研究報文

SIGNIFICANCE OF HORNBLENDE GABBROIC
INCLUSIONS IN CALC-ALKALI ROCKS

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Abstract: Hornblende gabbroic inclusions are often observed in alkali olivine basalts together with peridotite inclusions at the continental margins. We recently found hornblende gabbroic inclusions in calc-alkali rocks in Central Japan. These inclusions in both kinds of volcanic rock are mainly composed of tschermakitic hornblende and calcic plagioclase, and sometimes include minor aluminous clinopyroxene. From the mineralogical view point, they cannot be explained to have been formed at ordinary plutonic conditions. It is suggested from the similarity of mineralogical features and the confined distribution between the hornblende gabbroic inclusions in the calc-alkali rocks and those from the alkali basalts that they are derived from the same position in the depth and they have considerable development under the continental margins. We cannot give a definite conclusion about the source of these hornblende gabbroic inclusions, because we have not sufficient data on the water content near the Mohorovicic discontinuity and the stability field of such mineral assemblage. It is likely that they are originated at considerable depth in the earth, however, as for example, the basement of the crust.

INTRODUCTION

It is very important problem in petrogenesis to know of what materials, not only the upper mantle but also the basement of the crust, are composed. To approach this problem many petrologists have paid attention to some inclusions in volcanic rocks, because they may provide some important knowledges. They are, for examples, peridotite, garnet peridotite and eclogite inclusions in alkali basalts. Besides hornblende gabbroic inclusions are often observed in alkali basalts along with peridotite inclusions at the

continental margins. We found also hornblende gabbroic inclusions, which have similar mineralogical characters to those in alkali basalts, in the calc-alkali rocks in the geosynclinal zone of the Fossa Magna.

In this paper the present authors are going to give the results of their studies on hornblende gabbroic inclusions in calc-alkali rocks to which no special attentions have been drawn by any petrologists, with those in alkali basalts, and discuss their petrological significances in some detail.

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HOST ROCKS AND MODE OF OCCURRENCE OF HORNBLLENDE GABBROIC INCLUSIONS

Hornblende gabbroic inclusions were collected from calc-alkali volcanic rocks at Kujiranami, Niigata Prefecture, and Shigarami, Nagano Prefecture, and also from alkali olivine basalts at Ichinomegata, Akita Prefecture. These localities of gabbroic inclusions are shown in Figure 1.

The host rocks of gabbroic inclusions at Kujiranami are agglomerates of augite-hypersthene andesite with reddish brown color. The rock carries large crystal bombs of anorthite and hornblende. Phenocrysts of this andesite are plagioclase, augite, hypersthene, ore minerals and hornblende. Plagioclase often takes granulated form with marginal zone showing fine zonal structure, with many dusty inclusions often arranged parallel to it. Augite is sometimes oxidized and is brown or reddish brown in color. The (100) twin, often repeated, is common. Hypersthene is usually oxidized and changed to opaque or brown minerals. Hornblende is also oxidized and altered to opaque minerals. Apatite with many brown pigmental inclusions is present as microphenocryst.

Fig. 1. The localities of the hornblende gabbroic inclusions.

1 : Shigarami, 2 : Kujiranami, 3 : Ichinomegata, S : Sendai, T : Tokyo.

The groundmass is very fine grained. It carries plagioclase, hypersthene, augite, cristobalite, cryptocrystalline minerals and glass.

The mode of occurrence of gabbroic inclusions at Kujiranami, Niigata Prefecture, is described by Kawano (1943) in detail. Although small grains of anorthite and hornblende are widely scattered in agglomerates, gabbroic inclusions and large separated crystals are found only in restricted parts.

The host rocks of hornblende gabbroic inclusions at Shigarami, Nagano Prefecture, are tuff breccia. It is difficult to determine what is the essential materials, because there is no pumice or scoria. The matrix of the breccia consists of scattered crystals of plagioclase, augite, hypersthene, hornblende, magnetite and fine glassy fragments.

