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Key Bed "Kd38" Tuff Occurring near the Boundary between Tertiary and Quaternary from the Lowest Part of the Kazusa Group, Boso Peninsula, Central Japan

Takashi Mitsuoka[1], Naoki Takahashi[2] and Kazumi Yokoyama[1]

[1]Department of Geology and Paleonfology, National Science Museum,
3–23–1 Hyakunincho, Shinjuku-ku, Tokyo, 169–0073 Japan
E-mail: mitsuoka@kahaku.go.jp, yokoyama@kahaku.go.jp
[2]Department of Earth Science, Natural History Museum and Institute, Chiba,
955–2 Aobacho, Chuo-ku, Chiba city, Chiba, 260–8682 Japan
E-mail: takahashin@chiba-muse.or.jp

Abstract The "Kd38" tuff in the central part of the Boso Peninsula occurs near the boundary between Tertiary and Quaternary. Two types of "Kd38" tuffs had been described by many authors. Stratigraphic relationships of the "Kd38" tuffs were studied at four routes from the lowest part of the Kazusa Group.

One of the Kd38 tuffs is characterized by presence of Fe-rich orthopyroxene with $X_{Mg}=26$. It occurs in the middle zone of the Yoro route, whereas the other one is characterized by abundance of cummingtonite and is observed in the lower zone. The former one is recognized in the four routes, but the latter is found only in Yoro and Minato routes which are located at the eastern and western ends of the studied area, respectively. It suggests that a small rise was present in the central part where the cummingtonite tuff had been eroded out soon after deposition.
Key words: tuff, modal proportion, cummingtonite, Kazusa Group

Introduction

Almost continuous sequence from Middle Miocene to Pleistocene develops in the central part of the Boso Peninsula. As there are many tuff layers in the sequence, geological surveys in this region have been confirmed by the tuff layers as key beds. Microfossils and paleomagnetism were studied in detail in this region. Based on the microfossils, Takayama *et al.* (1995) concluded that Tertiary-Quaternary boundary is near a tuff layer "Kd38" which was originally described by Mitsunashi *et al.* (1959, 1979). Although the "Kd38 tuff" was described by many authors (Yoshikawa, 1996; NHMIC, 1990; Watanabe and Danhara, 1996; Yokoyama *et al.*, 1997), there is a confusion about locality of the "Kd38" tuff. Mitsunashi *et al.* (1959) pointed out a stratigraphic position of the Kd38 tuff in the Orikizawa route with a detailed columnar section and also plotted its locality in the tributary route of the Yoro River. Yokoyama *et al.* (1997) studied the modal proportions of heavy minerals and chemical composi-

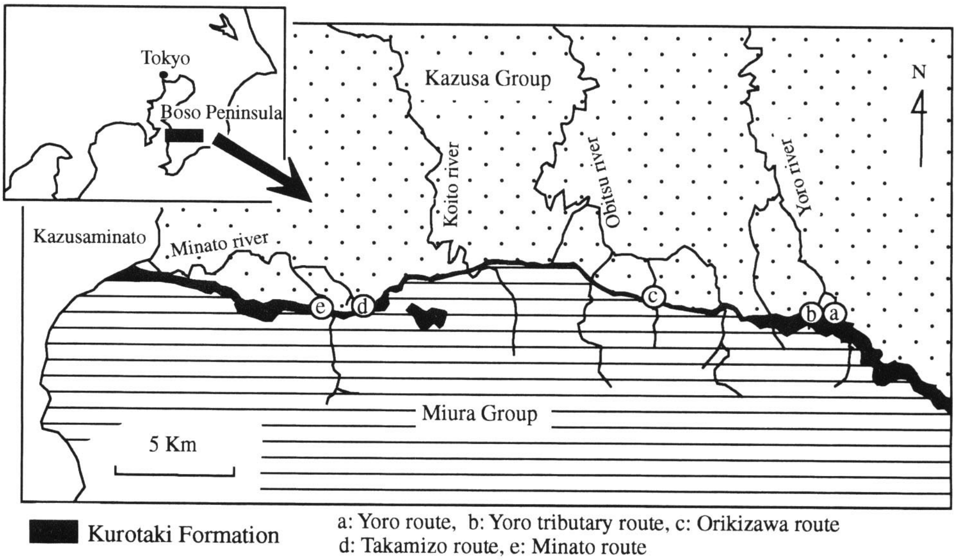

Fig. 1. Geological map at the central part of the Boso Peninsula with studied routes.

tions of orthopyroxene and cummingtonite in the tuffs in the Boso Peninsula. They concluded that the "Kd38" at the Orikizawa route is characterized by Fe-rich orthopyroxene, whereas that in the Yoro River is cummingtonite-rich tuff.

Yokoyama *et al.* (1998) presented modal proportions and chemical compositions of heavy minerals in about 100 tuffs from the lower sequence of the Kiwada Formation along the Yoro River. However, they failed to find out relationships between two kinds of Kd38 tuffs. In this paper, we analyse the modal proportions and chemical compositions of the heavy minerals in the tuffs in addition to the lithostratigraphic survey of several routes in the central part of the Boso Peninsula to deduce the relationships of the two kinds of "Kd38" tuffs.

