

Note on rock-forming minerals in the Joetsu district, Niigata Prefecture, Japan.

(13) Tremolite-actinolite from the Kotaki-Omi district.

Takanobu OBA*

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ABSTRACT

Actinolite-tremolite series occur in the contact between crystalline schists and serpentinite, and xenolith in serpentinite, Hisui-kyo (jadeite valley), Omi, Niigata Prefecture. Tremolite coexists with serpentine, chlorite and Cr-muscovite. The chemical variation of amphibole is small. Amphibole in pumpellyite, chlorite and actinolite bearing green rock from Hisui-kyo (jadeite valley), Kotaki varies in composition from tremolite through actinolite to magnesiohornblende. Tremolite molecule of the amphibole is from 67.5 mol. % to 88.7 mol. %, with small amounts of cummingtonite, edenite, richterite and glaucophane molecules. Unit-cell dimensions of actinolite coexisted with pumpellyite are $a = 9.886(8) \text{ \AA}$, $b = 18.12(1) \text{ \AA}$, $c = 5.223(6) \text{ \AA}$, $\beta = 105.3(1)^\circ$, $v = 902.3(13) \text{ \AA}^3$ and those of tremolite coexisted with Cr-muscovite are $a = 9.854(9) \text{ \AA}$, $b = 18.06(1) \text{ \AA}$, $c = 5.223(2) \text{ \AA}$, $\beta = 105.0(2)^\circ$, $v = 898.4(13) \text{ \AA}^3$. These unit-cell dimensions of these amphiboles are similar.

KEY WORDS

Actinolite, Amphibole, Kotaki, Omi, Pumpellyite, Tremolite

Introduction

Amphibole of tremolite-actinolite series is common mineral in the tectonic blocks of serpentinite (Seki et al. 1963, Nishiyama and Miyazaki 1987, Sakamoto 1997). Actinolite-tremolite series forms under low temperature and high-medium pressure of some metamorphic events. The International Mineralogical Association's subcommission on nomenclature recommended that the series be split into tremolite with $\text{Mg}/(\text{Mg} + \text{Fe}^{2+}) > 0.90$, actinolite with $\text{Mg}/(\text{Mg} + \text{Fe}^{2+}) 0.50-0.90$ and ferro-actinolite with $\text{Mg}/(\text{Mg} + \text{Fe}^{2+}) < 0.5$ (Leake et al. 1997). $\text{Mg}/(\text{Mg} + \text{Fe}^{2+})$ ratio of amphibole depends on bulk composition of host rock or physical conditions. The three different occurrences were observed in this district. Therefore, I give the chemical composition and the description on the occurrence and the physical properties of the amphibole of actinolite-tremolite series.

* Department of Geoscience, Joetsu University of Education

Occurrence

The occurrences of actinolite-tremolite series are three types. Sample 1 occurs as block (10 cm x 5 cm) in serpentinite (Fig.1a). This rock consists mainly of pumpellyite with small amounts of actinolite-tremolite series, chlorite, diopside and sphene. Albite occurs as small vein (0.1 mm in width). The photomicrograph in Fig. 2a shows that the gap among pumpellyite and relic amphibole (Amph 1) is filled with aggregate of fine fibrous actinolite-tremolite (Amph 2) at the center part and fine fibrous chlorite at the contact with pumpellyite. Second type, actinolite-tremolite series occurs in the contact between chlorite-muscovite-albite-quartz schist and serpentinite from Hashidate, Omi district. The thickness of reaction part at the contact is about 30 cm. Specimens 2 and 3 are collected at serpentinite side of the different contacts. Radiating actinolite-tremolite crystals are aligned further along a particular direction in the foliation plane (Fig. 1b). The photomicrograph shows needle-shaped oriented amphibole and muscovite texture in Fig. 2b. Each orientation of tremolite in sample 3 is not distinct (Fig. 2d). The grain size of tremolite in sample 2 is smaller than that of sample 3. The mineral assemblage of samples 2 and 3 is actinolite, fuchsite, chlorite, talc, serpentine and chromian spinel. The type 3, the actinolite-tremolite rock occurs as lenticular shapes (9cm x 7cm) in serpentinite (Fig. 1d). Fig. 2d shows that amphibole in the actinolite-tremolite rock enclaved in serpentinite is coarse grained crystal (about 0.3 mm in width). Actinolite-tremolite rock is composed with Ca-amphibole, chlorite and diopside with trace amounts of muscovite and opaque mineral.