At Shigarami, the hornblende crystals are scattered widely, in

the tuff breccia but the gabbroic inclusions are found in the lower part of the tuff breccia. The gabbroic inclusions of the same kind were found in two pyroxene andesite in Shigarami formation and briefly described by Yagi and Yagi (1958).

Table 1. Bulk and normative compositions of the host rock of the hornblende gabbroic inclusions at Kujiranami.

1			
Wt. %		Norm	
SiO ₂	51.27	q	8.58
TiO ₂	0.71	or	9.23
Al ₂ O ₃	16.69	ab	17.13
Fe ₂ O ₃	5.37	an	39.95
FeO	3.70	di	3.57
MnO	0.10	hy	9.91
MgO	4.11	mt	7.80
CaO	9.22	il	1.35
Na ₂ O	2.03	ap	0.49
K ₂ O	1.56		
H ₂ O +	1.07		
H ₂ O -	1.00		
P ₂ O ₅	0.20		
Total	100.03		

1: Hypersthene augite andesite from Kujiranami, Niigata Prefecture (Kawano, 1943).

Both pyroclastic rocks were erupted in the Miocene to Pliocene age in the geosynclinal zone of the Fossa Magna.

The chemical composition of hypersthene-augite andesite (Kawano, 1943), which is a host rock of hornblende gabbroic inclusion at Kujiranami, together with its normative composition is shown in Table 1.

CHEMICAL COMPOSITIONS OF HORNBLLENDE GABBROIC INCLUSIONS

Bulk and normative compositions of hornblende gabbroic inclusions in calc-alkali rocks are given in Table 2. Although modal compositions are highly variable, analysed specimens are the typical one in each locality. The analysed specimen from Shigarami is richer in hornblende compared with that from Kujiranami, and judging from the faintly stained plagioclase in pale brown color, it may be altered a little. The specimen from Kujiranami is very fresh.

These inclusions have characteristic features in chemistry,

namely low contents in silica and high contents of alumina and lime. Normative nepheline is calculated in both of them. Chemical differences between the two specimens from Kujiranami and Shigarami are due to differences of modal proportions of hornblende and plagioclase.

Table 2. Bulk and normative compositions of hornblende gabbroic inclusions.

	1 Sg-1	2 Kj-1		1 Sg-1	2 Kj-1
Wt. %			Norms		
SiO ₂	40.22	41.56	or	2.89	3.61
TiO ₂	1.55	1.30	ab	5.87	3.04
Al ₂ O ₃	21.74	22.36	ne	6.30	3.26
Fe ₂ O ₃	5.50	3.32	an	48.51	53.43
FeO	4.05	4.76	di	14.17	12.51
MnO	0.09	0.11	ol	8.14	13.56
MgO	7.08	8.36	mt	7.98	4.80
CaO	13.51	14.00	il	2.95	2.46
Na ₂ O	2.07	1.27	ap	0.13	0.10
K ₂ O	0.49	0.61			
H ₂ O+	2.05	1.53			
H ₂ O-	1.29	0.67			
F ₂ O ₅	0.05	0.04			
Total	99.69	99.89			

1 : Hornblende gabbroic inclusion from Shigarami,
Nagano Prefecture.

2 : Hornblende gabbroic inclusion from Kujiranami,
Niigata Prefecture. Analyst : T. Tiba.

In Table 3, chemical compositions of amphibolites and appinite from some regions, which have a similar mineral assemblage to the above mentioned hornblende gabbroic inclusions, are given for comparison.

Hornblende gabbroic inclusions are more aluminous and calcareous, but poor in silica than amphibolites and appinite. Total iron contents of these rocks are nearly equal, but inclusions have higher ferric-ferrous ratios. Amphibolites are higher in soda contents and appinite shows higher potash content than inclusions.

