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Geologic Study on the Myoko Volcanoes, Central Japan
—Part 2. Petrography—

By

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Abstract

In the Myoko volcanoes*, pyroxene andesite and hornblende andesite are very common, and basalt which belongs to the high-alumina basalt by Kuno (1960) is also accompanied in subordinate amount. Generally, the rocks tend to change from lower to upper in each group as follows: basalt→pyroxene andesite→hornblende andesite.

The rocks of these volcanoes may be distinguished form the Quaternary volcanic rocks just east of MYOKO in common occurrence of hornblende phenocrysts, and from those of the Southwest Japan in absense of biotite phenocrysts. The features of the chemical composition such as high K_2O and Al_2O_3 contents and low CaO content, and of the mineral assemblage such as common occurrence of hornblende phenocrysts, have well resemblance to those of the Chokai volcanic belt, and they form a striking contrast to those found along the Pacific Ocean side.

The K_2O content of the rocks of MYOKO tends to increase northward. This tendency is keeping with the increase of K_2O content from the Pacific Ocean side to the Japan Sea side.

The xenoliths, and inclusions assumed to be xenoliths, are commonly found in the rocks of MYOKO. They are very common in the hypersthenic series rocks, but are rather rare in pigeonitic series rocks. They have generally reacted with magma, and perfectly or partly changed their original mineral compositions and textures.

Characteristic large crystals of plagioclase, 3 cm long in maximum, are discovered in the basalt of the Myoko volcano. They correspond to the so-called "large anorthite crystal" named by Ishikawa (1951). Their size, An-content, inclusion, zoning, and twinning are remarkably different from those of the common plagioclase phenocrysts in the host basalt. Under the microscope, a continuous transition in texture and mineral assemblage is traced from accidental xenoliths of the basal Neogene sedimentary rocks (pelitic or psammitic rocks) to the large anorthite crystals. Therefore, the large anorthite crystals may have been formed through the reaction between the xenoliths and the host magma. It is assumed that water included in the xenoliths may be one of the most important factors to form the large anorthite crystals.

Many characteristic inclusions which are somewhat globular and more mafic than their host rocks are in the horblende andesites from MYOKO. They generally contain glass, and are porous. They have been called cognate inclusion, and interpreted as fragments of the rocks crystallized at an earlier stage in the same "evolutional series" as the host rocks. As the result of the microscopic observation of the rocks of the Myoko IVth stage, a continuous transition in texture, mineral assemblage, and nature of minerals is traced from the accidental xenoliths in the basalt through

* The term of the Myoko volcanoes will be symbolized by "MYOKO" in this paper.

the inclusions in the basic andesite to the so-called cognate inclusions in the acidic hornblende andesite. Such inclusions in the hornblende andesite, therefore, are considered to have been formed through the reaction of accidental xenoliths with magma.

From a view-point of field occurrence, the hornblende andesite of MYOKO is regarded to be derived from basaltic magma. The addition of water in magma from xenolith seems to be one of the essential factors for producing the hornblende andesite.

I. INTRODUCTION

MYOKO are situated at the prefectural border region between Nagano and Niigata, Central Japan. The region of MYOKO represents one of the most remarkable Quaternary volcanic fields in the northern part of the Fossa Magna. There, six volcanoes of old and young age, the Yakeyama as an active volcano, Myoko as a main volcano, Kurohime, Iizuna, Madarao, and Sadoyama as the oldest volcano, are crowded.

MYOKO are constructed from the various rocks such as basalt, pyroxene andesite, and hornblende andesite. The pigeonitic and hypersthenic series rocks defined by KUNO (1950, 1954) are observed. These rocks are closely related to the growth-history of the volcano in their occurrence, and the xenoliths also occur with close relation to the growth-history and the nature of their host rocks. This relationship is very important when the genesis of the volcanic rocks of this region is considered.

The rocks of MYOKO commonly include hornblende phenocrysts, but no biotote phenocryst. These rocks, therefore, are clearly distinguished from the Quaternary volcanic rocks generally containing biotite phenocrysts of the Southwest Japan, and from those generally containing few hornblende phenocrysts just east of the present region such as the Takayashiro, Kenashi, and so forth. Moreover, they may be distinguished from the basement volcanic rocks often containing biotite phenocrysts. Thus, MYOKO occupy the interesting position on the problems of the petrographic province. Therefore, MYOKO are a theme worth making a detailed petrographical study.

The petrographical studies of MYOKO have been published by YAGI et al. (1958) and YAMADA (1934) for the Kurohime and Iizuna volcanoes and YAMADA (1929) for the Madarao volcano. But no petrographical study which discussed the relation with the growth-history of the volcano has been published.

The writer has applied his energies to the stratigraphical study of MYOKO subordinately associated with the petrographical study since the spring of 1966. A summarized description of the stratigraphy was published in another paper (HAYATSU, 1976). In the present paper, the mineral assemblage, features of the rock-forming minerals, and bulk chemical characters of each rock will be described first in keeping with relation to the growth-history, and the xenoliths commonly included in the rocks of MYOKO will be stated next. This study must be supplemented by the further detailed petrographical investigation.

The writer repeatedly wish to express his sincere thanks for the guidance, discussions, and encouragements kindly offered by all the persons who published their names in Part 1 of this series (HAYATSU, 1976). The writer's special thanks are due to Prof. Emeritus H. YOSHIZAWA, Prof. I. HAYASE, Prof. K. NAKAZAWA, and Dr. S. ISHIDA of the Kyoto University, and Prof. K. KOBAYASHI of the Shinshu University for their kind guidance. He also greatly appreciates the constant advice and encouragement since the beginning by Dr. S. KAWACHI of the Hokkaido University who first suggested the writer to study the geology of MYOKO by pointing out the necessity of the work. Finally, the writer is indebted to Mr. Y. MIYASHITA of the Arai High School and Miss H. FUJIKAWA of the Kyoto Univesity for preparing his manuscript.

II. MICROSCOPIC PETROGRAPHY

MYOKO consist of basalt, andesite, and dacite, and are characterized especially by occurrence of hornblende andesite (and dacite), but the ratio of basalt-andesite-dacite is variable in each volcano and in each group. The rocks exhibit striking contrast to those of the southern Fuji volcanic sub-belt and also those of the Nasu volcanic belt (both are situated in the Pacific Ocean side of Japan) which include few hornblende andesite. And also, they are easily distinguished from the Quaternary calc-alkaline volcanic rocks of the Southwest Japan in having no biotite phenocryst.

The microscopically characteristic features of the rocks and minerals are described in the present chapter.

A. Rocks of each volcano and stage

1. The rocks of the Sadoyama volcano

The rocks constructing the Sadoyama volcano are grayish white to pale purplish gray, pyroxene-hornblende andesite. The microscopic petrography is rather uniform in comparison with those of other Myoko volcanoes. Augite-hypersthene-hornblende andesite (Vld, Vle)* is the commonest. The hornblende is green or opacitized oxyhornblende, and the rocks including the latter show always pale purplish to purplish gray due to oxidation. Pyroxene phenocryst, especially augite phenocryst, is rather subordinate in amount. Sometimes, corroded quartz crystals are found. The groundmass of the rocks is composed of plagioclase, hypersthene,

* According to KUNO's scheme (KUNO, 1950; 1954).

clinopyroxene, glass, silica mineral, and ore mineral. The texture is generally hyalopilitic. Sometimes, xenolith-like inclusions are included in the rocks of the Sadoyama volcano.

2. The rocks of the Madarao volcano

According to TAKEUCHI (in TOMIZAWA, 1970), the rocks of the Madarao volcano are augite-olivine-hypersthene andesite (Vc), olivine bearing augite-hypersthene andesite (Vc), augite-hypersthene andesite (Vc, Vd→c, Vd), and hypersthene-augite andesite. YAGI et al. (1958) reported the occurrence of the hornblende andesite from this volcano. The result of the present observation, limited on the western slope of the volcano, shows a general tendency that, as a whole. the pigeonitic series rocks and the hypersthenic series rocks occur at the lower part and the upper part, respectively. In the andesite, pyroxene (generally hypersthene is superior to augite in modal composition of phenocryst) occurs frequently, and olivine and hornblende are contained occationally.

3. The rocks of the Iizuna volcano.

The detailed characteristic features of the rocks constituting the eruptives of the Ist stage are not fully known because of the limited exposure. The rocks of the IInd stage, keeping with the growth of the volcano, change from pyroxene-olivine basalt through pyroxene andesite to hornblende andesite. In other words, the rocks change from the basic rocks belonging to the pigeonitic rock series to acidic ones belonging to the hypersthenic rock series. Hypersthene phenocryst invariably predominate over augite phenocryst in the modal composition of each rock excepting the Iizuna basalts. The mineral assemblages of the representative eruptions are shown in Fig. 1.

a). The rocks of the Ist stage

Most of the rocks of the Ist stage are pyroxene andesite and hornblende andesite belonging to the hypersthenic rock series. The hypersthene is common, augite subordinate in amount, and some of the rocks lack in augite. The relationship between the growth-history and petrography will be clarified from the future study.

b). The rocks of the IInd stage

(i) The stratovolcano stage

The Iizuna basalts, the first eruptives of the IInd stage, are augite-olivine basalt, excepting hypersthene-olivine-augite basalt of the Menoyama lava. The basalts contain olivine crystals surrounded by minite grains of clinopyroxene as phenocryst and as a groundmass constituent. The Iizuna lavas, the second eruptives, are augite -hypersthene andesite belonging to the pigeonitic rock series, and rarely include very small amount of olivine crystals. The groundmass is composed of plagioclase,

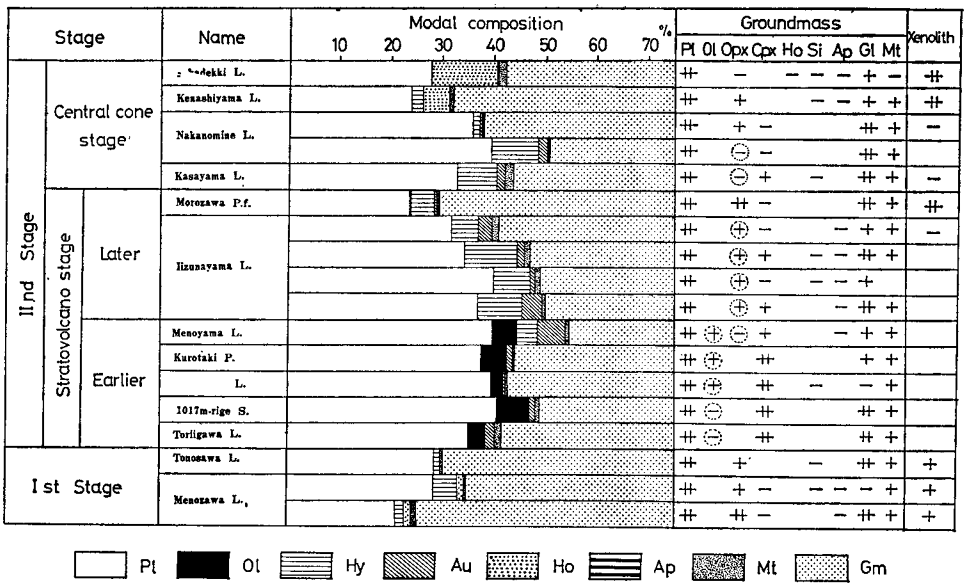

Fig. 1. Mineral assemblage of the rocks of the Iizuna volcano.
L: Lava, Ls: Lavas, P.f: Pyroclastic flow deposit, P.r: Pyroclastic rocks, S: Scoria, Pl: Plagioclase, Ol: Olivine, Hy: Hypersthene, Au: Augite, Ho: Hornblende, Ap: Apatite, Mt: Ore mineral, Gm: Groundmass, Opx: Orthopyroxene, CPx: Clinopyroxene, Si: Silica mineral, Gl: Glass, −: Poor, +: Medium, ++: Rich, Dotted circle: Reaction rim of clinopyroxene.

clinopyroxene, ore mineral, hypersthene, silica mineral, apatite, and glass. Groundmass hypersthene is very small in amount, and is rimmed by small grains of clinopyroxene. The lavas contain sometimes a few xenoliths. They show rather uniform mineral assemblage in spite of their large volume. The Morozawa pyroclastic flow deposit, the latest eruptives of this stage, consists of the essential blocks and ash of olivine bearing hornblende-hypersthene andesite belonging to the hypersthenic rock series. The essential blocks are characterized by the presence of many xenolith-like inclusions.

(ii). The lava dome stage

The rocks of the lava dome stage are mainly characterized by hornblende andesite, and a small amount of pyroxene andesite is also found. The Takadekki, Tengudake, and 1,340 m high ridge lavas are apatite bearing hornblende andesite, same in nature each other and rarely contain a very small amount of hypersthene as a core of hornblende. The hornblende is green or oxyhornblende. The Kenashiyama lava is hypersthene-hornblende andesite, and the hornblende is distinctly opacitized oxyhornblende. The groundmass of the hornblende andesites is made up of plagioclase, orthopyroxene, silica mineral, apatite, glass, ore mineral, and hornblende. Many xenolith-like inclusions are always included in the hornblende andesite. Sometimes, a few fragments of siltstone are also included as xenolith. Some of them are partially melted into glass. The Nakanomine and Kasayama lavas are augite-hypersthene andesite belonging to the pigeonitic rock series, and the petrographic features are closely allied to those of the Iizuna lavas. The Kasayama lava includes a small amount of large hornblende crystal with thick opacitized margin (generally several centimeters in length) probably as xenocryst.