Mineralogical data and discussion

Chemical composition: Major and trace elements of four samples were analyzed by X-ray fluorescence spectrometer (Rigaku S3030 model) at Joetsu University of Education. The chemical analysis data of the four actinolite-tremolite rocks are given in Table 1. The three samples except for sample 1 have similar chemical compositions and are rich in Cr, Ni and MgO. Electron microprobe analyses of amphibole, pumpellyite, chlorite and muscovite were performed using JEOL 733 superprob at the National Institute of Polar Research. They are given in Table 2 together with their structural formulae. According to the classification by Leake et al. (1997), Ca-amphiboles from Hisui-kyo (jadeite valley), Kotaki and Omi districts vary in composition from tremolite through actinolite to magnesiohornblende, as shown in Fig. 3a. The chemical compositions of Amph 1 and Amph 2 in the sample 1 are similar. The amphiboles in Table 2 are the average compositions of ten-odd grains. Amphiboles 1 and 3 are actinolite, and amphiboles 2 and 4 are tremolite.

I show two examples as amphibole from the similar occurrence. Ca-amphiboles in actinolite-tremolite rock from the Osayama ultramafic body in the Sangun metamorphic

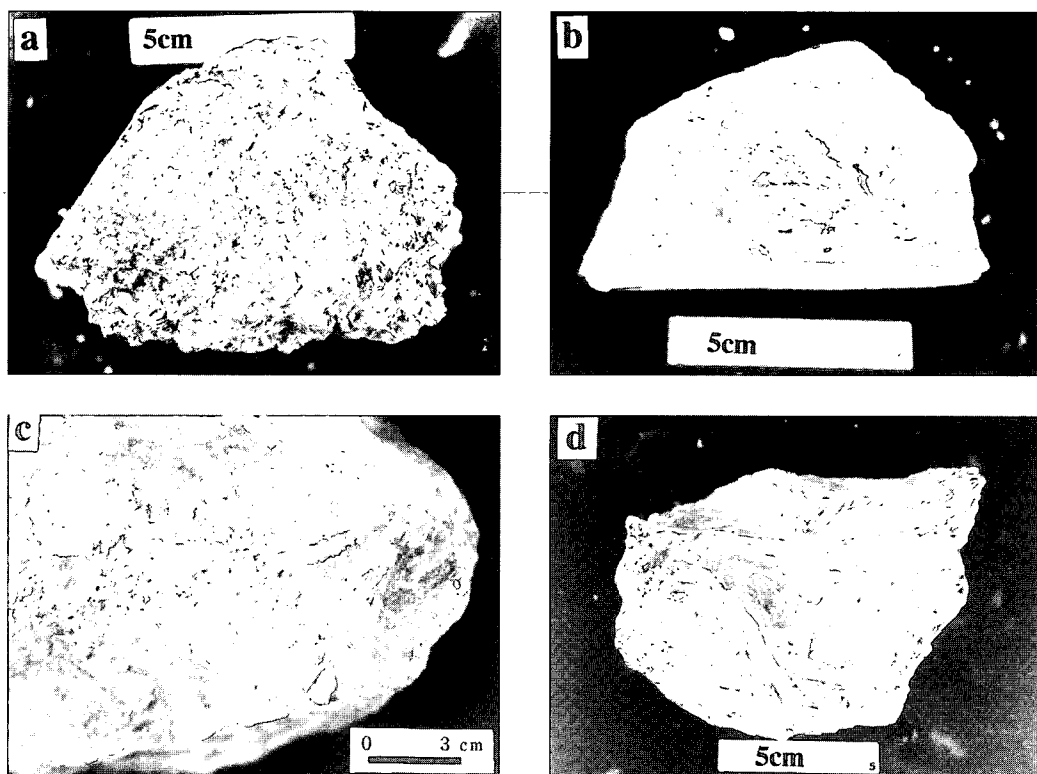


Figure 1. Photographs of actinolite-tremolite rock from the Kotaki-Omi district.
a: Sample 1 in serpentinite from Hisui-kyo, Kotaki. b and c: Samples 2 and 3 from Hashidate Hisui-kyo, Omi. d: Sample 4 from Siritakazawa, Omi.