Since these rocks have a similar mineral assemblage, chemical differences among them are mainly due to differences of chemical natures of main constituent minerals. Plagioclase of gabbroic inclusions is anorthite (An₉₃) from optical properties, but that of ordinary amphibolite and appinite is more sodic than labradolite. Appinite usually contains some amounts of modal orthoclase and

Table 3. Chemical compositions of amphibolites and appinites compared with the hornblende gabbroic inclusion.

	Kj-1	1	2	3
SiO ₂	41.56	49.45	48.13	48.68
TiO ₂	1.30	0.72	1.87	1.34
Al ₂ O ₃	22.36	17.13	17.34	17.66
Fe ₂ O ₃	3.32	2.87	2.51	2.17
FeO	4.76	7.15	8.18	6.72
MnO	0.09	0.14	0.22	0.03
MgO	8.36	7.24	6.58	7.78
CaO	14.00	9.64	8.09	9.32
Na ₂ O	1.27	3.48	3.95	2.22
K ₂ O	0.61	0.89	0.76	1.90
H ₂ O+	2.05	0.15	2.00	1.74
H ₂ O-	0.67	0.99		0.22
P ₂ O ₅	0.04	0.11	0.24	0.13
Total	99.89	99.96	99.87	99.91

Kj-1: Hornblende gabbroic inclusion from Kujiranami.

1: Amphibolite, after Heier, K.S. (1962).

2: Amphibolite, after Evans, B.W. and Leak, B.E. (1960).

3: Appinite, after Nockolds, S.R. (1940).

quartz. As discussed later, hornblende in ordinary amphibolites and appinites are not so aluminous as those in gabbroic inclusions. Hornblende gabbroic inclusions described in this paper may be formed under different conditions than those of the appinites and amphibolites.

MINERALOGY OF HORNBLLENDE GABBROIC INCLUSIONS

Plagioclase: Modal proportion of plagioclase is highly variable in all specimens, but optical properties are the same. Plagioclase has no zoning under the microscope. Chemical compositions determined optically are An₉₃₋₉₅. Such highly calciferous nature of plagioclase is not expected in ordinary plutonic rocks.

In his study on plagioclase in metamorphic and igneous rocks, Gorai (1951) divided plagioclase twins into two main types, A-twin and C-twin, and pointed out that A-twin is commonly present in igneous rocks as well as in metamorphic rocks, while C-twin is restricted to, or characteristic of, igneous rocks. Since C-twin is predominant in gabbroic inclusions, it seems likely these inclusions do not belong to the metamorphic rocks in strict sense.

Hornblende: Hornblende is rather large, and often encloses poikilitically plagioclase and/or clinopyroxene. Clinopyroxene and hornblende have a random orientation, and there is no reaction relation between them. Hornblende from Kujiranami is usually

oxidized and fresh one is very rare. Kawano (1943) reported on the hornblende from Kujiranami from the view point of mineral chemistry. The hornblende analysed in this paper is greenish brown or brown in Z-axial color and is affected by slight oxidation.

Table 4. Chemical compositions of hornblendes

	1 Sg-1	2 Sg-2	3 Kj-1	4 Iht-1	5 Ihg-1	6 Ihg-2
SiO ₂	40.42	40.45	41.27	40.29	39.75	41.18
TiO ₂	2.23	2.59	2.06	2.32	1.90	1.62
Al ₂ O ₃	15.12	15.03	13.96	16.99	17.36	16.55
Fe ₂ O ₃	5.23	5.06	5.35	2.44	2.16	2.78
FeO	6.41	6.32	6.76	9.55	9.74	7.30
MnO	0.21	0.19	0.18	0.18	0.17	0.22
MgO	13.46	13.49	13.88	12.03	11.85	13.51
CaO	12.13	11.96	11.81	12.04	11.76	12.28
Na ₂ O	1.89	1.91	1.72	1.44	1.49	1.80
K ₂ O	0.78	0.79	0.98	0.33	0.97	0.31
H ₂ O +	1.36	1.59	1.51	1.78	2.10	1.98
H ₂ O -	0.45	0.35	0.46	0.27	0.28	0.23
Total	99.69	99.73	99.94	99.66	99.53	99.76

