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Geochemical implication for the maximum flooding of the Jomon transgression in the coastal lagoon sediments, San'in district, SW Japan

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Abstract

The Holocene Jomon transgression was recorded in sediments at the archeological site in the Shimane University, which were deposited in the most inner part of the lagoon. Marine mud deposition in back marsh condition indicates start of the transgression, which is marked by the Kikai–Akahoya tephra of 6300 yrs BP.

Marine muds are characterized by fluctuating values of LOI (loss on ignition), total sulfur contents (TS), and Fe_2O_3/Al_2O_3 ratios and these values are relatively higher than those of the non–marine ones in this section. Rb/K also shows fluctuation, indicating Rb enrichment in under marine condition, probably related to Rb adsorption on clays. The sediments of this section show higher CIA (80～85) suggesting derivation of highly weathered material from the source or sorting of the clays. Ti/Zr shows gradual increase in the Jomon age, suggesting heavy mineral fractionation related to the transgression.

High stand in sea–level probably lasted until middle Jomon age (4500 yrs BP), and consequently effects of fluvial inputs were dominated due to lowered sea–level. Gradual decrease in Al_2O_3/TiO_2, SiO_2/Al_2O_3 and Ti/Zr, and increase in Nb/Y and Zr/Y may be related to the source compositional changes due to the widening of the paddy field in the Yayoi age from 2400 yrs BP.

Key words: Holocene, coastal lagoon, Jomon transgression, organic muds, geochemistry

Introduction

The Jomon transgression was evaluated by examination of the distribution of shell mound in the Kanto Plain, and the level of maximum flooding was two meters higher than that of the present level (Ota and Yonekura, 1987). The environemental change clearly appears in lithology, namely, coarser sediments gradually change into organic black muds. These muds are characterized by higher concentration of total sulfur (TS=over 0.3%) which was traped in sediments under sulfur reducing reaction in anoxic condition (Berner, 1984). Thus TS concentration, and total organic carbon / TS ratios (TOC/TS=over 5) are useful indicator of marine condition (Berner and Raiswell, 1984 ; Sampei et al., 1997). To evaluate sedimentary environment, TS and TOC are utilized in the coastal lagoon sediments, because they had an effect of frequent sea–level changes during the Holocene (Sampei et al., 1997).

The invasion of sea–water into the coastal plain resulted in environmental change which may have reflected in geochemical change of sediments. However, geochemical composition may be influenced by grain size fractionation (Taylor and Mclennan, 1985; McLennan et al., 1993; Garcia et al., 1994), thus muds deposited in back swamp condition were utilized for this analysis. This is because swamp is usually barriered from direct effect of fluvial detritus due to dence vegetation.

Geologic outline of the Nakaumi and Shinjiko lagoons

The Lakes Nakaumi and Shinji have remained as brackish lakes after the last sea–level rise in Jomon age (Tokuoka et al., 1990), which initiated at 10 k yrs BP (Ota and Yonekura, 1987; Ota et al., 1982; Umitsu, 1991) (Fig.1). This transgression was followed by the Yayoi fall in sea–level (2400 yrs BP) (Tokuoka et al., 1990). Sea water invasion was recorded in many archeological sites in the coastal lagoons, where black muds with higher concentration of total sulfur and total organic carbon were formed (Nakamura and Tokuoka, 1997; Sampei et al., 1996). Sediments deposited during the Jomon transgression is called Shinjiko Formation in the coastal region of Lake Shinji (Tokuoka et al., 1995), and gradually changed into coarser clastics (Tokuoka et al., 1990).

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The previous lagoonal environment was probably influenced by fresh water to produce brackish condition, and coastal plains were expanded in this region (Fig. 1).

The examined section of the archeological site in the Shimane University is situated in the most inner part of the Shinjiko lagoon, and the Tertiary basement rocks are distributed. The Shinjiko Formation overlaps the Tertiary rocks.

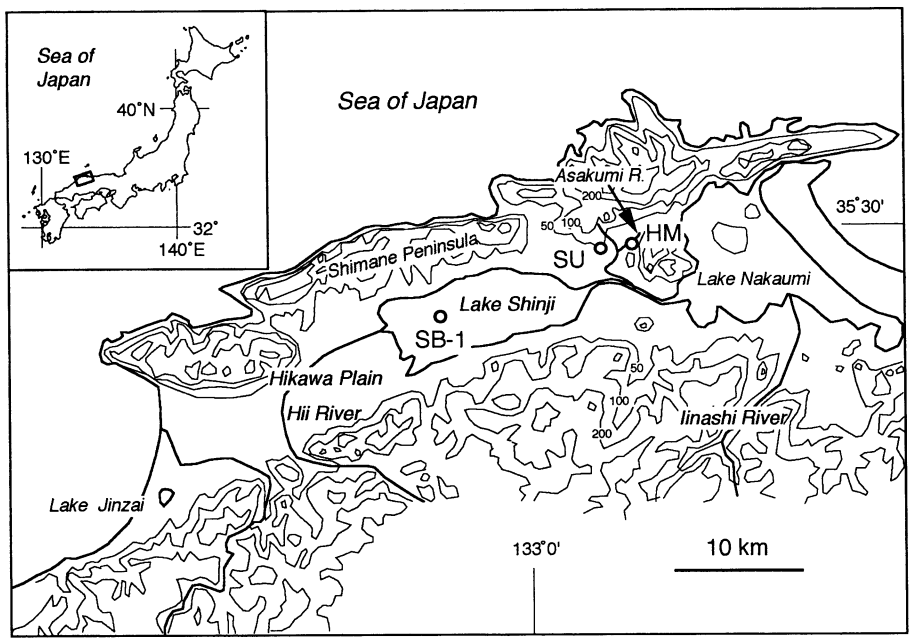

Fig. 1 Location of SU (Shimane University) section and topography of Shinji–Nakaumi lagoon, San'in district of Southwest Japan. Locations of HM section (Haranomae archeological site) of the Asakumi River and SB–1 of Shinjiko boring samples are also shown.