belt (Sakamoto 1997) and in the Nagasaki metamorphic rocks (Nishiyama and Miyazaki 1987) are plotted on the boundary of tremolite and actinolite (Fig. 3b). The plotted area is the same as that of amphibole in the present study in Fig. 3a.

The end members used here are cummingtonite ($\text{Mg}_7\text{Si}_8\text{O}_{22}(\text{OH})_2$), edenite ($\text{NaCa}_2\text{Mg}_5\text{Si}_7\text{AlO}_{22}(\text{OH})_2$), glaucophane ($\text{Na}_2\text{Mg}_3\text{Al}_2\text{Si}_8\text{O}_{22}(\text{OH})_2$), Cr-glaucophane ($\text{Na}_2\text{Mg}_3\text{Cr}_2\text{Si}_8\text{O}_{22}(\text{OH})_2$), richterite ($\text{NaNaCaMg}_5\text{Si}_8\text{O}_{22}(\text{OH})_2$), tremolite ($\text{Ca}_2\text{Mg}_5\text{Si}_8\text{O}_{22}(\text{OH})_2$), tschermakite ($\text{Ca}_2\text{Mg}_3\text{Al}_2\text{Si}_6\text{Al}_2\text{O}_{22}(\text{OH})_2$), Cr-tschermakite ($\text{Ca}_2\text{Mg}_3\text{Cr}_2\text{Si}_6\text{Al}_2\text{O}_{22}(\text{OH})_2$) and kaersutite ($\text{NaCa}_2\text{Mg}_4\text{TiSi}_6\text{Al}_2\text{O}_{23}(\text{OH})$). FeO and MnO expressed as MgO, and K_2O as Na_2O . Tremolite molecules of amphiboles 1, 2, 3 and 4 are 68, 89, 84 and 71 mol. %, respectively. Fig. 4 shows that Ca-amphiboles in the sample 1 are plotted on line representing tremolite-pargasite. Amphiboles in the samples 2, 3, and 4 are plotted near tremolite-richterite line. Amphibole in the sample 1 has edenite and tschermakite substitutions. Others have richterite and glaucophane substitutions.

As the most important distinction between the major amphibole groups is in the occupancy of the M4 site in Fig. 5, each amphibole is plotted in terms of relative proportions of Na, (Mg+Mn+Fe) and Ca. Amphiboles in the sample 1 are plotted on the Ca-(Mg+