- 1: Hornblende in hornblende gabbroic inclusion from Shigarami, Nagano Prefecture.
- 2: Hornblende in clinopyroxene bearing hornblende gabbroic inclusion from Shigarami, Nagano Prefecture.
- 3: Hornblende in hornblende gabbroic inclusion from Kujiranami, Niigata Prefecture.
- 4: Hornblende in hornblendite inclusion from Ichinomegata, Akita Prefecture (Onuki, 1965).
- 5: Hornblende in hornblende gabbroic inclusion from Ichinomegata, Akita Prefecture (Onuki, 1965).
- 6: Hornblende in clinopyroxene hornblende gabbroic inclusion from Ichinomegata, Akita Prefecture. Analyst; H. Onuki

In Table 4, chemical compositions of hornblendes in hornblende gabbroic inclusions in calc-alkali rocks along with those of hornblendes in hornblendite and hornblende gabbroic inclusions (Onuki, 1965) and also in the clinopyroxene hornblende gabbroic inclusion in scoria of alkali olivine basalt from Ichinomegata, Akita Prefecture, are shown. In Table 5, atomic ratios of these hornblendes on the basis of 23 oxygen atoms are given. Hornblendes in these inclusions are highly aluminous compared with alkali contents and therefore they may be called tschermakitic hornblende.

Because complexities of chemical compositions of minerals are mainly due to substitutions of ions or atoms in them, we must discuss their chemical natures by the character of substitutions. To consider

Table 5. Atomic ratios on basis of 23 oxygens of hornblende of Table 4.

	1	2	3	4	5	6
Si	5.892	5.894	6.014	5.886	5.854	5.965
Al	2.592	2.577	2.394	2.920	3.008	2.822
Ti	0.244	0.283	0.225	0.254	0.209	0.176
Fe ⁺³	0.572	0.553	0.584	0.266	0.238	0.303
Fe ⁺²	0.778	0.768	0.820	1.161	1.195	0.881
Mn	0.026	0.024	0.022	0.022	0.021	0.022
Mg	2.943	2.948	3.034	2.636	2.617	2.936
Ca	1.894	1.867	1.844	1.885	1.856	1.906
Na	0.533	0.539	0.484	0.407	0.424	0.504
K	0.145	0.147	0.182	0.061	0.182	0.057

the substitution we often postulate some end members in solid solution. It is more desirable that end members are present as natural minerals, but it is not always necessary. In the case of hornblende, isomorphous substitutions are very complicated, and many end members are proposed by some authors. Shido (1958) has proposed eight end members derived from the tremolite as a primary formula of calciferous amphiboles by considering various substitutions. In addition to those, Shido and Miyashiro (1959) have suggested a new end member, namely calcium cummingtonite. Out of these nine end members, Onuki (1965) has omitted the sodatremolite in the case of calciferous amphiboles. The calculation of hornblende into their molecular components is very useful, for it makes clear the complicated features of substitutions. The authors have presently adopted the calculation method of calciferous amphiboles into their molecular components, which is slightly modified from Shido's method. In Table 6, several substitutions and end members which are used by the present authors are shown. The calculated molecular proportions of hornblendes from inclusions are given in Table 7.

In hornblende, Al^{IV} enters tschermakite molecules and also glaucophane molecules. The glaucophane molecule may not always be considered as the pressure indicator, because this mineral is stable over a wide range of P-T conditions (Ernst, 1961). Although silica deficient environment may be favorable for the Al-Si substitution, it is not necessary favorable for the MgSi-AlAl substitution. Considering the pressure effect on the chemical compositions of hornblende, we must consider the MgSi-AlAl substitution, which is calculated as tschermakite molecule.