Geological Framework and Analytical Method

In the central part of the Boso Peninsula, the Kazusa Group is widely distributed (Fig. 1). It covers unconformably the Tertiary Miura Group on its southern part. The lowest part of the Kazusa Group is the Kurotaki and Takeoka formations consisting of conglomerate. It followed by the Kiwada Formation or its equivalents where coarse-grained sedimentary rocks develop at their lower part. According to Mitsunashi *et al.* (1979), Kd38 tuff layer runs from eastern part to the western end of the peninsula. In the studied area, it should run in the lowest part of the Kazusa Group and locally in the basal conglomerate layer. As shown in Fig. 1, four routes along the four rivers were selected to study the relations between two kinds of "Kd38" tuffs.

They are Yoro, Orikizawa, Takamizo and Minato routes. Along the Yoro River, about 100 samples were collected and modal proportions and chemical compositions have been described by Yokoyama *et al.* (1998). In the other routes, mostly thick tuffs were selected for the analyses. All the tuffs were collected from the Kiwada and Takeoka formations overlying the basal conglomerate layer, because tuffs are dispersed in the conglomerate.

The locality of "Kd38" tuff in the Orikizawa route was pointed out in the columnar section of Mitsunashi *et al.* (1959). It was accepted as "Kd38" by Yoshikawa (1996) and others. The "Kd38" is well characterized by presence of Fe-rich orthopyroxene (Yokoyama *et al.*, 1997). Detailed sampling was done in the other routs where the Fe-rich "Kd 38" may occur. In addition to the four major routes, samples were collected in the tributary of the Yoro River where Mitsunashi *et al.* (1959) plotted the locality of "Kd38" in a detailed topographic map.

Analytical method was reported in the foregoing paper (Yokoyama *et al.*, 1997). The procedure was described briefly here. Tuffs were disaggregated by boiling in water with 5% of hydrogen peroxide. They were subsequently dried and sieved into four fractions: A (0.5–0.25 mm), B (0.25–0.125 mm), C (0.125–0.063 mm), D (<0.063). Heavy minerals were separated from the fractions by mixing with methylene iodide with specific gravity around 2.8. Micaceous and carbonate minerals are present in both heavy and light fractions. Hence, these minerals except for biotite were not included in the following mineral count. Pyrite and goethite are common in some tuffs. Most of them are considered to be secondary formed as an authigenic mineral or replacing magnetite. They are not included in the mineral proportion.

Most of the minerals were identified by means of profiles obtained by energy dispersive spectrometer (EDS, LINK Systems). Orthopyroxene and cummingtonite were analyzed by wave-length spectrometer (JXA8800 of JEOL) using an accelerating voltage of 15 kV, a 20 nA beam current and a 3 μm beam diameter. The most homogeneous pyroxenes in the Kd39 tuff (Yokoyama *et al.*, 1997) were analyzed routinely to check for any machine drift.

Heavy Minerals

Modal proportions and chemical compositions of heavy minerals in a tuff are more or less different from fraction to fraction divided by grain size, and heavy minerals such as zircon and magnetite are strongly enriched in the fine-grained fraction (Yokoyama *et al.*, 1997). In this paper, we mostly use fraction B (0.25–0.125 mm) for the modal and chemical analyses. Fine-grained fraction C is used occasionally in the fine-grained samples or white tuffs. Although more than 12 minerals were observed in the heavy fraction from the tuffs, pyroxene and amphibole in addition to magnetite and ilmenite are dominant in the fraction B (Table 1). Cummingtonite is one of major phases in some tuffs. Modal proportions of pyroxenes, amphiboles and biotite are

Table 1. Modal proportions of mafic minerals and chemical compositions of orthopyroxene and cummingtonite in the tuffs from the Boso Peninsula.

Yoro route

		Modal proportion					zone	Chemical compositon of opx and cummingtonite, 100xMg/(Mg+Fe) ratio																														
sample	size	opx	cum	cpx	hb	bi		80	78	76	74	72	70	68	66	64	62	60	58	56	54	52	50	48	46	44	42	40	38	36	34	32	30	28	26	24	22	20
YK-10	B	61		39												1	10	14	14	1																		
YK10-1	B	70		30									2	7	17	16	1																					
YK10-1'	B	60		40							1		1	17	18	11	1	1																				
YK10-1b	B	82		18							1	3	1	15	29																							
YK10-2U	B	74		26										1	20	22																						
YK10-2L	B	65		35											23	17	3	1																				
YK10-2'	B	67		33								1			32	20	1																					
YK10-2a	B	65		35											25	16	2																					
10-2a-1	B	64		28	6	2				1	1	3	3	30	31	6	5	3	4	4	2	1		1		1							1					
10-2a-1	CD	62		28	11		mid					4	5	18	9	2	8	8	14	5	5	1	1	2	1	2			5	4		2			2			
YK10-2b	B	49		51												9	34																					
YK10-2b'	B	49		51										1	3	5	38	3																				
YK10-2c'	B	61		39									6	36	8																							
YK10-3	B	39		61								1	3	10	12	15	4																					
YK10-4	B	49		51									1		3	25	14																					
YK10-5	B	61		39									2	1	4	27	6	1	1																			
YK-11	B	70		30							2			1		2	6	15	13	1																		
YK11-1	B	30		70								4	11	9	9	2	7	1	1																			
YK11-2	B	45		55									1	1	1	25	13																					
YK11-3	B	58		42											2	39	3																					
YK11-4	B	69		15	16								1	1	24	18	1																					
YK11-5	B	81		19									1	1			2	5	21	13	1	1																
YK11-6	B	54		46	1									3	13	27			1																			
YK11-7	B	71		29								1	2	2	3	5	2	1	6	17	4																	
YK11-8	B	72		27	1								3	10	19	8	1	1			1																	
YK-12	B	69		31										1		6	23	9			1																	
Yo6/1	B	51		46	3							2	2	3	8	17	4	4																				
YK-13	B	45		52	3					1		5	6	10	7	5	2	1	2	1																		
Yo5	B	68		31	1						1	3	3	3	18	14	2				1																	
Yo4	B	32		18	51						1		2	2	8	6	24	2																				
YK-14	B	20	55	18	7							1		**23**	**15**	1																						
Yo3	B	57	4	36	2						1		1	5	**19**	13	3		**2**	1																		
Yo2	B	54	12	26	9							1	4	5	16	9	1	**2**	**2**	**4**	**1**																	
YK-15	B	53		10	38		low							2	1	2	7	28																				
Yo1	B	67		33						1			3	16	19	2	1																					
Kd38-1	A	53	13	15	19						1		1	**8**	13	9	7				1																	
Kd38-1	B	49	18	17	16						1	1	2	**9**	**15**	11		1																				
Kd38-1	C	58	9	26	7						1	1		**5**	27	6																						
Kd38-4	A	51	22	6	21						1		1	**6**	**14**	17	1																					
Kd38-4	B	41	33	7	20							1		**16**	**8**	11	1	1				1																
Kd38-4	C	26	44	12	18							1		**24**	**11**	3		1																				
Kd38-6	A	12	58	22	7						4	3		**28**	**5**																							
Kd38-6	B	3	85	4	8					1				**36**	**3**																							
Kd38-6	C	3	86	1	10								1	**36**	**2**																							
YK-16	B	19		9	72								2	2	17	19																						
YK16-1	B	63		24	13								4	6	16	16	2	1																				
YK16-2	B	67		33	1								4	19	16	4	1			1																		