4. The rocks of the Kurohime volcano

The rocks consisting the Kurohime volcano are generally andesite. The commonest rocks are augite-hypersthene andesite, which constructs the main part of the 2nd stage-eruptives. The most basic rock is olivine-augite basalt of the 1st stage. Comparatively acidic hornblende andesite occurs only as lapilli of a lapilli fall deposit. Plagioclase and pyroxene (especially hypersthene) are common, but hornblende is

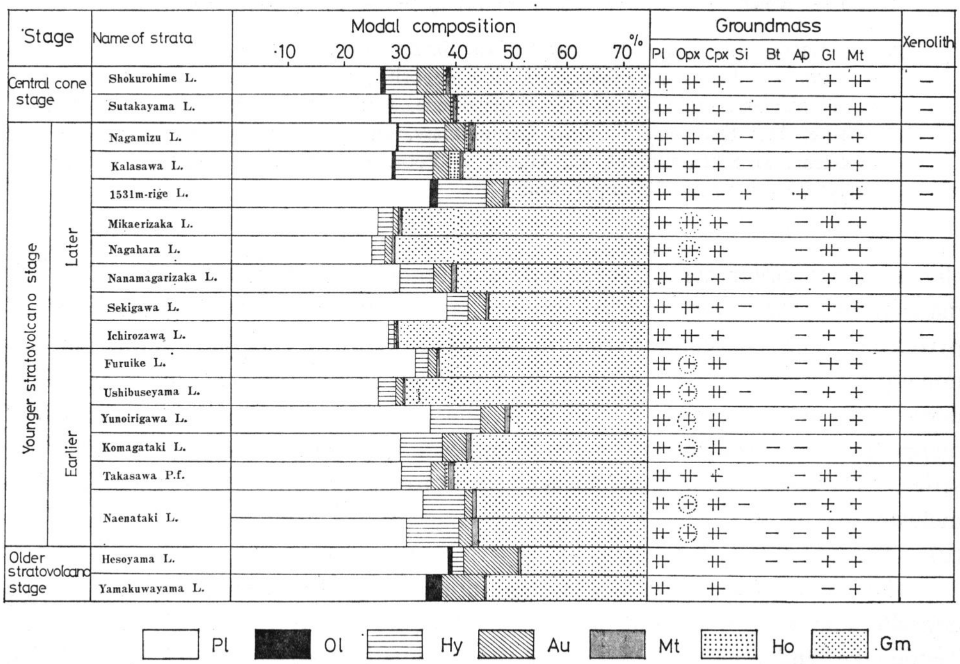

Fig. 2. Mineral assemblage of the rocks of the Kurohime volcano.
L: Lava, P.f: Pyroclastic flow deposit, Pl: Plagioclase, Hy: Hypersthene, Au: Augite, Mt: Ore mineral, Ho: Hornblende, Gm: Groundmass, Opx: Orthopyroxene, Cpx: Clinopyroxene, Si: Silica mineral, Bt: Mica, Ap: Apatite, Gl: Glass, —: Poor, +: Medium, ++: Rich, Dotted circle: Reaction rim of clinopyroxene.

rather rare in contrast to the Myoko, Sadoyama, Yakeyama, and Iizuna volcanoes. A small amount of olivine and hornblende coexist from the latest time of the 2nd stage to the 4th stage. The crystallinity of the groundmass is generally low, and glass is common. Xenolith is rare in general, and is sometimes recognized microscopically in the rocks of the hypersthenic rock series. But the hornblende-rich rocks, for example the essential lapilli of the lapilli fall deposit (Sc-3), include many xenolith-like inclusions. Throughout the growth of the Kurohime volcano, the rocks change as follows: basalt→pyroxene andesite of the pigeonitic rock series →pyroxene andesite and hornblende andesite of the hypersthenic rock series. Hornblende bearing rocks are often accompanied with a small amount of olivine. The mineral assemblage of eruptives is shown in Fig. 2.

a). The rocks of the older stratovolcano stage (2nd stage)

The rocks of this stage are represented by the basic rocks belonging to the pigeonitic rock series such as olivine-augite basalt (IVc) and olivine-hypersthene-augite andesite (Vc). Olivine crystals as groundmass constituent have reaction rim of minute grains of clinopyroxene. Augite phenocryst is always richer than hypersthene phenocryst in each rock. Any xenolith is found neither macroscopic in field nor microscopic in lavoratory.

b). The rocks of the younger stratovolcano stage (3rd stage)

All rocks of the earlier substage of the younger stratovolcano are augite-hypersthene andesite (Vd—c) belonging to the pigeonitic rock series, except for the fragments of the Takasawa pyroclastic flow and fall deposits, and rarely include a very samll amount of olivine. Augite is always more predominant than hypersthene in the modal composition of phenocrysts. Groundmass hypersthene is small in amount and large in size, and is always surrounded by minute grained clinopyroxene. Few xenoliths are found in the rocks. The rocks of the earlier substage have the greatest volume in the Kurohime volcano as far as the author concerns.

In the later substage of the younger stratovolcano, most of the rocks are augite-hypersthene andesite (Vd) and olivine-hornblende bearing augite-hypersthene andesite (VId) belonging to the hypersthenic rock series, and subordinate ones are augite-hypersthene andesite (Vd—c) belonging to the pigeonitic rock series. The petrographic features of the latter have strong resemblance to those of the earlier substage-rocks. The former have more hypersthene crystals than clinopyroxene crystals as ground-mass constituent in contrast to the rocks of the earlier substage. Hornblende and/or olivine phenocrysts are subordinate constituent in some rocks. Hornblende is opacitized brown one, and most of olivine crystals are surrounded by vermicular magnetite and hypersthene. Xenolith is sometimes included in the rocks of the hypersthenic rock series. In comparison with those of the earlier substage, the rocks of the later substage are limited in amount, but more varied in mineral assemblage and texture.

c). The rocks of the central cone stage (4th stage)

The rocks composing the eruptives of the latest time of the Kurohime volcano are olivine-hornblende bearing augite-hypersthene andesites, which are much similar to those of the later substage of the younger stratovolcano. The olivine is frequently surrounded by a corona of porphyritic hypersthene and vermicular magnetite. The hornblende is distinctly or completely opacitized. A few xenoliths are included in the rocks.

5. The rocks of the Myoko volcano

All rocks of the Myoko volcano are ranging from basalt through predominant andesite to dacite. The most basic rock is augite-olivine basalt, and the most acidic rock is hypersthene-hornblende dacite. At the IInd, IIIrd, and IVth stages, the rocks change from basalt of the pigeonitic rock series to hornblende andesite of the hypersthenic rock series, in keeping with the growth of the volcano respectively. Xenoliths are commonly contained in the rocks of the hypersthenic rock series. Hornblende andesite contains many xenolith-like inclusions.

a). The rocks of the older Myoko volcano

The Jigokudani lavas, consisting of basalt and basic andesite, show a slight variation in mineral assemblage. Plagioclase, olivine, augite, hypersthene, hornblende, and ore mineral are seen as phenocryst. In some rocks, olivine and/or hornblende are lacking. The hornblende of the Jigokudani lavas is small in amount, and changes completely into the aggregate of fine grained pyroxene and ore mineral. Most of the rocks are subjected to hydrothermal alteration, and most part of glass and olivine, and a part of plagioclase and pyroxene are altered. The relation between the growth-history of the volcano and petrography is unknown.

b). The rocks of the younger Myoko volcano

(i). The Ist stage

The rocks of the Ist stage are intermediate and acidic andesites belonging to the hypersthenic rock series. Most of them are not altered. The phenocrysts commonly consist of plagioclase, augite, hypersthene, hornblende, and ore minerals. Olivine and/or quartz sometimes occur in a small amount. Some of the rocks are characterized by coexistence of corroded olivine and hornblende with thin opacite margin.

The groundmass is made of plagioclase, clinopyroxene, hypersthene, ore minerals and glass. Apatite, tridymite, quartz, cristobarite, and mica are also subordinately present as groundmass constituent. Xenolith-like inclusion is common in the rocks of this stage.

(ii). The IInd stage

The rocks composing the IInd stage-eruptives vary from basalt to dacite. The rocks of the earlier time of this stage are represented by hypersthene bearing augite-olivine basalt belonging to the pigeonitic rock series. The groundmass olivine is sorrounded by minute grains of clinopyroxene. The hypersthene is subordinate amount as groundmass constituent, and is lacking in some rocks. It is always rimmed by minute grains of clinopyroxene. Any xenolith is not found in this rock.

Pyroxene andesite (Vd→c) belonging to the pigeonitic rock series represents the rocks of the middle time, and generally includes xenoliths.

The eruptives of the later time are composed of olivine-pyroxene-hornblende andesite (VId). The rock is characterized by coexistence of olivine and distinctly opacitized hornblende. The rock contains many xenoliths. The essential block of pyroclastic flow deposits erupted at the latest time is pyroxene-hornblende andesite (dacite), which contains olivine rarely. It is very heterogeneous, and includes many xenolith-like inclusions.

The rocks of this stage are changing in keeping with the growth of this volcano as follows: pyroxene-olivine basalt of the pigeonitic rock series→pyroxene andesite of the pigeonitic rock series→pyroxene-olivine-hornblende andesite of the hypersthenic rock series→(olivine bearing) pyroxene-hornblende andesite (and dacite) of the hypersthenic rock series. The mineral assemblages of the representative eruptives of the IInd stage are summarized as shown in Fig. 3.

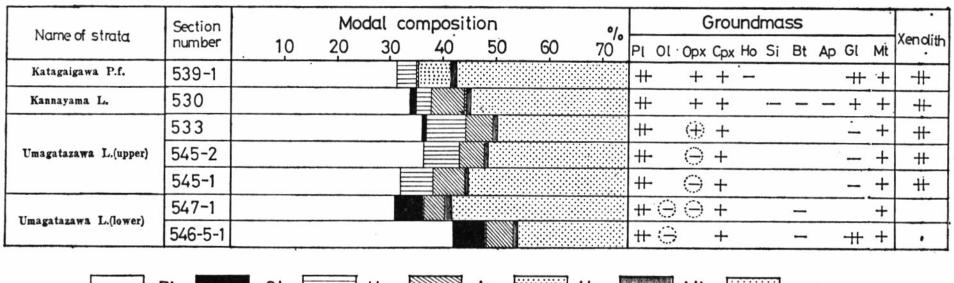

Fig. 3. Mineral assemblage of the rocks of the Myoko volcano II stage. Symbols are same as those in Fig. 5. (p. 11)

(iii). The IIIrd stage

The mineral assemblages of the IInd stage-rocks are shown in Fig. 4. The most basic rock of this stage is olivine-pyroxene basalt (Kanbazawa scoria fall) ejected at the earliest time. The hypersthene and olivine, both of phenocryst and groundmass constituent, are surrounded by minute clinopyroxene grains.

The Mitaharayama lavas, the second eruptives, consist of pyroxene bearing olivine basalt in the lower part and olivine-pyroxene andesite in the upper part. They include much olivine crystals which are surrounded by groundmass clinopyroxene and range from phenocryst to groundmass in size. The hypersthene has always reaction rim of clinopyroxene. Few xenoliths are found in the lavas and scoria mentioned above.

The Shibutamigawa pyroclastic flow deposit, the youngest eruptives of this

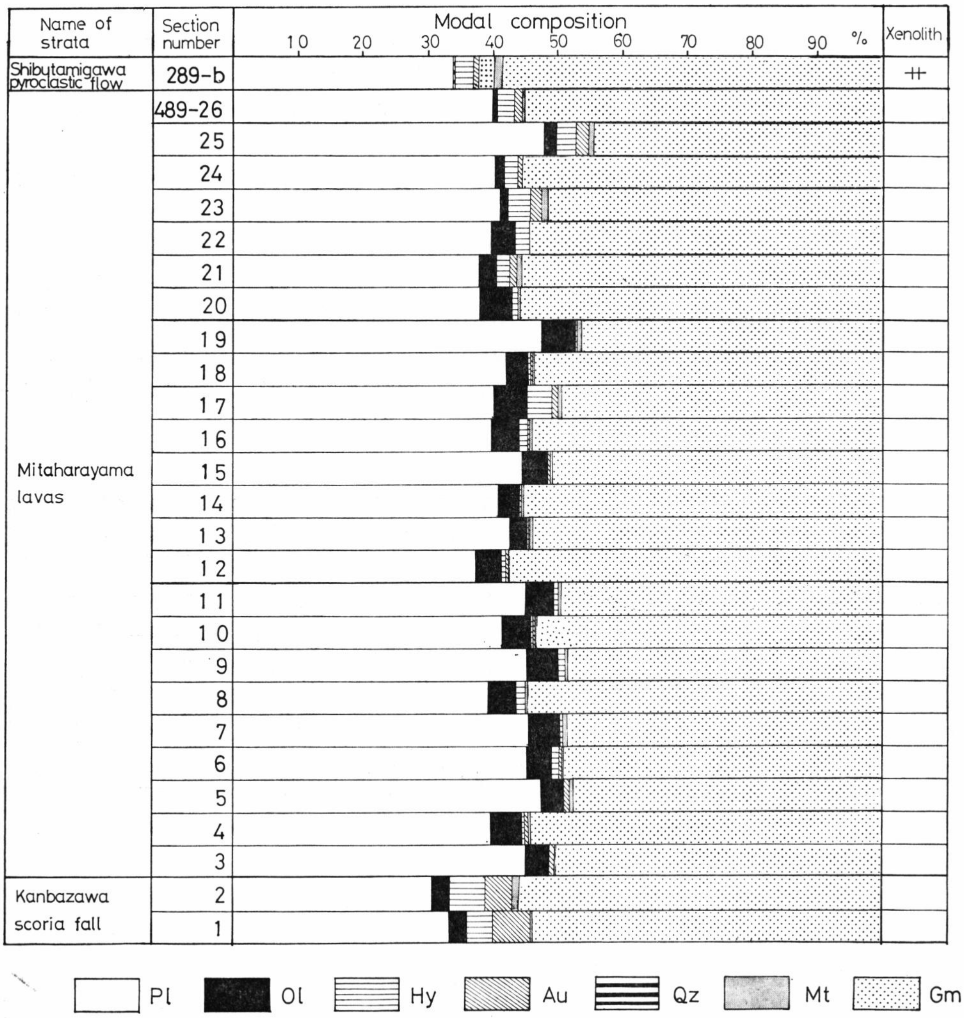

Fig. 4. Mineral assemblage of the rocks of the Myoko volcano III stage. Symbols are same as those in Fig. 5. (p. 11)

stage, is composed of the essential blocks of olivine bearing pyroxene-hornblende andesite. The rocks are very heterogeneous, and contain xenolith-like inclusion in large amount.

The rocks of this stage are changing in keeping with the growth of the volcano as follows: Pyroxene-olivine basalt of the pigeonitic rock series→olivine-pyroxene basalt of the pigeonitic rock series→olivine-pyroxene basic andesite of the pigeonitic rock series→olivine bearing pyroxene hornblende andesite (and dacite) of the hypersthenic rock series. Judging from the order of eruption, the composition of hypersthene and olivine (see later), the common presence of porphyritic hypersthene surrounding olivine and of corroded hypersthene as a core of hornblende, the order of the crystallization of phenocrystic colored minerals may be presumed as follows: augite, hypersthene→olivine→augite, hypersthene→hornblende.

(iv). The IVth stage

As shown in Fig. 5, the rocks of the IVth stage consist of pyroxene-olivine basalt (Nishikawadani lava and scoria) at the earlier substage, and hornblende-olivine-pyroxene andesite and pyroxene-hornblende andesite (and dacite) at the later substage.

The basalt includes much phenocrystic to groundmass olivine with reaction rim of clinopyroxene, and a small amount of hypersthene rimmed by minute grained clinopyroxene as groundmass constituent. It is characterized by many xenoliths and large plagioclase as described later in detail.

