68	0.11	13.85	99.55
696	56.42	15.70	6.18	0.74	0.05	0.96	2.82	3.36	2.52	0.12	11.11	99.98
715	56.48	15.60	6.34	0.73	0.05	1.30	2.78	3.32	2.33	0.12	10.59	99.64
756	55.15	15.44	6.23	0.71	0.05	2.66	2.83	3.29	2.25	0.12	10.96	99.69
797	56.67	15.95	6.51	0.76	0.06	1.01	3.00	3.45	2.17	0.12	9.69	99.39
817	56.24	15.80	6.36	0.75	0.05	1.18	2.90	3.47	2.21	0.12	10.37	99.45
847	56.34	15.86	6.34	0.77	0.05	1.06	2.85	3.37	2.32	0.12	10.13	99.21

<sup>1</sup>LOI=loss of ignition.

The relative concentrations of major elements in the two cores are shown in Tables 2 and 3, respectively.

**Core 94PC-2:** By means of chemical stratigraphic analysis of major elements, four main geochemical lithologic units are identified (Fig. 3). The significant chemical switching points occur at about 11, 25 and 30 kyr. The first geochemical boundary around 11 kyr is characterized by an abrupt downcore increase in aluminum, iron, titanium, magnesium and potassium concentrations and by a distinctive downcore decrease in sodium content. The intervals of the second and third geochemical boundaries are also characterized by specific excursions of most major elements. The time of the first boundary around 11 kyr matches well with the time of the Younger Dryas cold event in the East Sea (Park *et al.*, 1997). The third geochemical unit seems to correspond to the low-salinity event in the East Sea as reported by Oba *et al.* (1991). In addition, large fluctuation of most major elements during the glacial period is a notable characteristic in this sediment.

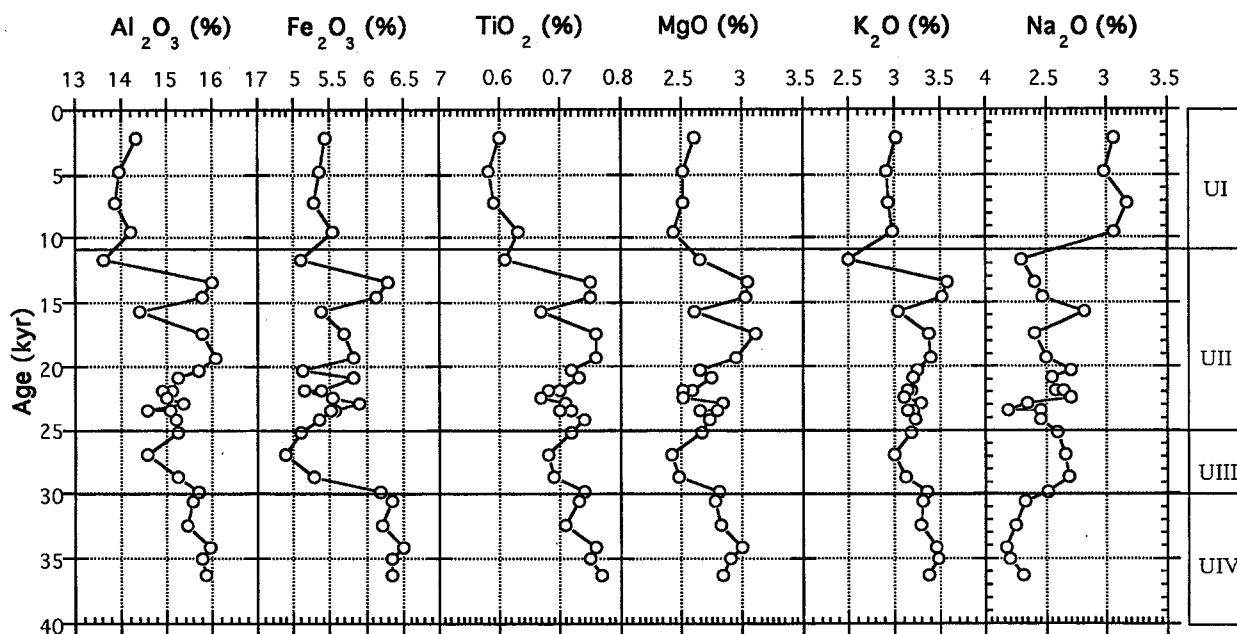
**Core 95PC-4:** Four geochemical stratigraphic units are identified (Fig. 4). Geochemical boundaries are present around 10, 25 and 32 kyr. Most of chemical components show a similar downcore pattern between 25 and 32 kyr. This concordant variation indicates that sediment in this interval was derived from the same source of materials. This interval seems to correlate with the low-salinity event in the East Sea as shown by Oba *et al.* (1991). The variation of TiO<sub>2</sub>/Al<sub>2</sub>O<sub>3</sub> ratio supports chemical changes at the boundary intervals.