Mud samples of the Shimane University

Mud samples were collected at an archeological site in Shimane University (SU section). The 3.5 m section is characterized by the occurrence of alternating beds of black and white–gray muds (Figs. 2, 3). The muds unconformably overlies basic Tertiary pyroclastics. The surface of the unconformity dips 20 degrees to the south, and undulates.

Stratigraphy

According to lithology and archeological material, the column is subdivided into 7 beds in ascending order (Figs 4 and 5). Bed 7 muds show gray in color, while bed 6 consists of alternation of black muds and white muds with individual beds several cm thick. Beds 5 and 4 are white and black muds, respectively, and bed 3 muds are yellow and also has sands. Muds at this site are rich in higher plant remains, especially so far black muds. Diatoms occur in both black and white beds. Considering dominance of plant remains, absence of coarser clastics, and low sedimentation rates, muds in this section are inferred to have been deposited in back marsh conditions with influence of marine invasion shown by total sulfur contens as discussed later.

Age

The K–Ah tephra (6300 yrs BP) is intercalated between beds 7 and 6. Bed 3 yielded middle Yayoi remains (2100 yrs BP), and intercalation of coarse clastics may be related to lowered sea–level in Yayoi age.

Slow sedimentation rate (SR=0.08 cm/yr) after 6300 yrs BP can be inferred, which is significantly lower than that of Lake Nakaumi (0.11～0.37 cm/y) after 6300 yrs BP as determined by Sampei et al. (1996).

Sample preparation and analytical method

Mud samples from the SU section were collected at 10 cm intervals (n=37) for analysis. Dried samples (at 110℃ for 24 hours) were utilized for analysis of total

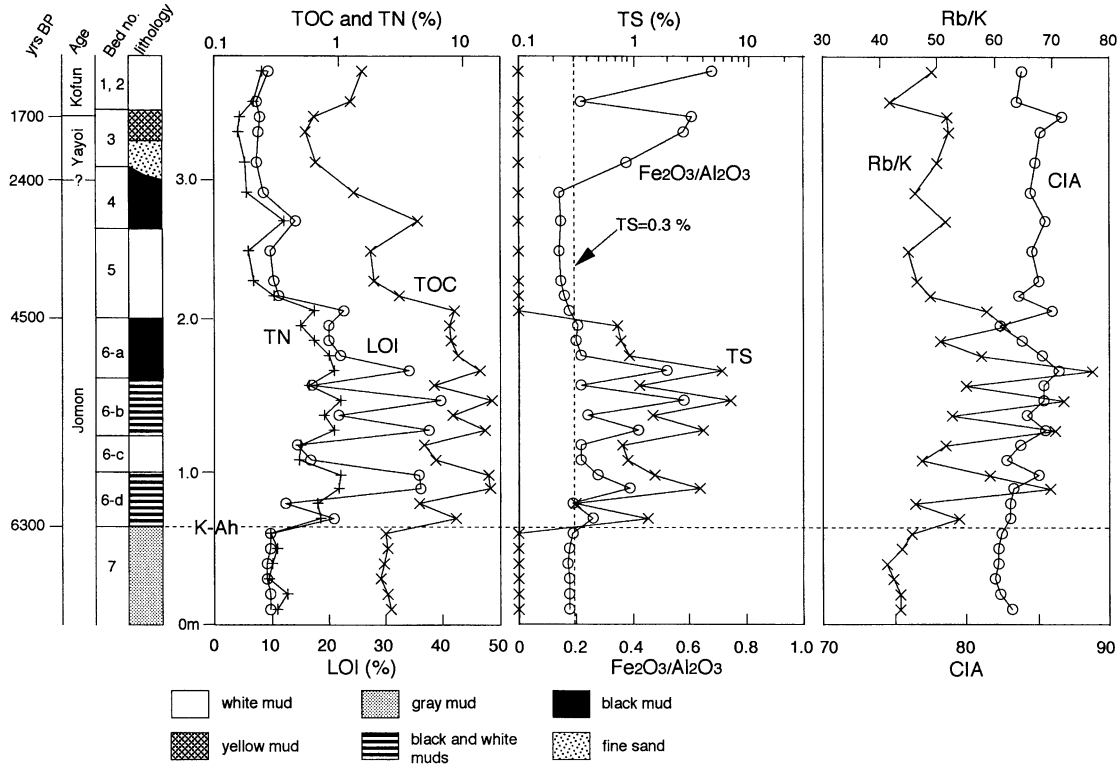

Fig. 2 Stratigraphic variation of LOI, TOC, TN, TS, Fe_2O_3/Al_2O_3, CIA and Rb/K of the muds at the archeological site in Shimane University (SU section), San'in district of Southwest Japan. K–Ah represents Kikai–Akahoya tephra of 6300 yrs BP. Bed numbers are indicated.

