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Cummingtonite-bearing Clay in the Kanto Plain: Reconnaissance Study for Body Paste of Ancient Pottery

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Abstract Cummingtonite is a rare mineral found in volcanic ashes from the Japanese Islands. It is frequently present in whitish or bluish-gray clays collected near the surface at several localities on terraces in the Kanto Plain. The clays are a member of the Shimosueyoshi Stage of the Late Pleistocene and contain sandy- to silty-size minerals. About 70 samples from in and around the clay layers were collected on the Kounan and Sakado terraces, Saitama Prefecture, and Shimousa Terrace, Chiba Prefecture. Modal proportions of heavy minerals and chemical compositions of orthopyroxene and cummingtonite were measured. Even though modal proportions of the heavy minerals are different from sample to sample and also from terrace to terrace, most of the clay samples are characterized by presence of cummingtonite. Cummingtonite in the clays on the Kounan Terrace are relatively common. The clays from the Sakado Terrace are characterized by abundant epidote and only rarely cummingtonite, whereas the clays from the Shimousa Terrace are characterized by enrichment of calcic amphibole. Cummingtonite in the Kounan Terrace has chemical composition with an X_{Mg} of 62–64. In the other terraces, X_{Mg} values of 66–68 or around 54 are recognized in addition to that of 62–64. The characteristic mineral assemblage and chemical composition furnish an indicator between the clay and the body paste of ancient pottery found at a local archaeological site.
Key words :

Introduction

The Kanto Plain is widely covered by volcanic ash derived successively from its western and northern sides. The ash layer is more or less weathered and is usually brownish in color. Such weathered ash is collectively known as “Kanto Loam” and is divided into four stages: from lower to upper, Tama, Shimosueyoshi, Musashino and Tachikawa. Whitish to grayish clay has been considered to belong to the Shimosueyoshi Loam stage of the Late Pleistocene. It occurs near the surface on terraces in the Kanto Plain.

The clay contains sandy- to silty-size minerals parentally derived from volcanic eruption. In this paper, we studied modal proportions and chemical compositions of heavy minerals in the samples in or around the clay layers in the Kanto Plain. Modal proportion and chemical composition of heavy minerals provide us with important information for provenance or correlation study (Yokoyama *et al*., 1990; Morton, 1991). Light minerals, such as quartz and feldspar, are less diagnostic for the correlation. This method is essentially the same as that of the petrological study of early Pleistocene tuffs in the Boso Peninsula (Yokoyama *et al*., 1997 & 1998).

The clay studied here is thought by some investigators to form the body paste of some ancient pottery found at a local archeological site. Cummingtonite was recognized from both the pottery and the clay from the Kounan Terrace

(Oya *et al*., 2006). However, the clay has not previously been petrologically studied in detail and no correlation has been attempted between the paste of the pottery and the clay. This paper provides the basic data for such a correlation.

Sampling Site

The clay layers occur near surface of terraces in the Kanto Plain. Most of the samples are collected at the archeological sites on the Kounan Terrace (Fig. 1). The sites for the KM and KN series samples have been reported in detail by the Saitama Cultural Deposits Research Corporation (SCDRC, 1993) and Kounan Town Board of Education (KTBE, 2005), respectively. The KH series samples from a small cliff on the Kounan Terrace are the same as those described by Machida *et al*. (2002). The other two sites at the Saitama Prefecture are from the archeological sites at Yorii (SCDRC, 2006) and Sakado (SCDRC. 2008). In the Shimousa Terrace, Chiba Prefecture, the clay samples and associated loams were collected from small cliffs at Otake and Matsumushi, Inba Village (Fig. 1), where many archeological sites occur. In addition to these clay samples on the Kanto Plain, volcanic ashes were collected at Shinano Town, Nagano Prefecture, 150 km northwest of the Kounan Terrace as a possible source of the cummingtonite in the Kanto Plain.

Simplified columnar sections at the sampling sites are shown in Fig. 2. On the Kounan Terrace, clay sample is white to bluish-gray, occasionally grayish-brown or brown in color. Although the clay bed usually overlies a gravel or sand bed, it is sometimes difficult to distinguish it from the overlying brownish loam. In the Sakado Terrace, clays are yellowish-gray or yellowish-brown in color. They also overly gravel or sand. On the Shimousa Terrace, Chiba Prefecture, the clay is bluish or white, locally yellowish and overlies a sand bed.

At Shinano Town, volcanic ashes and intercalating sediments were collected at the same outcrop as that studied by Furukawa and Oba (2003). Ashes termed by them as KT-a, KT-b, KT-c and NY correspond to IB-21, IB-19, IB-14 and IB-8 in the current study, respectively (Fig. 2).

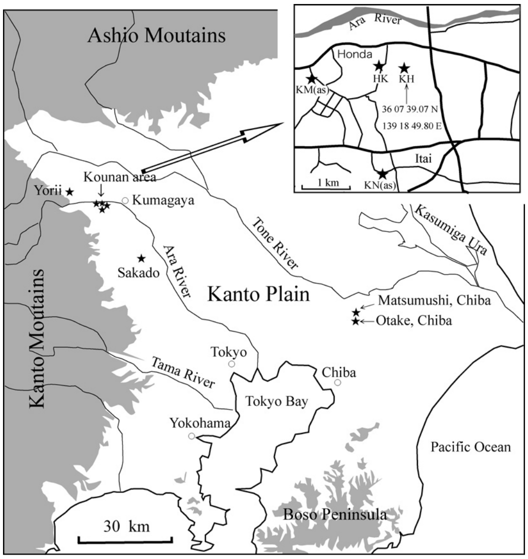

Fig. 1. Locality map of the collected samples. Grayish zone is hill or mountain with height more than 100 m.

Analytical Procedures

The procedures used for separation and identification of heavy minerals in the samples were described in detail by Yokoyama *et al*. (1990 & 1997). All the samples are loosely packed. They were washed in running tap water to remove fine particles. Subsequently, they were dried and sieved. The fractions used for analyses were less than 250 μm in diameter. The specific gravity of methylene iodide was reduced to 2.82 to recover composite grains and aggregates of the heavy and light minerals. Carbonates, micaceous minerals and authigenic pyrite were not further examined.

Most of the minerals were identified from an X-ray profile done with an Energy Dispersive Spectrometer (EDS). Many grains were composed of a single mineral species (Fig. 3), but composite grains and aggregates were also com-