The rocks of the later substage are divided into basic andesite and acidic andesite (and dacite). The former is represented by the Tsubame lava, and the latter by the Myokosan lava, most of the Myokosan pyroclastics, and the Otagirigawa and

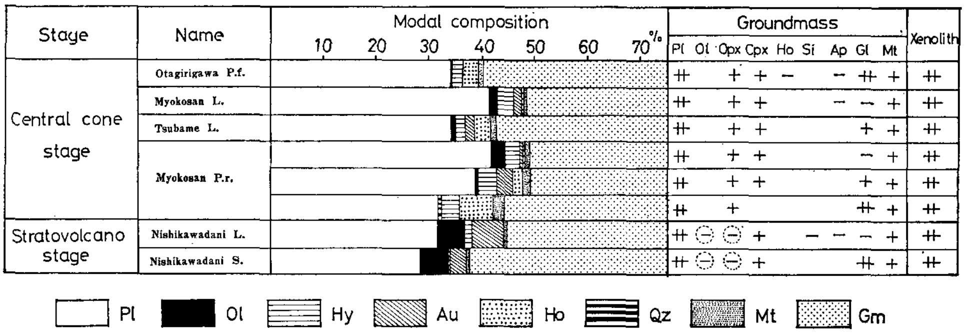

Fig. 5. Mineral assemblage of the rocks of the Myoko volcano IV stage.
L: Lava, P.f: Pyroclastic flow deposit, P.r: Pyroclastic rocks, S: Scoria, Pl: Plagioclase, Ol: Olivine, Hy: Hypersthene, Au: Augite, Ho: Hornblende, Qz: Quarz, Mt: Ore mineral, Gm: Groundmass, Opx: Orthopyroxene, Cpx: Clinopyroxene, Si: Silica mineral, Bt: Mica, Ap: Apatite, Gl: Glass, −: Poor, +: Medium, ++: Rich, Dotted circle: Reaction rim of clinopyrpxene.

Akakura pyroclastic flow deposits. They belong to the hypersthenic rock series. The basic andesite contains phenocrysts of plagioclase, olivine, augite, hypersthene, ore mineral, and perfectly opacitized hornblende, and has many xenolith-like inclusions. The acidic andesite has plagioclase, greenish brown or oxyhornblende, hypersthene, ore mineral, and a small amount of olivine and augite as phenocrysts. The augite is rather microphenocryst. The acidic andesite is generally very heterogeneous, and often shows the alternated band of grayish white acidic part and dark gray basic part. The xenolith-like inclusion is very common.

The rocks change from basalt of the pigeonitic rock series to hornblende andesite, in keeping with the growth of the volcano at the IVth stage as well as at the IInd and IIIrd stages. The basalt is exceedingly small in volume, and the hornblende andesite (and dacite) is overwhelmingly predominant.

6. Rocks of the Yakeyama volcano

All rocks of the Yakeyama volcano are always intermediate to acidic andesite with many hornblende phenocrysts. The petrography is rather uniform. No basaltic rock is present in contrast to the Iizuna, Kurohime, and Myoko volcanoes. Plagioclase, hornblende, hypersthene, augite, olivine, and ore mineral are common as phenocryst and sometimes corroded quartz is contained. Olivine and hornblende often coexist. The groundmass is composed mainly of plagioclase, hypersthene, clinopyroxene, glass, and ore mineral, and rarely of silica minerals, alkali feldspar, apaite, and mica. Many xenolith-like inclusions are contained in all rocks of the Yakeyama volcano as well as hornblende andesite of other volcanoes in MYOKO.

B. Minerals and their optics

1. Plagioclase

Plagioclase is the commonnest mineral in the rocks of MYOKO as phenocryst and grounmass constituent. The phenocrystic plagioclase is generally less than 2 mm in size, but sometimes attains to 5 mm. It is generally smaller than that of hornblende-biotite andesite in Southwest Japan. Albite and Carlsbad twining is common, and pericline twinning is also present. The composition of some plagioclase phenocrysts in the Myoko volcano is shown in Fig. 6. The plagioclase usually shows zonal structure, roughly the normal, oscillatory, and reverse forms (Fig. 7). The normal form crystal consists of more calcic, comparatively homogeneous core and more sodic thin rim or margin of fine oscillatory zoning. The reverse form crystal is more sodic at the core, and more calcic at the margin. Some plagioclase phenocrysts are clear because of few inclusions, but some contain more or less inclusion of glass, pyroxene, ore mineral, and fine grained dusts. The dusty inclusions show a tendency to be crowded either into the core or into a definite zone in the

Table 1. Characteristic features of minerals composing the Kurohime volcanic rocks.
L: Lava, Ls: Lavas, P.f.: Pyroclastic flow deposit, S: Stout prism, E: Elongate prism, T: Tabular, Opx: Orthopyroxene, Cpx: Clinopyroxene, +: Common, ++: Strong or rich, +++: Perfectly opacitized, *: See Fig. 7.

Name of strata	Section number (KH)	Plagioclase (Phenocryst)						Orthopyroxene										Augite (Phenocryst)						Olivine				Hornblende			
		Form	Size		Type of * Zoning	An% and refractive index after Yagi et al. (1958)		Phenocryst							Groundmass			$C\wedge Z$	2V (+)		Color	Maximum size (mm)	Parallel inter-growth with Opx	Form	Maximum size (mm)	2V (−) Refractive index	Reaction rim	Form	Maximum size (mm)	$C\wedge Z$	Degree of opacitization
			Maximum	General				2V (−)		Average En %	Pleochroism			Maximum size (mm)	2V (−)		Average En %														
								Range	N		X	Y	Z		Range	N			Range	N											
Shokurohime L.	354	T, S>E	2.0	0.5	1a, 1b, 2	65~87	α=1.562 γ=1.584	65~67°	5	71	Pale purplish brown	Pale brown	Very pale green	0.9	67~69°	2	73	44°	50~51°	3	Pale green	1.0	++	Corroded	0.4	88~89° 1.728	Opx, Cpx	Corroded	0.5		+++
Sutakayama L.	344	T, S>E	2.1	0.5	1b, 2			64~66°	4	70	Pale purplish brown	Pale brown	Very pale green	1.1	62~64°	3	69	44°	51~52°	3	Pale green	1.1	+	Corroded	0.6	83°	Opx, Cpx	Corroded	0.9		+++
Nagamizu L.	92	T, S, E	3.0	0.8~1.0	1b, 2	72~87		61~66°	5	70	Pale brown	Pale brown	Pale green	2.0				44°	53~54°	4	Pale brown	0.8	+	Corroded			Opx, Partly Cpx	Elongate prism	1.0	15°	++
Karasawa L.	90	T, S, E	4.0	1.0	1b, 2	65~82		64~66°	4	70	Pale brown	Pale brown	Pale green	1.3	68°	1	73	45°	52~54°	3	Pale brown	1.2	+	Corroded			Opx, Partly Cpx	Elongate prism	1.3	21°	+
1531m-ridge L.	196	S>E	2.2	0.7~1.0	1a			60~65°	3	69	Pale purplish brown	Pale purplish brown	Pale green	1.1	67~68°	2	73	45°	52°	1	Pale brown	1.0	++	Corroded			Opx, Partly Cpx	Corroded			++
Mikaerizaka L.	309-b	S, E	3.4	1.1	1a>1b			61~69°	10	70	Pale purplish brown	Pale brown	Pale green	1.3	58~61°	1	65	42°	51~52°	3	Pale brown	0.7									
Nagahara L.	32-a	T, S>E	2.5	1.0	1a>1b	63~82	α=1.560 γ=1.580	63~70°	5	72	Purplish brown	Pale brown	Pale green	1.3	63~64°	2	70	43°	53°	1	Pale brown	1.8									
Nanamagarizaka L.	295	S, E	2.7	1.0	1b, 2			61~63°	8	68	Pale brown	Pale brown	Pale green	2.8	63~69°	6	70	44°	51°	1	Pale green	1.3	+	Corroded			Opx, Partly Cpx	Corroded			++
Sekigawa L.	31-2	E>S	2.3	1.0~1.5	1b, 2			62~63°	3	68	Pale brown	Pale brown	Pale green	0.9	54~60°	6	62	43°	52°	2	Pale brown	1.0									
Ichirozawa L.	D	E>S>T	2.0	0.7~1.0	1b, 2>1a			64~65°	2	70	Pale brown	Pale brown	Pale green	2.2	60°	1	66	43°	51~54°	3	Pale brown	3.0									
Furuike L.	78	E>S	2.8	0.8~1.0	1a, 1b≫2			65°	1	70	Pale purplish brown	Pale brown	Very pale green	1.7	57~60°	3	64	42°	52~53°	2	Pale green	2.3									
Ushibuseyama L.	E	S>E	2.5	0.7~1.0	2≫1b			63°	1	68	Pale purplish brown	Pale brown	Very pale green	0.7	59~61°	2	66	45°	52°	3	Pale green	2.3		Corroded		83°	Opx, Partly Cpx				
Yunoirigawa L.	137	S, E	1.8	0.6~1.0	1a, 1b≫2			62~70°	4	72	Pale purplish brown	Pale brown	Very pale green	1.7				44°	49~51°	4	Pale brown	2.4									
Komagataki L.	6	T, S>E	2.8	0.7	2>1b			57~61°	2	64	Purplish brown	Pale brown	Pale green	1.6	56°	1	58	45°	49~51°	3	Pale green	2.3	+								
Takasawa P. f.	13	E>T, S	2.0	0.8	1b>2	49~62		61~62°	3	67	Purplish brown	Pale brown	Pale green	1.1	63~64°	3	69	45°	53~54°	3	Pale green	1.0						Elongate prism	1.1	15°	+
Naenataki L. (Upper)	29-a	S>E	3.0	0.8	2≫1b	68~89	α=1.563 γ=1.584	64~65°	4	70	Purplish brown	Pale brown	Pale green	1.8	60~62°	5	67	42°	50~52°	4	Pale green	2.6									
Naenataki L. (Lower)	29-c	T, S>E	2.2	1.0	2≫1b			64~66°	5	70	Purplish brown	Pale brown	Pale green	1.7	58~64°	2	67	43°	50~51°	3	Pale green	2.8	+								
Hesoyama Ls.	304	E>S>T	2.5		1a						Very pale purplish brown		Very pale green	1.1				45°	49~52°	3	Pale brown	2.5		Corroded	2.7		Cpx, Partly Opx				
Yamakuwayama Ls.	204	E>S>T	2.5		1b													45°	49~52°	4	Pale brown	1.2		Wedge-like Rounded	0.5	86~88°	Cpx				

Table 2. Characteristic features of minerals composing the Myoko volcanic rocks.
OM: Older Myoko volcano, N: Measured number of crystal, L: Lava, p.f.: Pyroclastic flow deposit, p.r.: Pyroclastic rocks, S: Stout prism, E: Elongate prism, T: Tabular, −: Week or poor, +: Medium, ++: Strong or rich, Opx: Orthopyroxene, Cpx: Clinopyroxene, *: See Fig. 7.

Stage	Name of strata	Locality number (MK)	Plagioclase (Phenocryst)						Olivine (Phenocryst)				Orthopyroxene									Augite (Phenocryst)						
			Form	Size (mm)		Degree of inclusion	Zoning *		Form	Maximum size (mm)	Reaction rim	2V (−)	Phenocryst						Groundmass			C∧Z	Maximum size (mm)	Form	Color	2V (+)		Parallel intergrowth with Opx
				Maximum	General		General type	Reverse type					Pleochroism		Maximum size (mm)	2V (−)	N	Average En %	2V (−)	N	Average En %					Range	N	
													X	Z														
IV	Otagirigawa p.f.	1-a	S, E, T	3.0	0.9~1.2	+	1a, 2		Corroded	1.2	Opx, (or Cpx)		Very pale purplish brown	Very pale green	1.4	61~64	4	68										
	Tsubame L.	222	S, T>E	1.9	0.6~0.9	+	1a, 1b≫2	+	Corroded Wedge-like	0.8	Opx or Cpx	86	Very pale purplish brown	Very pale green	0.9	58	3	62	61~64	4	68	45	1.1	S	Pale brown	46	2	++
	Myokosan L.	490-2	S, T>E	2.4	0.9~1.0	+	1b, 2	+	Corroded	0.7	Opx or Cpx		Pale reddish brown	Pale green	1.4	53~58	3	60	66	3	70	45	1.1	S>E	Pale purplish brown	51	1	+
	Myokosan p.r.	262	S, T>E	2.2	1.0~1.2	+	1a	+	Round	0.8	Opx or Cpx		Very pale purplish brown	Very pale green	0.6	60	1	66	65~67	5	71	45	0.4	S	Pale purplish brown	42	2	+
		225-2	E, S, T	1.7	0.6~0.9	+	1a, 1b≫2	+	Round Wedge-like	0.3	Opx or Cpx		Pale purplish brown	Pale green	1.4	56~57	2	60	65~67	4	71	43	0.8	S>E	Pale greenish brown	42~43	3	+
		225-1	S, T>E	2.0	0.6~0.9	−	1b, 2						Pale reddish brown	Pale green	1.4	53~56	4	58	52~53	4								
	Nishikawadani L.	322	E>S, T	1.7	0.5~0.8	−	1a, 1b		Wedge-like, Round	0.8	Cpx partry Opx	83~86	Pale purplish brown	Pale green	1.1	65~66	2	70	60~62	2	66	42	1.3	E, S	Very pale brown	49~50	3	
III	Mitaharayama Ls.	425-1	E>S, T	1.8	0.7~0.8	−	1a>1b		Round	0.6	Cpx partry Opx	81~82	Very pale purplish brown	Very pale green	0.6	62~63	3	67	57~59	4	62	42	0.7	S	Pale purplish brown	47	1	
		425-2	E>S, T	2.6	0.7~0.9	−	1a>1b		Round	1.2	Cpx partry Opx	81~82	Very pale purplish brown	Very pale green	0.6	61~63	3	67	58	1	62	42	0.9	S	Pale purplish brown			
		425-3	E>S	1.7	0.7~0.9	−	1a>1b		Round Wedge-like	0.4	Cpx partry Opx	81~82	Pale purplish brown	Pale green	0.5	57~58	2	62	61~62	4	66	42	1.7	S	Pale purplish brown	48~49	2	
		318	E>S	3.2	0.7~0.9	−	1a, 1b		Round Wedge-like	1.1	Cpx partry Opx	86	Pale purplish brown	Pale green	0.6	57	2	60	63~64	4	68	42	2.0	S	Pale purplish brown	48~50	2	
	Kasumizawa L.	278	E	3.4	1.1~1.5	−	1a, 1b<2		Round Wedge-like	5.1	Cpx partry Opx	85~86										42	2.0	S	Pale greenish brown	52~54	3	
II	Otaniuchi L.	308	E>S	1.2	0.5~0.8	+	1a, 2						Pale purplish brown	Pale green	1.7	63~65	3	69	59~62	5	65	45	1.2	S	Pale purplish brown	48~49	2	+
	Makuiwa L.	424-1	T, S, E	1.5	0.6~0.9	+	1b, 2>1a	+	Round	1.0	Cpx partry Opx	82~84	Pale greenish brown	Pale green	2.0	59	2	64	59	2	64	44	1.9	S>E	Pale greenish brown	49~50	2	
	Kotaki L.	423-1	T, S, E	2.3	0.8~1.0	+	1b, 2>1a	+	Round Wedge-like	0.6	Cpx partry Opx	85~89	Pale greenish brown	Pale green	1.1	58~61	4	65	66~69	5	71	44	0.7	S>E	Pale brown	49	2	+
		423-2	T, S, E	2.1	0.7~0.9	+	1b, 2>1a	+	Round Wedge-like	0.9	Cpx partry Opx	87	Pale greenish brown	Pale green	1.5	53~55	2	58	59~63	5	65	43	0.8	S>E	Pale brown	48~50	2	
I	Osawa L.	282-2	E>S>T	1.6	0.5~0.6	+	1b>2	+					Pale purplish brown	Pale green	1.7	58~60	3	64	63~64	4	68	42	0.8	S, E	Pale greenish brown	49~50	3	++
	Maruyama L.	259-1	S, T	2.0	0.6~1.1	+	1b, 2>1a	+	Corroded	0.2	Opx		Very pale purplish brown	Very pale green	1.1	58~61	3	65	64~65	4	70	45	1.4	S	Pale brown	49	3	
		259-2	S, T	3.0	0.8~1.0	+	1b, 2>1a	+	Corroded	0.2	Opx		Very pale purplish brown	Very pale green	0.9	58~59	2	64	66	1	70	44	2.1	S>E	Pale brown	49~54	1	
	Shirasawa p.f.	399-2	E>S	1.8	0.8~1.0	+	2	+					Pale reddish brown	Pale green	1.2	58~60	4	64	61~62	4	66	44	2.4	S>E	Pale greenish brown	53~54	3	+
	Seki Ls.	206	E, S>T	2.0	0.5~0.8	+	2, 1b>1a		Corroded	0.4	Opx		Pale greenish brown	Pale green	2.0	61~64	6	68	57	2	60	43	1.5	S	Pale brown	49	3	
	Byobuiwa Ls.	426	S, T>E	2.3	0.5~0.8	+	2, 1b>1a		Corroded	1.1	Opx		Pale reddish brown	Pale green	1.4							45	0.8	S>E	Pale brown			++
OM	Jigokudani Ls.	217-1	S, T>E	1.7	0.6~0.8	+	2, 1b>1a		Round	0.6	Opx		Pale purplish brown	Pale green	1.5							45	0.9	S	Very pale greenish brown			++