In the calculation of molecular proportions of hornblendes, we adopted Mg as Fe⁺² + Mn + Mg. The Fe/Mg ratio of mafic minerals is one of the most important values and is shown in Figure 2.

Table 6. End members resulting from the various types of substitutions and the order of calculation.

Name	Structural positions					Type of substitution
	A	W	X + Y	Z		
Titano amphibole		Ca ₂	Mg Ti ₄	Al ₈	O ₂₂ (OH) ₂	MgSi ₂ —TiAl ₂
Cummingtonite		Mg ₂	Mg ₅	Si ₈	O ₂₂ (OH) ₂	Ca —Mg
Calcium cummingtonite		Ca ₂	Ca ₅	Si ₈	O ₂₂ (OH) ₂	Mg —Ca
Calcium edenite	Ca ₄	Ca ₂	Mg ₅	Al ₈	O ₂₂ (OH) ₂	Si ₂ —CaAl ₂
Glaucophane		Na ₂	Mg ₃ Al ₂	Si ₈	O ₂₂ (OH) ₂	CaMg—NaAl
Edenite	Na ₈	Ca ₂	Mg ₅	Al ₈	O ₂₂ (OH) ₂	Si —NaAl
Tschemakite		Ca ₂	Al ₆	Al ₅ Si ₃	O ₂₂ (OH) ₂	MgSi —AlAl
Tremolite		Ca ₂	Mg ₅	Si ₈	O ₂₂ (OH) ₂	

Mg ; Mg+Fe⁺²+MnAl ; Al+Fe⁺³

after Shido (1958) and Shido and Miyashiro (1959).

Table 7. Molecular proportions of hornblendes of Table 4.

	1	2	3	4	5	6
Ti-am	0.488	0.566	0.450	0.508	0.418	0.352
Cum	0.188	0.188	0.372	0.508	0.568	0.440
Ca-cum	.....	.....	.....	.....	.....	.....
Ce'	.....	.....	.....	0.060	.....	0.034
Gl	0.236	0.344	0.252	.....	0.008	.....
Ed'	0.619	0.600	0.603	0.468	0.604	0.561
Tsch'	1.602	0.504	0.493	1.725	1.798	1.822
Tr	4.828	4.828	4.830	4.659	4.604	4.490

Besides hornblendes from inclusions, those from Glen-Tilt (Deer, 1950), Glenelg-Ratagain diorite (Nicholls, 1950), Walmington gabbroes (Rosenzweig and Watson, 1954) and mafic and ultramafic rocks in the Kitakami mountainland (Onuki, 1963; 1964; 1965) are plotted in Figure 2. Hornblendes in granitic rocks have usually greater Fe/Mg ratios than one, and therefore they are omitted in this figure.

These hornblendes are clearly divided into the three zones in Figure 2 according to their modes of occurrence. Hornblendes from mafic and ultramafic intrusive rocks are plotted in the zone, confined to the central part in the figure. Hornblendes in diorites are plotted in the upper zone and those in gabbroic inclusions including hornblendite inclusion are plotted in the lower part in this figure. In other words, it is shown that hornblendes in diorities and gabbroes are richer in iron and have small proportions of

tschermakite molecule, and those in gabbroic inclusions are richer in magnesium as well as in tschermakite molecule. Many Mg-rich hornblendes are reported from mafic and ultramafic intrusive rocks, but they do not contain such high contents of tschermakite molecule as those in gabbroic inclusions. The nature of Mg-rich and high tschermakite molecule in hornblende are common in eclogitic ones (Alderman, 1936).

The Figure 2 may reflect the physico-chemical environments of the hornblende stability field.

Fig. 2. The $(\text{Fe}^{+2} + \text{Mn}) / \text{Mg}$ -tschermakite molecule relation of Mg-rich igneous hornblendes. Open circle; in gabbroic inclusions, closed circle; in basic and ultrabasic intrusive rocks, open square; in diorites.