Tributary of Yoro river

		Modal proportion					zone	Chemical compositon of opx and cummingtonite, 100xMg/(Mg+Fe) ratio																														
sample	size	opx	cum	cpx	hb	bi		80	78	76	74	72	70	68	66	64	62	60	58	56	54	52	50	48	46	44	42	40	38	36	34	32	30	28	26	24	22	20
YS-1	B	17	1	73	10						1	4	9	**14**	13	4	2	1	2																			
YS-2	B	41		40	19				2	1	1	1	4	13	8	4	3	12	1																			
YS-3	B	43		7	50									1	1	2	7	33	4																			
YS-4	B	39	5	19	38							1		**9**	8	29	3																					
YS-5	B	16		6	78		low				1	1	4	2	18	18	2			1								1		1								
YS-6	B	16		15	68						1		2	3	19	20	4					1																
YS-7	B	40		54	6							1	6	10	17	10	1	1	1		1																	
YS-8	B	64		36										17	24	6				1			1															
YS-9	B	16	6	10	68						1	1	1	**20**	**14**	11	2																					
YS-10	B	2		2	96							1		2	7	36	3	1																				

Abbrev. opx:orthopyroxene, cpx:clinopyroxene, cum:cummingtonite, hb:calcic amphibole, bi:biotite.
Grain size, A:0.5-0.25mm, B:0.25-0.125, C:0.125-0.063, D:<0.063. Zone, upp:upper, mid:middle, low:lower.
Number in box includes data of cummingtonite.

Table 1. Continued.

Takamizo route

		Modal proportion					zone	Chemical compositon of opx and cummingtonite, 100xMg/(Mg+Fe) ratio																														
sample	size	opx	cum	cpx	hb	bi		80	78	76	74	72	70	68	66	64	62	60	58	56	54	52	50	48	46	44	42	40	38	36	34	32	30	28	26	24	22	20
TK-17	B	47		53										5	9	25	6																					
TK-Z	B	55	1	36	8	1					1	3	6	[13]	23	13	9	6	1	1		2																
TK-16	B	52	1	39	6	2					1	1	5	6	5	[9]	5	3	1	1	1	2	2								1							
TK-15	B	60		40								2	7	8	17	10	1																					
TK-Y	B	61		39							1	4		10	24	6																						
TK-X	B	52		48									1	15	55	5			1																			
TK-14	B	63		38									1	1	27	10	5	1																				
TK-1B	B	55		45			upp								10	26	4																					
TK-2B	B	52		29	19									1	3	14	13		3	5		1																
TK-3	C	63		28	9																																	
TK-4B	B	56		44									1	9	19	11																						
TK-5B	B	60		40										3	13	20	4																					
TK-6B	B	65		35	1										2	12	26																					
TK-7C	C	60	1	35	4	1					2	11	12	23	29	25	13	5	[1]	5	5	4	1		1		1	1				1		2				
TK-13-1	B	34	2	32	10	22					2	2	3	[6]	[11]	11	1			1																		
TK-13	B	32		42	20	5				1	1	7	4	6	5	5	7	1	2			1																
TK-12	B	41		58	1					1	4	4	15	10	15	7	10	7	2	2	1				1			1										
TK-11	B	59		41						1	1			5	7	25	4	1																				
TK-10	B	8		92								16	15	3	4	2																						
TK-9	B	47		53						1	10	14	2	3	1	4	2		1	4	1	1	1															
TK-8	B	39		61								1		6	20	15	3																					
TKu-9	B	54		46									2	1	1	2	31	10	3																			
TKu-8	B	21		79								11	3	3	19	11	2																					
TKu-7	B	44		56								2	2	13	25	7	1																					
TKu-6	B	28		72								11	5	2	4	17	7	2																				
TKu-5	B	43		57							1	9	3	4	8	11	10	3	1																			
TKu-4	B	36		64								6	16	7	2	2	4	7	2	4																		
TKu-3	B	58		35	6	1						2	6	13	10	4	7	6	1																			
TKu-2	B	70		30											1	3	19	25	2																			
TKu-1	B	67		33									1		1	2	14	20	12																			
KT'8-2	B	68		32										3		8	7	17	12	2	1																	
KT'8-1	B	65		34	1									1		4	3	16	17	7	2																	
KT'7	B	65		35								1		24	14	7																						
T17	B	64		36									1	15	21	11	2																					
KT'6	B	54		46							1		1	1	44	3																						
T16	B	67		33											25	23	1																					
T15b	B	66		26	7					1		5	5	32	18	12	1		2						2	1	1	1		2			1	2	7			
T15a	B	72		26	2						1	3	5	15	16	5	1		2				1															
T15	B	66		29	5		mid				2	2	2	13	20	5	3	1																				
T14	B	66		28	5									36	9	1																						
T13	B	52		48													45	3																				
T12	B	47		53											19	29																						
T11	B	52		48												13	35																					
T10	AB	40		60							1	1	7	6	3		9	19	2	1	1																	
T09	B	44		56								2		1	9	37	1																					
T08	B	33		67								1	7	9	8	11	3	1	3	1	3	1	1		1													
T07	B	49		51											14	35	1																					
T06	B	44		56										4	2	22	20	1																				
T05	B	43		57										4	5	31	9																					
T04	A	66		34											17	23																						
T03	A	74		24	2						1	1	2	4	4	23	14	1																				
T02	A	73		9	18		low					1	1	3	26	19																						
T01	A	70		30										1		4	27	18																				