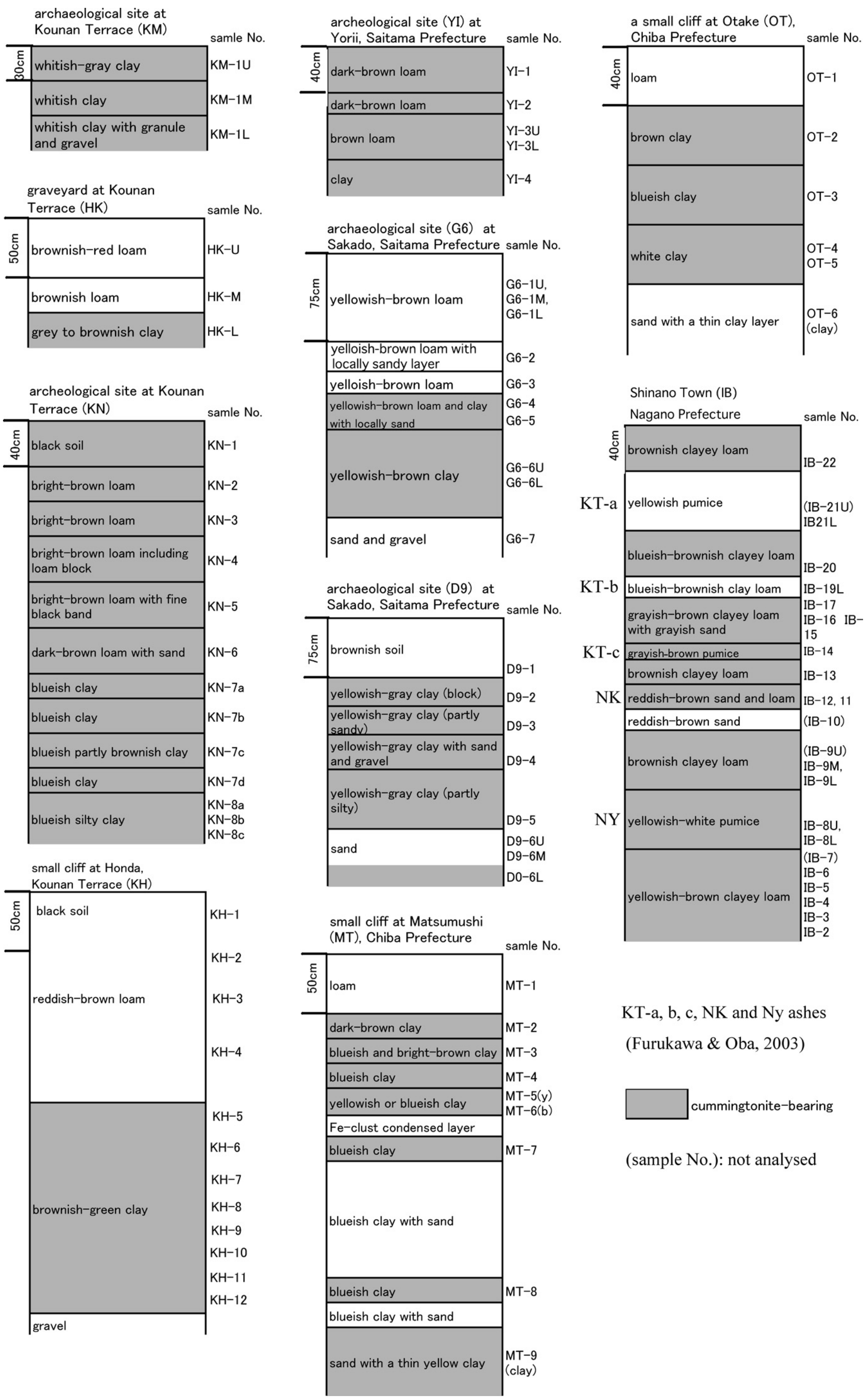

Fig. 2. Simplified columnar sections for the collected samples.

mon. For the latter, we measured the major constituent. A total of about 200 grains were identified from the heavy fraction. In the X-ray profiles, minerals with the same chemical compositions were described as polymorphs, e.g. TiO_2 polymorphs for rutile, anatase and brookite. Epidote-group minerals sometimes compromised one of the major heavy mineral suites. Their compositions varied from zoisite to epidote, and are tentatively and collectively denoted as "epidote" here. As orthopyroxene cannot be simply distinguished from cummingtonite by the X-ray profile, they were calculated based on chemical compositions obtained by an electron-microprobe analyzer (EPMA, JEOL 8800). The modal proportions of the heavy minerals in the clay, loam and sand are listed in Tables 1, 2 and 3.

Heavy Minerals and Modal Proportions

As listed in Tables 1–3, more than fifteen mineral species were observed in the samples. In the Kanto Plain, magnetite and ilmenite usually dominated as did sediments. Other major minerals are orthopyroxene, cummingtonite, clinopyroxene, calcic amphibole and epidote. Zircon, olivine and TiO_2 polymorphs are mostly rare minerals, but occasionally observed as important constituents. Whatever the samples were volcanic ash or reworked sediment, the modal proportions of heavy minerals were highly affected during transportation or volcanic eruption by the density of the minerals. The relative proportions are shown in Figs. 4 to 9 by the selected minerals with similar density: orthopyroxene, cummingtonite, clinopyroxene, calcic amphibole and epidote. These minerals have density from 3.1 to 3.5 and are expected to behave in similar way during gravitational settling.

All the samples are essentially volcanic in origin. Orthopyroxene is well preserved in the loam at the top of the sequences (Fig. 3A). However, it is highly dissolved in the clay layer (Fig. 3B). Although discussion of the persistence of a mineral after deposition is inevitable for the provenance study (Pettijohn, 1941; Morton, 1991), the difference of dissolution may be due to deposition on land, i.e. terrestrial deposition, in the former, whereas the latter is aqueous or marine deposit. Similar dissolution occurs in the other pyroxene and amphiboles. Cummingtonite is relatively well preserved in some clay layers (Fig. 3C), but mostly highly dissolved in the layers (Fig. 3E & F). Cummingtonite-bearing ash from the Shinano Town, Nagano Prefecture, was deposited on land at a similar time as the clay as discussed latter. Cummingtonite are well preserved (Fig. 3D).

The KM, HK, KH and KN series samples were collected on the Kounan Terrace. Among them, the KH series section has a clear loam layer at the top. The loam samples are composed mainly of orthopyroxene with a subordinate amount of clinopyroxene and without cummingtonite. Cummingtonite appears in the clay layers. In two samples, KH-8 and KH-9, cummingtonite is predominant. Although modal proportions of pyroxenes, amphiboles and epidote are variable in the other samples, it is noted that the clay samples are characterized by the consistent presence of cummingtonite. In the other localities on the Kounan Terrace, the samples consist mainly of orthopyroxene and calcic amphibole with a subordinate or small amount of cummingtonite. One sample, KN-8c, similar to those of KH-8 and KH-9, occurring at the bottom of the KN sequence contains abundant cummingtonite. Clay samples in the Yorii site are essentially similar to those from the Kounan Terrace, having a subordinate or trace amount of cummingtonite.

At the Sakado archaeological site, orthopyroxene is abundant in the loam samples occurring at the top of the G6 sequence. In the other samples, pyroxenes and cummingtonite are small in amount due to strong dissolutions of the minerals. Instead of these minerals, the clay samples are composed mainly of epidote with a subordinate amount of calcic amphibole, probably due to relatively resistance against dissolution.

In the Shimousa Terrace, Chiba Prefecture, loams at the top of the MT and OT sequences are composed mainly of orthopyroxene with subordinate amounts of clinopyroxene and calcic amphi-

Table 1a. Heavy minerals of the samples from various localities in the Saitama Prefecture. Numerical value shows a number of counted grain of each mineral. Localities: archaeological site- KM, graveyard on the Kounan Terrace-HK, small cliff at the Kounan Terrace-KH. Minerals abbreviations; opx: orthopyroxene, cum: cummingtonite, cpx: clinopyroxene, hb: calcic amphibole, oli: olivine, ilm: ilmenite, mt: magnetite, epi: epidote, tit: titanite, Cag: Ca-rich garnet, gar: Ca-poor garnet, apa: apatite, all: allanite, spi: spinel, zir: zircon, TiO: TiO_2 polymorphs, tou: tourmaline.