#### *Variation in sediment composition during the Holocene and last glacial maximum (LGM)*

It is well known that accumulation of terrigenous materials is extremely variable between glacial and interglacial periods. Strong wind gradients between high and low latitude allow providing high sedimentation during the last glacial maximum (LGM). Thus, it is expected that the sediment source could be differentiated in accordance to its pathway and

**Table 3.** Relative concentrations (wt. %) of major elements in Core 95PC-4

Depth (cm)	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	TiO <sub>2</sub>	MnO	CaO	MgO	K <sub>2</sub> O	Na <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>	<sup>1</sup> LOI	Total
16	53.35	14.45	5.65	0.62	0.07	0.64	2.65	3.21	3.88	0.11	14.36	98.99
46	55.77	13.27	5.03	0.57	0.05	0.64	2.49	3.03	3.86	0.10	14.32	99.13
63	54.15	14.83	5.23	0.62	0.06	0.80	2.40	3.54	4.25	0.12	13.01	99.01
87	54.11	13.12	4.96	0.60	0.12	2.70	2.37	2.71	3.43	0.12	14.65	98.89
136	54.33	15.36	5.07	0.68	0.08	0.91	2.36	3.64	3.82	0.14	12.99	99.38
163	49.74	14.53	5.84	0.72	0.06	0.88	2.71	3.23	4.22	0.16	16.88	98.97
184	50.47	14.75	5.34	0.72	0.06	1.03	2.18	3.27	4.16	0.17	16.79	98.94
230	49.51	14.38	5.21	0.65	0.06	0.97	2.15	3.19	4.25	0.17	18.41	98.95
293	51.81	14.14	5.99	0.65	0.13	3.48	2.57	2.75	2.78	0.12	14.36	98.78
323	51.47	14.14	5.83	0.65	0.09	4.10	2.47	2.68	2.89	0.13	14.18	98.63
377	51.50	14.27	6.11	0.65	0.08	3.27	2.53	2.67	2.74	0.13	15.39	99.34
414	51.15	14.09	5.89	0.64	0.08	3.96	2.48	2.65	2.67	0.13	15.06	98.80
443	51.65	13.68	5.22	0.62	0.06	4.31	2.53	2.49	2.67	0.13	15.45	98.81
497	50.39	13.57	5.35	0.61	0.07	4.89	2.53	2.53	2.62	0.12	14.96	97.64
526	51.97	14.09	5.50	0.64	0.06	3.61	2.59	2.71	2.68	0.13	14.95	98.93
567	51.57	13.75	5.41	0.61	0.06	4.27	2.60	2.67	2.72	0.12	14.69	98.47
609	53.98	14.23	6.11	0.68	0.06	1.69	2.88	3.01	2.78	0.15	12.99	98.56
639	52.53	12.81	4.67	0.58	0.04	4.77	2.44	2.50	2.81	0.14	15.18	98.47
684	51.52	11.80	4.35	0.54	0.04	6.28	2.24	2.34	2.74	0.16	16.35	98.36
725	52.68	12.34	5.09	0.57	0.04	4.64	2.35	2.45	2.77	0.15	14.97	98.05
756	53.88	12.98	5.04	0.60	0.05	3.91	2.45	2.64	2.67	0.14	13.57	97.93
789	56.42	15.07	6.02	0.70	0.07	1.20	2.88	3.21	2.76	0.15	11.07	99.55
828	53.96	12.52	4.55	0.60	0.04	4.00	2.48	2.52	2.61	0.15	15.20	98.63
867	52.29	13.43	5.14	0.64	0.05	3.14	2.66	2.83	2.74	0.14	15.55	98.61
906	52.69	12.85	5.90	0.61	0.06	3.07	2.72	2.82	2.89	0.15	14.91	98.67
937	52.20	11.64	4.67	0.54	0.04	4.93	2.26	2.27	3.00	0.14	16.70	98.39