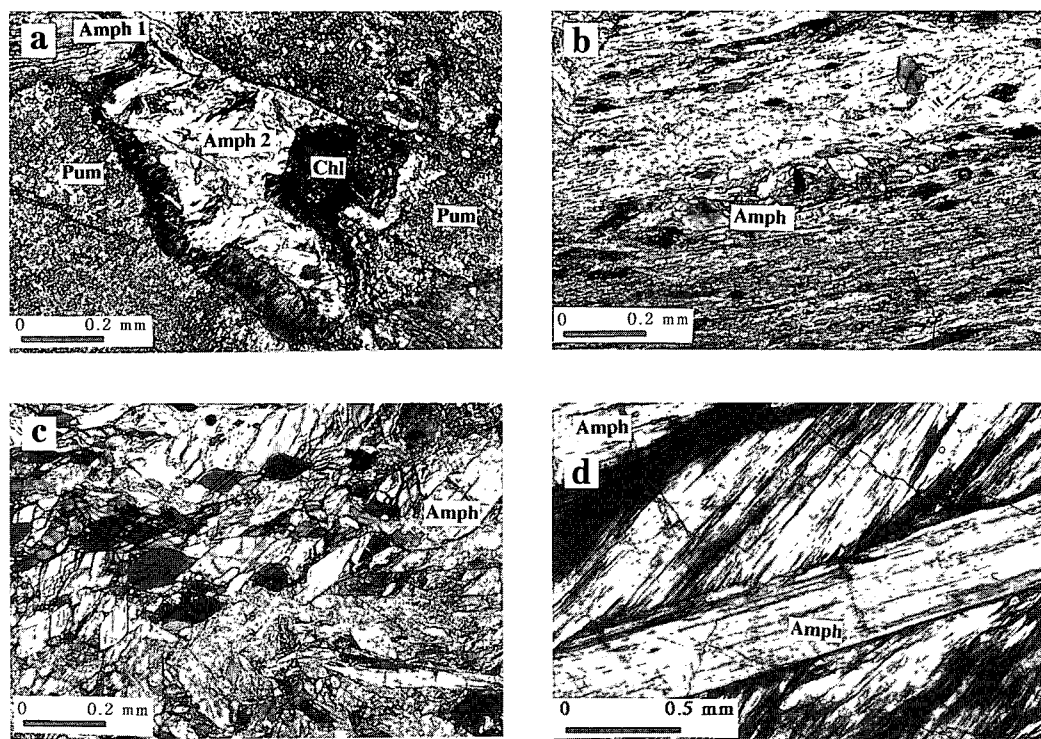


Figure 2. Photomicrographs of the amphiboles from the Kotaki-Omi district.

a: Needle shaped amphibole surrounding chlorite filled between the blocks of pumpellyite. b: Aggregate of oriented needle shaped amphibole and muscovite. c: Aggregate of slight oriented amphibole and muscovite. d: Coarse grained actinolite with small amounts of clinopyroxene, muscovite and chlorite. Amph: amphibole, Chl: chlorite, Pum: pumpellyite.

Mn+Fe) line near Ca corner. Amphiboles in the samples 2 and 3 are projected near Ca corner. Amphiboles in the sample 4 are plotted on the Ca-Na join. Fig. 5 shows that all amphiboles are Ca-amphibole.

The composition of pumpellyite is $\text{Ca}_{3.98}(\text{Mg}_{0.69}\text{Mn}_{0.01}\text{Fe}^{3+}_{0.53}\text{Al}_{4.70})_{1.88}(\text{Al}_{0.09}\text{Si}_{5.91})_{6.00}\text{O}_{23}(\text{OH})_3 \cdot 2\text{H}_2\text{O}$. The chlorites from the samples 1 and 4 are pycnochlorite.

The chemical composition of amphibole is strongly influenced by the bulk chemistry and physical condition. As compared with other three samples, Al_2O_3 content of the bulk composition in sample 1 is high, and MgO is low. However, in spite of the different bulk composition of sample 1, it is similar to that of other amphiboles. The similar physical condition of crystallization of amphibole is the fact suggests that the chemical composition of amphibole from the sample 1 is not influenced by the bulk chemistry.

The occurrence of relic actinolite (Amph 1) and pumpellyite in the sample 1 suggests that actinolite coexisted with pumpellyite. After then, chlorite and fibrous actinolite (Amph 2) form at the boundary of the aggregate of pumpellyite and actinolite crystals. Seki (1958)

Table 1. Major and trace elements of actinolite-tremolite rocks from the Kotaki-Omi district.

Sample No	1	2	3	4
SiO ₂	45.71	57.08	56.01	54.61
TiO ₂	0.35	0.01	0.09	0.02
Al ₂ O ₃	20.05	1.15	1.73	1.44
Fe ₂ O ₃	4.91	4.76	5.95	3.25
MnO	0.10	0.14	0.14	0.10
MgO	6.12	21.21	20.65	21.47
CaO	16.06	12.81	11.94	16.19
Na ₂ O	1.37	0.35	0.42	0.78
K ₂ O	0.29	0.25	0.49	0
P ₂ O ₅	0.05	0.03	0.02	0.03
Total	95.01	97.79	97.44	97.89

	trace element ppm			
Ba	0	0	0	0
Co	18	21	23	16
Cr	194	833	915	462
Cu	15	14	14	15
Nb	2.9	4.2	3.9	2.3
Ni	81	1052	957	719
Rb	7	6	5	0
Sr	17	11	24	103
V	90	3	35	10
Y	11.7	8.6	9.4	8.9
Zn	24	31	29	7.5
Zr	10.5	1.6	8.9	17.1