	KM-1U	KM-1M	KM-1L	HK-U	HK-M	HM-L	KH-1	KH-2	KH-3	KH-4	KH-5	KH-6	KH-7	KH-8	KH-9	KH-10	KH-11	KH-12
opx	84	80	47	92	89	16	100	100	100	100	18	24	4	1	1	2		2
cum	16	20	37		1	13					7	6	26	83	99	7	12	6
cpx	12	9	5	3	7	1	26	23	32	24	5	4	1		1		1	1
hb	30	71	100	16	21	27	2	1	3	2	50	40	47	11	17	12	2	7
oli				1				1										
ilm	10	52	28	36	22	45	12	15	2	3	151	93	214	74	43	28	61	27
mt	6	20	4	120	56	22	55	31	12	29	43	102	24	23	31	120	100	146
epi	8	12	25	3	4	15		1			7	12	39	12	13	12	18	12
tit																		
Cag	1	2	5		1	2					3	1	1					1
gar					1							1	1				2	1
apa						1												
all			1															
spi											2	1			1	2	1	
zir		1				2					1		5	2			1	1
TiO	2	1	3	1	1	1					3	3	1	4	1	6	2	3
tou																	1	

Table 1b. The samples from the Yorii archaeological site (YI) and Kounan archaeological site (KN).

	YI-1	YI-2	YI-3U	YI-3L	YI-4	KN-1	KN-2	KN-3	KN-4	KN-5	KN-6	KN-7aU	KN-7aL	KN-7b	KN-7c	KN-7d	KN-8a	KN-8b	KN-8c
opx	92	94	45	64	4	80	95	86	97	45	34	3	16	8	8	20	22	33	
cum	8	6	5	7	18	20	5	14	3	5	6	34	21	16	36	26	19	4	100
cpx	44	49	2	4		26	18	11	45	2	2								
hb		1	31	55	36	1				34	20	40	50	50	50	100	100	100	18
oli		1		2															
ilm		4	48	11	118	4	3	6	3	84	125	222	127	199	136	121	24	18	68
Mgt	10	25	74	32	70	5	4	8	8	66	66	7	3	10	8			1	5
epi			3	1	18					1	2	10	2	8	5	3	3		5
tit																			
Cag			2		1					2	1	2	1	1					
gar				1	2						1			1					
apa																			
all													1						
spi											1	1							1
zir					1							3				4	1	1	2
TiO		1			7							1	2						2
tou					2														

Table 1c. The samples from the Sakado archaeological site (D9 and G6).

	D9-2	D9-3	D9-4	D9-5L	D9-6U	D9-6M	D9-6L	G6-1U	G6-1M	G6-1L	G6-2	G6-3	G6-4	G6-5	G6-6U	G6-6L	G6-7
opx	6	1	2	2	13	6	33	69	73	61	14	7	4	3	5	4	24
cum	2	2	1	1	1		2		1				1	1	2	2	1
cpx					2		3	4	3	7	2	3					2
hb	13	9	23	21	22	11	35	4	14	14	20	4	14	16	14	26	46
oli								1	1				1				
ilm	85	84	44	94	82	82	32	9	14	23	33	24	27	63	60	34	39
Mgt	23	15	17	16	41	73	37	76	91	82	169	175	120	109	86	50	74
epi	80	93	83	74	82	24	81	3	5	6	6		21	50	53	97	79
tit		1	1	5	5	2	4							2	2	2	3
Cag						1	1									3	
gar	2	1	1	1										1		3	1
apa																	
all																	
spi	4	5	4	3	2	5	3	1				1	1	3	3	3	3
zir	6	4	8	5	4	1	1		1	1				1	6	1	1
TiO	4	9	4	9	6	2	3			1		1	1	1	3	1	2
tou																	

Table 2. Heavy minerals of the samples from two cliffs at the Matsumushi (MT) and Otake (OT) on the Shimousa Terrace, Chiba Prefecture. Numerical values shows a number of counted grains of each mineral. Mineral abbreviations are the same as those in Table 1.

	MT-1	MT-2	MT-3	MT-4	MT-5	MT-6	MT-7	MT-8	MT-9	OT-1	OT-2	OT-3	OT4	OT-5
opx	50	9	2			2	2	8		100	1	2	1	
cum		3	6	10		3	8	5	2		4	6	11	19
cpx	9	1								13				
amp	16	30	32	61	100	50	62	60	51	18	45	43	75	87
oli										13				
ilm	39	123	248	190	164	137	70	70	161	18	136	103	56	58
mt	157	222	75	12	10	24	25	20	6	79	27	11	5	9
epi	1	3	4	4	3	14	6	24	7	1	20	21	29	20
tit														
Cag							1							
gar							2				3	1		
apa														
all		1		1							2		1	
spi			1			1	1	1			2			
zir			9	11	4	3	1	1	1		6	5	6	6
TiO				2	1	4	5	4	2		2	2	3	1
tou			1			1					1	1	1	

bole as found in loams from the Kounan Terrace. In the clay layer below the loam, calcic amphibole is predominant with small or trace amounts of orthopyroxene and cummingtonite. Clinopyroxene is usually scarce or absent. Both orthopyroxene and cummingtonite show strong dissolution texture (Fig. 3 F).

The samples from the Shinano Town, Nagano Prefecture, are volcanic ashes or sediments deposited on land. All the minerals are well preserved (Fig. 3D). The volcanic ashes at the top and bottom of the sequence are composed of amphibole and orthopyroxene. Most of the other samples are composed of cummingtonite and calcic amphibole. Epidote and clinopyroxene are usually absent or present in trace amount.

Chemical Compositions of Minerals

The chemical compositions of orthopyroxene and cummingtonite were analyzed. Their compositional variations are shown in Figs. 4 to 9 with X_{Mg}, $100\times Mg/(Mg+Fe)$ atomic ratio. As the difference of X_{Mg} in orthopyroxene between the core and the rim is mostly less than 2 % as X_{Mg} (Yokoyama *et al.*, 1997), we chose to analyze the central part of the grain.

In a simple volcanic eruption, the X_{Mg} value of minerals in the ash layer should have a strong peak in the diagram shown in Figs. 4 to 9. How-

Table 3. Heavy minerals of the samples from the Shinano Town (IB) , Nagano Prefecture Numerical value shows a number of counted grains of each mineral . Mineral abbreviations are the same as those in Table 1.

