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AEIRINE-AUGITE AND SODIC AUGITE FROM
THE SAMBAGAWA AND THE CHICHIBU BELTS
IN THE OSHIKA DISTRICT, CENTRAL JAPAN,
WITH SPECIAL REFERENCE TO Na-METASOMATISM

by

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(with 7 Figures and 4 Tables)

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Abstract

The mode of occurrence and chemical composition of aegirine-augite and sodic augite from the Sambagawa and the Chichibu metamorphic rocks in the Oshika district are described.

Aegirine-augite occurs in a) marginal part of relict Ca-pyroxene, b) aggregation with Na-amphibole, c) contact between relict Ca-pyroxene and albitic veins, and d) albitic veins or layers.

The occurrence of aegirine-augite of a) and b) may be related to the characteristic chemical composition of the host rock, i.e. high $\text{Fe}_2\text{O}_3 / \text{FeO}$ and $\text{Fe}_2\text{O}_3 / \text{Al}_2\text{O}_3$ ratios. The aegirine-augite of c) and d), however, is considered to be metasomatic in origin, i.e. addition of Fe, Al, Si and Na. The sodic augite occurs as monomineralic veins, and may be related to the emplacement of ultramafic rocks.

Introduction and Outline of Geology

The Sambagawa and the Chichibu metamorphic rocks occur in two parallel-striking belts running through Honshu, Shikoku and Kyushu. The Chichibu belt, which is mainly composed of upper Paleozoic rocks, is located on the outer side (the Pacific side) of the Sambagawa belt. The Oshika district, Shimoina-gun, Nagano prefecture, covers the northeastern portion of both belts (Fig. 1).

The Sambagawa and the Chichibu belts in the Oshika district, strike roughly N-S as shown in Fig. 1. The western margin of the Sambagawa belt is marked by a major fault, the Median Tectonic Line. The boundary between the Sambagawa and the Chichibu belt is a fault zone (the Todai Tectonic Line), in which lower Cretaceous rocks occur (Matsushima et al., 1957; Watanabe,

1970). The Shimanto belt composed of Mesozoic-Tertiary rocks, is situated to the east of the Chichibu belt. The Butsuzo-Itokawa Tectonic Line, a large fault, serves as a boundary between the both belts. The Sambagawa belt is mainly composed of mafic schists, pelitic schists, siliceous schists, hornblendites, greenstones and isolated ultramafic masses with minor gabbroic rocks. The Chichibu belt is mainly composed of weakly metamorphosed rocks, such as pelitic, psammitic and mafic rocks, and limestones.

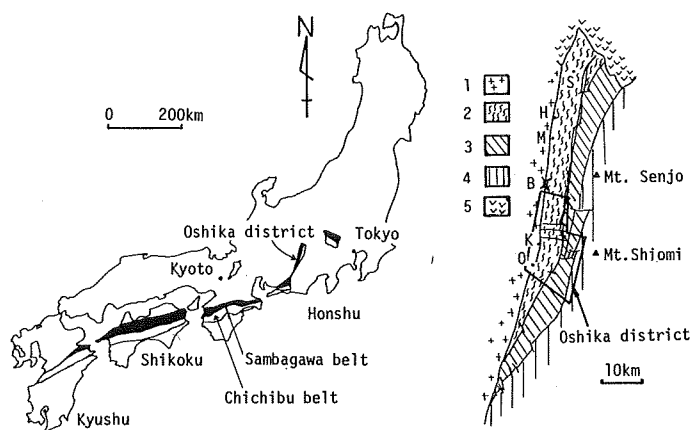


Fig. 1 Distribution of the Sambagawa and the Chichibu belts(left), and simplified geologic map of the Oshika district(right).

1: Ryoke belt, 2: Sambagawa belt, 3: Chichibu belt, 4: Shimanto belt, 5: Cenozoic effusive rocks. Unshaded narrow strips between the Sambagawa and the Chichibu belts are the Todai formation of the lower Cretaceous.

B: Bungui pass, H: Hiji, K: Kashio, M: Mizoguchi, O: Okawara, S: Shibira.

The Sambagawa and the Chichibu belts have been affected by the Sambagawa metamorphism, though the boundary of both belts is cut by a fault zone. On the basis of the mineral assemblages in the mafic rocks, the following metamorphic zones can be established;

Zone I: Characterized by presence of pumpellyite and absence of Na-amphibole.