Abbrev. Opx:orthopyroxene, cpx:clinopyroxene, cum:cummingtonite, hb:calcic amphibole, bi:biotite.
Grain size, A:0.5-0.25mm, B:0.25-0.125, C:0.125-0.063, D:<0.063. Zone, upp:upper, mid:middle, low:lower.
Number in box includes data of cummingtonite.

Table 1. Continued.

Minato route

		Modal proportion					zone
sample	size	opx	cum	cpx	hb	bi	
M21b	B	25		75			
M21a	B	51		46	3		
M20	B	54		46			
M19	B	64		36			
M18	B	62		38			
M17	B	49		30	18	3	
M16	B	64		29	7		mid
M15	B	51		49			
M14	B	46		54			
M13	B	65		35			
M12	B	37		63			
M11	B	44		56			
M10	B	63		38			
M09	B	54		26	20		
M08	B	64		36			
M07	B	63		36	1		
M06	B	4		15	80	1	
M05	B	4	88		8		
M04	B	31	36	23	9	1	low
M03	B	22	1		77		
M02	B	33	9	44	13		
M01b	B	13	72	7	9		
M01a	B	2	92	4	2		

	Chemical compositon of opx and cummingtonite, 100xMg/(Mg+Fe) ratio																														
sample	80	78	76	74	72	70	68	66	64	62	60	58	56	54	52	50	48	46	44	42	40	38	36	34	32	30	28	26	24	22	20
M21b					15	29	2	1	3																						
M21a				1	4	7	5	18	7	3				1				1						1							
M20					1	1			8	14	22	3																			
M19								1	3	10	22	11	2																		
M18					1	2	22	18	5	2																					
M17					2	6	8	8	4	1	2	5	5	1	1				1	1		1			1	1	2	7	1		
M16				3	2	5	17	14	4		1	1																			
M15				1	6	6	12	13	6	4	1																				
M14					6	30	2	2	1	7	2																				
M13					2		2	2	5	8	27	4																			
M12						1		13	34	2																					
M11						1		21	27	1																					
M10					1	5	3	3	29	9																					
M09							9	35	6																						
M08					2	2	3	5	9	17	10	2																			
M07				1	1	1	2	2	16	23	4	1	1																		
M06					4	5	4	12	6			1																			
M05							[25]	[20]	[1]		1																				
M04				1		4	8	6	3	[1]	[10]	[14]	[3]	[1]																	
M03			1			2	6	18	17	[6]	2																				
M02						1	[13]	16	12	1	3	2	1	1																	
M01b							[40]	[3]	1	2		1																			
M01a				1			[43]	[3]																							

Orikizawa route

		Modal proportion					zone
sample	size	opx	cum	cpx	hb	bi	
KT-16	B	58		42			
KT-15	C	76		16	8		upp
KT-14	B	12		21	1	66	
KT-13	B	35		65			
KT-12	B	38		63			
KT-11	B	61		39			
KT-10	B	49		51			
KT-9	B	56		44			
KT-8	B	66		34	1		mid
KT-7	B	68		32			
KT-6	B	62		38			
KT-5	C	42		14	44		
KT-4	B	69		28	3		
KT-3	B	73		21	5	1	
KT-2	B	69		31			
KT-1	B	59		41	1		

	Chemical compositon of opx and cummingtonite, 100xMg/(Mg+Fe) ratio																														
sample	80	78	76	74	72	70	68	66	64	62	60	58	56	54	52	50	48	46	44	42	40	38	36	34	32	30	28	26	24	22	20
KT-16							1	11	26	2																					
KT-15			1		2	2		9	9	3	1	9	2	1	1																
KT-14				2	3	2	3	8	4	9	5		1	2	1																
KT-13				3	9	1	11	4	3	1			1	5	14	20	6	1			1										
KT-12							2	26	11	1																					
KT-11					1	1			24	14																					
KT-10						1	4	26	8	1																					
KT-9								1	6	11	15	7																			
KT-8					1		2	3	4	6	5	15	3	1																	
KT-7					1	1	20	14	4																						
KT-6						1		29	10																						
KT-5					1	4	3	5	3		3	3	1	3		1			1	1	1		2	1			1	4	1		1
KT-4				1	8	12	31	12	9	4	2	1																			
KT-3						2	4	4			2	8	1	2								1	1		1	1		11	1		
KT-2				1		1		2	5	4	10	17																			
KT-1					1			9	28	1	1																				