	IB-1	IB-2	IB-3	IB-4	IB-5	IB-8L	IB-8U	IB-9L	IB-9M	IB-11	IB-12	IB-13	IB-14	IB-16	IB-17U	IB-19L	IB-20	IB-21L	IB-22
opx	50	16	9							5	24		42	29	3	25	4	55	15
cum			7	60	60	100	100	100	60	14	3	61	18	31	17		5		1
cpx	2									12	43	3	2	3			1		
amp	28	61	30	6	9	65	18	28	74	48	7	67	86	93	100	100	100	100	100
oli											105								
ilm	7	12	25	16	12	5	6	23	8	11		22	6	2	6	10	10	3	4
mt	226	179	202	123	86	50	41	159	117	262	106	193	72	77	60	56	57	24	52
epi	2	4	5					1				1							
tit																			
Cag	5									1									
gar																			
apa						8													
all																			
spi			1																
zir		3	3		1			1											
TiO																			
tou		1								1									

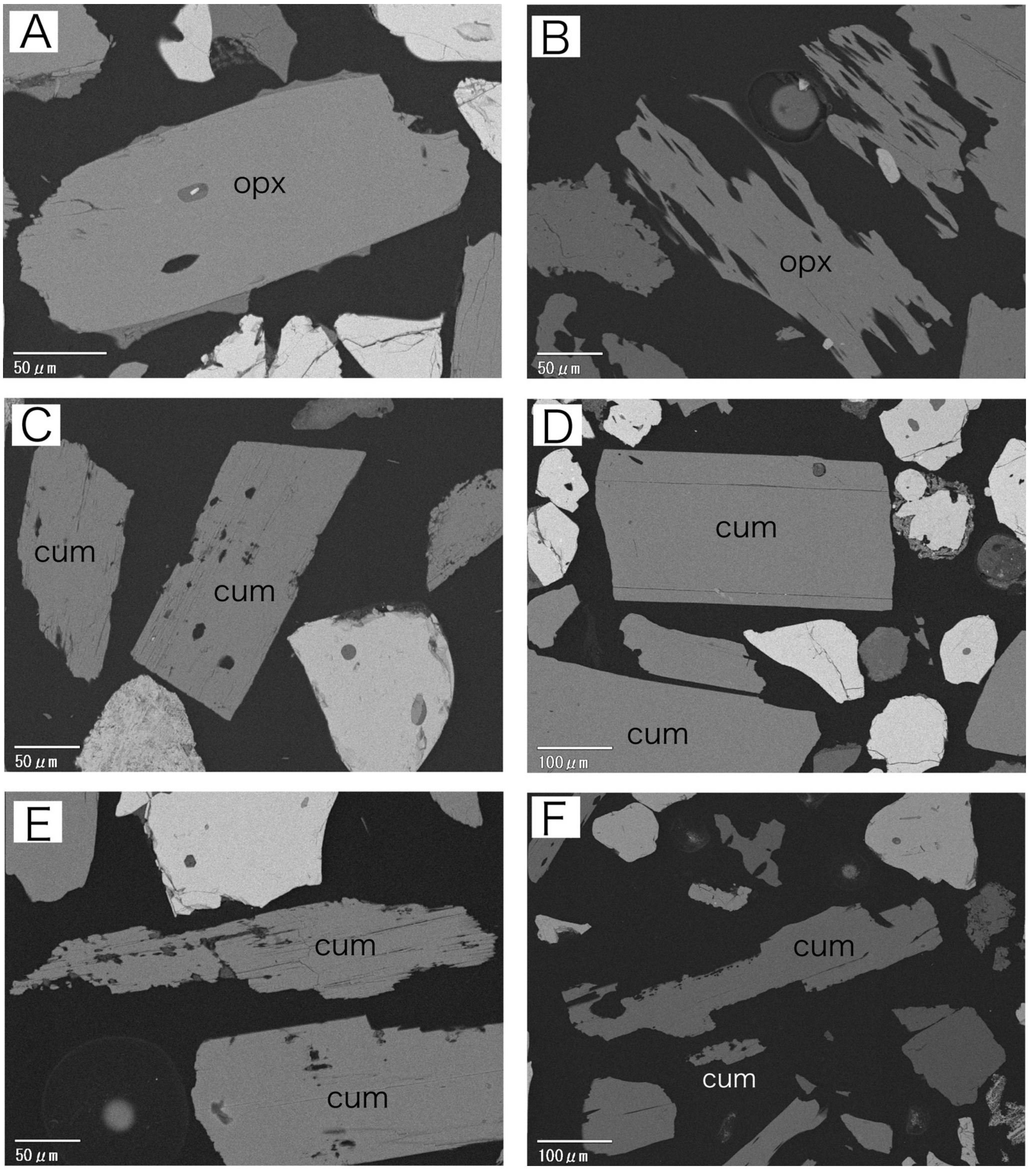

Fig. 3. Back-scattered electron image of orthopyroxene (opx) and cummingtonite (cum). A: fresh orthopyroxene partly surrounded by volcanic glass, sample KH-1. B: highly dissolved orthopyroxene, sample KN-8b. C; relatively fresh cummingtonite, sample KH-8. D; fresh cummingtonite, sample IB-4. E; highly dissolved cummingtonite, sample KN-8c. F; highly dissolved cummingtonite, sample MT-4.

ever, the ratio is more or less variable even in an eruption and bimodal or trimodal distribution is sometimes recognized. These characteristics are mainly due to mixing of essential, accessory and accidental fragments at the eruption. In Shinano Town where most of the layers are composed of volcanic ash, orthopyroxene and cummingtonite have a strong peak at X_{Mg}=62-64 (Fig. 9). Such strong peaks show that the minerals are essential ones formed in a magma chamber. The X_{Mg} ratio of orthopyroxene in two samples, IB-12 & IB-1, varies from 62 to 72. It is probable that they are