described that the assemblage actinolite-pumpellyite is situated in the transition zone bordering the prehnite-pumpellyite facies in the Sanbagawa metamorphic belt. Deer et al. (1997) reported that the assemblage actinolite-pumpellyite occurs in many low-grade metamorphic terrains and forms the basis of an independent facies located between the prehnite-pumpellyite and greenschist facies. Ernst (1988) indicated that the assemblage has been shown to be stable at temperatures below 350°C and a fluid pressure of less than 5 kbar and at temperatures between 350 and 375°C with P fluid between 5 and 8 kbar. The stability field of pumpellyite reported by Schiffman and Liou (1980) is compatible with the occurrence of pumpellyite-actinolite facies at intermediate to high pressure.

The occurrence of the assemblage actinolite-pumpellyite in the sample 1 from the Kotaki district suggests the low-grade metamorphic condition located between the prehnite-pumpellyite and greenschist facies.

X-ray powder study: The X-ray powder data for amphibole in the present study are given in Table 3. The unit-cell

parameters obtained from the 20-odd sharp reflections with asterisk by using silicon as an external standard. They were refined by a least-squares method (Sakurai, 1968). The results given in Table 4 show that the cell volumes, cell dimensions *b* and *c*, β of four amphiboles are close to those of tremolite. The cell dimension *a* of amphibole 1 suggests the influence substituted by pargasite molecule. The cell dimension *a* of amphibole 4 shifted to small value, shows the substitutions of cummingtonite and richterite. Unit-cell dimensions of actinolite coexisted with pumphyeite are $a = 9.886(8) \text{ \AA}$, $b = 18.12(1) \text{ \AA}$, $c = 5.223(6) \text{ \AA}$, $\beta = 105.3(1)^\circ$, $v = 902.3(13) \text{ \AA}^3$ and those of tremolite coexisted with Cr-muscovite are $a = 9.854(9) \text{ \AA}$, $b = 18.06(1) \text{ \AA}$, $c = 5.223(2) \text{ \AA}$, $\beta = 105.0(2)^\circ$, $v = 898.4(13) \text{ \AA}^3$.

Table 2. Chemical compositions of amphibole and coexisting chlorite, pumpherite and muscovite.