Zone II: Distinguished by appearance of Na-amphibole.

Zone III: Characterized by disappearance of pumpellyite.

A distribution map of each zone is shown in Fig. 2, and the range of appearance of constituent minerals is shown in Fig. 3. Aegirine-augite and sodic augite, studied in this paper, are found in greenstones of Zone II. The metamorphic zoning of the Oshika district is discussed in more detail in another paper (Watanabe, 1974).

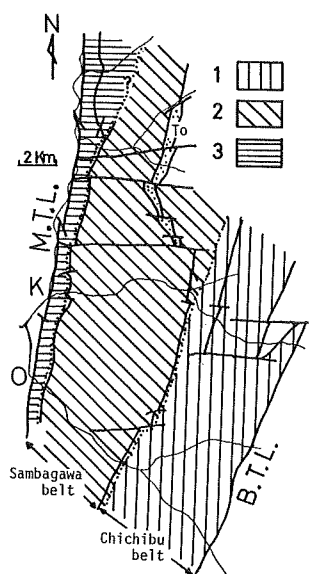


Fig. 2 Distribution map of the three metamorphic zones in the Oshika district.

1: Zone I, 2: Zone II, 3: Zone III

M.T.L.: Median Tectonic Line, B.T.L.: Butsuzo-Itokawa Tectonic Line, O: Okawara, K: Kashio, To: Todai formation

Zone	I	II	III
actinolite			
pumpellyite			
Na-amphibole			—?
Na-pyroxene		— — —	
chlorite			
epidote			
calcite			
albite			
quartz			
sphene			
stilpnomelane		— — —	
white mica		— — —	

Fig. 3 Range of appearance of the metamorphic minerals in the mafic rocks of the Sambagawa and the Chichibu belts in the Oshika district.

Mode of Occurrence

Aegirine-augite is frequently found in greenstones in the Oshika district as shown in Fig. 4. The following mode of occurrence is distinguished:

- marginal part of relict Ca-pyroxene,
- aggregation with Na-amphibole,
- contact between relict Ca-pyroxene and albitic veins, and
- in albitic veins or layers.

In case a), the C-axes of Ca-pyroxene and aegirine-augite have almost the same direction. Aegirine-augite ($2V_x = 76^\circ - 80^\circ$) shows distinct pleochroism

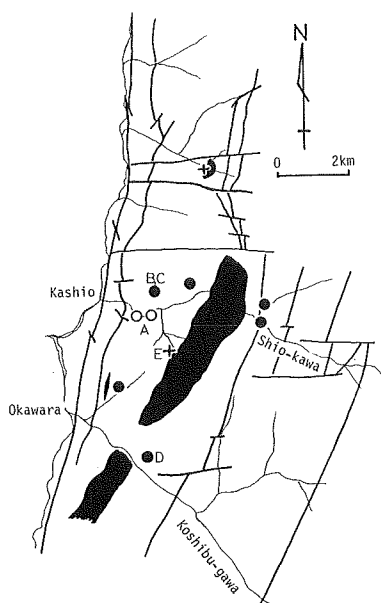


Fig. 4 Locality map of aegirine-augite and sodic augite in the Oshika district.
 open circles: aegirine-augite at the marginal part of relict Ca-pyroxene
 solid circles: aegirine-augite in albite vein
 black area: ultramafic rocks
 Nos. A – E represent the locality number of pyroxene in Table 2.

(X = green, Y = pale green, Z = greenish yellow) and high birefringence. Actinolite and sometimes Na-amphibole (b = Z: X = blue, Y = pale purplish blue, Z = faint yellow) may occur as overgrowth on the rim of aegirine-augite. Aegirine-augite does not co-exist with quartz in this case.

In case b), aegirine-augite ($N_{\gamma} = 1.789 \pm 0.003$; X = greenish yellow, Y = yellow, Z = pale yellow) occurs as aggregations with Na-amphibole (b = Z: X = blue, Y = pale purplish blue, Z = faint yellow) in some of rocks containing aegirine-augite of case a). The aggregations, up to 2mm in size, are mantled with chlorite, and rarely includes minor actinolite.