<sup>1</sup>LOI=loss of ignition.**Fig. 3.** Vertical profiles of major elements in Core 94PC-2.

sedimentological and oceanographic conditions between the Holocene and the LGM. Large fluctuation of carbonate content and grain texture of the two cores (Bahk *et al.*, 1997) may reflect rather

complicated sedimentological and paleoceanographic changes.

In evaluating terrigenous supply, we used the ratio of two typical terrigenous elements, Al and Ti.

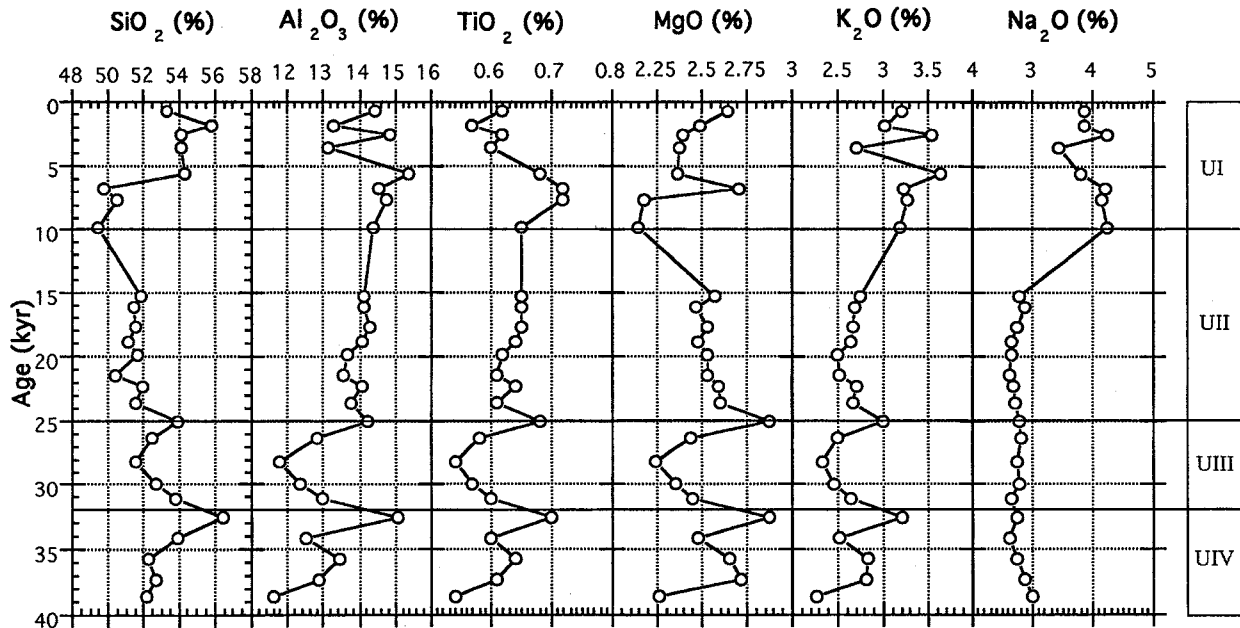


Fig. 4. Vertical profiles of major elements in Core 95PC-4.

It is believed that the variation of the two elements can indicate the differences in provenance of terrigenous materials (Goldberg and Arrhenius, 1958; Spears and Kanris-Sotirios, 1976; Moorby, 1983). As shown in Fig. 5, the  $TiO_2/Al_2O_3$  ratios vary between approximately 0.042 and 0.050. Distinctive variation occurs at the boundary of 11 kyr: a gradual upward decrease in Core 94PC-2 and an abrupt increase in Core 95PC-4. Although a slight fluctuation may be seen between 15 and 25 kyr, the ratio generally ranges between 0.044 and 0.049 before 11 kyr. The boundary of 11 kyr is the most significant point. Thus, it seems that the provenance of terrigenous materials would change at the boundary of 11 kyr. Additionally, large fluctuations of the ratio between 5 and 10 kyr in Core 95PC-4 are another characteristic of this sediment.