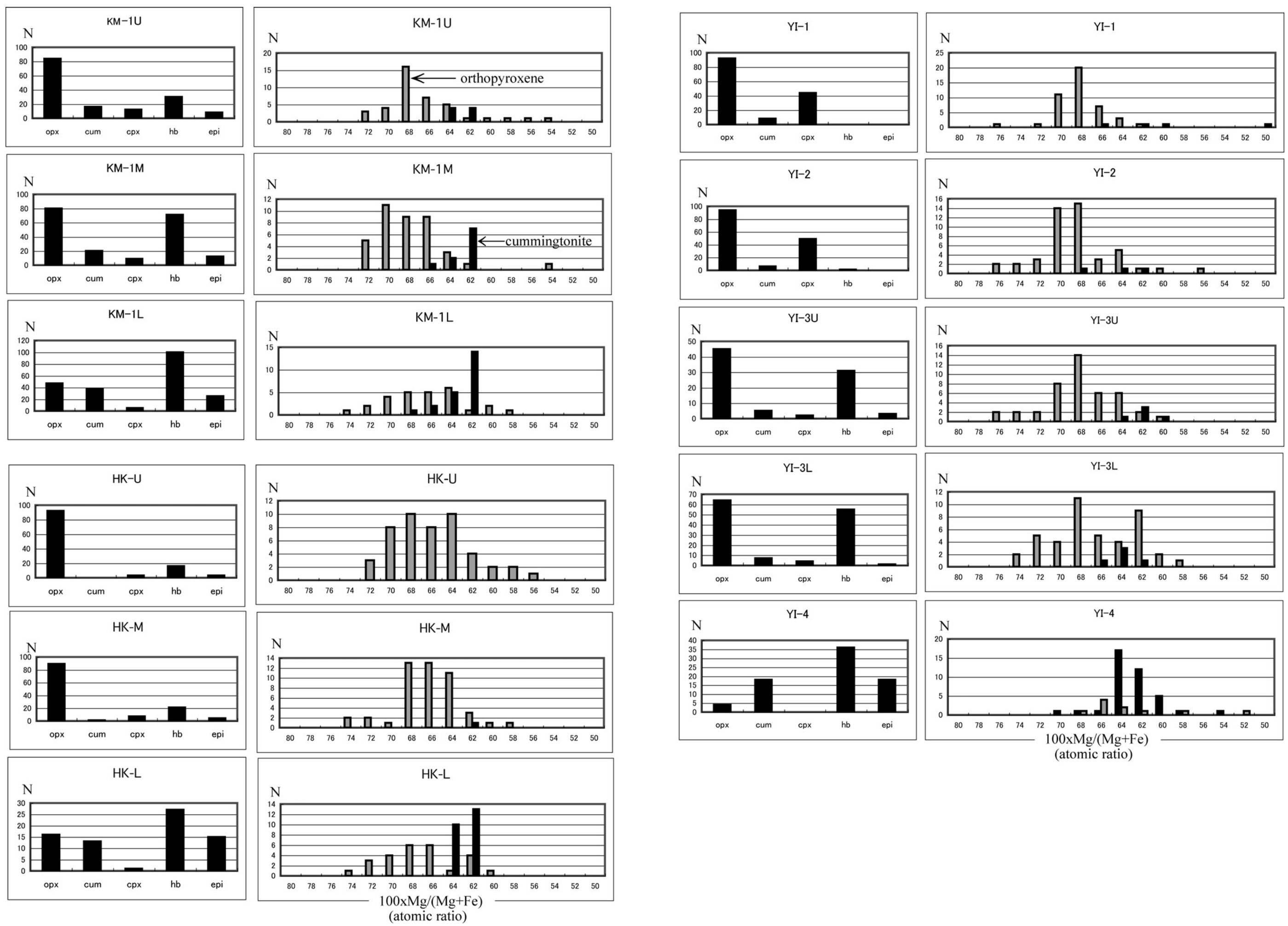

Fig. 4. Histograms of representative heavy minerals and compositional variations of orthopyroxene and cummingtonite in the samples from the Kounan Terrace (KM & HK) and Yorii site (YI). Vertical axis, N, is a number of grains counted or analyzed.

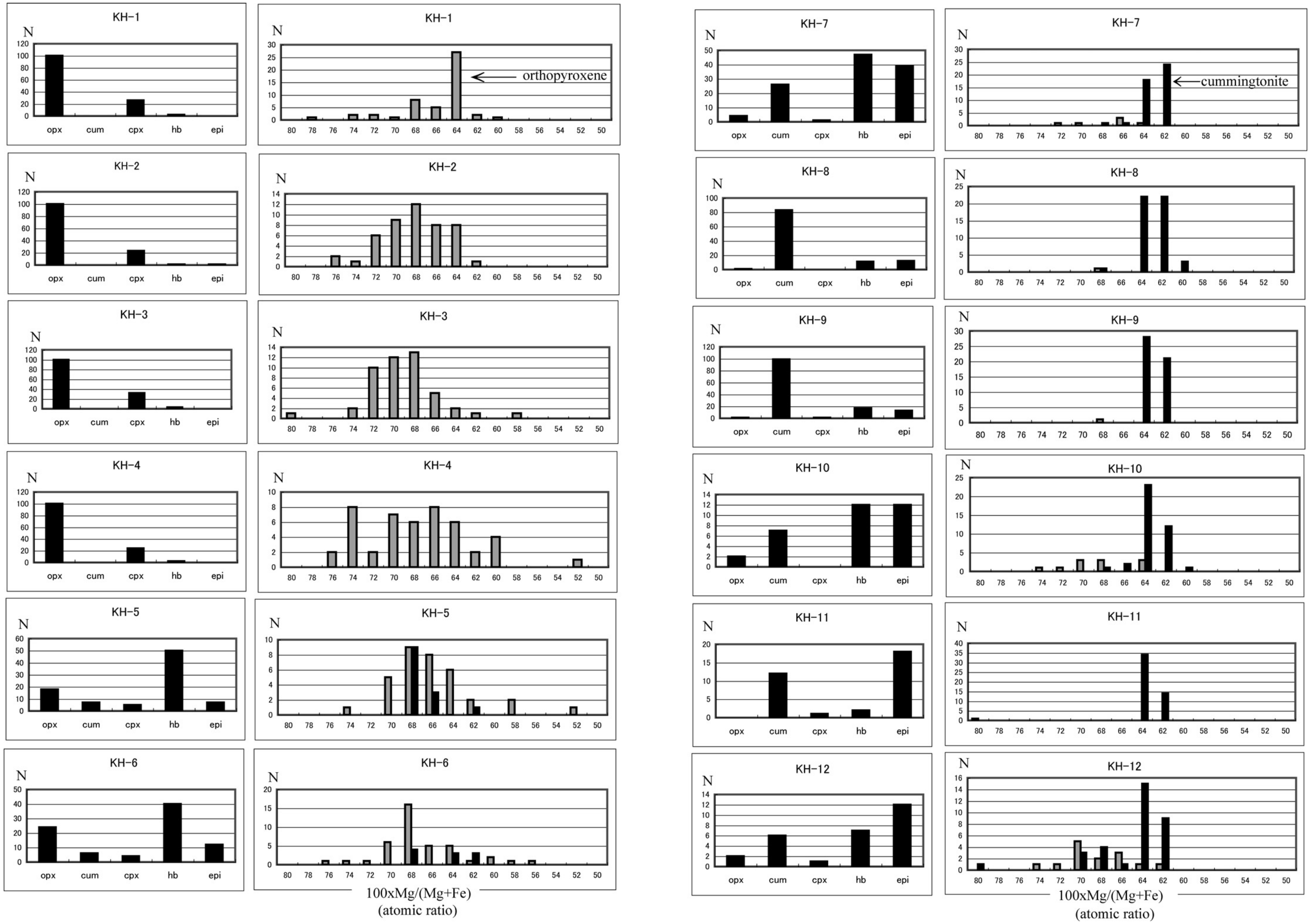

Fig. 5. Histograms of representative heavy minerals and compositional variations of orthopyroxene and cummingtonite in the samples from a small cliff, the Kounan Terrace (KH). Vertical axis, N, is a number of grains counted or analyzed.