Mineral assemblages* of the rocks in which aegirine-augite of cases a) and b) occurs, are as follows:

aegirine-augite – Na-amphibole – epidote – chlorite – actinolite – sphene
 (with or without minor quartz** and albite)

aegirine-augite – Na-amphibole – actinolite – sphene – albite – quartz*
 (with minor chlorite and calcite)

In these rocks, original igneous textures, such as ophitic and subophitic textures, are well preserved. The chemical composition of one of these rocks is characterized by high $\text{Fe}_2\text{O}_3 / \text{FeO}$ and $\text{Fe}_2\text{O}_3 / \text{Al}_2\text{O}_3$ ratios as compared with aegirine-augite free greenstones (Table 1).

* In this paper, mineral assemblage does not mean contact mineral paragenesis (Kawachi and Watanabe, 1974).

** Quartz is not in contact with aegirine-augite.

Table 1 Chemical composition of greenstones from the Oshika district.

	1	2	3	4	5
SiO ₂	42.73	41.03	44.16	46.95	46.75
TiO ₂	1.19	0.47	1.03	1.47	1.10
Al ₂ O ₃	9.52	17.51	7.92	16.79	15.67
Fe ₂ O ₂	7.22	2.04	3.55	4.47	5.25
FeO	7.03	11.01	9.08	7.67	8.28
MnO	n.d.	n.d.	0.14	0.11	0.13
MgO	14.62	9.21	17.69	6.09	6.67
CaO	11.25	9.65	10.95	9.94	9.95
Na ₂ O	1.45	2.54	0.53	3.36	3.06
K ₂ O	0.14	0.40	0.28	0.24	0.42
P ₂ O ₅	n.d.	n.d.	0.09	0.04	0.05
H ₂ O (+)	4.77	5.35	3.80	2.78	2.76
H ₂ O (–)	0.14	0.20	0.24	0.14	0.23
Total	100.06	99.41	99.46	100.04	100.34
Fe ₂ O ₃ /FeO	1.03	0.19	0.39	0.58	0.63
Fe ₂ O ₃ /Al ₂ O ₃	0.76	0.12	0.45	0.27	0.34

1: aegirine-augite – Na-amphibole – epidote – chlorite rock (with relict Ca-pyroxene)

2: epidote – chlorite – actinolite rock (with relict Ca-pyroxene)

3: chlorite – actinolite rock (with relict Ca-pyroxene)

4: actinolite – epidote – chlorite rock (with minor pumpellyite – quartz – albite)

5: actinolite – epidote – chlorite rock (with minor quartz – albite)

Analyst. T. Watanabe

In case c), aegirine-augite is usually developed along the direction of the c-axes of relict Ca-pyroxene. The c-axes of both minerals are nearly parallel. Aegirine-augite is the only mineral present at the contact between relict Ca-pyroxene and albitic veins. When the albitic vein is in contact with other minerals, such as chlorite, epidote, and actinolite, no reaction relation exist between them. Aegirine-augite ($2V_x = 80^\circ\text{--}85^\circ$) is pleochroic (X = pale green, Y = faint green, Z = very faint green) and has moderate birefringence. Albitic veins are typically 0.5cm in maximum width.

The mineral parageneses of the marginal part of the albitic veins are as follows:

aegirine-augite – pumpellyite – chlorite – albite (with minor epidote) (Fig. 5, upper)