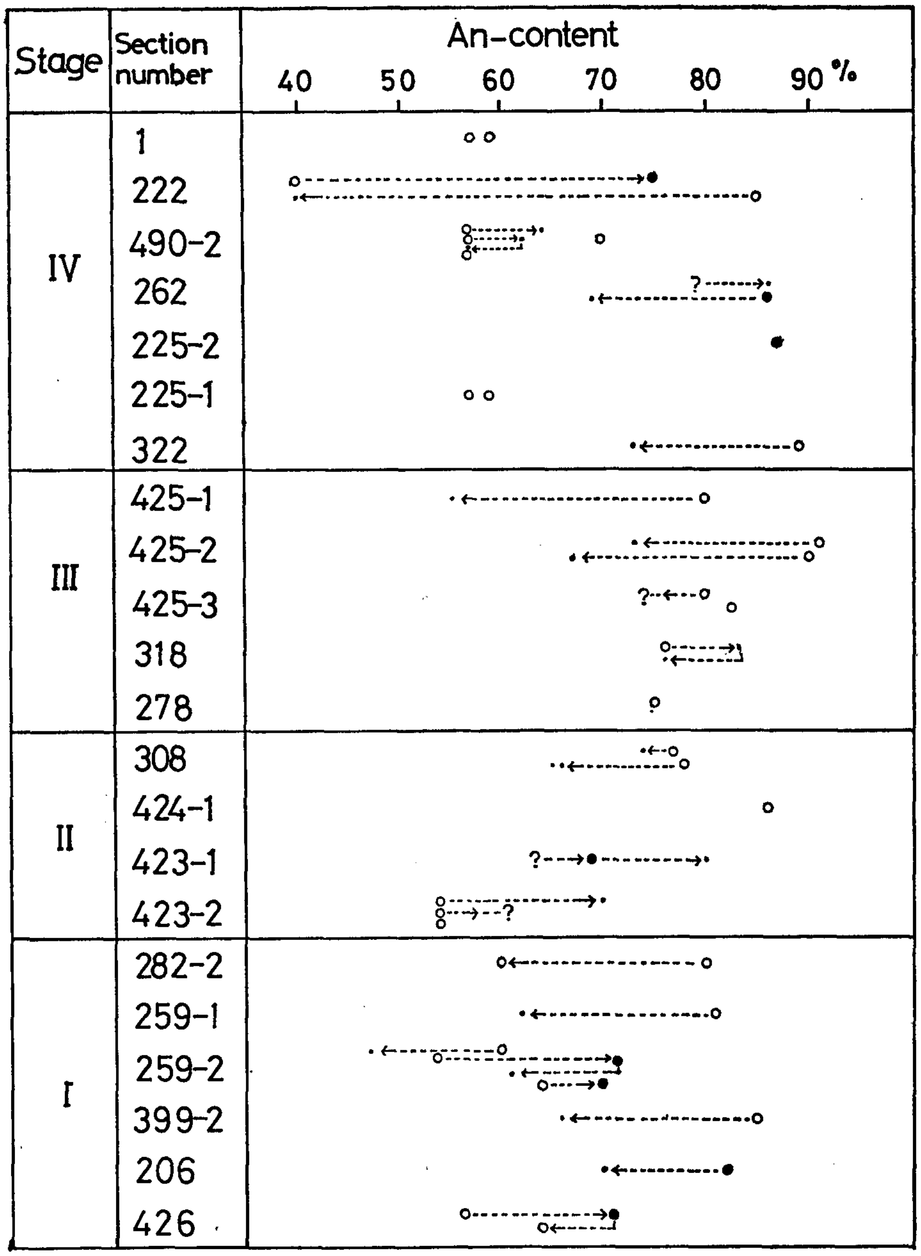

Fig. 6. An-content of plagioclase in the rocks of the Myoko volcano.
Open circles: Clear zone, Solid circles: Dust inclusion-rich zone, Dots: Thin rim or zone, Core······→Margine.

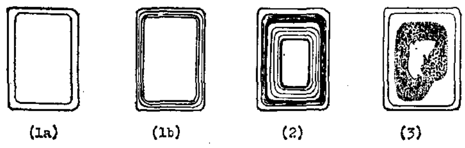

Fig. 7. Form of zoning in plagioclase phenocryst.
(1a) and (1b). Normal form, (2). Oscillatory form, (3). Reverse form.

outer part of the crystal. In some instances, the zone of the dusty inclusions is distinctly more calcic than adjacent zones. In other instances, a narrow calcic zone is developed just at the outside of the inclusion zone. The plagioclase phenocryst which shows the reverse form zoning and has the dusty inclusion zone, is seen generally in the rocks belonging to the hypersthenic rock series.

2. Silica minerals

Silica minerals are uncommon in the rocks of MYOKO. Quartz occurs as corroded phenocryst in some rocks. It is rarely surrounded by minute grains of clinopyroxene. Tridymite and cristobalite are in the groundmass, or in the druse. In some cases, interstitial quartz is found in the groundmass with high crystallinity.

3. Olivine

Olivine in the area of MYOKO occurs mainly at two stages of each basalt-andesite series, namely the basalt stage and the hornblende andesite stage.

At the basalt stage, the olivine is the commonest mafic mineral as phenocryst, microphenocryst, and groundmass constituent, and is generally surrounded by minute grains of clinopyroxene or rarely by orthopyroxene. It shows mostly euhedral form, and various stage forms of crystal development illustrated by Kuno (1950) are found. Forsterite content is decreasing from the core to the margin of a single olivine crystal, and it is generally decreasing from olivine of the older basaltic rock to that of the younger one in each basalt-andesite series. Namely, the forsterite content of olivine is decreasing in keeping with the crystallization.

At the hornlende andesite stage, olivine also occurs in small amount as phenocryst generally. It is commonly surrounded by corona of porphyritic hypersthene and vermicular magnetite, and sometimes by minute grained clinopyroxene. In the former case, each olivine crystal shows a corroded form, but in the latter case a euhedral or subhedral form. The olivine at the this stage occurs frequently as aggregate of two or more crystals, the interstitial spaces are filled mainly by euhedral plagioclase of microphenocryst or groundmass and sometimes glass. Forsterite content of olivine of the hornblende andesite is sometimes higher than that of the basalt and basaltic andesite (Fig. 8~10). The olivine of this stage probably came

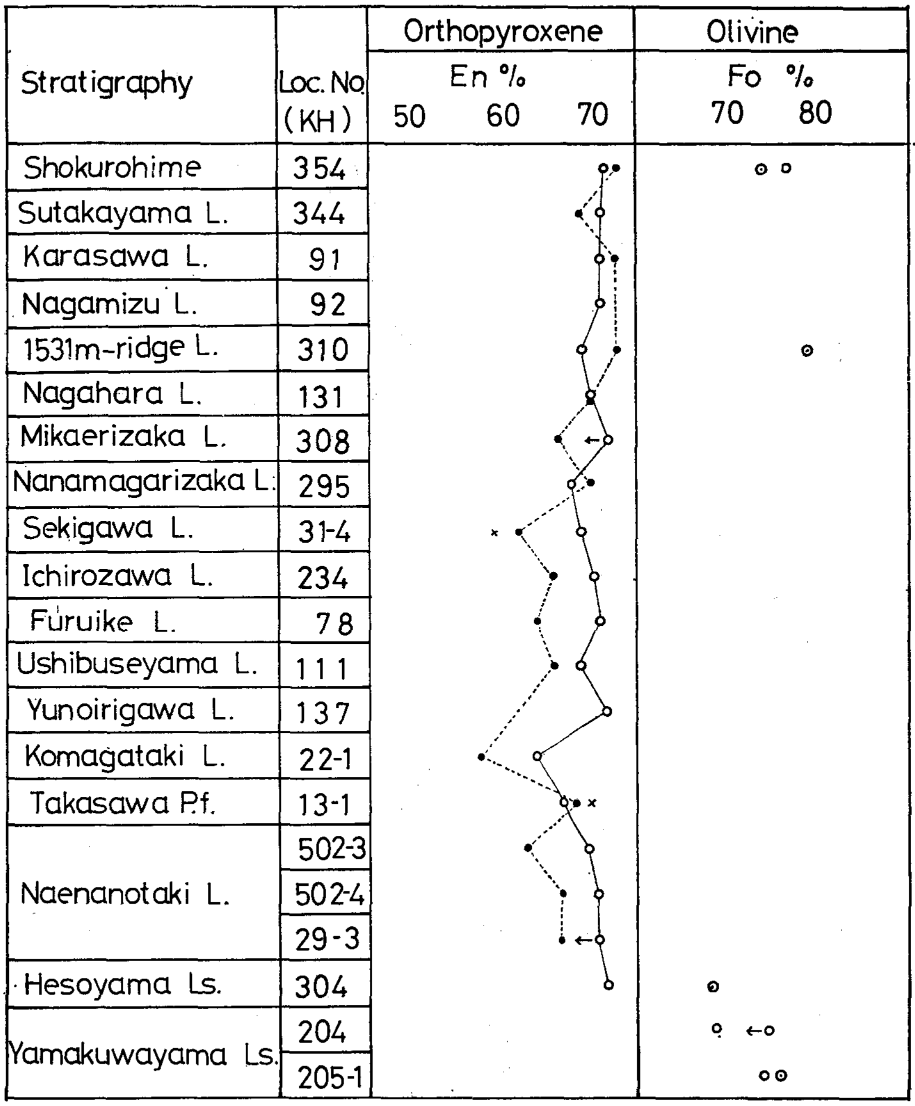

Fig. 8. En-content of orthopyroxene and Fo-content of olivine in the rocks of the Kurohime volcano.

L: Lava, P.f: Pyroclastic flow deposit, Ls: Lavas, Open circle: Phenocryst, Solid circle: Groundmass, Cross: Marginal zone of phenocryst, Open circle with dot are Fo-content estimated by reflactive indices γ, and others are En- or Fo-contents estimated by optic axial angle. Core→Margin.

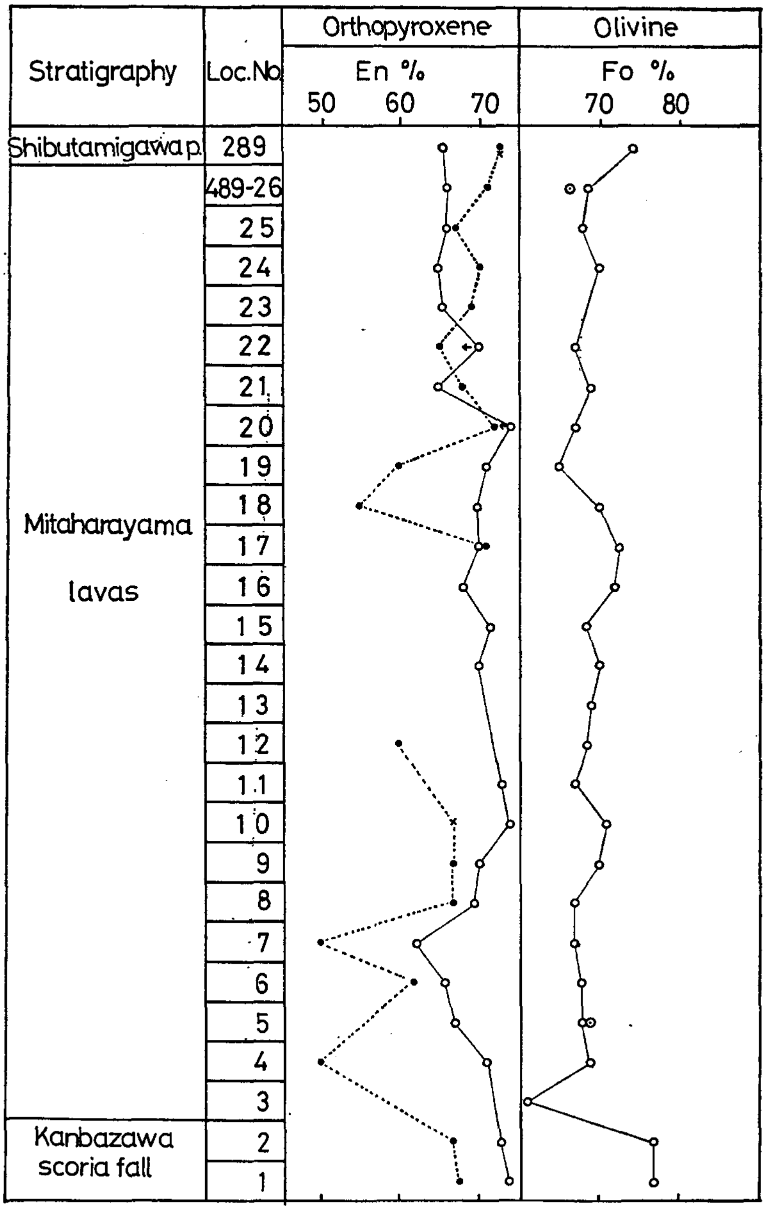

Fig. 9. En-content of orthopyroxene and Fo-content of olivine in the rocks of the Myoko volcano III stage. Symbols are same as those in Fig. 8.