Road cut of Orikizawa rout

		Modal proportion					zone
sample	size	opx	cum	cpx	hb	bi	
CM38-5	A	60		36	4		
CM38-5	C	68		26	6		
CM38-5	D	77		15	8		
CM38-6	A	64		34	2		
CM38-6	B	74		25	2		mid
CM38-6	C	67		24	9		
CM38-6	D	68		26	6		
CM38-7	A	65		31	4		
CM38-7	B	80		18	1		
CM38-7	C	84		13	3		
CM38-7	D	83		9	9		

		Chemical compositon of opx and cummingtonite, 100xMg/(Mg+Fe) ratio																														
sample	size	80	78	76	74	72	70	68	66	64	62	60	58	56	54	52	50	48	46	44	42	40	38	36	34	32	30	28	26	24	22	20
CM38-5	A				1	4	6	16	9	2	1							1														
CM38-5	C			1		8	7	17	11	2	4	6	10	1	1		2		1		1			1			1	2	4			
CM38-5	D				1	3		3	1	5	7	8	13	2	1	1	1	1				5		1	2	2		4	15	1		
CM38-6	A					1	3	15	18	2	1																					
CM38-6	B					1	2	28	7	1			1																			
CM38-6	C					1	3	18	5	1		1	5								1	1						1	3			
CM38-6	D					2		12	6		2	2	4	2			1				1		1			2			4			
CM38-7	A					2	1	11	21	5																						
CM38-7	B					1		18	11			1	4	1								1			1		1			1		
CM38-7	C					1	3	4	2				10	2	1					1				1			2	1	11	1		
CM38-7	D						1	3			1	2	4	2		1		1						2	1	1	2	3	15	1		

Abbrev. Opx:orthopyroxene, cpx:clinopyroxene, cum:cummingtonite, hb:calcic amphibole, bi:biotite.
Grain size, A:0.5-0.25mm, B:0.25-0.125, C:0.125-0.063, D:<0.063. Zone, upp:upper, mid:middle, low:lower.
Number in box includes data of cummingtonite.

presented in Table 1. These minerals have similar density to each other and were expected to behave in a similar way during gravity settling. Biotite is present in the light and heavy fractions. Its modal proportion may not be compared with heavier pyroxene and amphibole. Biotite occurs only in a few samples which are useful markers in the sequence from the Kiwada Formation. Hence, it was tentatively calculated as well as the pyroxenes and amphiboles in Table 1.

Modal Proportion and Chemical Composition

Ortho- and clinopyroxenes are mostly major phases and present in almost all the samples (Table 1). Yokoyama *et al.* (1998) divided the lower part of the Kiwada Formation in the Yoro route into three zones on the basis of the modal proportion of hornblende. Analytical data from the middle and lower zones are shown in Table 1. Although hornblende is rare in the middle zone, two tuffs in newly collected samples contain hornblende. Most of the samples from the tributary of the Yoro River are rich in hornblende (Table 1), corresponding to the lower zone of the Yoro route. The "Kd38" tuff pointed originally by Mitsunashi *et al.* (1959) is located between YS4 and YS9 tuffs.

In the Minato route, twenty-three thick tuffs were selected for modal and chemical analyses (Table 1). The samples from the lower part, M01a to M09, contain hornblende. They correspond to the lower zone of the Yoro route. In the upper part from the sample M09, hornblende is rare as well as the samples from the middle zone of the Yoro route. Two tuffs at the bottom of the sequence are the most specific. They are collected from a composite tuff, totally 1 m in thickness, consisting of yellowish and dark yellow layers. Modal proportions of cummingtonite exceeds more than 70% in both the samples. Such a cummingtonite tuff is corresponding to the "Kd38" cummingtonite tuff in the Yoro route.

In the Orikizawa route, "Kd38" tuff was pointed out in the columnar section by Mitsunashi *et al.* (1959) and was described by Yoshikawa (1996). Yoshikawa (1996) divided the Kd38 tuff into three layers which correspond to the samples KT3 to KT5 in this study. The samples were collected from the riverbed. Kd38 tuff described by NHMIC (1990) occurs at the road cut about 100 m from the riverbed samples mentioned above. It is a white fine-grained tuff with about 1 m in thickness and is apparently different from the riverbed samples. Modal proportions of samples collected from many positions in the layer were studied by Yokoyama *et al.* (1997). Part of the data is reproduced in Table 1.

In the Takamizo route, Watanabe and Danhara (1996) described "Kd38" as a suite of several tuffs. The samples from T14 to T17 in Table 1 correspond to their "Kd38". Hornblende-bearing tuffs occur commonly at the upper part of the sequence in this route. These tuffs belong to the upper zone defined in the Yoro route by Yokoyama *et al.* (1998).

Major and minor elements in the orthopyroxene and cummingtonite were analyzed. Their compositional variations are represented by $100 \times Mg/(Mg+Fe)$ ratio, X_{Mg}, in Table 1. The ratio of orthopyroxene varies from 20 to 78 in the tuffs studied. It is more or less variable even in each tuff and bimodal distribution is common. These characteristics are mainly due to mixing of essential, accessory and accidental fragments at eruption or reworking at deposition. Cummingtonite is rather narrow compositional variation in each tuff. Its X_{Mg} ratio is mostly from 66 to 70, and rarely down to 54.