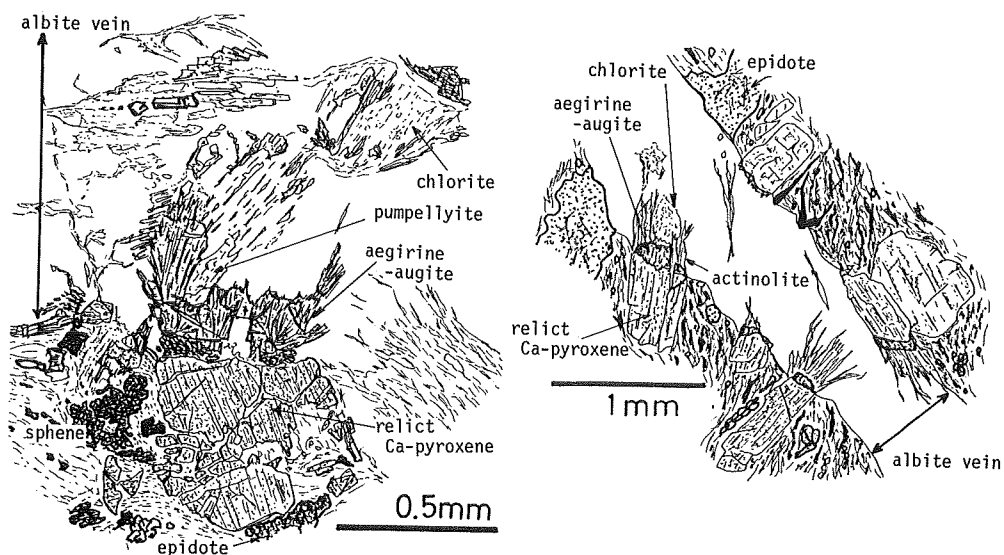


Fig. 5 Occurrence of aegirine-augite at the contact of albitic vein and relict Ca-pyroxene.

aegirine-augite – actinolite – chlorite – albite (Fig. 5, lower)

aegirine-augite – calcite – quartz – albite

In the rock of the first mineral assemblage, pumpellyite does not occur in the host rock but is restricted to the vein, and relict Ca-pyroxene along the vein is partially granulated. The chemical composition of the host rock is shown in Table 1. The vein of the second mineral assemblage cut an epidote vein but is cut by another epidote vein.

In case d), aegirine-augite is not in contact with relict Ca-pyroxene. If the reaction between relict Ca-pyroxene and albitic vein is continued, the Ca-pyroxene will be consumed, while aegirine-augite will be produced in the albitic vein.

Sodic augite is also present in a few localities adjacent ultramafic rocks in this district (Fig. 4), and occurs as monomineralic veins of 0.5 – 1 cm in width. The sodic augite ($2V_x = 76^\circ\text{--}80^\circ$, $N_\gamma = 1.701$) is very pale green, without pleochroism, and has low birefringence.

Table 2 Chemical composition of aegirine-augite and sodic augite from the Oshika district. Locality of each pyroxene is shown in Fig. 4.

(Analysis by EPMA)

wt%	A		B		C		D		E		
SiO ₂	53.0		52.50		52.40		51.62		55.36		
TiO ₂	0.4		0.15		n.d.		0.00		0.06		
Al ₂ O ₃	4.0		3.98		2.24		0.47		3.05		
FeO	19.9		16.30		17.76		16.71		9.46		
MnO	0.1		0.26		0.00		0.48		0.52		
MgO	4.2		6.08		6.73		8.77		9.32		
CaO	5.5		10.75		11.72		17.01		18.30		
Na ₂ O	10.2		8.56		7.30		3.94		3.08		
K ₂ O	0.1		0.00		n.d.		0.00		0.00		
Total	97.4		98.58		98.15		99.00		99.15		
	(99.6)*		(100.39)*		(100.13)*		(100.85)*				
O = 6 (total iron = FeO)											
Si	2.09	2.09	2.02	2.02	2.05	2.05	2.02	2.02	2.06	2.06	
Al ^{IV}	0.00		0.00		0.00		0.00		0.00		
Al ^{VI}	0.19	2.16	0.18	2.20	0.10	2.11	0.02	2.11	0.13	1.91	
Ti	0.01		0.00		0.00		0.00		0.00		
Fe ²⁺	0.65		0.53		0.58		0.55		0.29		
Mn	0.00		0.01		0.00		0.02		0.02		
Mg	0.25		0.35		0.39		0.51		0.52		
Ca	0.23		0.49		0.49		0.71		0.73		
Na	0.78		0.64		0.55		0.30		0.22		
K	0.05		0.00		0.00		0.00		0.00		
O = 6 (total iron = Fe ₂ O ₃)											
Si	1.98	2.00	1.95	2.00	1.95	2.00	1.92	1.94			
Al ^{IV}	0.02		0.05		0.05		0.02				
Al ^{VI}	0.16	1.99	0.12	2.02	0.05	1.99	0.00	2.00			
Ti	0.01		0.01		0.00		0.00				
Fe ³⁺	0.62		0.50		0.56		0.52				
Mn	0.00		0.01		0.00		0.00				
Mg	0.24		0.34		0.38		0.49				
Ca	0.22		0.43		0.47		0.68				
Na	0.74		0.61		0.53		0.29				
K	0.00		0.00		0.00		0.00				