	1	2	3	4	5	6	7	8	9
	Amph	Amph	Amph	Amph	Pump	Mus	Cr-Mus	Chl	Chl
SiO ₂	53.52	56.55	55.96	56.96	36.31	46.69	48.59	28.94	31.13
TiO ₂	0.38	0.02	0.01	0.02	0.03	0.19	0.09	0	0.03
Al ₂ O ₃	2.60	0.80	0.81	1.02	24.95	26.81	25.11	19.29	15.74
Cr ₂ O ₃	0.13	0.26	0.51	0.19	0	1.66	3.35	0	0.43
FeO	7.96	4.15	4.88	3.45	3.87	1.68	1.00	17.11	7.60
MnO	0.13	0.13	0.11	0.14	0.10	0.07	0.02	0.16	0.10
MgO	19.09	21.36	20.52	22.62	2.84	3.52	3.48	21.24	29.26
CaO	11.91	12.47	12.29	11.93	22.83	0.01	0.02	0.17	0.07
Na ₂ O	0.63	0.56	0.80	1.04	0.11	0.38	0.21	0	0
K ₂ O	0.03	0.04	0.06	0.08	0.02	10.16	10.15	0	0.01
Total	96.44	96.35	95.95	97.43	91.06	91.17	92.01	86.91	84.36
structural formulae on the basis of O=23, O=14 for chlorite, O=22 for muscovite and O=24.5 for pumpellyite.									
Si	7.647	7.921	7.910	7.866	5.910	6.559	6.748	2.930	3.096
Al ^{IV}	0.353	0.079	0.090	0.134	0.090	1.441	1.252	1.070	0.904
Al ^{VI}	0.085	0.053	0.045	0.032	4.696	2.998	2.858	1.232	0.940
Ti	0.041	0.002	0.001	0.002	0.004	0.020	0.009		0.002
Cr	0.015	0.029	0.057	0.021	0	0.184	0.368		0.034
Mg	4.066	4.460	4.324	4.657	0.689	0.737	0.720	3.206	4.338
Fe ²⁺	0.793	0.456	0.573	0.288	*0.528	0.197	0.116	1.449	0.632
M1-3	5.000	5.000	5.000	5.000					
Fe ²⁺	0.158	0.030	0.004	0.110					
Mn	0.016	0.015	0.013	0.016	0.014	0.008	0.002	0.014	0.005
Ca	1.823	1.871	1.861	1.765	3.981	0.002	0.003	0.018	0.007
Na	0.003	0.084	0.122	0.109	0.035				
M4	2.000	2.000	2.000	2.000					
Na	0.172	0.068	0.097	0.169		0.104	0.057		
K	0.005	0.007	0.011	0.014	0.004	1.821	1.798		0.001
A	0.177	0.075	0.108	0.183					
Total	15.182	15.075	15.108	15.183	15.951	14.071	13.931	9.919	9.959
Mg/(Mg+Fe ²⁺)	0.810	0.902	0.882	0.921	0.567	0.789	0.861	0.689	0.873
Glaucofane	0.1	4.1	5.9	5.1					
Cr-Glaucofane			2.8	1.0					
Cr-tschermakite	0.7	1.4							
Kaersutite	4.1	0.2	0.1	0.2					
Richterite			5.7	6.9					
Edenite	13.6	1.5		3.0					
Tschermakite	5.0								
Tremolite	67.5	88.7	84.3	71.2					
Cummingtonite	8.9	4.0	1.3	12.6					

1, 5, 8: Sample 1

2, 7: Sample 2

3, 6: Sample 3

4, 9: Sample 4

* Fe is calculated as Fe³⁺

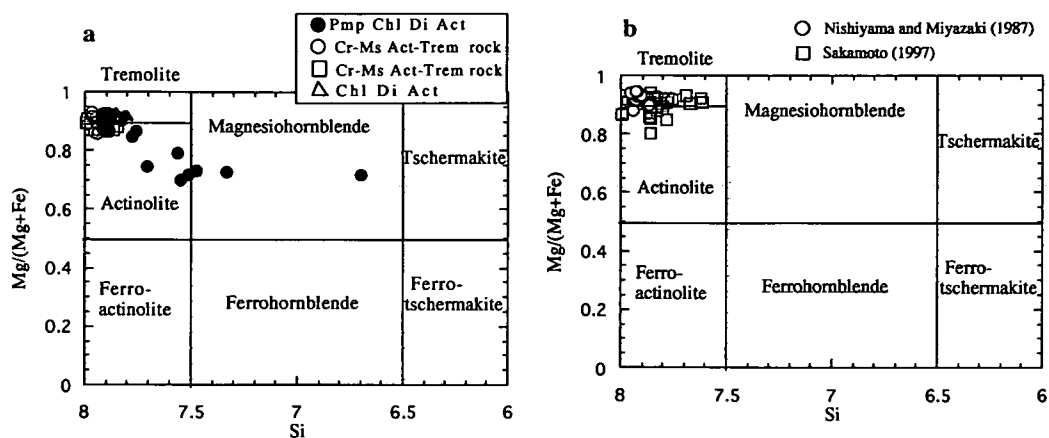


Figure 3. Classification of the calcic amphiboles.
a: Amphiboles from the Kotaki-Omi district in the present study. b: Amphiboles from the Osayama ultramafic body in the Sangun metamorphic belt (Sakamoto 1997) and in the Nagasaki metamorphic rocks (Nishiyama and Miyazaki 1987).