Clinopyroxene: Clinopyroxene is present as minor constituent in the gabbroic inclusion. It is usually scattered between plagioclase and hornblende. Each grain of clinopyroxene takes random orientation.

In Table 8, chemical compositions and atomic ratios on the basis of 6 oxygens of clinopyroxenes in gabbroic inclusions from Shigarami and Kujiranami are given. These clinopyroxenes have a rather similar character, very high in alumina and low in alkalis and titania contents. In other words, large amounts of Ca-Tschermak's molecule are calculated in them (cf. Table 9) by Kushiro's method (Kushiro, 1962).

Table 8. Chemical compositions of clinopyroxenes from gabbroic inclusions.

	1 Sg-2	2 Ihg-2		1 Sg-2	2 Ihg-2
	Wt. %		Atomic Ratios, 0=6		
SiO ₂	49.77	48.17	Si	1.854	1.797
TiO ₂	0.90	0.89	Al	0.212	0.294
Al ₂ O ₃	4.83	6.70	Ti	0.025	0.025
Fe ₂ O ₃	2.54	2.05	Fe ⁺²	0.071	0.057
FeO	4.75	6.22	Fe ⁺³	0.148	0.193
MnO	0.15	0.17	Mn	0.005	0.005
MgO	13.80	13.01	Mg	0.771	0.728
CaO	21.47	22.23	Ca	0.857	0.889
Na ₂ O	0.91	0.37	Na	0.066	0.025
K ₂ O	0.14	0.04	K	0.007	0.002
H ₂ O+	0.19	nd.			
H ₂ O-	0.25	nd.			
Total	99.70	99.85			

1: Clinopyroxene in clinopyroxene bearing hornblende gabbroic inclusion from Shigarami, Nagano Prefecture.

2: Clinopyroxene in clinopyroxene hornblende gabbroic inclusion from Ichinomegata, Akita Prefecture.

Analyst: H. Onuki.

Table 9. Molecular proportions of clinopyroxenes of Table 8, calculated by Kushiro's method.

	1	2
NaFe ⁺³ Si ₂ O ₆	7.1	2.6
NaAlSi ₂ O ₆	0.2	—
CaTiAl ₂ O ₆	2.5	2.5
CaFe ⁺³ AlSiO ₆	—	3.0
CaAl ₂ SiO ₆	8.0	10.5
CaFe ⁺³ ₂ SiO ₆	—	—
CaSiO ₃	37.6	36.1
MgSiO ₃	38.6	35.7
FeSiO ₃	7.7	9.7

Ca-Tschermak's molecule can enter diopside pyroxene as solid solution up to 20 per cent at 1 atm. in silica-undersaturated condition (de Neufville and Schairer, 1962). The higher the pressure, the wider the solid solution becomes and at 20 kb. a complete solid solution is formed in the system Ca-Tschermak's molecule-diopside

(Clark et al., 1962). On the other hand, in the silica-saturated or oversaturated condition, the solid solution is not produced at 1 atm., but when pressure is increased the immisibility gap gradually decreases. In the natural undersaturated rocks Ca-Tschermak's molecules in clinopyroxenes are usually less than 20 per cent, therefore, we cannot directly adopted these molecules as the pressure indicator, though they are useful in the case of the silica-saturated or oversaturated rocks.

The above mentioned discussion may be restricted in dry system. The solid solution relations of clinopyroxenes may be disturbed when hornblende crystallizes at wet condition, but we do not know to what extent such effect is present. The distribution coefficient of MgSi-AlAl substitution between clinopyroxene and hornblende is a very interesting problem, but this cannot be discussed here, owing to the insufficient data.