* Total iron = Fe₂O₃

Chemical Composition

Four samples of aegirine-augite and one sample of sodic augite were analyzed by EPMA (JEOL — 5A) of the Geological Survey of Japan. Operating condition were 15 kv in accelerating potential and 0.02 — 0.03 μ A in specimen current. Electron beam diameter was kept 5 — 10 microns. The data were computed into oxide percentage using the correction program by K. Okumura and Y. Kawachi for EPMA quantitative analysis, which was prepared after the method of Sweatman and Long (1969). Structural formulae of the minerals were calculated using the program developed by Y. Kawachi.

Analyses of aegirine-augite and sodic augite from the Oshika district are shown in Table 2 and represented in a triangular diagram in Fig. 6, in which the author treats the Al^{VI} content as being proportional to the molecular ratio of [jadeite] / [aegirine-augite + Ca-pyroxene] and that of the Na content to the molecular ratio of [jadeite + aegirine] / [Ca-pyroxene]. Pyroxene nomenclature is based on the classification by Essene and Fyfe (1967).

Aegirine-augite of sample A occurs at the marginal part of relict Ca-pyroxene in the greenstones of No. 1 of Tabel 1. This aegirine-augite is richer in the aegirine molecule than other Na-pyroxenes from the Sambagawa belt. Other analyses of aegirine-augite in this paper are comparatively poor in Al_2O_3 . Aegirine-augite of samples B and C occur in the same albitic vein. The pyroxene of sample B is contact with relict Ca-pyroxene, while that of sample C is not. Pumpellyite occurs in the vein with the aegirine-augite. Aegirine-augite of sample D also occurs in the contact zone of relict Ca-pyroxene and vein, and is accompanied by actinolite and chlorite. Sodic augite of sample E occurs as a vein.

Genesis of Aegirine-Augite and Sodic Augite

i) Aegirine-augite in cases a) and b)

In the Sambagawa and the Chichibu belts, Na-pyroxene found in mafic rocks is not aegirine or aegirine-augite (Shido, 1959; Seki et al., 1960; Iwasaki, 1960a, 1963; Banno, 1964; Ernst et al., 1970) (Fig. 6), except for acmitic pyroxene reported by Asai (1955). Aegirine-augite has generally been reported from the more siliceous schists of the Sambagawa belt (Kojima and Hide, 1958; Banno, 1959; Iwasaki, 1960b; Kanehira and Banno, 1960). However, in the Oshika district, aegirine-augite is present in greenstone (sample A). This occurrence may be related to the characteristic chemical composition of the host rock, i.e. high Fe_2O_3/FeO and Fe_2O_3/Al_2O_3 ratios. Relict Ca-pyroxene included in the above rock has a high Al_2O_3 content (5.09% as shown in Table

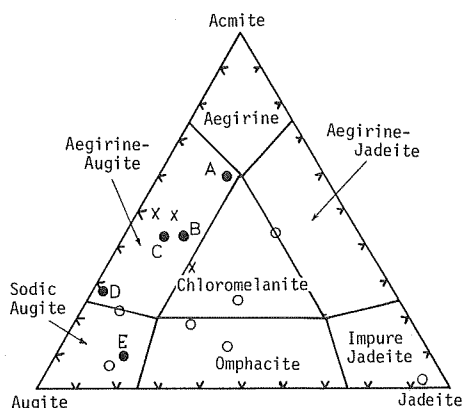


Fig. 6 Diagram showing composition of Na-pyroxene from the Oshika district and other parts of the Sambagawa belt.

solid circles: Na-Pyroxene from the Oshika district. Nos. A – E correspond to those in Table 2 and Fig. 4.

open circles: Na-pyroxene in mafic rocks from other parts (Shido, 1950; Seki et al., 1960; Iwasaki, 1963; Banno, 1964)

crosses: Na-pyroxenes in siliceous rocks from other parts (Iwasaki, 1963; Banno, 1964)

Table 3 Chemical composition of a relict Ca-pyroxene included in the rock of No. 1 in Table 1.