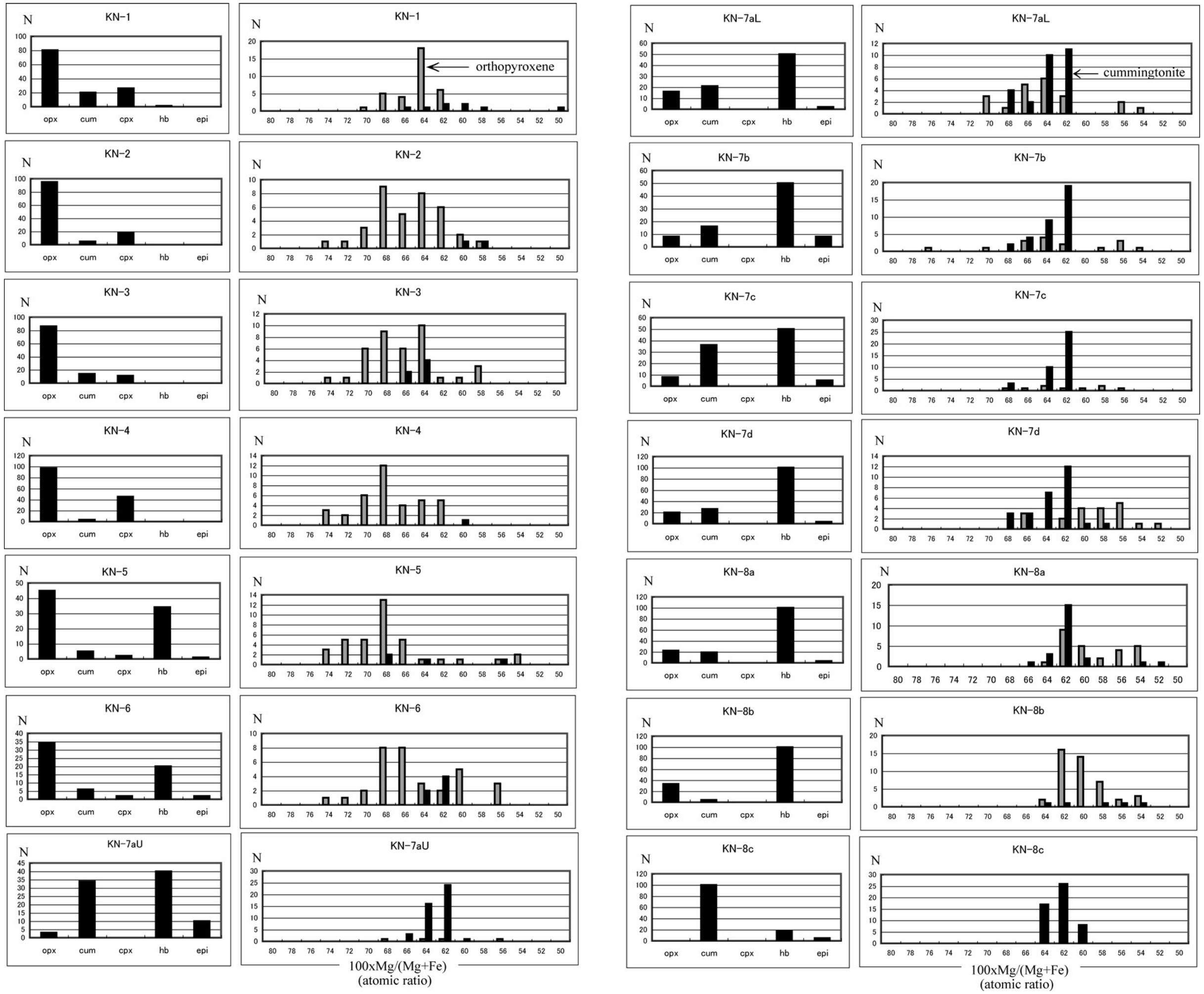

Fig. 6. Histograms of representative heavy minerals and compositional variations of orthopyroxene and cummingtonite in the samples from archaeological site, Kounan Terrace (KN). Vertical axis, N, is a number of grains counted or analyzed.

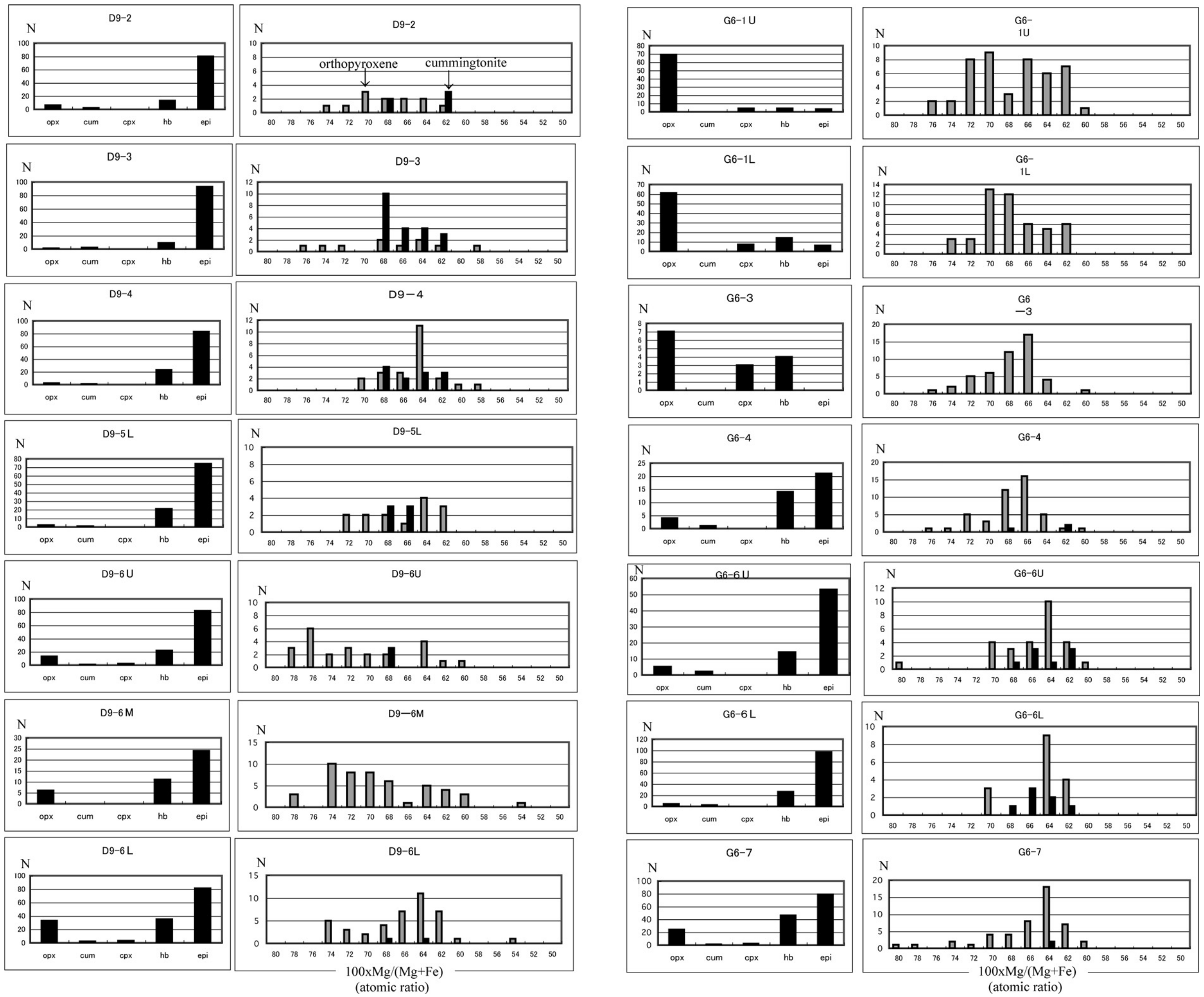

Fig. 7. Histograms of representative heavy minerals and compositional variations of orthopyroxene and cummingtonite in the samples from the Sakado archaeological site (D9 & G6). Vertical axis, N, is a number of grains counted or analyzed.