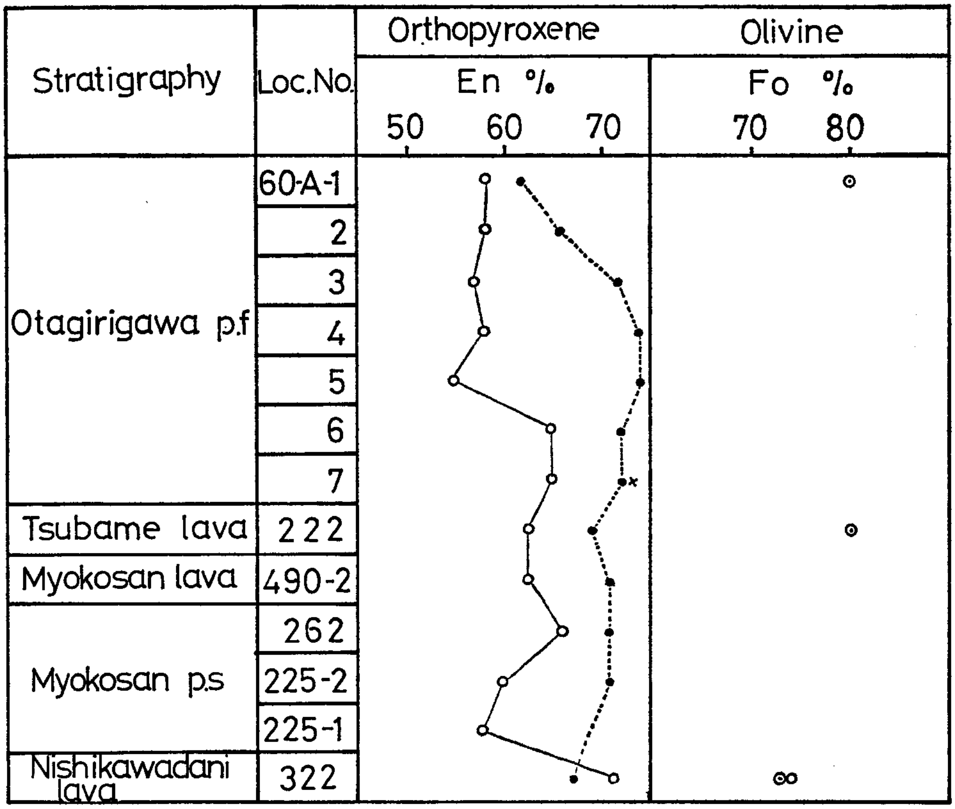

Fig. 10. En-content of orthopyroxene and Fo-content of olivine in the rocks of the Myoko volcano IV stage.
P.r: Pyroclastic rocks. Other symbols are same as those in Fig. 8.

from the xenolith-like inclusion in the hornblende andesite because it has the completely same nature as that of the inclusion.

Olivine is sometimes included in pyroxene andesite probably as xenocryst, and it is mostly rimmed by vermicular magnetite and porphyritic orthopyroxene.

4. Orthopyroxene

Orthopyroxene is almost always present as phenocryst and groundmass constituent. In the Kurohime and Iizuna volcanic rocks except for basalts, the orthopyroxene phenocryst predominates over augite phenocryst, in the Myoko volcanic rocks. But the ratio orthopyroxene to augite in phenocryst is variable. Generally orthopyroxene has euhedral outline as elongate prism, and shows weak pleochroism: X=pale to very pale purplish brown, Y=very pale greenish brown, Z=pale to very pale green.

The optic angle 2V(−) varies from 50° to 70°. In the rocks belonging to the pigeonitic rock series, the optic angle 2V(−) of phenocryst is generally larger than that of groundmass, and is reversed in the rocks belonging to the hypersthenic rock series. In other words, groundmass orthopyroxene is richer in enstatite content than phenocrystic orthopyroxene in the rocks of hypersthenic rock series. The optic angle 2V(−) of phenocryst is generally smaller in acidic rocks than in basic rocks (Fig. 8∼10). In some cases, the optic angle 2V(−) of phenocryst is variable even in a single thin section of the rock.

Parallel intergrowth of orthopyroxene and augite is often recongnized in phenocryst and microphenocryst, and always augite encloses orthopyroxene, sometimes completely.

5. Clinopyroxene

Augite phenocryst is commonly observed in all rocks except for some hornblende rich rocks. The crystal is generally in euhedral stout prism, and rarely attains to 3 mm in length. The augite is larger in the basalt than in other rocks. It shows pale brown or pale greenigh brown. The angle $C \wedge Z$ varies from 42° to 45°. The optic angle 2V(+) is from 45° to 55°. The twinning on 100 is often observed. The zonal structure can be seen in many crystals.

Groundmass clinopyroxene is sometimes presented as minute prism, and sometimes as rounded grain. In some rocks, pigeonite is associated with augite. It often occurs as a reaction rim of orthopyroxene and olivine.

6. Hornblende

Hornblende is commonly observed as phenocryst in the rocks of the Myoko, Yakeyama, and Sadoyama volcano, but it is rather uncommon in the rocks of the Kurohime and Madarao volcano. It is variable in amount among each volcano and each basalt-andesite series. In general, it occurs, at the latest stage of each basalt-andesite series with small amount of olivine. The essential blocks constructing the comparatively large scale pyroclastic flow deposits in the present area always contain the hornblende.

The hornblende is mostly brown hornblende, but sometimes green hornblende or oxyhornblende. The former is found in the rocks having a small amount of hornblende cyrstals, and the latters are found in the rocks having a large amount of ones. The brown and oxyhornblende crystals are generally sorrounded by thick opacitized margin, and often completely replaced by minute grains mainly of pyroxene and magnetite. Some opacites have the core as aggregate of minute grains of pyroxene and the magnetite, and margin as aggregate of somewhat coarse grains of clinopyroxene, orthopyroxene, plagioclase, and magnetite. At the more advanced stage of opacitization, the constituents of the margin is separated into plagioclase grains at the inside and clinopyroxene grains at the outside. The clinopyroxene grains become larger in size taking a certain optical orientation and form, and they lastly become a single crystal as a mantle of opacite.

The hornblende occurs often as mantle of hypersthene and rarely as mantle of corroded augite. A few examples mantled by phenocrystic augite are also seen. The phenocrystic or microphenocrystic hornblende is often surrounded by fibrous clinopyroxene which crystallized at the groundmass stage. No hornblende occurs as groundmass constituent except for a few examples.

7. Other minerals and glass

a). Biotite

Biotite is not observed as phenocryst in the rocks of MYOKO, although it is found commonly in the basement volcanic rocks, and sometimes in the xenolith-like inclusions. Small amount of mica is sometimes seen as groundmass constituent, and as mantle of porphyritic magnetite.

b). Ore minerals

Magnetite is almost always seen as phenocryst and groundmass. Phenocrystic magnetite is not seen only in the Kasumizawa lava (augite-olivine basalt) of the Myoko volcano. It usually shows the subhedral outline, and is often found as vermicular aggregate. It is, in general, inclined to associate closely with other porphyritic minerals.

Ilmenite appears in small amount, and hematite also in some rocks.

c). Apatite

Stout prismatic and needle apatite is present in small amount in groundmass. In most of apatite crystals, purplish brown and subtransparent dusts are running parallel to their c-axes.

Hornblende andesite of the lava dome stage of the Iizuna volcano often contains the apatite phenocrysts which are clear without dust inclusion.

d). Glass

Glass is found in groundmass of many rocks, especially of hornblende-rich andesite. It is usually colorless, but sometimes brown or pale brown. The brown or pale brown glass occurs especially as spots in porphyritic plagioclase or interstitial material of glomeroporphyritic aggregate. Dark brown glass is found in some basalts.

e). Alkali feldspar

Alkali feldspar sometimes occurs as a marginal phases of plagioclase in groundmass with comparatively high crystallinity, and also as interstitial constituent of some xenoliths or xenolith-like inclusions.

f). Spinel

Deep green spinel is sometimes found in xenoliths and xenolith-like inclusions.

III. CHEMISTRY OF THE ROCKS

On the rocks of MYOKO together with the basement volcanic rocks, 55 chemical analyses are available, of which 23 are newly analyzed by an electron probe micro-analyzer (Hitachi Model XMA-5A) at Kanazawa University by the method of MORI et al. (1971), and the others are reported by YAMADA (1934), TSUYA (1937), YAGI et al. (1958), YAMASAKI et al. (1961), and KUNO (1962). The results are compiled in Table 3 and Table 4. As seen in tables and figures, the results indicate, as a whole, a definite trend, although they are made separately by five analysts.

A conventional diagram, in which the weight percent of each oxide is plotted

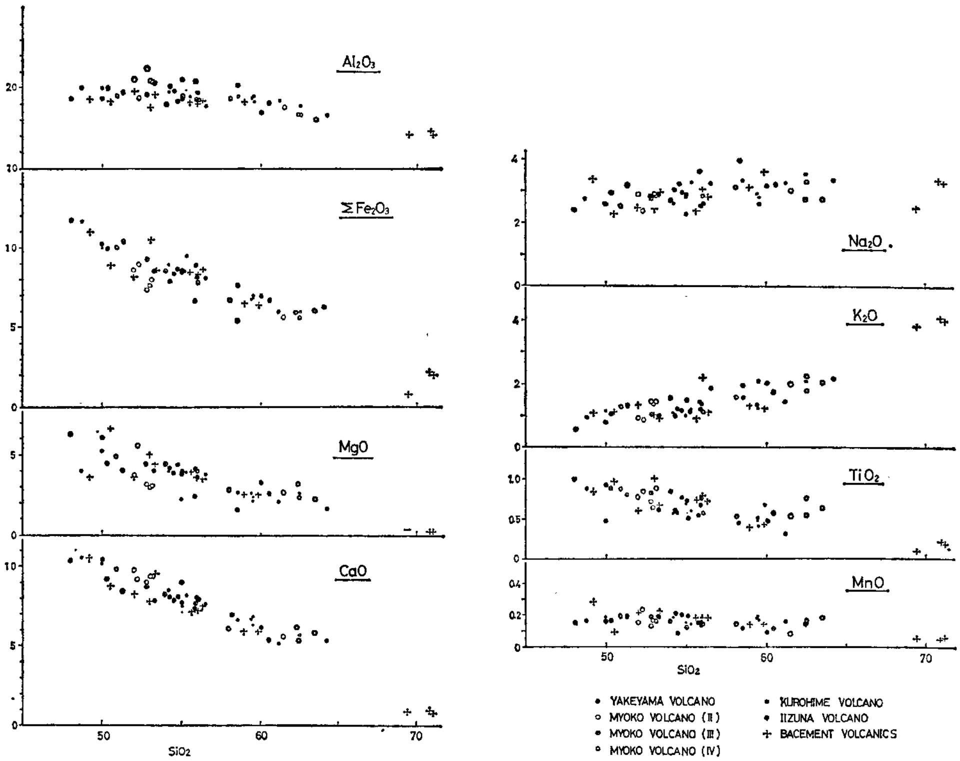

Fig. 11. Variation diagrams of the rocks of the Myoko volcanoes as plotted against the weight percentage of SiO_2. Analyses of the Yakeyama are in OGAWA (1968).

Table 3. Already-reported buck compositions of the rocks of the Myoko volcanoes.

No.	1	2	3	4	5	6	7	8	9	10
SiO_2	63.51	55.96	58.13	62.44	56.45	52.06	52.75	52.99	57.79	55.91
TiO_2	0.63	0.57	0.52	0.76	0.69	0.77	0.82	1.01	0.42	0.67
Al_2O_3	16.13	18.46	18.70	16.72	18.09	21.08	19.14	17.56	18.29	19.49
Fe_2O_3	2.28	2.97	2.81	2.26	3.18	2.43	2.37	5.89	2.40	2.33
FeO	3.50	4.36	2.61	3.68	4.59	5.58	6.28	4.14	3.62	5.70
MnO	0.18	0.14	0.14	0.14	0.26	0.15	0.18	0.17	0.14	0.15
MgO	2.26	3.94	2.74	3.16	4.23	3.67	4.44	4.95	2.47	3.56
CaO	5.85	8.02	6.09	6.26	8.21	9.75	8.74	7.83	5.91	8.08
Na_2O	2.68	2.83	3.10	2.67	2.47	2.84	2.79	2.38	3.58	2.56
K_2O	1.98	1.03	1.56	1.75	1.20	0.90	1.02	0.99	1.21	1.19
P_2O_5	0.17	0.25	0.20	0.22	0.20	0.28	0.22	0.08	0.28	0.24
$H_2O(+)$	0.91	0.51	0.54	0.52	0.75	0.35	1.00	1.27	1.21	0.28
$H_2O(-)$	0.13	0.38	0.77	0.21	0.26	0.10	0.53	0.50	0.41	0.14
Total	100.21	99.42	99.91	100.79	100.58	99.96	100.28	99.76	99.73	100.30
Analist	N. Nakanishi	T. Katsura	T. Katsura	N. Nakanishi	N. Nakanishi	T. Katsura	T. Katsura	T. Katsura	T. Katsura	S. Tanaka

No.	11	12	13	14	15	16	17	18	19	20	21
SiO_2	61.20	59.50	59.44	59.40	54.18	55.06	50.09	55.32	48.70	55.60	50.47
TiO_2	0.31	0.41	0.50	0.48	0.59	0.70	0.48	0.60	0.88	0.73	0.96
Al_2O_3	18.04	18.39	19.00	18.81	19.68	21.13	20.09	19.04	20.07	18.25	18.23
Fe_2O_3	5.62	3.22	5.24	6.17	3.76	2.28	2.48	2.95	3.62	3.55	3.11
FeO	0.34	3.29	1.42	0.58	4.68	5.61	6.81	5.93	7.16	4.41	5.19
MnO	0.16	0.17	0.18	0.18	0.18	0.15	0.18	0.14	0.16	0.18	0.09
MgO	2.10	2.36	2.15	2.57	4.03	2.15	5.26	3.92	3.95	3.93	6.58
CaO	5.18	6.35	6.85	6.69	8.53	7.55	10.23	8.22	10.56	7.14	8.71
Na_2O	3.22	2.82	2.58	2.89	2.58	2.27	2.55	3.26	2.73	2.34	2.26
K_2O	1.40	2.07	1.25	1.29	1.07	0.99	1.14	1.15	0.92	0.88	1.08
P_2O_5	0.17	1.05	0.20	0.18	0.23	0.24	0.11	0.20	0.14	0.19	0.30
$H_2O(+)$	1.53	1.05	0.78	1.07	0.79	1.55	0.87	0.36	0.50	1.88	1.72
$H_2O(-)$	0.87	0.85	0.57	0.19	0.27	0.74	0.35	0.12	0.92	1.09	0.99
Total	100.14	100.66	100.16	100.50	100.57	100.31	100.60	100.51	100.31	100.17	99.69
Analist	T. Katsura	T. Katsura	S. Tanaka	T. Katsura	T. Katsura	S. Tanaka	T. Katsura	S. Tanaka	S. Tanaka	H. Matsumoto	H. Matsumoto