The ratio of Ti/Al is higher for sediments deposited in humid area than those deposited under arid condition. The average value of  $TiO_2/Al_2O_3$  is known to about 0.040 in clay sediments (Goldschmidt, 1954), that in continental-lagoonal clay is 0.051 and that in nearshore marine clay is 0.057 (Spears and Kanris-Sotirios, 1976). Bhatt (1974) used this ratio as a climatic indicator. In clastic sequence, the ratio is a function of quartz content and thus of the energy of the depositional environment. Thus, the whole-rock  $TiO_2/Al_2O_3$  ratio could provide information on the energy of the depositional environment. In this study,  $TiO_2/Al_2O_3$  varies

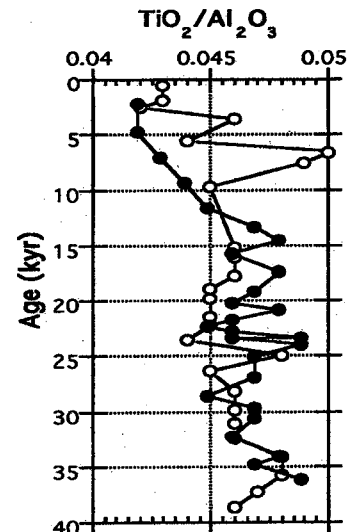


Fig. 5.  $TiO_2/Al_2O_3$  variations. Filled and open circles indicate Cores 94PC-2 and 95PC-4, respectively.

between approximately 0.042 and 0.050 (Fig. 5), suggesting the differences in source materials and in depositional environment. Source rock composition is considered as an important factor controlling sediment composition.

#### *Chemical index of weathering (CIW) and chemical index of alteration (CIA)*

The terrigenous fractions of the total sediments are composed of several different source materials, such as eolian dust and volcanic ash. Thus, sed-

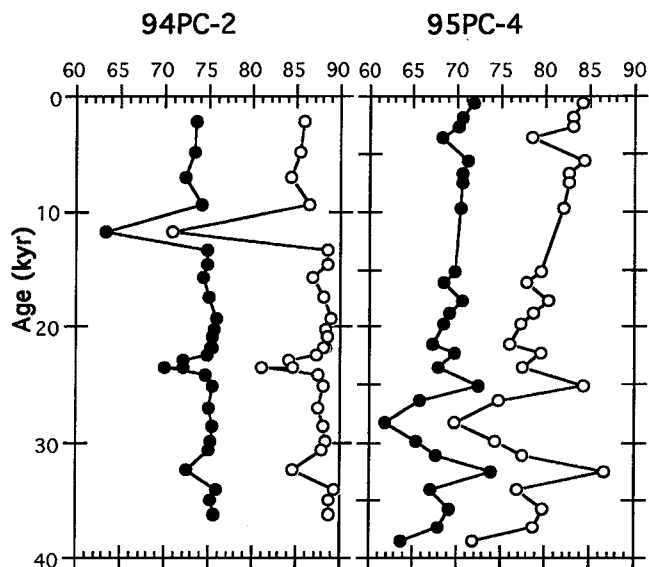


Fig. 6. Chemical index of weathering (CIW) and chemical index of alternation (CIA) of the two cores. Filled circles are CIA and open circles are CIW.

iment component has a powerful key in determining the effect of their sources. To evaluate this, we used the CIA (Nesbitt and Young, 1982) and CIW (Harnouis, 1988) which are used to assess degree of weathering of source area. The difference of CIA and CIW is in treatment of potassium. In this study, potassium is considered as a mobile element although in some cases it is considered as an immobile element (Roaldest, 1972).