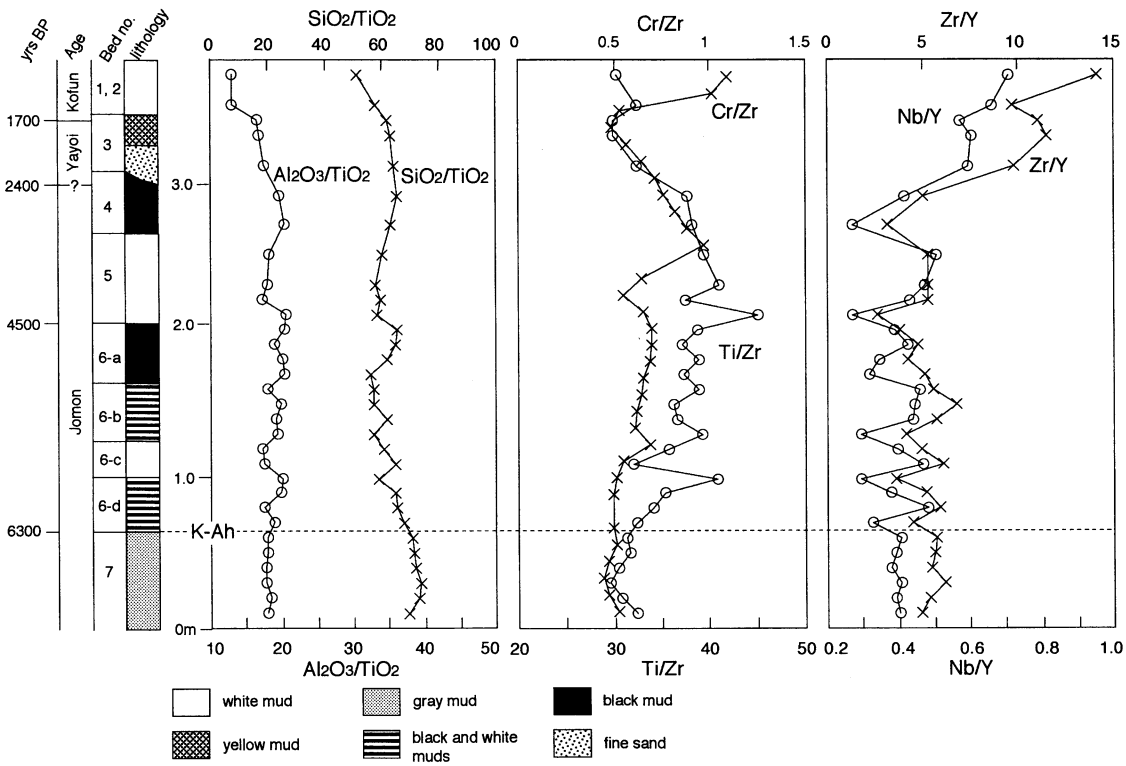

Fig. 3 Stratigraphic variation of Al_2O_3/TiO_2, SiO_2/Al_2O_3, Ti/Zr, Cr/Zr, Nb/Y and Zr/Y of the muds at the archeological site in Shimane University (SU section), San'in district of Southwest Japan. K–Ah represents Kikai–Akahoya tephra of 6300 yrs BP .

organic C, total N and total S, and major and trace elements.

Total organic carbon and total nitrogen

Total organic carbon (TOC), and total nitrogen (TN) were measured using a CHN-corder (Yanako MT-3). The method is outlined in Suzuki et al. (1986) and Sampei (1991).

Total Sulfur

Total sulfur (TS) was measured on 200 mg samples by combustion and infrared absorption spectrometry using a HORIBA EMIA-120, following the procedure of Terashima (1979). The errors (coefficient of variation) inherent to this analysis were less than 3%.

Major and trace elements

Major elements (SiO_2, TiO_2, Al_2O_3, Fe_2O_3*, MnO, MgO, CaO, Na_2O, K_2O, and P_2O_5) and trace elements (V, Cr, Co, Ni, Cu, Zn, Y, Zr, Nb, Rb, Sr, and Ba) were analyzed using the RIX 2000 XRF system (Rigaku Denki Co. Ltd.) of Shimane University. Analysis were made on glass beads prepared with lithium tetraborate flux with a flux to sample ratio of 5:1, fundamentally followed by Norrish and Hutton (1969).

Results are given in Table 1. For analytical errors, standard deviations of analyzed values (n=10) of USGS standard SCo-1 (Cody Shale) are shown in comparison with preferred values from Potts et al. (1992).

L O I (Loss on ignition)

Loss on ignition was determined by ignition of powdered samples at 1100℃ in a muffle furnace for 1 hour.

Geochemical characteristics of the Holocene muds

LOI, TOC, TN and TS

Muds of bed 7 show consistent values in LOI, TOC, TN and TS, and change their values at the boundary of beds 7 and 6. Within the bed 6, they show fluctuation and black muds have higher concentration in LOI (over 35%), TOC (over 10%), TN (over 1%) and TS (over 1%) relative to those of white muds. Variation of these elements in bed 6 correlate well with Fe_2O_3/Al_2O_3 and Rb/K ratios. Higher TOC and TOC/TN (~16.2) are suggestive of enriched organic matter probable derived from higher plants. High TOC/TS (~10.9) and increase in Fe_2O_3/Al_2O_3 are suggestive of deposition under marine condition in previous swamp

Table 1 Analyses of the muds at the archeological site in SU section (Shimane University), San'in district of Southwest Japan. Numbers are sample numbers in stratigraphically descending order with 10 cm thick intervals. -: less than 0.01% for TS. Total Fe is given as Fe_2O_3.