Discussion

Tuff has been used as a key bed in a sequence of the Boso Peninsula where numerous tuff layers are intercalated. Modal proportions and chemical compositions of heavy minerals are one of the indicators for the correlation of the tuff layers. As shown in Fig. 2, the sequence in the Yoro route was divided into three zones based on the modal proportion of hornblende (Yokoyama *et al.*, 1998). In the upper zone, Kd23, one of the thickest tuffs in the sequence, is compared well with those in the Orikizawa and Takamizo routes by the modal proportion and chemical composition of heavy minerals. Two kinds of the "Kd38" tuffs occur in the lower part of the middle zone and lower zone. Detailed correlation about the tuffs in the four routes was discussed to deduce the relationships between the two "Kd38" tuffs.

Cummingtonite Tuff

"Kd38" tuff in the lower zone at the Yoro route consists mostly of cummingtonite. Such a tuff is not observed in the Takamizo and Orikizawa routes. Four samples from the lower zone of the Minato route (Table 1) are probable candidates for the "Kd38" in the Yoro route. Referring to the chemical composition, M01a and M01b are corresponding to the cummingtonite tuff in question. Modal proportion and chemical composition of M01a in the Minato route are compared with Kd38-6 from the Yoro route in Fig. 3. Both samples have strong peaks in 68 as X_{Mg} of cummingtonite. Whereas, other two samples in the Minato route have Fe-rich variation. M04 tuff above the M01 has Fe-rich cummingtonite ranging from 54 to 62 in X_{Mg}. Such Fe-rich cummingtonite occurs in a tuff, Yo2, above the "Kd38" in the Yoro route. Cummingtonite tuffs with 68 and 66 in X_{Mg} peak occur above M04 and Yo2 in both the routes. Thus, as shown in Fig. 2, three kinds of cummingtonite-bearing tuffs are well comparable in both the Yoro and Minato routes.

Cummingtonite-bearing tuffs occur at the tributary of the Yoro River. Even though Mitsunashi *et al.* (1959) plotted the "Kd38" in the tributary, there is no suitable counterpart for cummingtonite tuff in the Yoro route. Presence of hornblende in most of the tuffs indicates that they belong to the lower zone of the Yoro route. Two

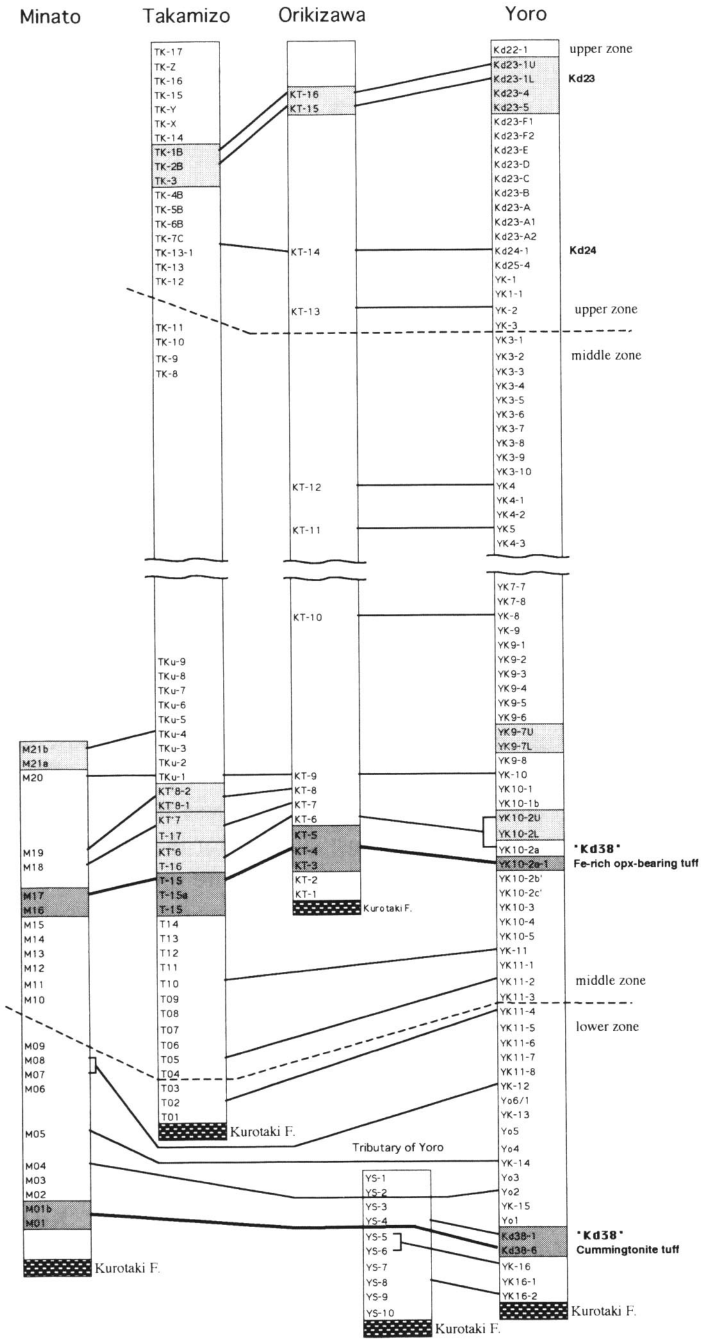

Fig. 2. Correlation of tuffs at the four main routes at the central part of the Boso Peninsula. Samples in each shaded box were collected from a composite tuff layer or from a homogeneous layer to reconfirm the modal proportions and chemical analyses.