The variations of CIA and CIW in the two cores are illustrated in Fig. 6. Higher weathering effect is recognized in Core 94PC-2. Both of CIA and CIW show a slight decrease since 11 kyr with one extremely low value in Core 94PC-2. The gradual downcore decrease in CIA and CIW from top to 15 kyr in Core 95PC-4 is one of the important characteristics. On the whole, Core 95PC-4 shows slightly low values of CIA and CIW. This indicates that the sediment at Core 95PC-4 has been less weathered. It is likely that terrigenous materials in Core 94PC-2 were supplied from Korean peninsula, judging from the short distance from the land. On the other hand, the terrigenous materials at Core 95PC-4 are thought to be transported longer distance from inland China and/or Korean peninsula. Thus, the difference in degrees of CIA and CIW between the cores reflects difference in source area. Extremely low values of CIA and CIW occurred at about 11 kyr at Core 94PC-2, and an interval occurred between 25 and 33 kyr at Core 95PC-4 are

well matched with the Younger Dryas event as suggested by Park *et al.* (1997) and low salinity event in the East Sea resulting from freshwater supply as indicated by Oba *et al.* (1991), respectively. These two distinctive major-element excursions are thought to be a consequence of sedimentological changes resulting from climatic and oceanographic changes.

The variations of major element oxides are plotted with respect to silica contents for all samples (Fig. 7). In Core 95PC-4, silica content ranges from about 49 to 57 wt. % belonging to the range of basic and/or intermediate rock compositions. However, silica content in Core 94PC-2 varies mostly between 53 and 57 wt. % except only one sample, suggesting that most of sediment was derived from intermediate rocks. Silica contents of the two core sediments thus clearly indicate different sources of each sediment. One sample from Core 94PC-2 and three from Core 95PC-4 are excluded in consideration because they have high values of loss of ignition (LOI) and CaO content, which represent dilution effect. In Fig. 7, major elements at Core 95PC-4 are divided into two groups: linear and non-linear distributions with respect to silica (left side) and random distribution (right side). The elements such as aluminum, iron, titanium and manganese seem to have a random distribution with respect to silica variation. Whereas, other remaining elements seem to have a positive or negative linear relationship except for several points. Therefore, chemical variation implies that these four elements (aluminum, iron, titanium and manganese) are sensitive enough to be a paleoenvironmental tracer. However, these elements are usually considered as an immobile elements, suggesting complicated contributions of aluminosilicate materials. In Core 94PC-2, distribution of major elements does not show a good relationship with respect to silicate content. All of the major elements are independent of the silica content. In this case, these elements are considered as bounded material with aluminosilicate lattice, indicating their sensitivity in evaluation weathering history of source area.

Sodium and calcium are considered as typical mobile elements in weathering, whereas potassium is a relatively stable element in weathering. Thus, these three elements are most useful in characterizing the provenance of sediment (Nesbitt and Young, 1982; Harnouis, 1988). As shown in Fig. 8, vertical profiles of potassium and sodium show quite