No.	22	23	24	25	26	27	28	29	30	31	32
SiO_2	53.28	56.27	55.97	49.21	51.94	58.90	70.73	70.83	76.30	69.41	58.05
TiO_2	0.66	0.72	0.78	0.82	0.59	0.39	0.21	0.21	0.02	0.09	0.45
Al_2O_3	19.23	18.30	17.92	18.58	19.57	18.17	14.57	14.14	13.10	14.19	17.90
Fe_2O_3	2.27	3.71	3.48	5.74	4.66	3.40	1.14	1.07	0.26	0.02	3.50
FeO	5.64	4.46	4.27	4.66	3.12	2.77	0.94	0.83	0.67	0.71	2.64
MnO	0.22	0.18	0.18	0.28	0.21	0.14	0.04	0.05	0.03	0.05	0.10
MgO	4.38	3.48	3.58	3.54	3.58	2.53	0.24	0.19	0.26	0.32	2.56
CaO	9.46	7.52	7.25	10.54	8.24	5.95	0.96	0.87	0.27	0.91	7.05
Na_2O	2.93	2.82	3.04	3.34	2.43	3.08	3.33	3.23	3.47	2.40	3.01
K_2O	0.89	1.08	2.16	1.06	1.31	1.30	3.93	3.90	3.57	3.73	0.91
P_2O_5	0.22	0.24	0.24	0.37	0.27	0.19	0.14	0.21	0.06	0.06	0.16
$H_2O(+)$	0.54	0.42	1.00	1.15	2.57	2.06	2.87	3.57	1.08	5.23	1.32
$H_2O(-)$	0.17	0.84	0.25	0.90	1.29	1.23	0.65	0.65	0.79	3.25	1.65
Total	99.89	100.04	100.12	100.19	99.78	100.11	99.76	99.71	99.92	100.37	100.50
Analist	H. Matsumoto	H. Matsumoto	H. Matsumoto	H. Matsumoto	H. Matsumoto	H. Matsumoto	H. Matsumoto	H. Matsumoto	H. Matsumoto	H. Matsumoto	S. Tanaka

1. Hypersthene-hornblende andesite, Otagirigawa pyroclastic flow deposite, Sakaguchi-shinden, YAMASAKI et al. (1961).
2. Augite-hornblende-olivine-hypersthene andesite, Tsubame lava, Cliff at So-taki west of Tsubame, H. KUNO (1962).
3. Olivine-augite-hypersthene-brown hornblende andesite, Myokosan lava, Summit of central cone, H. KUNO (1962).
4. Hypersthene-hornblende andesite, Myokosan lava, Summit of central cone, YAMASAKI et al. (1961).
5. Cognate inclusion of Myokosan lava, Summit of central cone, YAMASAKI et al. (1961).
6. Olivine-augite-hypersthene andesite, Mitaharayama lavas, Summit of Okura-yama, H. KUNO (1962).
7. Olivine-augite-hypersthene andesite, Eruptives of the IInd stage of Myoko volcano, Ridge just west of Kanna-yama, H. KUNO (1962).
8. Olivine-hypersthene-oxy hornblende andesite, Norikosi pyroclastic flow Deposit?, Ridge between Okura-yama and Kanna-yama, H. KUNO (1962).
9. Green hornblende-augite-hypersthene andesite, Dyke, So-taki west of Tsubame, H. KUNO (1962).
10. Hypersthene-augite andesite, Summit of Kurohime-yama, S. YAMADA (1934).
11. Hypersthene bearing oxy hornblende andesite, Kenashiyama lava, Western foot of Kenashi-yama, YAGI et al. (1958).
12. Hypersthene bearing green hornblende andesite, Takadekki lava, Southern foot of Takadekki-yama, YAGI et al. (1958).
13. Hypersthene bearing oxy hornblende andesite, Takadekki lava, Summit of Takadekki-yama, S. YAMADA (1934).
14. Hypersthene bearing oxy hornblende andesite, Takadekki lava, Summit of Takadekki-yama, YAGI et al. (1958).
15. Augite-hypersthene andesite, Iizuna lavas, Western foot of Takadekki-yama, YAGI et al. (1958).
16. Olivine bearing augite-hypersthene andesite, Iizuna lavas, Summit of Reisenji-yama, S. YAMADA (1934).
17. Hypersthene-augite-olivine basalt, Menoyama lava, Summit of Meno-yama, YAGI et al. (1958).
18. Augite bearing hornblende-hypersthene andesite, Katsurasawa lava, Northern foot of Iizuna volcano, S. YAMADA (1934).
19. Augite-olivine basalt, Toriigawa lava (basalt), 1 km east of Torii-gawa Ohashi at the northern foot of Iizuna volcano, S. YAMADA (1934).
20. Hornblende bearing augite-hypersthene andesite, Funa-dake at Furuma, YAGI et al. (1958).
21. Olivine-augite basalt, Kuroiwa basalt, Kuroiwa at Imoi, YAGI et al. (1958).
22. Pigeonite-hypersthene-augite andesite, Mujinakoji-yama at Imoi, YAGI et al. (1958).
23. Augite-hornblende-hypersthene andesite, Base rock, YAGI et al. (1958).
24. Hypersthene-augite andesite, Base rock, Togakushi village, YAGI et al. (1958).
25. Augite-olivine basalt, Ogawamura basalt, Mid-slope of Iizuna-yama, Ogawa village, YAGI et al. (1958).
26. Hypersthene-augite porphyrite, Summit of Ichiya-san, Kinasa village, YAGI et al. (1958).
27. Quartz bearing hornblende porphyrite, Summit of Takazuma-yama, Togakushi village, YAGI et al. (1958).
28. Biotite rhyolite, Miyamae welded tuff, Togakushi village, YAGI et al. (1958).
29. Biotite rhyolite, Sarumaru welded tuff, Sarumaru, Togakushi village, YAGI et al. (1958).
30. Biotite rhyolite, Koichi, Amori, YAGI et al. (1958).
31. Biotite rhyolite, Hanakami, Amori, YAGI et al. (1958).
32. Brown hornblende-two pyroxene dacite, Sadoyama volcanic rocks, Eastern mid-slope of Sado-yama, H. TSUYA (1937).

Table 4. New bulk compositions of the rocks of the Myoko volcanoes. Analyzed in using of EPMA (Hitachi Model XMA-5A) by the method of MORI et al. (1971).

No.	1	2	3	4	5	6	7	8	9	10	11
SiO_2	48.12	49.94	53.25	55.13	54.28	58.46	55.82	54.42	54.67	60.00	51.30
TiO_2	0.99	0.92	0.61	0.51	0.60	0.44	0.54	0.57	0.77	0.47	0.80
Al_2O_3	18.57	18.72	20.57	18.65	20.22	20.45	20.86	19.71	18.46	17.00	19.49
Fe_2O_3	11.76	10.25	8.52	8.62	7.95	5.40	6.70	8.40	8.68	6.95	10.41
MnO	0.15	0.16	0.19	0.19	0.21	0.13	0.15	0.08	0.20	0.09	0.19
MgO	6.37	6.08	3.97	3.93	4.14	1.56	2.37	3.90	4.40	3.25	3.96
CaO	10.43	10.40	7.85	8.02	8.10	7.06	7.38	7.88	8.11	6.17	8.42
Na_2O	2.37	2.56	2.85	2.86	3.02	3.96	3.58	3.19	2.93	3.13	3.15
K_2O	0.54	0.77	0.97	1.10	0.98	1.53	1.39	1.18	1.13	1.99	1.29
Total	99.33	99.88	98.78	99.01	99.50	98.99	98.79	99.33	99.35	99.05	99.01

No.	12	13	14	15	16	17	18	19	20	21	22	23
SiO_2	50.28	55.07	55.87	53.98	60.41	52.32	52.91	52.76	53.11	61.50	50.88	62.53
TiO_2	0.89	0.72	0.75	0.84	0.57	0.84	0.64	0.72	0.88	0.53	0.87	0.54
Al_2O_3	20.00	19.08	18.54	17.93	18.09	18.75	20.99	22.40	20.79	17.70	18.99	16.66
Fe_2O_3	10.01	8.53	8.93	8.56	6.74	8.95	7.63	7.27	8.07	5.65	10.04	5.65
MnO	0.16	0.12	0.13	0.16	0.11	0.23	0.16	0.13	0.16	0.08	0.19	0.16
MgO	4.43	3.80	4.08	4.41	2.56	5.61	2.94	3.07	3.01	2.64	4.82	2.32
CaO	9.20	7.72	7.67	8.21	5.42	9.17	9.29	9.00	9.40	5.98	9.85	5.43
Na_2O	2.89	2.83	2.48	2.66	3.19	2.35	2.86	2.74	2.80	3.00	2.49	3.30
K_2O	1.06	1.43	1.33	1.52	1.71	0.86	1.33	1.41	1.41	1.96	1.26	2.17
Total	98.92	99.30	99.78	98.27	98.80	99.08	98.75	99.50	99.63	99.04	99.20	98.76

1. Olivine-augite basalt, Yamakuwayama lavas (Scoria), Northern mid-slope of Kurohime volcano (KH-205).
2. Olivine-augite basalt, Yamakuwayama lavas, Northern mid-slope of Kurohime volcano (KH-204).
3. Augite-hypersthene andesite, Naenataki lava, Naenanotaki west of Suginosawa (KH-29-3).
4. Augite-hypersthene andesite, Komagataki lava, Northern foot of Kurohime volcano (KH-31-a).
5. Augite-hypersthene andesite, Ushibuseyama lava, Northern mid-slope of Kurohime volcano (KH-206).
6. Augite bearing hypersthene andesite, Sekigawa lava, Ninotaki west of Suginosawa (KH-31-2).
7. Augite-hypersthene andesite Nagahara lava, Nagahara plateau (KH-1).
8. Olivine bearing hornblende-augite-hypersthene andesite, Karasawa lava, Ridge of Karasawa (KH-91).
9. Olivine-hornblende bearing augite-hypersthene andesite, Sutaka-yama lava, Sutaka-yama at the northwestern foot of Kurohime volcano (KH-348).
10. Quartz-olivine bearing augite-hypersthene hornblende andesite, Lapilli (Sc-3), Kami-yama west of Nojiri Lake (KH-292).
11. Hypersthene bearing augite-olivine basalt, Lowermost part of Umagatazawa lavas (Scoria), Northern mid-slope Myoko volcano (MK-546-5).
12. Hypersthene bearing augite-olivine basalt, Lower part of Umagatazawa lava, Northern mid-slope of Myoko volcano (MK-547-1).
13. Augite-hypersthene andesite, Upper part of Umagatazawa lava, Northern mid-slope of Myoko volcano (MK-545-1).
14. Olivine-augite-hypersthene andesite, Upper part of Umagatazawa lava, Northern mid-slope of Myoko volcano (MK-533).
15. Hornblende-olivine-hypersthene augite andesite, Kannayama lava Seki spa (MK-530).
16. Quartz-olivine bearing augite-hyperthene-hornblende andesite. Katagaigawa pyroclastic flow deposit (Bread-crust bomb), Northern foot of Myoko volcano (MK-539-1).
17. Olivine-hypersthene-augite basalt, Kanbazawa scoria fall deposit (Scoria), Caldera-wall west of central cone (MK-489-1).
18. Hypersthene bearing augite-olivine basalt, Mitaharayama lavas, Caldera-wall west of central cone (MK-489-5).
19. Augite-hypersthene bearing olivine basalt, Mitaharayama lavas, Caldera-wall west of central cone (MK-489-15).
20. Olivine-augite-hypersthene andesite, Mitaharayama lavas (Bomb), Caldera-wall west of central cone (MK-489-26).
21. Quartz-olivine bearing augite-hypersthene-hornblende andesite, Shibutamigawa pyroclastic flow deposit (Bread-crust bomb), Southern foot of Myoko volcano (MK-323).
22. Hypersthene-olivine-augite basalt, Nishikawadani lava, Southern mid-slope of Myoko volcano (MK-322).
23. Quartz-olivine bearing hypersthene-hornblende andesite, Otagirigawa pyroclastic flow deposit (Bread-crust bomb), Myoko-ohashi across the Otagiri-gawa (MK-60-A-1).

against the weight percent of SiO_2, is shown in Fig. 11. On the whole, Al_2O_3, total iron as Fe_2O_3, MgO, CaO, TiO_2 and MnO are decreasing, whereas K_2O and Na_2O increase with SiO_2. The range of SiO_2 is from 48.12 to 63.51% except for the basement rocks. All basalts show very high content in Al_2O_3, and belong to the high-alumina basalt defined by KUNO (1960). Al_2O_3, CaO, and K_2O of MYOKO are compared with those of the Chokai volcanic belt (CH), Nasu volcanic southern subbelt (NA), and Izu-Hakone region (IH), as follows:

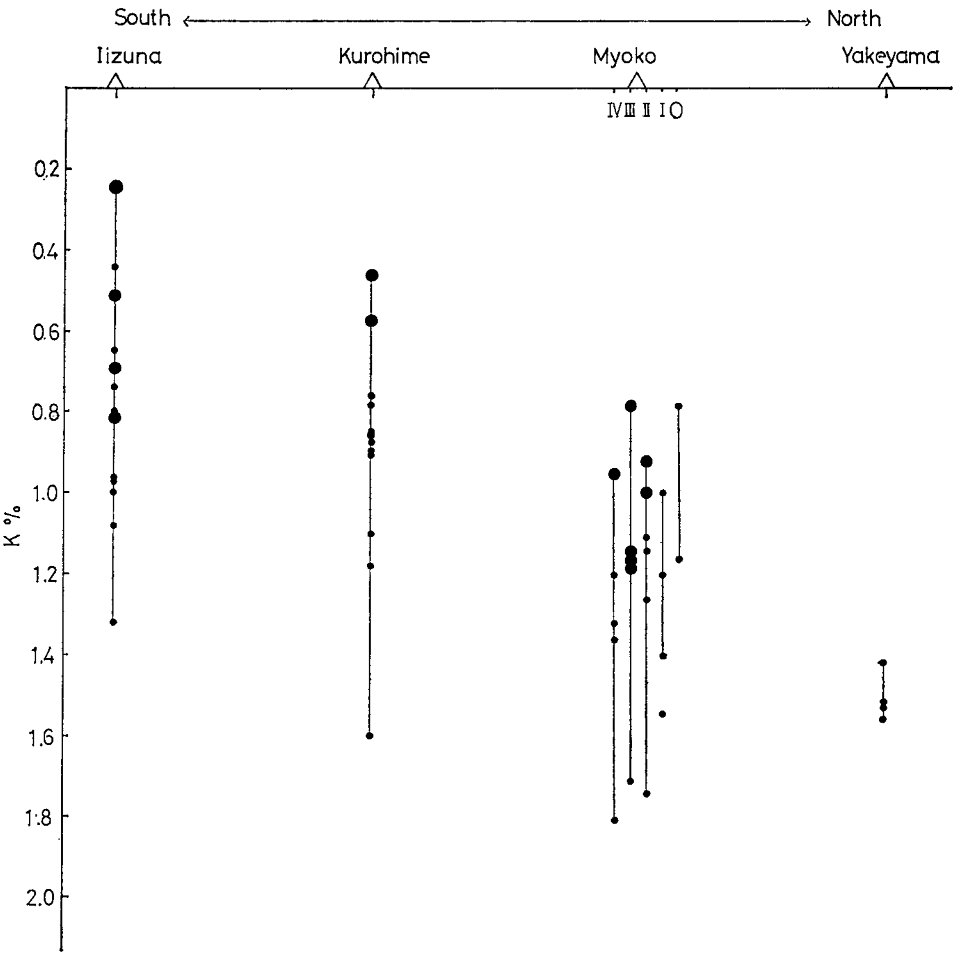

Fig. 12. Comparison of K-content among the volcanoes of the Myoko volcanoes.
Large solid circles: Basaltic rocks (SiO_2<53%), Small solid circles: Andesitic rocks (SiO_2≥53%), O: Older Myoko, I: I stage, II: II stage, III: III stage, IV: IV stage.