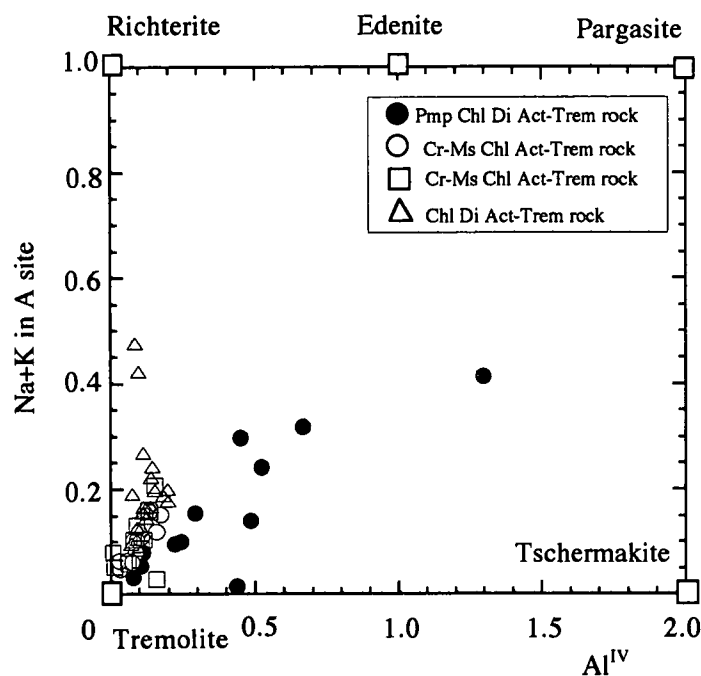


Figure 4. The chemical variation of the amphiboles from the Omi-Kotaki district expressed as the numbers of (Na+K) and Al^{IV} atoms per formula unit.

Table 3. X-ray powder data of amphiboles

	1			2			3			4		
HKL	dÅ (obs)	dÅ (cal)	I/Io	dÅ (obs)	dÅ (cal)	I/Io	dÅ (obs)	dÅ (cal)	I/Io	dÅ (obs)	dÅ (cal)	I/Io
1 1 0	8.47*	8.44	60	8.43*	8.42	67	8.42*	8.42	31	8.43	8.43	61
1 3 0	5.107*	5.103	10	5.098*	5.089	4	5.092*	5.088	3	5.087*	5.088	7
2 0 0	4.756*	4.767	27	4.764*	4.759	6	4.762*	4.758	6			
0 4 0	4.528*	4.531	15	4.519*	4.517	5	4.515*	4.516	4			
2 2 0	4.219*	4.219	13	4.211*	4.211	12	4.209*	4.209	6	4.217*	4.215	10
1 5 0	3.387*	3.388	14	3.382*	3.378	8	3.381*	3.377	5			
2 4 0	3.283*	3.284	26	3.275*	3.276	17	3.272*	3.275	14	3.276*	3.277	71
3 1 0	3.131*	3.130	100	3.124*	3.125	100	3.122*	3.124	100	3.130*	3.130	100
$\bar{1}$ 5 1	2.948*	2.939	86	2.939*	2.934	13	2.937*	2.930	6			
3 3 0	2.810*	2.813	16	2.807*	2.807	14	2.805*	2.806	8	2.811*	2.810	17
1 5 1	2.711*	2.698	23	2.704*	2.695	18	2.704*	2.696	10	2.706*	2.706	14
0 6 1	2.597*	2.590	13	2.592*	2.586	7	2.592*	2.584	3	2.590*	2.588	5
3 5 0	2.388*	2.389	11	2.382*	2.384	6	2.382*	2.383	5	2.390*	2.385	8
3 5 $\bar{1}$							2.320	2.333	5			
1 1 2	2.299*	2.274	16	2.275*	2.277	3	2.285*	2.278	3	2.299*	2.298	5
2 6 1	2.155*	2.158	11	2.162*	2.155	10	2.162*	2.157	5	2.163*	2.165	7
4 4 $\bar{1}$	2.133*	2.128	10									
2 0 2	2.022*	2.020	13	2.016*	2.023	8	2.016*	2.025	4			
2 8 0							2.043*	2.040	2	2.042*	2.045	3
3 7 0	2.007*	2.007	13	2.000*	2.002	5	2.001*	2.001	3	2.002*	2.002	3
5 1 0	1.895*	1.896	13	1.893*	1.893	15	1.892*	1.892	13	1.896*	1.896	12
5 3 0	1.816*	1.818	8	1.815*	1.815	8	1.814*	1.814	6	1.818*	1.817	6
4 6 1	1.653	1.642	11	1.650	1.645	12	1.650*	1.647	8	1.652*	1.651	9
4 8 0				1.638*	1.638	3	1.638*	1.637	5			
1 11 0	1.625*	1.623	12	1.618	1.618	4	1.617*	1.618	3	1.617*	1.617	7
6 0 0	1.590*	1.589	10	1.586*	1.586	5	1.586*	1.586	8	1.589*	1.589	4
$\bar{1}$ 5 3	1.561*	1.562	28	1.565*	1.564		1.561*	1.561	3			
4 0 2	1.541*	1.542	8				1.533	1.545	3			
0 12 0	1.507*	1.510	8	1.503*	1.505	4	1.503*	1.505	4	1.504*	1.504	16
7 1 0				1.356*	1.356	6	1.356*	1.355	5	1.358*	1.358	4