		Oxides (wt. %)											Trace elements (ppm)											wt. %		
Bed no.	sample no.	SiO2	TiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	P2O5	Total	LOI	V	Cr	Ni	Cu	Zn	Y	Zr	Nb	Rb	Sr	Ba	TOC	TN	TS
Bed 1, 2	SU-1	66.09	1.29	16.81	11.37	0.10	1.09	0.55	0.56	1.32	0.05	99.24	9.38	139	282	71	18	59	18	257	13	78	66	309	1.54	0.24	-
	SU-3	73.91	1.28	16.86	3.66	0.03	1.05	0.40	0.67	1.45	0.03	99.34	7.47	139	241	51	19	65	25	237	16	73	76	358	1.24	0.20	-
Bed 3	SU-4	66.18	1.07	17.81	10.91	0.02	1.06	0.30	0.45	1.49	0.08	99.37	7.80	122	114	39	09	83	20	215	11	93	53	340	0.63	0.16	-
	SU-5	66.66	1.06	17.66	10.18	0.07	1.14	0.36	0.54	1.54	0.07	99.29	7.70	138	102	37	08	84	19	212	11	96	57	371	0.53	0.16	-
	SU-7	68.58	1.07	18.72	7.08	0.08	1.25	0.42	0.57	1.65	0.06	99.48	7.40	119	113	33	08	82	20	199	12	99	65	384	0.64	0.17	-
Bed 4	SU-9	70.70	1.08	21.07	2.91	0.04	1.33	0.48	0.62	1.89	0.03	100.16	8.64	109	111	33	15	87	34	172	14	105	91	507	1.33	0.18	-
	SU-11	68.90	1.10	22.42	3.27	0.04	1.52	0.53	0.50	1.88	0.01	100.15	14.23	156	123	41	32	110	54	172	15	117	82	552	4.33	0.36	-
Bed 5	SU-13	69.81	1.17	21.25	3.07	0.03	1.50	0.44	0.59	2.04	0.05	99.95	9.85	138	135	32	18	128	34	177	17	111	77	518	1.81	0.19	-
	SU-15	69.27	1.21	21.67	3.29	0.04	1.59	0.46	0.59	1.97	0.05	100.13	10.25	138	145	36	22	94	33	177	16	110	80	560	1.94	0.20	-
	SU-16	70.12	1.19	20.46	3.36	0.04	1.54	0.51	0.63	2.00	0.06	99.89	11.27	141	167	38	25	86	36	190	15	118	86	529	3.08	0.30	-
	SU-17	66.05	1.14	23.49	4.17	0.06	1.77	0.67	0.39	1.97	0.08	99.79	22.77	207	147	51	62	127	57	151	16	139	84	525	8.51	0.63	-
Bed 6a	SU-18	68.02	1.04	21.30	4.50	0.06	1.57	0.95	0.62	1.83	0.08	99.97	20.08	141	104	62	34	38	43	161	17	136	145	533	7.77	0.49	0.72
	SU-19	69.49	1.08	20.47	4.13	0.05	1.42	0.68	0.49	1.92	0.07	99.79	19.92	123	95	43	24	-	37	174	16	117	95	548	8.13	0.63	0.78
	SU-20	67.60	1.10	22.12	4.89	0.06	1.54	0.81	0.37	1.78	0.09	100.36	22.05	135	111	46	27	12	40	169	14	124	96	538	9.05	0.84	0.91
	SU-21	60.31	1.08	22.05	11.49	0.06	1.65	0.81	0.30	1.60	0.10	99.44	34.12	223	120	161	54	179	34	173	11	148	85	502	13.74	0.91	5.89
Bed 6b	SU-22	67.98	1.19	21.42	4.62	0.04	1.61	0.58	0.44	1.88	0.07	99.83	17.10	120	127	53	28	100	33	183	15	125	84	514	5.93	0.57	1.10
	SU-23	60.28	1.06	21.06	12.13	0.05	1.73	0.77	0.37	1.70	0.10	99.24	39.78	215	120	168	46	91	26	175	11	147	79	467	16.89	1.05	6.88
	SU-24	67.73	1.09	20.93	5.08	0.04	1.72	0.61	0.47	2.04	0.07	99.79	21.75	158	117	47	29	-	31	179	14	130	83	498	8.42	0.75	1.46
	SU-25	63.32	1.11	21.42	8.96	0.06	1.74	0.86	0.36	1.59	0.11	99.53	37.60	195	109	97	53	05	41	169	12	135	86	510	15.12	0.91	4.02
Bed 6c	SU-26	69.95	1.16	19.86	4.30	0.04	1.49	0.56	0.55	1.92	0.06	99.88	14.32	131	120	61	20	107	39	194	15	119	83	493	4.95	0.49	0.79
	SU-27	70.82	1.10	19.12	4.19	0.04	1.49	0.51	0.56	2.07	0.06	99.95	16.65	131	126	38	26	131	34	206	16	118	80	471	6.20	0.48	0.88
	SU-28	65.27	1.11	22.30	6.14	0.05	1.81	0.85	0.38	1.86	0.11	99.87	35.90	198	112	60	46	69	45	163	13	132	86	519	16.30	1.04	1.49
Bed 6d	SU-29	65.54	1.01	20.03	7.88	0.05	1.65	0.84	0.42	1.86	0.09	99.36	36.22	161	93	61	33	60	33	172	13	157	85	477	16.35	1.01	3.77
	SU-30	71.42	1.09	19.11	3.68	0.03	1.46	0.46	0.58	2.05	0.05	99.94	12.46	117	98	40	16	47	33	192	16	114	74	466	4.53	0.66	0.32
	SU-31	69.56	1.03	19.41	5.00	0.04	1.40	0.64	0.60	1.85	0.07	99.59	20.99	149	94	56	29	171	43	191	14	120	78	502	8.95	0.71	1.34
Bed 7	SU-32	72.14	1.02	18.38	3.50	0.03	1.37	0.46	0.62	2.02	0.05	99.58	9.59	119	97	33	16	95	34	195	14	111	73	466	2.38	0.28	-
	SU-33	72.68	1.02	18.29	3.30	0.03	1.27	0.46	0.65	1.99	0.05	99.74	9.70	125	99	28	16	168	34	194	13	105	75	467	2.45	0.32	-
	SU-34	73.19	1.02	18.12	3.05	0.03	1.19	0.45	0.66	1.96	0.05	99.70	9.16	116	94	32	22	82	36	200	14	97	74	453	2.32	0.29	-
	SU-35	73.39	1.00	17.74	3.15	0.03	1.21	0.45	0.68	1.93	0.05	99.61	9.09	103	91	26	18	103	33	204	13	98	74	445	2.19	0.27	-
	SU-36	72.54	1.00	18.36	3.34	0.03	1.30	0.45	0.63	2.02	0.05	99.72	9.61	107	91	32	25	112	36	194	14	106	73	468	2.50	0.38	-
	SU-37	72.05	1.04	18.81	3.31	0.03	1.27	0.45	0.60	1.98	0.06	99.59	9.83	118	101	33	21	92	39	192	16	104	73	455	2.63	0.32	-