Al_2O_3: higher than CH, Na and IH.
CaO: nearly equal to CH, and lower than NA and IH.
K_2O: higher than Na and IH, and lower in basalt and higher in dacite than CH.

Roughly speaking, six basalt-andesite series of the Iizuna, Kurohime, Myoko (IInd, IIIrd, and IVth stages), and Yakeyama volcanoes show nearly the same tendency with each other, but the slight differences are recognized concerning the oxide trende of each basalt-andesite series. The difference may show that each basalt-andesite series has been formed independently throughout crystallization or generation of basaltic magma. In particular, it is noteworthy that the trend of K_2O is high in the Myoko and Yakeyama volcanoes, and low in the Iizuna and Kurohime. Recent analyses by Ishizaka show that K_2O contents of some Iizuna basalts are lower than

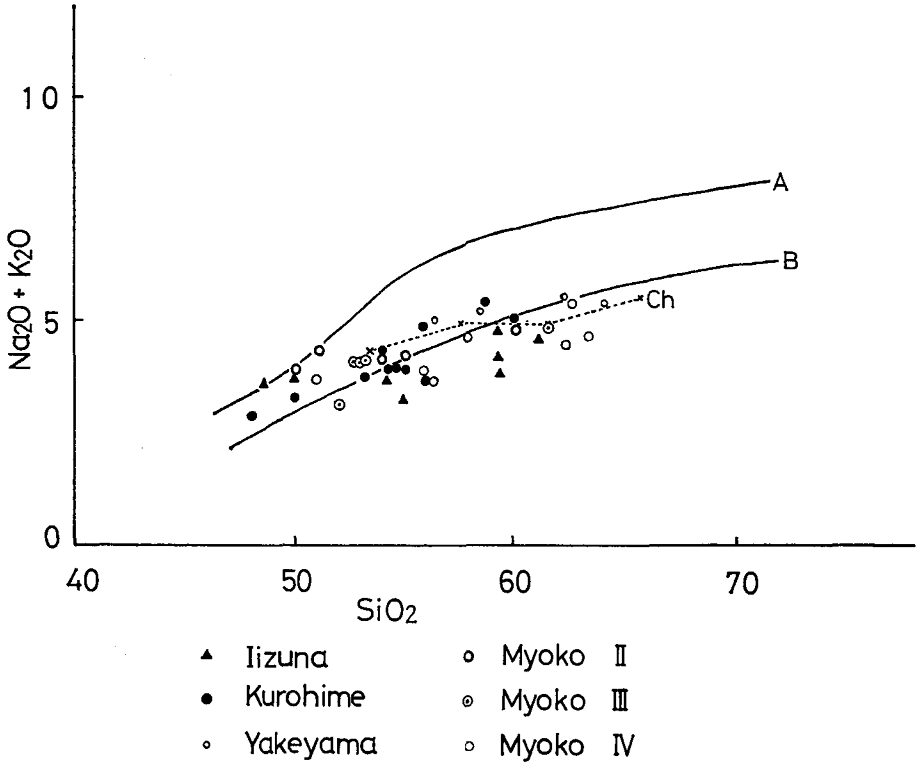

Fig. 13. Total alkalies-SiO_2 relation in the rocks of the Myoko volcanoes.
The lines A and B mark the general boundaries between the fields of the tholeiite series, high-alumina basalt series, and alkali rock series by KUNO (1966). Ch: Average of the Chokai volcanic belt (KAWANO et al., 1961).

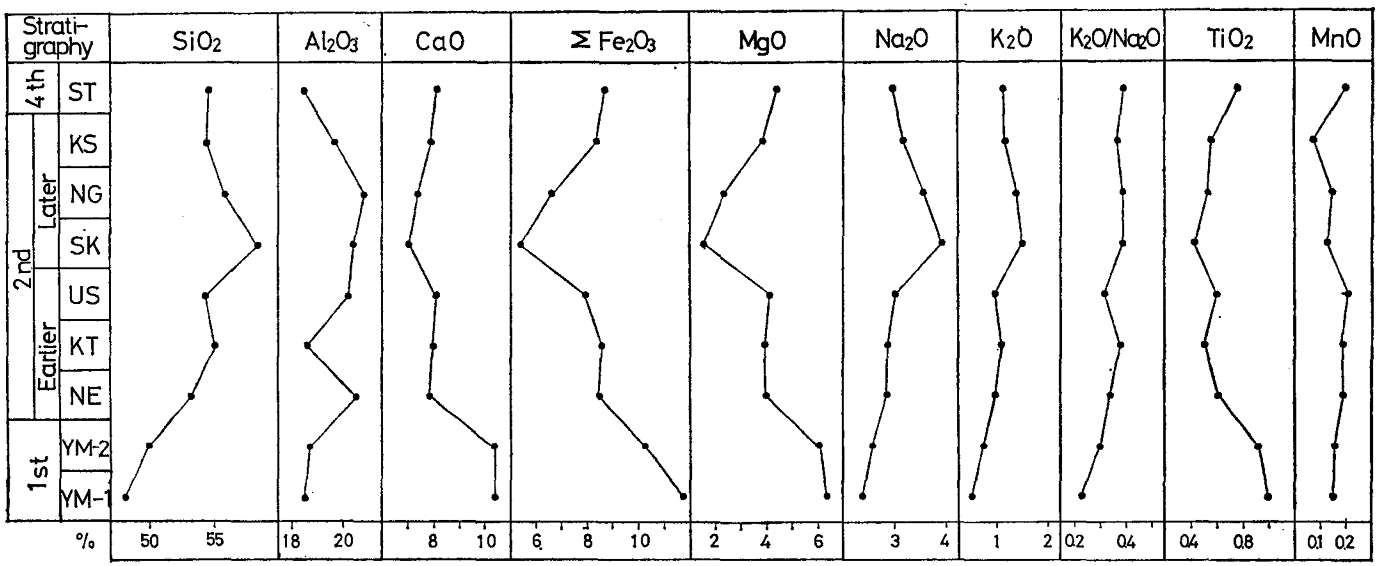

Fig. 14. Relation between the stratigraphy and chemistry in the Kurohime volcano.

ST: Sutakayama lava, KS: Karasawa lava, NG: Nagahara lava, SK: Sekigawa lava, US: Ushibuseyama lava, KT: Komagataki lava, NE: Naenataki lava, YM-2: Yamakuwayama lava (lava), YM-1: Yamakuwayama lava (scoria).

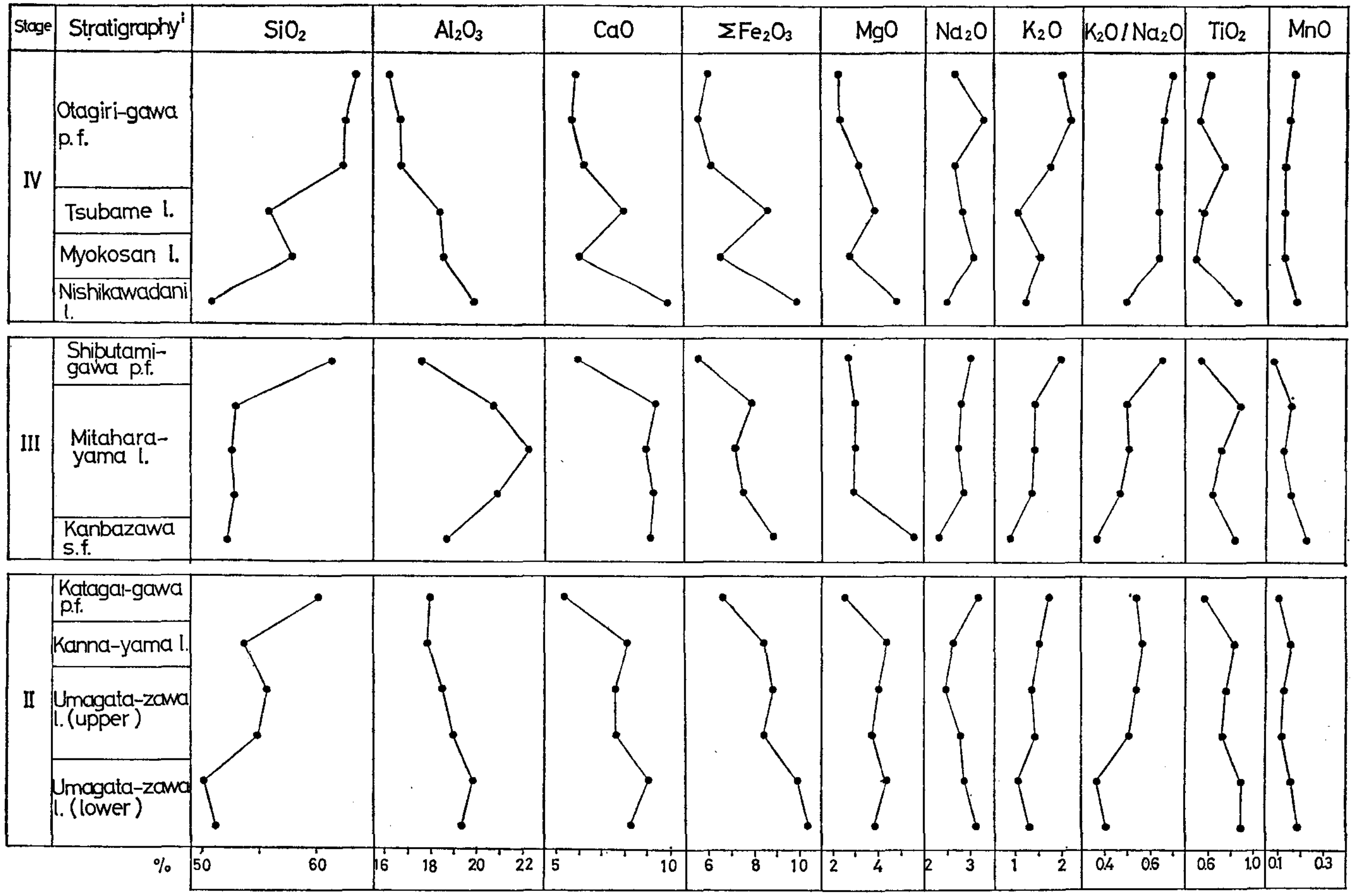

Fig. 15. Relation between the stratigraphy and chemistry in the Myoko volcano.
p.f.: Pyroclastic flow deposit, l: Lava, s.f.: Scoria fall deposit.

those of Kurohime (Ishizaka, Yanagi and Hayatsu, unpublished). Accordingly, K_2O content seems to become higher in a following order, Iizuna, Kurohime, Myoko, Yakeyama, namely from the south to the north (Fig. 12). Total alkalies—SiO_2 relation in the rocks of MYOKO are similar to that of the Chokai volcanic belt (Fig. 13).

The relations between the stratigraphic position of rocks and their chemical compositions are shown in Fig. 14 and Fig. 15. According to the figures, in general, SiO_2 increase 9～12 percent toward the later time in each basalt-andesite series. Al_2O_3 decreases at the IInd and IVth stages, and enriches at the middle of the IIIrd stage of the Myoko. CaO, total iron as Fe_2O_3, MgO, TiO_2 and MnO are decreasing to the later time, respectively, but they, as well as SiO_2, show a reverse trend from the 2nd to the 4th stage of the Kurohime volcano. A parallel variation of total iron as Fe_2O_3, TiO_2 and MnO is recognized. K_2O and Na_2O, especially K_2O, are increasing to the later time except for the upper part of the Kurohime volcano.

MFA diagrams for the Iizuna, Kurohime, and Myoko volcanoes are shown in Figs. 16～21. Each diagram shows a well succession from basalt to andesite (or dacite). In the figures, total iron as FeO is not significantly rich except for the Iizuna volcano and the IIIrd stage of the Myoko volcano. Generally, the rocks belonging to the pigeonitic rock series show a enriched tendency of total iron as FeO in the course of the differentiation in comparison with those belonging to the hypersthenic rock series. The boundary line between the rocks of the pigeonitic and hypersthenic rock series in the MFA diagram is lower in MYOKO than that of the Izu-Hakone region (KUNO, 1954) and Nasu northern subbelt (KAWANO et al., 1961),

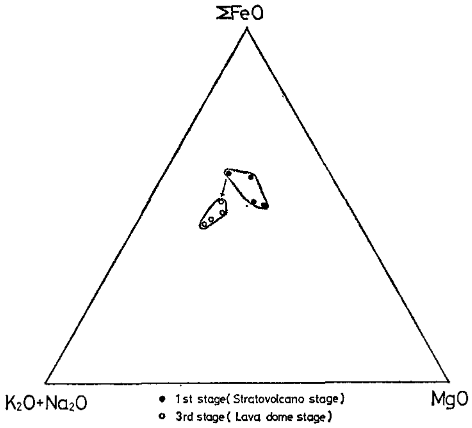

Fig. 16. Variation diagram of the rocks of the Iizuna volcano as plotted in the ternary diagram $MgO-FeO^*-Na_2O+K_2O$ ($FeO^*=FeO+0.9\ Fe_2O_3$).