We must pay attention to mineral assemblage in the rock as well as chemical environments to use Ca-Tschermak's molecule as the pressure indicator. Ca-Tschermak's molecules are not always useless among rocks having same mineral assemblage so far as the modal feldsparthoids are not present. Higher Ca-Tschermak's molecules in clinopyroxenes from gabbroic inclusions than in pyroxenes from ordinary gabbros may suggest that they were crystallized under relatively higher pressure than those from ordinary gabbroic rocks.

Ore mineral: As the minor constituent, idiomorphic ore minerals are scattered between hornblende and plagioclase. It forms only one phase under the reflection microscope, and shows no exsolution lamella. It is reflectively isomorphic and resembles magnetite. But it does not seem to be an ordinary magnetite, for it is not etched by conc. HCl at 50°C. The (111) etching cleavage, which are distinct in ordinary magnetite, come out at higher temperature etching. It is attracted easily by an ordinary horseshoes magnet and can be separated. These natures are common in both specimens from Shigarami and Kujiranami.

The ore mineral from Shigarami is separated and studied by X-ray diffraction powder method using Co K_{α} radiation, scanning speed of 1 degree per minute, time constant of 1 sec. The higher angle parts are reexamined in more detail, scanning speed of 0.25 degree per minute and time constant of 4 sec., for the diffraction peaks are very weak. The data are given in Table 10. From the X-ray diffraction data, the ore mineral is identified as magnetite. The unit cell edge from these data is $a_0=8.37\text{\AA}$, which is smaller than that of pure

Table 10. X-ray powder data of magnetite in the hornblende gabbroic inclusion from Shigarami.

hkl	d (Å)	I
220	2.96	26
311	2.52	100
400	2.09	10
333	1.61	32
440	1.48	5
553	1.09	v. w.
731		
751	0.967	v. w.
555		
840	0.936	v. w.
a=8.37		

magnetite, $a_0=8.396\text{\AA}$. In general, magnetite in igneous rocks contains some amounts of ulvospinel component, and has larger unit cell volume than pure magnetite. The unit cell volume of magnetite is decreased by solid solution with spinel series or by oxidation producing maghemite. The oxidation may be negligible in the magnetite from gabbroic inclusion, for no oxidation products are identified under the reflection microscope. It seems more reasonable that the magnetite contains considerable amounts of manganese and/or aluminium, and reflects high pressure environment when it crystallized.

GENETIC SIGNIFICANCE OF HORNBLENDE GABBROIC INCLUSIONS

The mineral assemblage of the inclusion resembles that of appinites and amphibolites, but chemical characters of constituent minerals are very different. From mineralogical view point, it is not likely that the inclusion are produced in normal plutonic condition or it is an equivalent of amphibolite. In calc-alkali rocks, normal gabbroic xenoliths with similar mineralogical composition to ordinary plutonic rocks, are naturally expected as accidental fragments from near the earth's surface, but such materials are excluded from the discussion in this paper from the above mentioned reasons.

The chemical equivalent of the gabbroic inclusion is kyanite eclogite. In Table 11, chemical compositions of some kyanite eclogites are given. Their characteristic features as highly aluminous and calcareous are common to the gabbroic inclusions. The appearance of kyanite in eclogites is controlled by chemical environments (Tilley, 1936). Although kyanite eclogites are usually saturated or oversat-

urated in silica, some kyanite eclogites have normative nepheline (Angel, 1957). Therefore, it may be said that if suitable chemical environments are present, kyanite eclogites with normative nepheline, which are chemical equivalents of gabbroic inclusions, are able to be present as a stable phase in eclogitic condition.

Eclogites are mainly composed of pyrope-rich garnet and omphacite. It may be stable only at dry condition, for the eclogitic garnet is unstable at wet condition (Yoder and Chinner, 1960a; 1960b; Yoder and Tilley, 1962). This chemical similarity between hornblende gabbroic inclusions and kyanite eclogites is one of the important evidences. There is not, however, direct evidences to show that hornblende gabbroic inclusions are formed by recrystallization from kyanite eclogites at shallower depth or wet condition.