during deposition of bed 6. LOI, TOC, TN and TS values of bed 5 decrese to similar level of bed 7 with some variation. This change may indicate sea-level fall and returning to non-marine condition. Higher values in Fe_2O_3/Al_2O_3 of bed 3 without relation to TS is perhaps due to diagenetic enrichment in Fe_2O_3.

SiO_2

SiO_2 concentration may be related to maturation of sediments, grain size and bigenic silica contamination (e.g. McLennan et al., 1993). Thus SiO_2 usually shows negative correlation with Al_2O_3 which represents clay contents. Muds of the examined section show weak negative correlation between SiO_2 and Al_2O_3 ($r^2=0.50$). High concentration of Al_2O_3 over 20 wt% may be related to enrichment of clays in the sediments.

Alkali and alkaline earth elements

Na_2O, CaO and K_2O show variation in the section which were affected by effects of weathering, sorting and absorption. Na_2O has negative correlation with Al_2O_3 ($r^2=0.61$), suggestive of presence of Na rich-feldspar or albitization of feldspar. Ca shows weak correation with Al_2O_3 ($r^2=0.64$), but K_2O has no correlation to Al_2O_3. Mg ($r^2=0.84$), Rb ($r^2=0.67$) and Ba ($r^2=0.78$) show correlation to Al_2O_3 (Fig. 4), suggesting effect of adsorption on clays of these elements. Sr has no correlation to Al_2O_3. Rb and Ba are depleted in beds 2, 1 compared to those of the other samples, probably due to less concentration of clays in mud samples.

TiO_2, Zr, Nb and Y

These elements are generally immobile during weathering process, but they may vary in concetration due to grain-size fractionation. TiO_2 shows weak correlation with Al_2O_3 ($r^2=0.59$) excluding two samples of beds 2, 1 (Fig. 4), which have the highest (1.28 and 1.29%) values in the samples. Al_2O_3/TiO_2 and SiO_2/TiO_2 show small variation in bed 7 and vary slightly in beds 6 to 4 (Fig. 3). Clear decrease in these ratios occurrs from bed 3 to 1. Although TOC, Fe/Al and TS show variation in the section, these immobile element ratios are relatively consistent.

Zr shows negative correlation with Al_2O_3 ($r^2=0.89$) (Fig. 4), and the uppermost two samples in bed 2 plot off this correlation line with least values of Al_2O_3. Zr, however, shows no correlation to TiO_2, suggesting that TiO_2 may be included as heavy minerals such as rutile or titanite. Ti/Zr shows gradual increase from bed 7 to bed 6, and decreases toward the top of the section (Fig. 3).

Nb/Y and Zr/Y correlate well with each other in the section, and show some variations from bed 7 to 5. They subsequently increase from bed 4 to bed 2. Nb shows no clear correlation with Al_2O_3, but Y does show weak correlation ($r^2=0.67$). In this context, increase in Nb/Y and Zr/Y from bed 4 may be related to placering or survival of heavy minerals containing Ti, Nb, and Zr. Pyribole, opaque oxides, titanite and zircon could be candidates. Heavy mineral enrichment in beds 2, 1 relative to clays were probably caused by lowered sedimentation rate with less acuumulation of clays or feldspar.

Cr, V, Ni, and Cu

Cr shows correlation to TiO_2 and two samples of the beds 2, 1 have the highest values. Ni, V and Cu concentrations were related to TS values in bed 6 (Fig. 4), and they have peak in this bed. Thus Cr is immobile under variable redox condition relative to V, Ni and Cu in the examined samples. Cr/Zr correlates to variation of Ti/Zr, excluding beds 2, 1 (Fig. 3). In beds 6 and 5, Cr/Zr show relatively less variation than that of Ti/Zr, suggestive existence of heavy minerals such as cromite which may behave similarly to zircon in sedimentary process (Taylor and McLennan, 1985; McLennan et al., 1993).

Weathering condition

To evaluate degrees of weathering, the chemical compositions of sedimentary rocks are plotted as molar proportions within Al_2O_3– (CaO^*+Na_2O) –K_2O (A–CN –K) compositional space, where CaO^* represents Ca in silicate-bearing minerals only (Nesbitt and Young, 1989: Fedo et al., 1995). The CIA (=Al/ (Al+Ca+Na+K) $\times$100, Nesbitt and Young, 1982) is a useful tool for evaluation of weathering, particularly the conversion of feldspar to secondary clay minerals such as kaolinite and illite (Fig. 5).

On this diagram, mud samples plot in a very small area, showing high CIA values (over 80) and significantly homogeneous composition. Supposition of a trend from source rock to this composition parallel to A–CN join is difficult, for their highly nature of CIA may be related to sorting effect as indicated by Nesbitt et al. (1996).