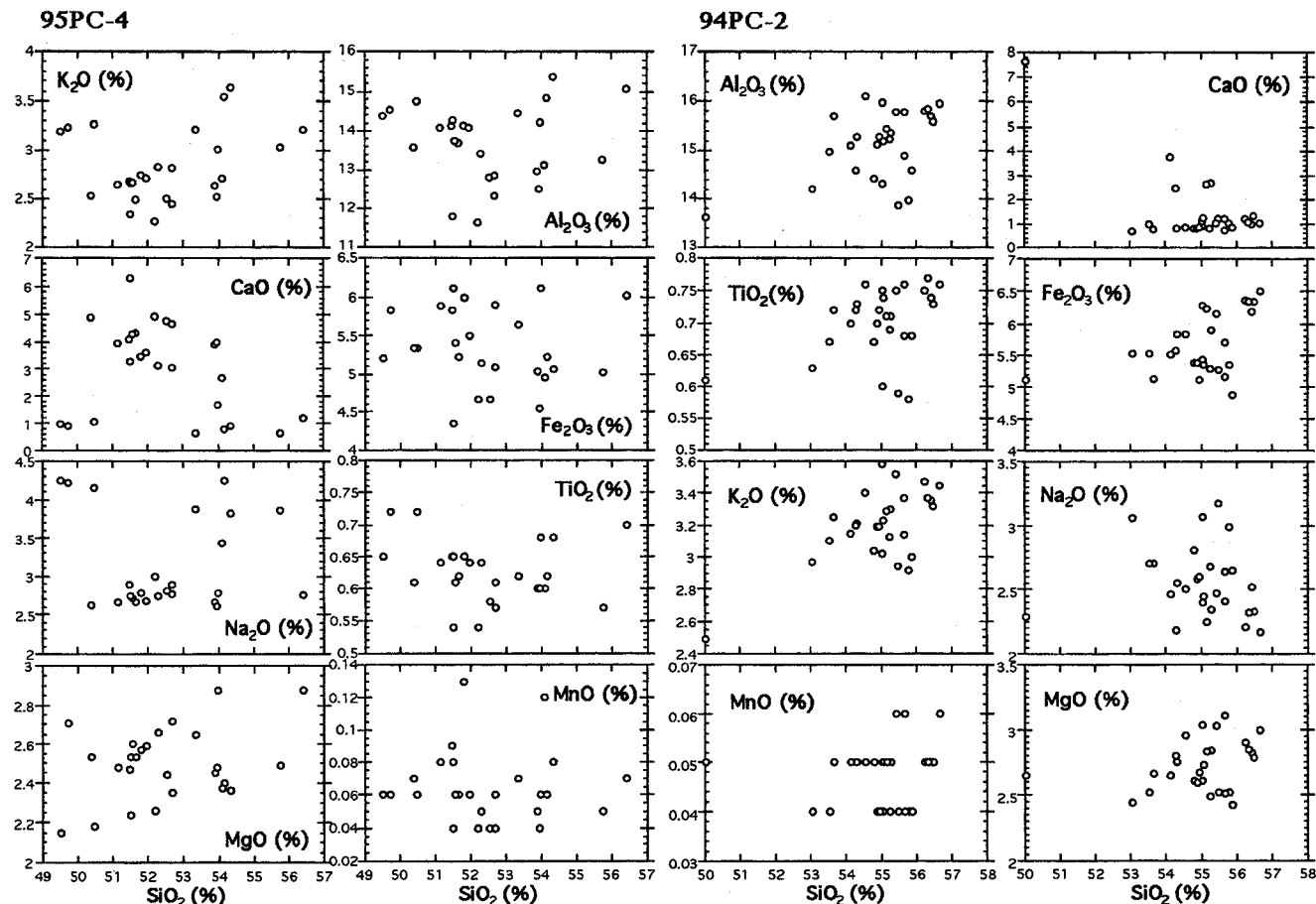


Fig. 7. Variation diagrams of major elements vs. silica content of the two cores.

different excursions at the boundaries of 11 and 15 kyr at Cores 94PC-2 and 95PC-4, respectively. In potassium variation, there appears a sudden drop at the boundary of 11 kyr at Core 94PC-2, whereas gradual upward increasing from 15 kyr is evident at Core 95PC-4. Significant switching at the point 11 kyr indicates that the supply of mobile element (sodium) has increased with a decrease of potassium at that time, probably resulting from the intensified weathering in the source area. In turn, this suggests that the climatic change occurred at that time. Highly fluctuating signals of the two elements since 15 kyr at Core 95PC-4 suggest unstable or multiple sources of sediment supply being related with climatic variation. Random distributions of aluminum, iron, titanium and manganese with respect to silica in Core 95PC-4, which are considered as immobile elements and have usually concordant variation with aluminosilicate detritus, clearly support multiple sources of sediment supply.

As shown in Fig. 9, distinctive two-group distribution is recognized between  $K_2O/CaO$  and  $Na_2O/K_2O$ .

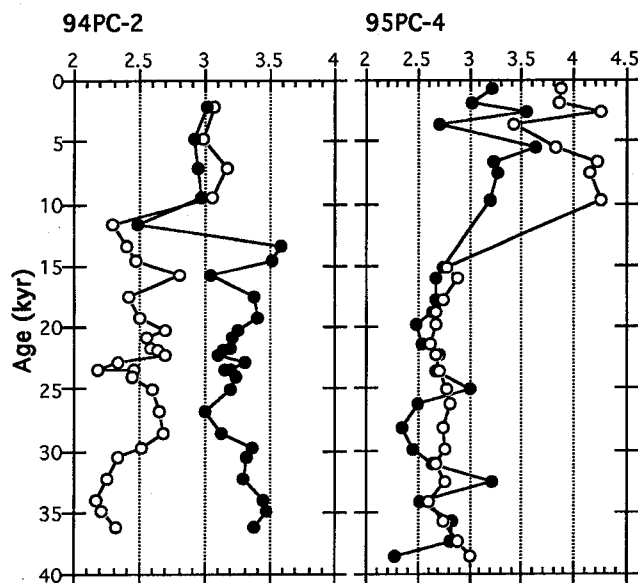


Fig. 8. Vertical profiles of potassium and sodium concentrations (wt. %) in the two cores. Open and filled circles indicate  $Na_2O$  and  $K_2O$ , respectively.