(Analysis by EPMA)

SiO ₂	48.97	Si	1.82	2.00
TiO ₂	0.64	Al ^{IV}	0.18	
Al ₂ O ₃	5.09	Al ^{VI}	0.04	
FeO	5.95	Ti	0.02	2.06
MnO	0.05	Fe ²⁺	0.18	
MgO	17.11	Mn	0.00	
CaO	21.55	Mg	0.94	0 = 6
Na ₂ O	0.69	Ca	0.86	
K ₂ O	0.01	Na	0.03	
Total	100.06	K	0.00	

3). This suggests that the greenstones are metamorphosed alkalic rocks. Chemical compositions of greenstone are plotted on an AMF diagram (Fig. 7), which demonstrates that the rock (No. 1) corresponds to poorly differentiated basaltic rocks. It is expected, therefore, that aegirine-augite will be found in mafic rocks from other parts of the Sambagawa belt, if they have a similar original composition to the host rocks in this study. Although, acmitic pyroxene in meta-gabbro has been reported by Asai (1955), the metamorphic mineral assemblage of this rock is different from that of the aegirine-augite bearing rock of the Oshika district in that it contains garnet instead of epidote. Therefore, its original chemical composition was probably different.

ii) Aegirine-augite in cases c) and d)

Aegirine-augite, such as samples B, C and D, which occur in contact part

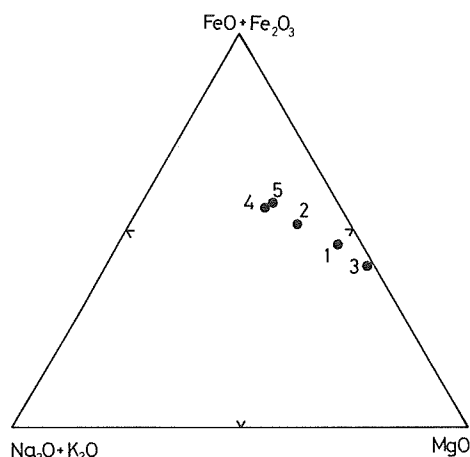
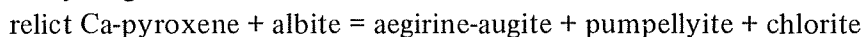


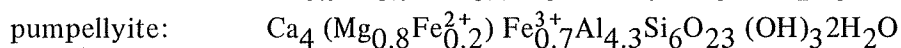
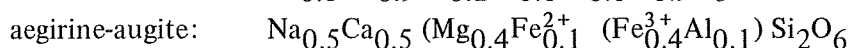
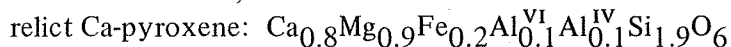
Fig. 7 $\text{Na}_2\text{O}+\text{K}_2\text{O} - \text{FeO}+\text{Fe}_2\text{O}_3 - \text{MgO}$ diagram for greenstones from the Oshika district. Numbers are same as those in Table 1.

between albitic vein and Ca-pyroxene, is considered to be metasomatic in origin. Reaction which led to the formation of aegirine-augite such as samples B and C may be given as:

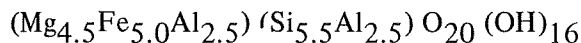


As chlorite occurs both in vein and host rock, chlorite may be present on either side of the equation. Quartz, however, can not be present on the right side, because quartz is not present in the vein.

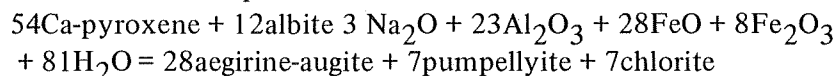
Chemical composition of pumpellyite co-existing with aegirine-augite and relict Ca-pyroxene in contact with aegirine-augite, are shown in Table 4. From the structural formulae, idealized formulae have been calculated as follows:



The structural formula of chlorite is estimated from refractive index ($\omega = 1.616$: $\epsilon - \omega = 0.003$) using Hey's diagram (Deer, Howie and Zussman, 1962, p.151). Using this data the following idealized formula for the chlorite was obtained:



From the idealized formulae of above minerals, coupled with the reaction given above, it is considered that some elements, such as Na, Al and Fe together with the $\text{NaAlSi}_3\text{O}_8$ molecule were supplied from the vein. Therefore, the following approximate reaction equation* can now be written:



* Coefficients of this reaction are shown as follows;

$$35775\text{Ca-pyroxene} + 7844\text{albite} + 668\text{Na}_2\text{O} + 15515\text{Al}_2\text{O}_3 + 18948\text{FeO} + 5373\text{Fe}_2\text{O}_3 \\ + 54282\text{H}_2\text{O} = 18360\text{aegirine-augite} + 4860\text{pumpellyite} + 4659\text{chlorite}$$

In the rock containing samples B and C, the amount of pumpellyite is less than that of aegirine-augite, which is in harmony with the result of the above equation. If more SiO_2 was supplied, Na_2O and Al_2O_3 reacted with SiO_2 molecule to produce albite and the jadeite molecule of aegirine-augite would have decreased. Therefore, jadeite molecule of aegirine-augite probably depends on the supply of SiO_2 from the albitic vein.

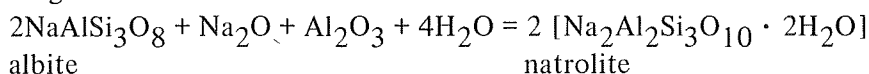
Table 4 Chemical composition of pumpellyite co-existing with aegirine-augite of samples B and C, and relict Ca-pyroxene in contact with aegirine-augite of sample B.

(Analysis by EPMA)		
	pumpellyite	relict Ca-pyroxene
SiO_2	37.47	49.49
TiO_2	0.00	0.38
Al_2O_3	22.31	3.95
FeO	6.74	7.56
MnO	0.00	0.10
MgO	3.01	16.29
CaO	23.11	20.29
Na_2O	0.00	0.52
K_2O	0.00	0.03
H_2O	6.39*	n.d.
Total	99.03	98.61
	O = 28	O = 6
Si	6.15	1.87
Al^{IV}	0.00	0.13
Al^{VI}	4.30	0.05
Ti	0.00	0.01
Fe^{2+}	0.93	0.24
Mn	0.00	0.00
Mg	0.74	0.92
Ca	4.06	0.82
Na	0.00	0.04
K	0.00	0.00
OH	7.00	

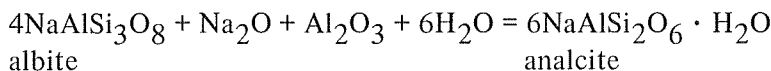
* not determined but calculated on the basis of OH = 7.00

A similar mineral assemblage, such as Na-pyroxene — pumpellyite — chlorite — albite — epidote, without quartz, has been reported by Iwasaki (1963) from a mafic rock in Zone II of the Sambagawa belt of eastern Shikoku, though the jadeite molecule of Na-pyroxene is rather different from that of the present study. Supposing that the jadeite molecule of aegirine-augite depends on the supply of SiO_2 , the P–T condition of vein formation in the Oshika district seems to resemble to that of the Zone II of Iwasaki (1963), though the amount of SiO_2 taking part the reaction was different from each other.

If the vein was formed under lower P–T conditions, Na_2O , Al_2O_3 and H_2O in the vein would have reacted with albite to produce zeolite by the following reactions:



or



The occurrence of aegirine-augite in a natrolite vein from Nemuro, Hokkaido, reported by Suzuki (1938) may correspond to the above case.

While, for the formation of aegirine-augite of sample D, actinolite occurs in the vein instead of pumpellyite. This may be because of the lower amount of Al_2O_3 in the vein.

Horikoshi (1934) has reported an occurrence of aegirine-augite in the contact part between albite veins and relict Ca-pyroxene from the Kanna-gawa area of the Kanto mountains, east of the Oshika district. In both districts, such aegirine-augite occurs restrictedly in greenstones. Therefore, it is considered that the albitic veins have originated as a “residual fluid phase” during metamorphism of the greenstones. It is possible, however, that the veins may have been formed in relation to the intrusion of basic rocks during the later stage of metamorphism.

iii) Sodic augite

Sodic augite usually occurs as monomineralic vein adjacent to ultramafic rocks in this district. This occurrence suggests that the sodic augite produced in relation to the emplacement of ultramafic rocks.

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