Data set of the Holocene muds (Asakumi Forma-

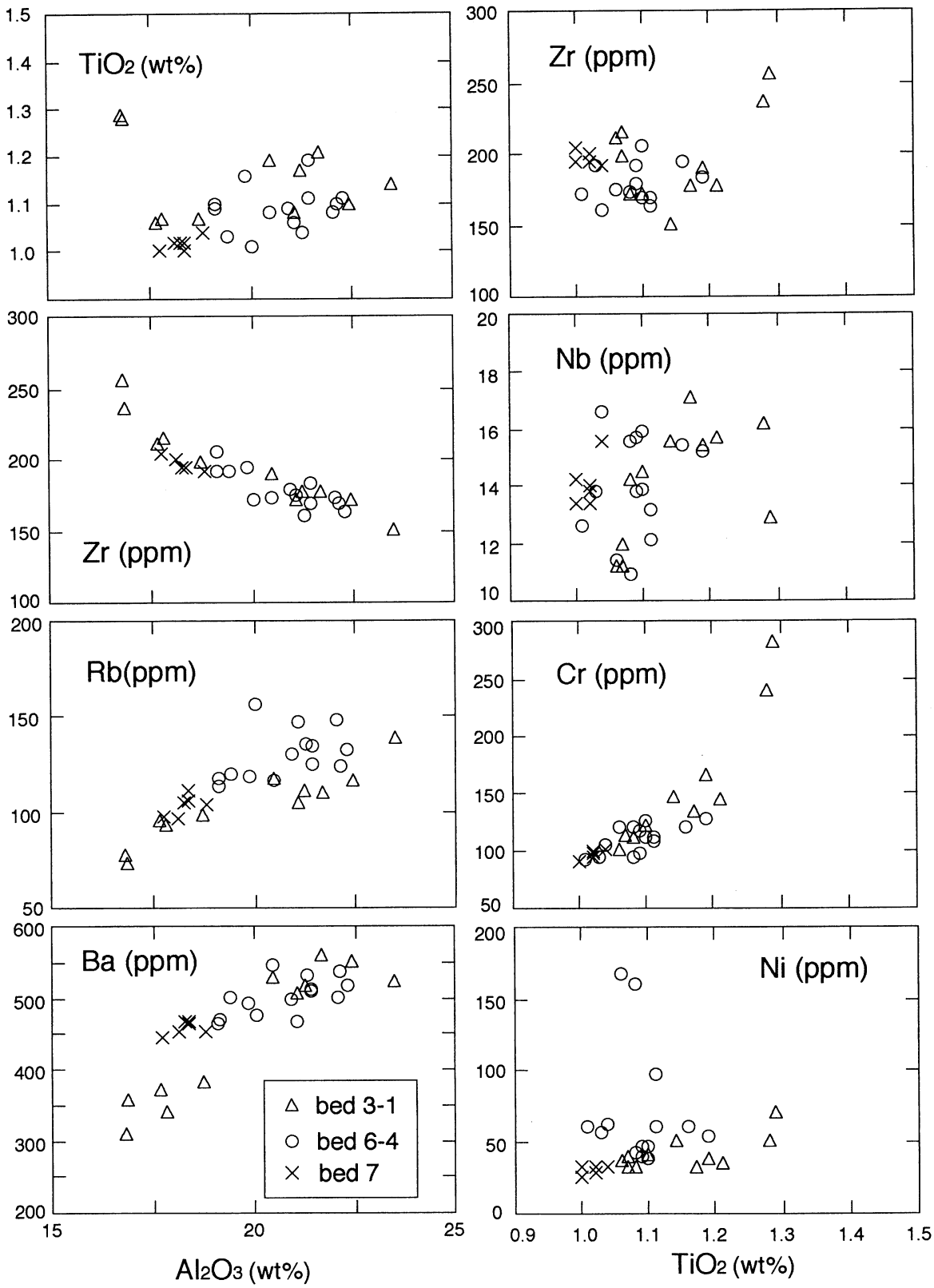

Fig. 4 TiO_2 (wt%), Zr (ppm), Rb (ppm) and Ba (ppm) vs. Al_2O_3 (wt%), and Zr, Nb (ppm) Cr (ppm) and Ni (ppm) vs. TiO_2 for mud samples at the archeological site in Shimane University (SU section), San'in district of Southwest Japan.

tion) from the archeological site along the Asakumi River plots on the line parallel to the A–CN join with CIA ranging from 76 to 85. Samples of the SU section lie on the end of this trend, suggesting they were derived from same source material similar to the Daito granodiorite.

Weak CIA variation in bed 6 correlates with change in Rb/k ratio. Rb/K fluctuation in bed 6 may be related to Rb enrichment due to adsorption of Rb on clays under marine condition.

Comparison with other Holocene mud composition

Holocene mud composition has been also examined at archeological site along the present Asakumi River