Because  $Na_2O$  is a mobile element in weathering but  $K_2O$  immobile, increasing value of  $Na_2O/K_2O$



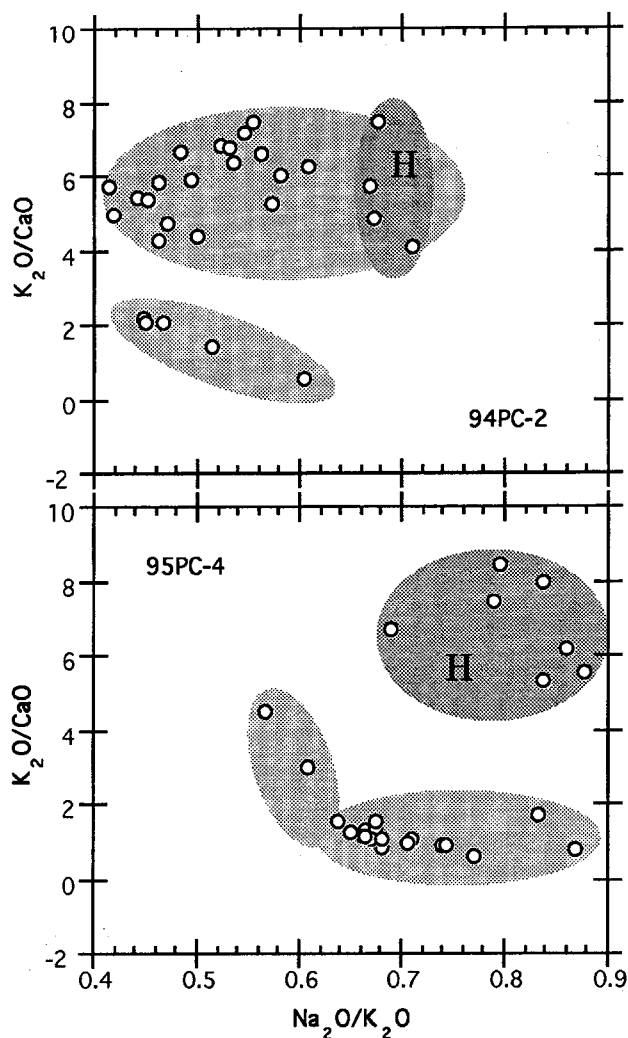


Fig. 9. Scattered distribution of  $K_2O/CaO$  vs.  $Na_2O/K_2O$  at the two cores. H means Holocene sediments.

indicates increasing experiences of weathering. In Core 95PC-4, relatively higher  $Na_2O/K_2O$  values (about 0.55 to 0.9) indicate higher degree of weathering. However, CIA and CIW appear higher in Core 94PC-2. This paradox can be explained by high amounts of potassium concentration in Core 94PC-2.

Points included in Group H (darker mark in Fig. 9) are Holocene sediments. All plots show separated group distribution in terms of  $Na_2O/K_2O$  (Core 94PC-2) and  $K_2O/CaO$  (Core 95PC-4). This indicates that low degree of weathering has been prevailed features during the Holocene period. Differentiation between the Holocene and the remaining parts clearly suggests that the climatic variation should have affected on the sediment supply to the East Sea.

#### *Paleoceanographic environmental changes linked with climatic variations*

Paleoceanography and sedimentology of the East Sea area are linked with climatic changes, which probably affect on sediment composition. In other words, from the detailed investigation of sediment composition, it is possible to evaluate climatic variation during the glacial and interglacial periods.