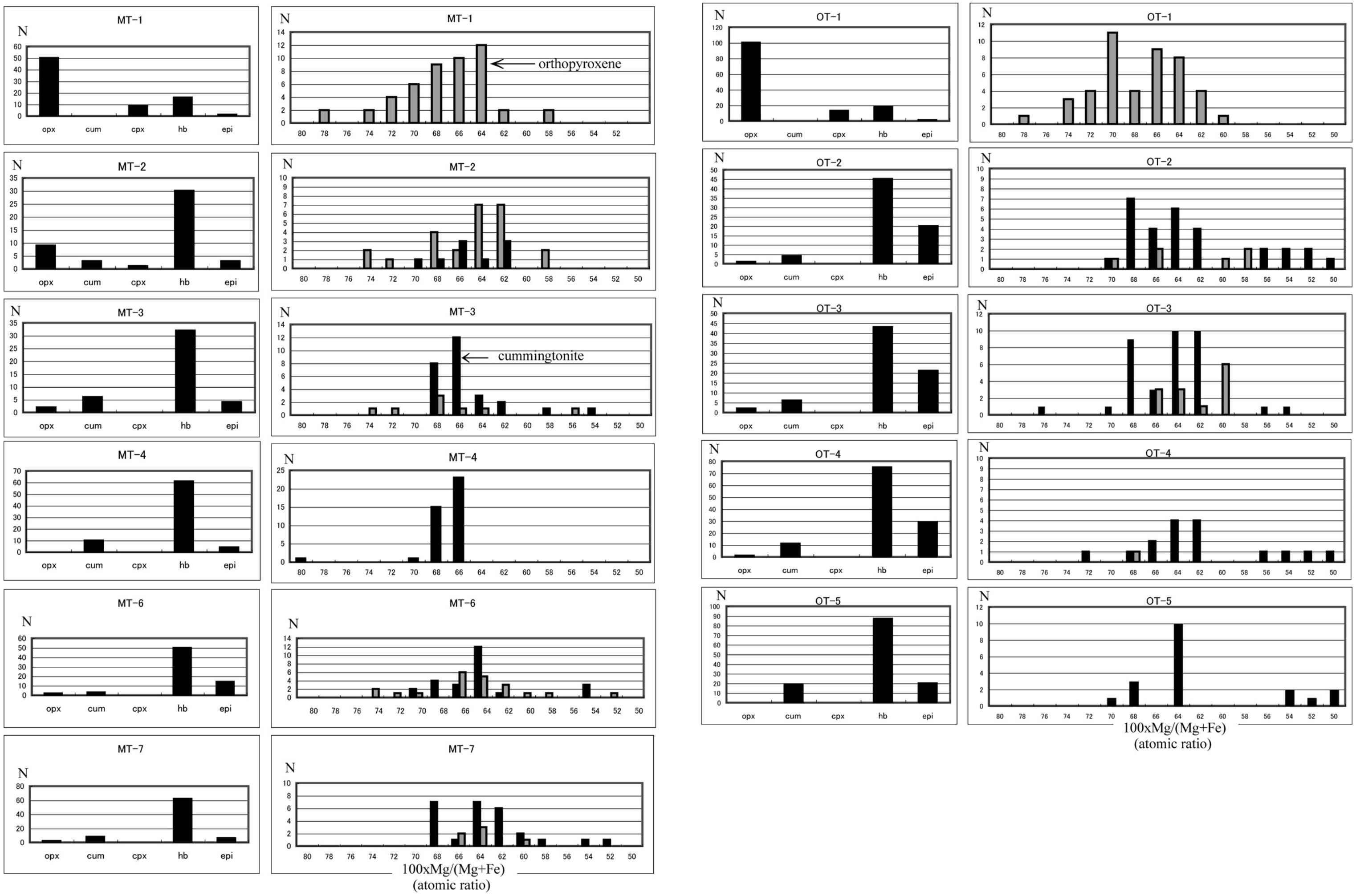

Fig. 8. Histograms of representative heavy minerals and compositional variations of orthopyroxene and cummingtonite in the samples from the Matsumushi (MT) and Otake (OT) on the Shimousa Terrace, Chiba Prefecture. Vertical axis, N, is a number of grains counted or analyzed.

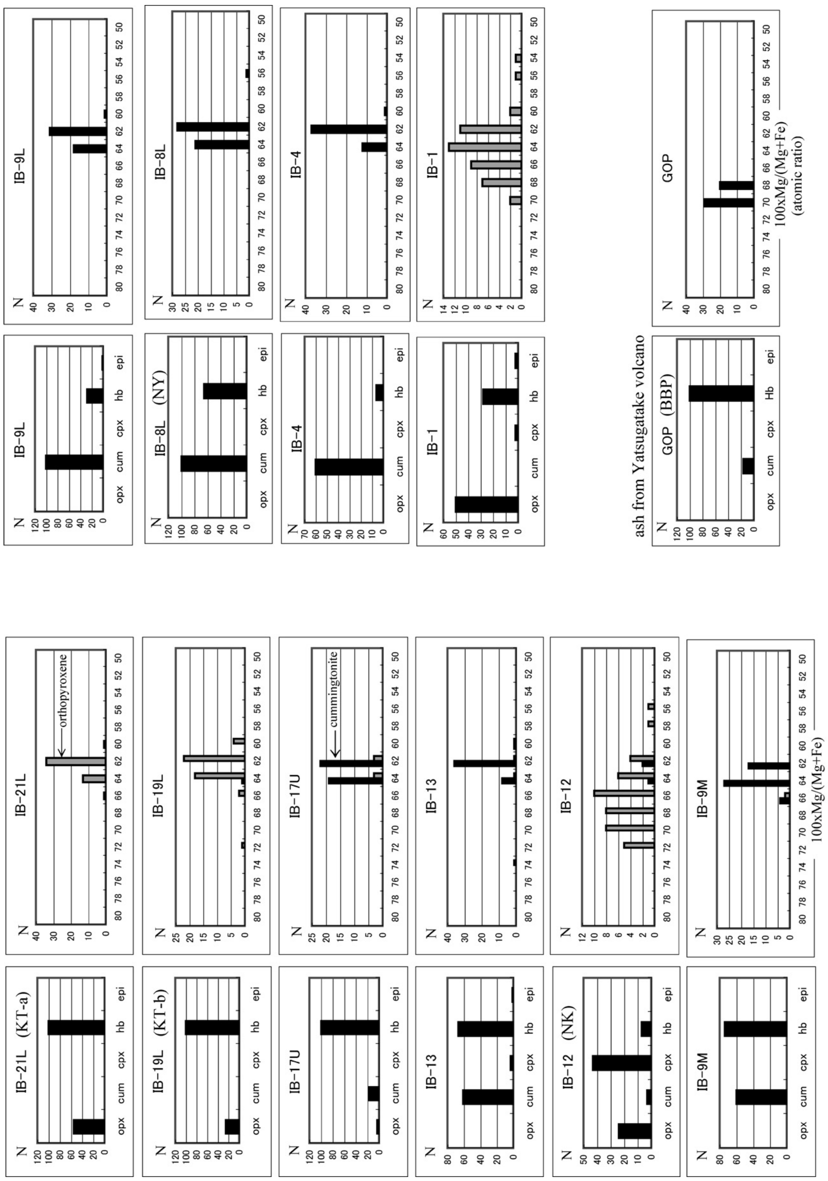

Fig. 9. Histograms of representative heavy minerals and compositional variations of orthopyroxene and cummingtonite in the samples from the Shinano Town (IB), Nagano Prefecture. Vertical axis, N, is a number of grains counted or analyzed. The sample GOP is a cummingtonite-bearing ash from the Mt. Yatsugatake, which erupted at about 300 ka ago.

mixture of essential, accessory and accidental fragments or sediments carried from a drainage basin.