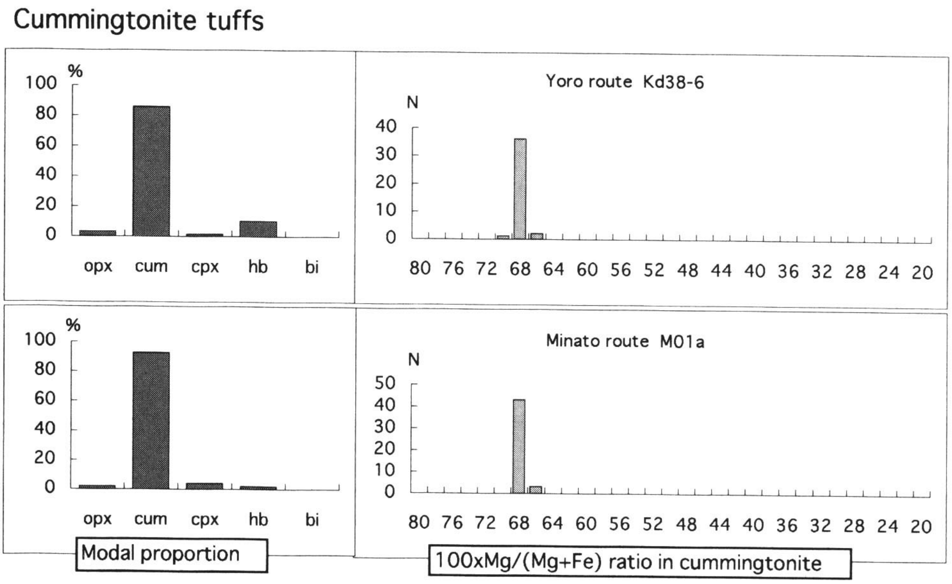

Fig. 3. Comparison of modal proportion and chemical composition of cummingtonite in "Kd38" tuff from the Yoro route and M01a tuff from the Minato route. Abbreviation of minerals are in Table 1.

tuffs below the "Kd38" tuff in the Yoro route are correlated with those in the tributary (Fig. 2). One is hornblende-poor tuff; i.e. YK16-2 and YS-8. The other one is hornblende–rich tuff: YK-16 and YS-5 or YS-6. Above these tuffs, cummingtonite-bearing tuff occurs in the tributary. It is the most suitable for the tuff to correlate with the uppermost sample, Kd38-1, of the thick cummingtonite tuff in the Yoro route. Such correlation suggests the "Kd38" cummingtonite tuff was deposited between YS-4 and YS-5 at the tributary and had been mostly eroded out.

Fe-rich Orthopyroxene-bearing Tuff

The "Kd38" tuff, KT3-KT5, in the Orikizawa route is consisting of three parts (Yoshikawa, 1996). Modal proportions and chemical compositions are different each other. However, KT3 and KT5 are characterized by Fe-rich orthopyroxene with X_{Mg} around 26 (Table 1). As shown in Fig. 4, such a Fe-rich orthopyroxene is found in four routes. In spite of the difference in color and thickness, the "Kd38" tuff at the road cutting is similar in modal proportion and chemical variation to those at the riverbed of the Orikizawa route. These samples are highly enriched in Fe-rich orthopyroxene. They contain more Mg-rich orhopyroxenes with peaks in X_{Mg} ratio around 68 and 58. The complex compositional variation is probably due to mixing with essential and exotic components or reworking after eruption.