The chemical aspects of aeolian dust from the Asian continent and the resultant climatic changes have been investigated (e.g. Windom, 1975; Rea and Janecek, 1982; Taylor *et al.*, 1983; Rea, 1990). The loess flux from China is directly linked with climatic variation, which is deduced by marine planktonic oxygen-isotope records and quartz contents in the north Pacific (Hoven, 1989). The results of Dersch and Stein (1994) indicate the dramatic shift of eolian sediment supply into the East Sea, and this would reflect on glacial/interglacial arid/humid climatic cycles in the East Sea. The paleontological aspect of the studied cores was already described by Woo *et al.* (1995). The drastic changes of benthic foraminiferal biofacies of the core sediments are interpreted as a consequence of changes in bottom-water condition owing to the inflow and shut down of Kuroshio warm current. Similarly, Kim *et al.* (1997) reported the repeated changes of oxygen level in the East Sea. Bahk *et al.* (1997) also indicated that cyclic occurrences of thinly laminated mud would relate oceanographic changes coupled with sedimentological changes. Microscopic observation from the sediment of Core 94PC-2 revealed that large amount of quartz is included in total sediment matrix. These detailed studies clearly indicate that the sediment composition in the East Sea has been closely related with the eolian input, thus climatic variations.

The CIW and CIA of the two cores show quite different excursions during glacial and Holocene periods with concordant variation during the Holocene. During the glacial and interglacial periods, large portions of sediment supplied from the inland China were quite variable. The chemical boundary occurred at 100 cm (11 kyr) of Core 94PC-2 corresponds with that of sedimentological boundary and that of Younger Dryas event as suggested by Bahk *et al.* (1997) and Park *et al.* (1997), respectively. Thus it is thought that sediment composition in the East Sea is expect to reflect paleoceanographic and sedimentological variations, and both of the factors have been controlled by the eustatic sea-level changes induced by climatic variations. Thus, this implicated synthetic circumstance of the

East Sea affects on the geochemical variation between the Holocene and the glacial sediments. The two clear events of Younger Dryas and low salinity occurred at about 11 kyr and at interval between 25 and 30 kyr support the synthetic paleoceanographic environmental changes in the East Sea.

Most striking switch of the major elements is presented at about 11 kyr, initiation of Holocene in the East Sea. The occurrence of distinctive fresh-water diatoms is also bounded in this boundary with no variation within all the Holocene period at the central East Sea (Tada et al., 1992). In addition, Tada (1997) suggested that oceanographic changes of the East Sea vary within the scope of global climatic variation, judging from the repetition of gray-colored sediment. Furthermore, gray-colored sediment is well matched with the diatom abundance and the events of Dansgaard Oeschger cycle recorded in Greenland ice core. Stable excursion of major element concentration since the Holocene suggests that oceanographic condition has been in stable condition since 10 kyr. All these sets of data also suggest that sediment composition from the East Sea cores was highly associated with climatic variations. Large fluctuations of major elements excursion also reflect oceanographic change within the scope of global climatic changes.

## CONCLUSIONS

The analytical data reveal following conclusions, considering the paleoceanographic changes and their implications for sediment provenance in the East Sea.

1. The variations of silica suggest that the source of the sediment is intermediate rock in Core 94PC-2, and intermediate/basic rock in Core 95PC-4, indicating difference of provenance.

2. Four geochemical units for Cores 94PC-2 and 95PC-4 are identified on the basis of major element analysis. These geochemical units correspond well with boundaries of sedimentary facies, and this fact implies that the climatic and sedimentary environmental changes are related with geochemical unit boundary.

3. The supply of terrigenous materials is slightly different between the Holocene and the glacial periods. The ratio of two typical terrigenous components of Ti and Al is quite variable between the Holocene and the glacial periods indicating that the

different source of terrigenous materials has been supplied since the last 11 kyr.

4. The variations of chemical index of weathering (CIW) and chemical index of alteration (CIA) are determined to evaluate the degree of weathering. The degree of weathering is higher in Core 94PC-2 with slight change at the boundary of 11 kyr. This difference imply different source of terrigenous materials.

5. Distinctive two-group distributions are recognized in two core sediments. This suggests that the provenance of source materials is different at the boundary of 11 kyr. Thus, climatic variation was considerable at the boundary of 11 kyr. Two geochemical events are well matched with previous works (Younger Dryas event and low salinity event) suggesting clear climatic variations.

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