In the Kounan Terrace, orthopyroxene shows a wide compositional variation of X_{Mg} from 54 to 74, and shows no strong peak (Figs. 4 to 6). Even within a single sample, a wide compositional variation is recognized. Cummingtonite also varies from 52 to 68, but usually shows a strong peak at 62 or 64. Another sharp peak is recognized in one sample, KH-5: 68 as X_{Mg}. A sharp peak in cummingtonite shows that it was derived from a single volcano, whereas wide variation of orthopyroxene shows that the samples are mixture, i.e. sediments derived from a drainage basin or products of various volcanic eruptions. If the clay was an aqueous sediment carried by a river, the relatively high proportion of epidote in the clays on the Kounan Terrace could be explained as a sediment derived from the Kanto and Ashio mountains where epidote is the main heavy mineral.

The X_{Mg} ratio of orthopyroxene from the Sakado Terrace also shows a wide variation like those from the Kounan Terrace (Fig. 7). Cummingtonite is mostly strongly dissolved and then it is usually small in amount. As the number of cummingtonite analyzed was restricted, a strong peak is not recognized except in one sample, D9-3, which has a X_{Mg} peak at 68. Cummingtonite with X_{Mg} from 62 to 64 is sporadically recognized in most of the samples.

Orthopyroxene in the Shimousa Terrace, Chiba prefecture, has a wide compositional variation (Fig. 8). Cummingtonite is also variable. In two samples, MT-3 & MT-4, s sharp peak is recognized at $X_{Mg}=66$. Bimodal or trimodal peaks are recognized in the some samples; peaks at 68 and 62–64 and a weak peak around 54. These data reflect a mixture of various types of volcanic products.

Discussion

The volcanic ash layer has been used as a key bed in the Middle to Late Pleistocene sequence in the Japanese Islands where successive volcanic eruptions occurred. More than 400 ashes have been described as a key bed (Machida and Arai, 1992). Among them only nine ashes contain cummingtonite. Numerous tuffs were described in the Early Pleistocene sequence from the Boso Peninsula (Yokoyama, *et al*. 1997 & 1998). Cummingtonite is rare mineral in the peninsula. Two cummingtonite ashes of Middle to Late Pleistocene age have been reported around the Kanto Plain. They are the ashes derived from the Iizuna volcano and a GOP ash from the Yatsugatake Volcano. The former ashes were collected from the Shinano Town for this study as a possible source of cummingtonite with an X_{Mg} of 62–64. The GOP ash is composed of calcic amphibole and cummingtonite (Fig. 9). As the GOP ash was formed about 300 ka ago (Machida and Arai, 1992) and cummingtonite has a peak at 70 as X_{Mg}, its source is clearly different to that of the minerals in the clays studied here.

Modal proportions and chemical compositions of heavy minerals are important indicators for the correlations of ash, tuff and sediment. Even when we used selected minerals with similar density, the clay samples from the terraces in the Kanto Plain were variable in the modal proportion of heavy minerals. This is probably due to mixing of essential, accidental and accessory fragment at the time of eruption, in addition to the supply of minerals from various drainage sources.

Clays occurring on the terraces in the Kanto Plain are locally known as the Jousou Clay or Itabashi Clay. It has been suggested that the clay was used for the paste of the pottery found in the archaeological site. This paper petrologically analyzed the samples in and around the clay layers to provide basic data to examine whether or not the clay was used in pottery manufacture. The clays are variable in modal proportion. It is, however, clear that the clay layers in the Kounan, Sakado and Shimousa terraces contain more or less cummingtonite which is a specific mineral in the Japanese Islands. In the Kounan Terrace, cummingtonite is abundant in some samples and

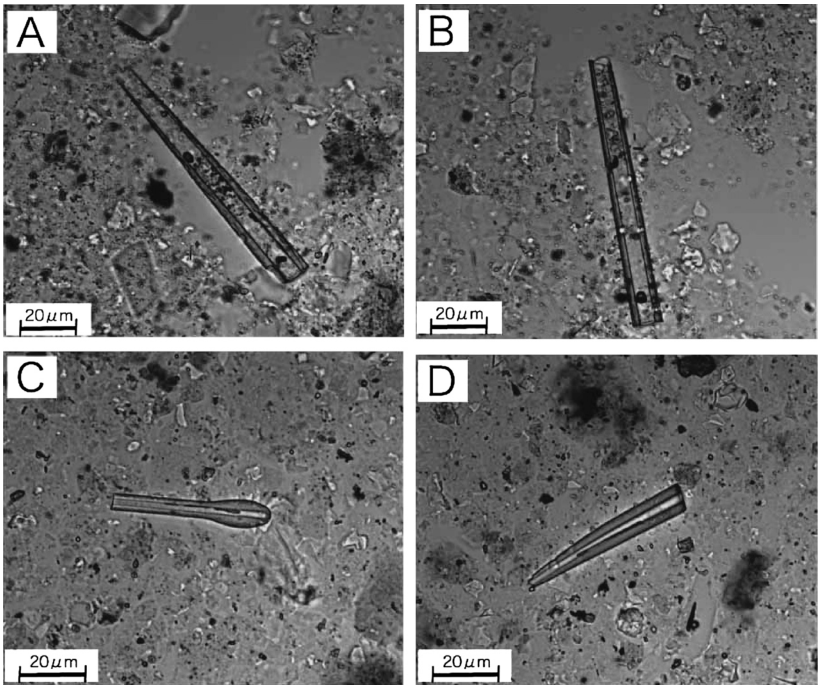

Fig. 10. Sponge spicules in the clay sample from the Kounan Terrace (A & B) ans Shimousa Terrace (C & D)

shows strong peak at 62–64 as X_{Mg} ratio. In the Sakado Terrace, epidote is the most common minerals, and pyroxene and amphibole are small in amount, but it is important that the cummingtonite with 62–64 was more or less recognized. In the Simousa Terrace, Matumushi and Otake, calcic amphibole is predominant and the cummingtonite content is small. Cummingtonite with 62–64 is confirmed in the Shimousa Terrace. Other peaks at around 68, 66 and 54 are also present. So far there is no candidate for the source rock for the various cummingtonite occurrences. Despite the uncertainty about the source, the sharp composition or bimodal and trimodal natures may act as a correlation marker of clay. The presence of cummingtonite and chemical compositions will be useful for the correlation between the clays and body paste of the ancient pottery at the archaeological site.

Nakazato and Nakazawa (2007) concluded that the cummingtonite ash in the Kounan Terrace was correlated with NY ash in the Shinano Town. The ash described by them will be similar to the samples, KH8, KH-9 and KN-8c. They thought that the other clay layers were eolian deposit formed around 180 ka ago. On the other hand, Suzuki (2001) concluded that the KT-a ash in the Shinano Town was formed at 125–150 ka. Pm-1 ash derived from the Ontake volcano has been recognized in the clay layers from the Kounan and Shimousa terraces. The age of Pm-1 is around 100 ka. The clays from both the Kounan and Shimousa terraces contain sponge spicules (Fig. 10), clearly showing sedimentation under aqueous conditions. The wide compositional variation of orthopyroxenes shows that they were derived from various sources and indicate that the sediments were aqueous. Furthermore, moderate amounts of heavy minerals, magnetite, ilmenite and zircon, do not support an eolian sediment deposited on land. If all the clay layers from the three terraces were formed by similar process, the abundance of epidote from the Sakado Terrace would also supports an aqueous origin. Even though depositional age of the clay layers is uncertain, most of the clays were essentially formed under lacustrine or marine conditions.

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