Unusual mineralogical characters of hornblende gabbroic inclusions in calc-alkali rocks are common to hornblende and hornblende gabbroic inclusions associated with peridotite inclusions in alkali basalts. The occurrence of the latter may be restricted in alkali basalts of the continental margins, but not in those of oceanic regions. Hornblende gabbroic inclusions in calc-alkali rocks are expected to be found at many places in the orogenic belts in the world. Both kinds of hornblende gabbroic inclusions in calc-alkali rocks and alkali basalts may be derived from the same position in depth from the similarity of mineralogical features. And also, it suggests the existence of similar materials to those hornblende gabbroic inclusions in considerable amounts under the continental margins.

In spite of great progress in experimental investigations of anhydrous minerals such as pyroxenes and garnets under high pressures and temperatures, only little has been known about hydrous minerals under such conditions. In peridotite, garnet peridotite and some eclogite inclusions which are currently considered to be derived from the upper mantle keeping their solid state, all constituent minerals are usually anhydrous. But, not only anhydrous minerals but hydrous minerals would be possible in the upper mantle, specially just below the Mohorovicic discontinuity. Oxburgh (1963; 1964) has noted the significance of hornblende in the upper mantle with special reference on the origin of parental basalt magmas.

Yoder and Tilley (1962) have shown that amphibolites of chemical equivalents of basalts are stable at 600°C., 10 kb. in water pressure. Though they have not determined chemical compositions of

Table 11. Chemical compositions of kyanitie eclogites

	1	2
SiO ₂	50.24	50.75
TiO ₂	0.26	0.12
Al ₂ O ₃	19.98	20.02
Fe ₂ O ₃	1.44	0.42
FeO	3.12	3.87
MnO	0.10	0.05
MgO	9.84	9.34
CaO	12.95	13.07
Na ₂ O	1.93	1.14
K ₂ O	0.09	0.15
H ₂ O (+)	0.31	0.70
H ₂ O (-)	nil.	0.50
P ₂ O ₅	0.02	tr.
S	0.35	n.d.
Total	100.13	100.10

1: Kyanite eclogite (Yoder and Tilley, 1962).

2: Kyanite eclogite (Tilley, 1936).

hornblende and plagioclase of the amphibolites, they have given an important suggestion on the stability field of the assemblage of hornblende and plagioclase.

If hornblende gabbroic inclusions are stable in the upper mantle near the Mohorovicic discontinuity, a considerable water pressure must be present at such a portion. At present we cannot give a definite conclusion about the source of hornblende gabbroic inclusions, because of the insufficient data on the stability field of such assemblage as tschermakitic amphibole and anorthite and the water content near the Mohorovicic discontinuity. Judging from their mineralogical characters, however, these hornblende gabbroic inclusions may be formed at considerable depth, as for example, the basement of the crust.

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カルクアルカリ岩中の角閃石斑糲岩質包裹物の意義

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摘 要

筆者等は最近日本中部の二、三のカルクアルカリ岩系集塊岩及び凝灰岩中に角閃石斑糲岩質包裹物が産出しているのを発見した。この斑糲岩質包裹物は主として角閃石と灰長石からなり、単斜輝石及び磁鉄鉱を少量含んでいる。角閃石、単斜輝石ともアルカリに比してアルミナに富んでおり、又磁鉄鉱は純粹のものに比して格子定数が小さいものである。造岩鉱物の性質から考えて、この斑糲岩質包裹物は通常の深成岩と同様の温度圧力の条件下で生じたものとは思われず、もつと地下深部からもたらされたものと考えられる。この種の斑糲岩質包裹物が安定に存在していた深さを直接決定する事はできないが、アルカリ橄欖石玄武岩中の斑糲岩質包裹物と同一の性質を示している事等から考えて、この種の斑糲岩質岩石が大陸周縁部の地下深部にかなりの分布を示すものと思われる。