1 : Sample 1 in serpentinite from Hisui-kyo,Kotaki

2 : Sample 2 from Hashidate Hisui-kyo,Omi

3 : Sample 3 from Hashidate Hisui-kyo,Omi

4 : Sample 4 from Siritakazawa, Omi

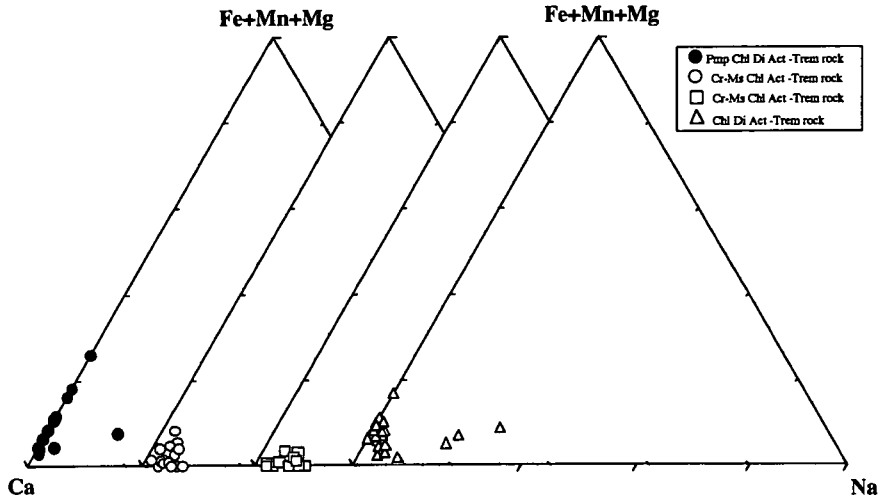


Figure 5. Relative proportions of Ca, Na and (Mg+Mn+Fe) in the M4 site for amphiboles from the Kotaki-Omi district.

Table 4. Unit-cell dimensions of amphiboles.

No		a Å	b Å	c Å	β°	v Å ³
1	Pum, Chl, Act	9.886(8)	18.12(1)	5.223(6)	105.3(1)	902.3(13)
2	Cr-Mus, Chl, Trem	9.854(9)	18.06(1)	5.223(2)	105.0(2)	898.4(13)
3	Cr-Mus, Chl, Act	9.837(5)	18.06(1)	5.211(7)	104.7(1)	895.3(14)
4	Chl, Di, Act	9.826(4)	18.05(1)	5.232(4)	104.0(1)	900.5(11)
5	Tremolite	9.833(5)	18.054(9)	5.268(4)	104.52(7)	905.3(10)
6	Trem75Rich25	9.812	18.010	5.237	104.69	895.2
7	Ferro-actinolite	9.87	18.34	5.30	104.5	939
8	Pargasite	9.906(10)	17.986(17)	5.265(8)	105.30(14)	904.7(19)
9	Cummingtonite	9.583	18.091	5.315	102.63	899.1

1: Sample 1 2: Sample 2 3: Sample 3 4: Sample 4
5, 6, 8: Colville et al. (1966) 7: Ernst (1966) 9: Klein (1964)

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