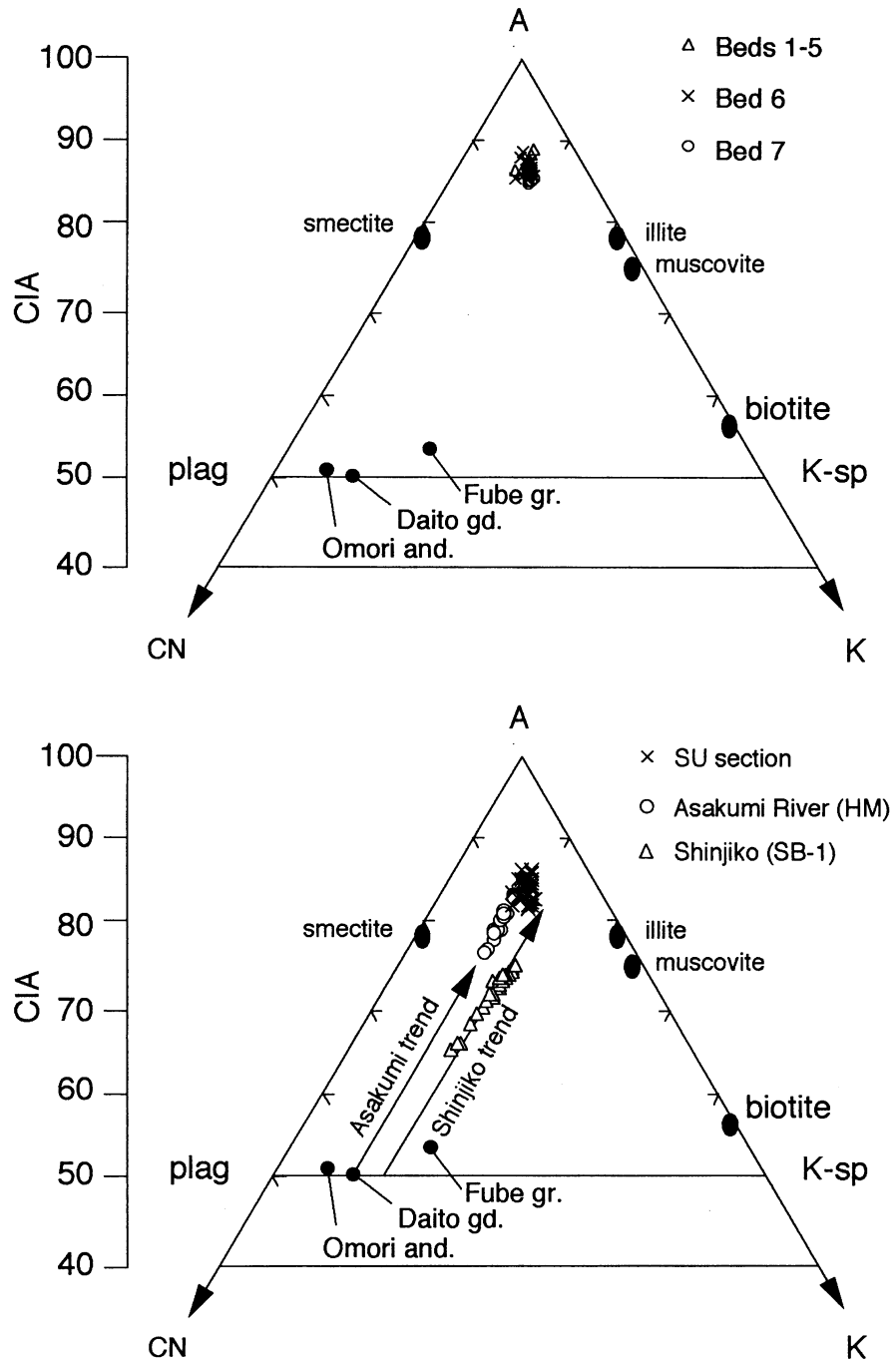

Fig. 5 Al_2O_3– ($CaO+Na_2O$) –K_2O diagram and CIA (chemical index of alteration) for the muds at the archeological site in Shimane University (SU section), San'in district of Southwest Japan. Compositions of granites (Fube granite), granodiorite (Daito granodiorite) and Omori (Omori andesite) are also given for estimation of source composition. The Omori andesite is intercalated in the Tertiary rocks. Data from Kano et al. (1994).

(HM; Haranomae remain of Tokuoka et al., 1995), and core samples in the Lake Shinji (SB–1 of Tokuoka et al., 1990). Analytical results are shown in Table 2 in average values and STD.

Plots on the A–CN–K diagram show that SB–1 samples lie on diffrent trend from the Asakumi trend (HM samples) with supposed source composition which occurs between the Daito granodiorite and Fube granite (Fig. 4). They are more silicic and have lower CIA (65–75) relative to samples of the HM section and SU section.

To evaluate difference of these Holocene mud composition, elements of the SU and HM samples are normalized by average values of the Holocene of the SB–1 core samples.

The enrichment and depletion for any element x (Ex^*) is given by the following equation:

$Ex^* = (C_x \text{ sample} / C_{Al} \text{ sample}) / (C_x \text{ standard} / C_{Al} \text{ standard})$

where: C_x sample is concentration of the element in the sample and C_{Al} sample is the sample Al content. C_x standard and C_{Al} standard are equivalent quantities for average values of the SB–1 samples.

SU and HM samples show similar patterns in this factor (Fig. 6). TiO_2, Cr, and Ni are enriched relative to SB–1 samples, while most alkali and alkaline earth elements are depleted compared with SB–1 muds, excluding Sr and Ba. Zr is most enriched in HM samples, and Y and Nb are slightly enriched in both SU and HM samples. Depletion in most alkali and alkaline earth elements relative to SB–1 samples show highly weathered nature of mud composition.

TiO_2, Cr and Ni concentration compared with SB–1 is suggestive of more mafic source for the sediments of the Asakumi fluvial system. Muds of the SB–1 may be related to local granites and granodiorites which are distributed in the Chugoku mountain regions (Editorial Board of Geological Map of Shimane Prefecture, 1982), while sediments of the Asakumi fluvial system have the provenance composed of Tertiary sediment and volcanic complexes. This may be significant for chemical composition. This implies that reworking of sedimentary rocks may result in relatively higher CIA, and may have an effect of immobile element concentration during sedimentary process. Lower sedimentation rate in the SU section may accenturate this effect and concentrated Al_2O_3, TiO_2, Cr and Zr during weathering process. SiO_2, CaO, Na_2O, K_2O, Sr and Zr enrichment in the HM samples may be due to grain size effect on composition compared with SU samples.