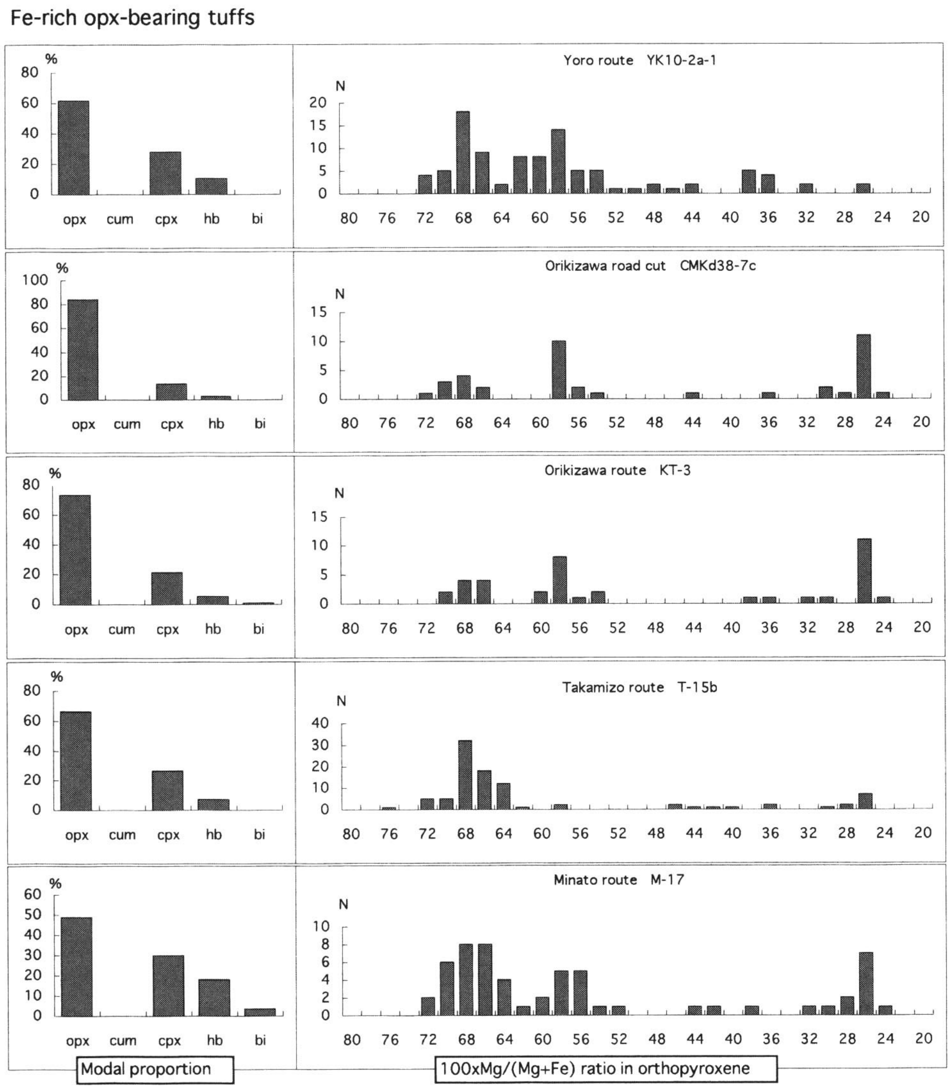

Fig. 4. Comparison of modal proportion and chemical composition of the Fe-rich orthopyroxene-bearing tuffs from the four routes in the central part of the Boso Peninsula. Abbreviation of minerals are in Table 1.

In the Yoro route where the most detailed analyses were done, the tuff corresponding to the Fe-rich orthopyroxene-bearing tuff is YK10-2a-1 which is one of newly collected samples. The tuff is observed in the middle zone where hornblende is rare. The tuff has a small amount of Fe-rich orthopyroxene with $X_{Mg}=26$, though modal proportion and more Mg-rich variation are similar to the "Kd38" tuff in the

Orikizawa route (Fig. 4). Two tuffs just above the samples are well comparable between the Yoro and Orikizawa routes (Fig. 2). The correlation supports that the YK10-2a-1 is corresponding to the Kd38 tuff at the Orikizawa route.

In the tuff, T-15b, from the Takamizo route, two peaks including Fe-rich orthopyroxene are corresponding to those in the Orikizawa route (Fig. 4). Similar modal proportions support that the T-15b is an extension of the Fe-rich orthopyroxene-bearing tuff in the Orikizawa route. The tuff was described as Kd38e, one of a suite of tuff layers "Kd38" described by Watanabe and Danhara (1996). Three tuffs above the T-15b in this route are comparable with the tuffs in the Orikizawa route (Fig. 2).

In the Minato route, M-17 is corresponding to the Fe-rich orthopyroxene-bearing tuff in the Orikizawa route. Although the tuff contains Mg-rich orthopyroxene more abundantly than the Fe-rich tuff in the Orikizawa route, three peaks in X_{Mg} are well comparable each other. Four tuffs above M-17 are correlated with those in the Orikizawa route (Fig. 2).

The tuffs recognized as the same ones in the four routes occur in a middle zone defined in the Yoro route by Yokoyama *et al.* (1998). There is no Fe-rich orthopyroxene with $X_{Mg}=26$ in other tuffs and some tuffs at the upper horizon of the Fe-rich one are well comparable in the four routes. Hence, the Fe-rich "Kd38" tuffs in four routes were confinmed as the same tuff as shown in Fig. 2. The "Kd38" tuff with Fe-rich orthopyroxene is located clearly above the "Kd38" tuff with cummingtonite. In the Yoro and Minato routes, the former runs several tens meters above the latter.

Summary

Compositional variation of orthopyroxene within a tuff layer is often significant. It will be due to mixing of essential, accessory and accidental fragment at the eruption in addition to sedimentary processes such as graded bedding, cross laminae and reworking. Although such complexities are recognized commonly in the tuffs, two kinds of "Kd38" tuffs were well compared in modal proportions and chemical compositions of heavy minerals in addition to the lithological works. One tuff is cummingtonite tuff occurring in the lower zone of the Yoro route. Cummingtonite is characterized by chemical composition with 68 as X_{Mg} ratio. Such a tuff is observed in the Minato route. Two cummingtonite-bearing tuffs with different X_{Mg} occur just above the cummingtonite tuff at both the routes. Another tuff is Fe-rich orthopyroxene-bearing tuff. The tuff was found in the middle zone from the four routes (Fig. 2). The correlation among the tuffs is supported by comparison of several tuffs above the Fe-rich tuff. The Fe-rich orthopyroxene-bearing tuff occurs about several tens meters above the cummingtonite tuff.

Lower zone developes in both the Yoro and Minato routes. In the Orikizawa route, lower zone has been eroded out, whereas, in the Takamizo route, uppermost

part of the lower zone occurs at the bottom of the sequence. These data indicate that a small rise was present at the Orikizawa area and most of the lower zone was eroded out before the deposition of the Fe-rich orthopyroxene-bearing tuff.

Tertiary and Quaternary boundary is around "Kd38" tuff (Takayama *et al.*, 1995). In this paper, we clarified the relationships between two "Kd38" tuffs which are the most characteristic tuffs in the studied sequence. However, exact position of the boundary has remained unknown, because no locality map of microfossil sample was presented by Takayama *et al.* (1995).

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