SU muds, however, show similar composition to HM samples, derived from the provenance of the Asakumi River system, while SB–1 of Shinjiko samples may represent more felsic source terrane of the Hii River system.

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Table 2 Average values of the muds in HM section (Haranomae remain in the Asakumi River) and Holocene muds in the SB–1 section of the Shinji Lake, San'in district of Southwest Japan. Analysis of USGS standard shale SCo–1 (Cody Shale) is also given with preferred values (p.v.) for comparison.

		Oxides (wt. %)											Trace elements (ppm)										
samples		SiO2	TiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	P2O5	Total	V	Cr	Ni	Cu	Zn	Y	Zr	Nb	Rb	Sr	Ba
Lake Shinji (SB-1)																							
Av. (n=38)		64.65	0.86	19.22	6.65	0.09	2.29	0.73	1.97	2.68	0.12	99.25	125	63	28	15	116	28	155	12	138	114	293
STD		4.03	0.03	1.33	1.82	0.01	0.47	0.05	0.16	0.18	0.00		14.9	6.9	5.2	2.4	18.7	0.8	26.8	2.3	5.3	1.6	75.9
Asakumi River																							
Av. (n=28)		72.41	0.98	16.66	5.39	0.05	1.36	0.65	1.09	1.80	0.06	100.46	92	104	40	14	79	27	210	12	76	136	396
STD		0.721	0.09	1.54	0.33	0.00	0.37	0.18	0.11	0.50	0.03		11.0	1.1	14.3	11.0	22.3	6.6	59.9	0.4	12.0	39.6	37.1
SCo-1	p.v.	64.13	0.64	13.96	5.25	0.05	2.78	2.68	0.92	2.83	0.21	93.45	134	69	28	29	105	27	163	11	114	178	582
	av. (n=6)	65.18	0.62	13.93	5.45	0.05	2.68	2.60	1.41	2.77	0.37	95.08	120	73	29	24	106	21	172	14	124	171	544
	STD	0.32	0.00	0.09	0.02	0.00	0.02	0.01	0.04	0.01	0.01		4.8	2.5	0.6	4.3	1.1	0.5	0.6	0.2	0.2	0.1	7.7

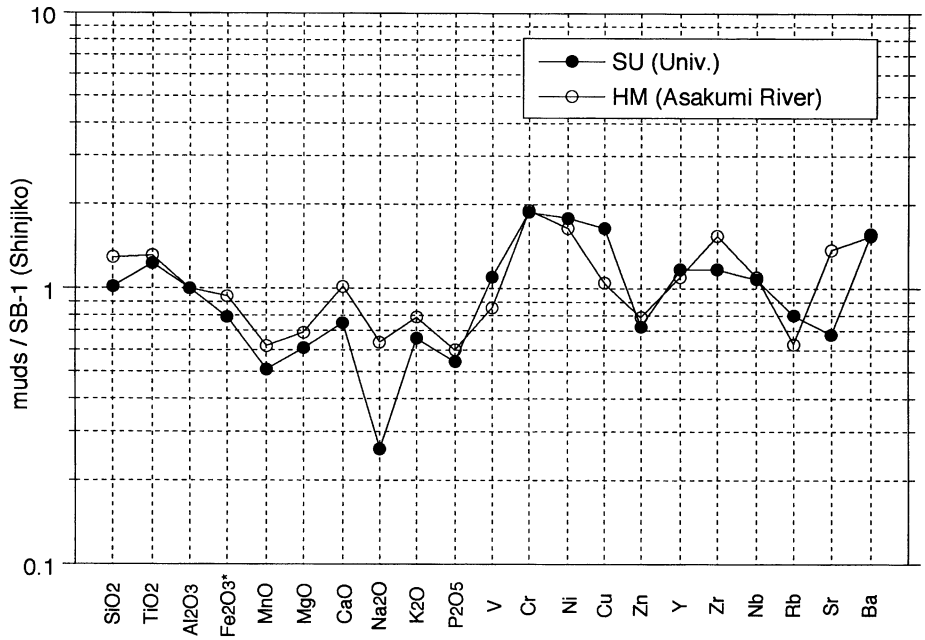

Fig. 6 Average enrichment factor diagram for the Holocene sediments in the SU (Shimane University) and HM (Haranomae remain in the Asakumi River) sections, normalized by Holocene sediments of the SB–1 core samples from the Shinji lagoon, San'in district, SW Japan.

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（要　旨）

石賀裕明・中村唯史・三瓶良和・徳岡隆夫・高安克己, 1998, 地球化学的にみた西南日本山陰地域の海跡湖堆積物に記録された縄文海進の最大海水準上昇, 島根大学地球資源環境学研究報告, 17, 11-20

完新統の縄文海進の地質学的記録の1つが島根大学にて行われた遺跡発掘現場の地層にみられる．この地点は当時の予想される海岸線の最も湾奥の後背湿地に位置する．堆積物の地球化学的特徴から非海成層から海成層への急激な変化が認められ，その基底にはアカホヤ火山灰（約6,300年前）が挟まれる．したがってこの層準は縄文海進の最大海水面上昇を示唆する．海成層は1.3 mあり，その上位には非海成層が重なる．この非海成層は下位の地層に比較して Al_2O_3/TiO_2, SiO_2/Al_2O_3, Ti/Zr, Nb/Y, および Zr/Y 比などが変化する．このことは弥生時代に始まる平野の開墾による後背地の変化を示唆する．