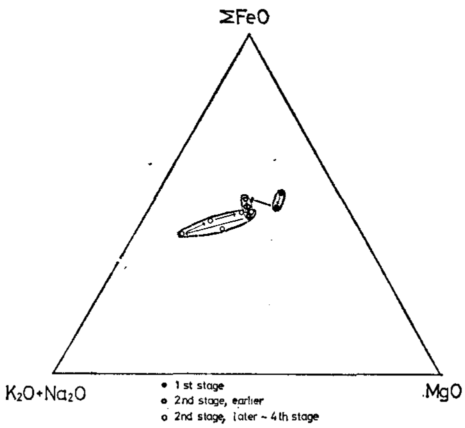

Fig. 17. Variation diagram of the rocks of the Kurohime volcano as plotted in the ternary diagram $MgO-FeO^*-Na_2O+K_2O$.

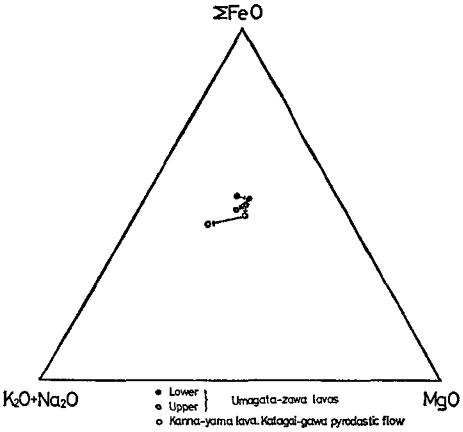

Fig. 18. Variation diagram of the rocks of the Myoko volcano II stage as plotted in the ternary diagram $MgO-FeO^{*}-Na_2O+K_2O$.

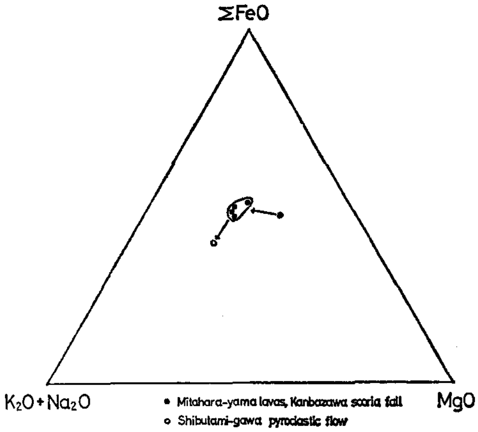

Fig. 19. Variation diagram of the rocks of the Myoko volcano III stage as plotted in the ternary diagram $MgO-FeO^{*}-Na_2O+K_2O$.

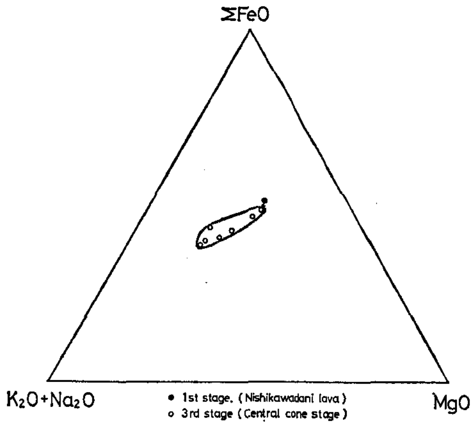

Fig. 20. Variation diagram of the rocks of the Myoko volcano IV stage as plotted in the ternary diagram $MgO-FeO^{*}-Na_2O+K_2O$.

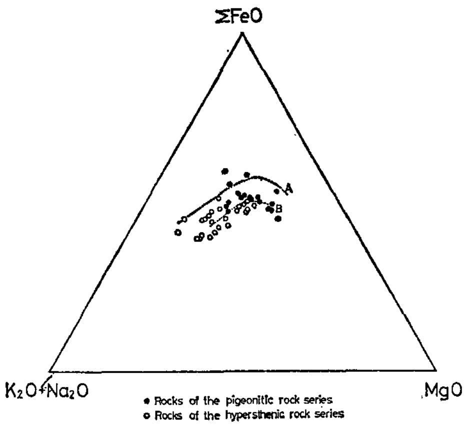

Fig. 21. Variation diagram of the rocks of the Myoko volcanoes as plotted in the ternary diagram $MgO-FeO^{*}-Na_2O+K_2O$. The dotted line A and B represent the boundary between the pigeonitic and hypersthenic rock series in the Izu-Hakone region, and in the southern sub-belt of the Nasu volcanic belt, respectively.

and almost equal with that of the Nasu southern subbelt (KAWANO et al., 1961).

YAMASAKI (1956) has discussed the effect of contamination of magma from the ratio of K_2O and Na_2O of the Fuji and Nasu volcanic belts. The rocks of MYOKO are plotted on the diagram of K_2O/Na_2O-SiO_2 (Fig. 22). The ratios of K_2O and Na_2O of the andesite or dacite of the Yakeyama and Myoko show the relatively high value in comparison with those of the Kurohime and Iizuna. In Fig. 22, the rocks of MYOKO are plotted between the Nasu volcanic belt (represented by the Akagi volcano) and the circum Japan sea petrographic province (represented by the Oshima-Oshima), and show the same value as the Chokai volcanic belt (represented by the Chokai volcano).

Fe_2O_3/FeO-SiO_2 relation in the rocks of MYOKO is shown in Fig. 23. The rocks of the hypersthenic rock series are generally higher in Fe_2O_3/FeO ratio than those of the pigeonitic rock series.

The alkali-lime index proposed by PEACOCK (1931) is tabulated for each basalt-andesite series (Table 5). The index of MYOKO ranges from 61.0 to 63.8, and the mean in 62.2 ($CaO=Na_2O+K_2O=5.2$), and this value is lower than that of the Izu-Hakone region (pigeonitic rock series, 66; hypersthenic rock series, 68) (KUNO, 1954), Nasu volcanic belt (64.2–65.2) (KAWANO et al., 1961), and is higher than the

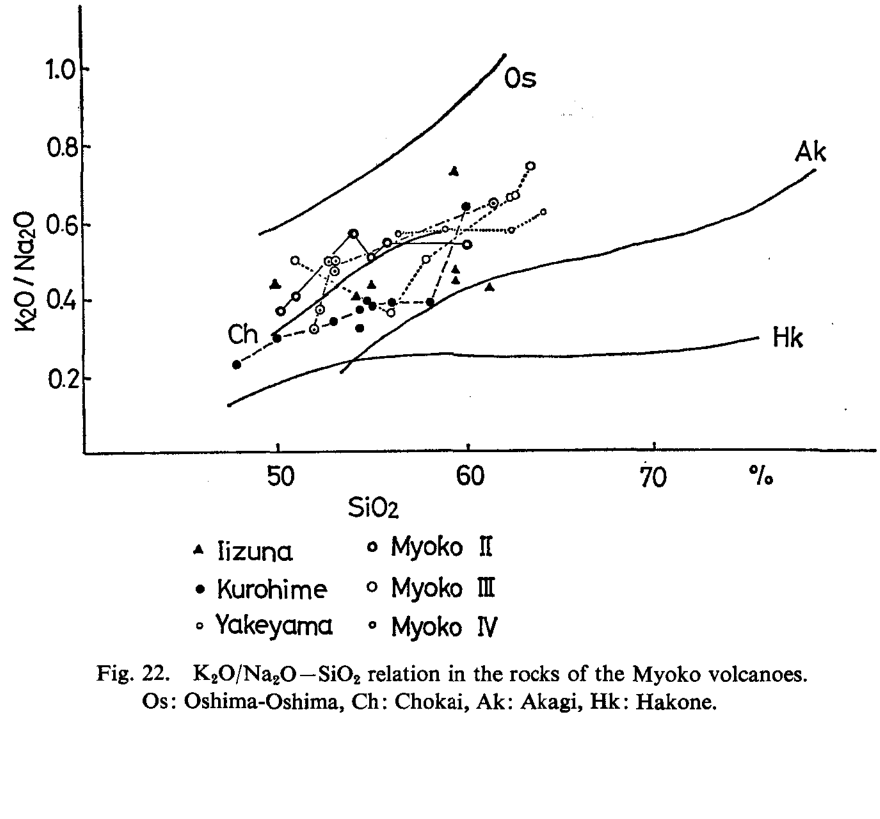

Fig. 22. K_2O/Na_2O-SiO_2 relation in the rocks of the Myoko volcanoes.
Os: Oshima-Oshima, Ch: Chokai, Ak: Akagi, Hk: Hakone.

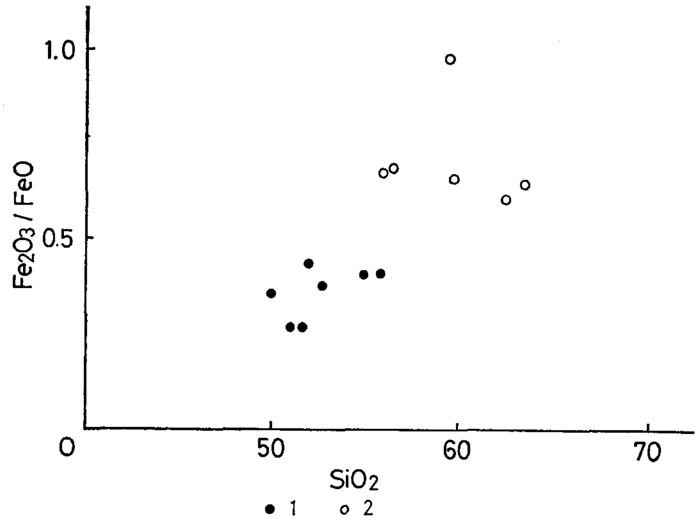

Fig. 23. $Fe_2O_3/FeO-SiO_2$ relation in the rocks of the Myoko volcanoes.
1: pigeonitic series rocks, 2: hypersthenic series rocks.

Table 5. Alkali-lime index in the Myoko volcanoes.

		Alkali-lime index	$CaO = Na_2O+K_2O$
Iizuna volcano II stage		63.1	5.1
Kurohime volcano		61.8	5.5
Myoko volcano	II stage	61.0	5.2
	III stage	62.8	5.2
	IV stage	63.8	5.3
Yakeyama volcano		63.2	5.5

value 53.1 in the circum-Japan sea petrographic belt (Tomita, 1935). In the rocks of the Myoko volcano, the alkali lime index slightly increases to the younger basalt-andesite series.

IV. THE XENOLITHS

A. General statement

Xenoliths, and inclusions assumed to be xenolith, are commonly found in the eruptives constructing MYOKO. They are very common in the Myoko volcano, sometimes in the Iizuna volcano, but rather rare in the Kurohime volcano. The xenolith-occurring horizon and the features of the host rocks in each volcano are briefly described below.

Myoko volcano

The Ist stage: Common throughout a whole horizon.

The IInd stage: Not in the lower basalt (lower Umagatazawa lavas). Rich in the upper pyroxene andesite (upper Umagatazawa lavas) and the uppermost hornblende andesite (Shiratagirigawa and Katagaigawa pyroclastic flow deposits).

The IIIrd stage: Extremely rare in the basalt and basic andesite (Kanbazawa scoria fall, Mitaharayama lavas). Rich in hornblende andesite of the uppermost horizon (Shibutamigawa pyroclastic flow deposit).

The IVth stage: Rich in the lower Nishikawadani scoria and lava (basalt). Rich in the Tsubame lava (basic andesite) and hornblende andesite of the central cone stage.

Kurohime volcano

A small amount in the eruptives of the later 2nd stage to the 4th stage. Never distinct in the rocks of the pigeonitic rock series of the earlier 2nd stage and basalt of the 1st stage. Rich in hornblende andesite composing lapilli fall deposit (Sc-3).

Iizuna volcano

The Ist stage: Existence.

The IInd stage: Not in the lower basalt (Iizuna basalts). A small amount in a part of pyroxene andesite. Rich in hornblende andesite of the upper horizon and in pumice fall deposit of the lava dome stage as lithic fragments.

Xenoliths in the present area except for those in pumice fall deposit of the Iizuna, are usually reacted with magma and are changed their mineral assemblage and texture partly or perfectly. The reaction is, generally speaking, more proceeded in the upper horizon than in the lower one in each group (basalt-andesite series). The original rocks of accidental xenolith are always basal Neogene sedimentary rocks such as pelitic and psammitic rocks as far as confirmed. Most of xenolith included in the hornblende andesite are those which have been called "cognate inclusion" by the previous workers (Section IV-D).

B. Xenoliths in the Nishikawadani lava

The Nishikawadani lava and scoria of the IVth stage of the Myoko volcano include characteristically a large amount of xenoliths. In the following, xenoliths of the Nishikawadani lava are described in detail.

1. Occurrence in the field

The Nishikawadani lava contains many xenoliths throughout the bed. At MK-322 point (HAYATSU, 1975 a), the volume ratio of xenolith, whose long diameter is longer than 1 cm, to whole rock is 2.9% (point-counted in 4 m^2). The xenoliths range from 25 cm to microscopic scale in size, and are mostly measured several centimeters. They are mostly rounded in form, commonly oval shape, sometimes irregular, and rarely angular. Some xenoliths have obscure boundary line with host rock. It is noticed that a boundary part between xenolith and host rock retains usually trace of marked vesiculation. The xenolith in the Nishikawadani scoria is also very similar occurrence to those in the Nishikawadani lava.

2. Microscopic observation

Microscopic observation of xenolith shows wide varieties from nonmetamorphosed to completely metamorphosed appearance by the reaction with magma. Even in a single xenolith, the mineral assemblage is often changed from the core to the margin. Several different features concerning the occurrence of xenolith are recognized as follows. The xenolith contains a) the original minerals (original rock type), b) mainly pyroxene and plagioclase (pyroxene type), c) mainly olivine and plagioclase but no hornblende (olivine type), and d) hornblende and other minerals (hornblende type).

a). Original rock type of xenolith

All xenoliths which have preserved the mineral assemblage and texture of the original rocks as a result of no or weak reaction with magma, are siltstone and fine grained sandstone, as far as confirmed. Some of them contain quartz overwhelmingly, and the others contain quartz and plagioclase. Most of them contain dusty minute materials as matrix.

In the siltstone and sandstone, mineral grains are somewhat melted to pale yellowish brown glass. Small biotite and ore mineral are produced in some case. In keeping with corrosion of quartz, quartz becomes smaller and more rounded, and colorless glass increase in amount. During this reaction stage, some minerals such as sillimanite (or mullite), cordierite, orthopyroxene, plagioclase, clinopyroxene, and ore minerals begin to cristallize. At the next stage of the reaction, sillimanite (or mullite), and cordierite disappear and plagioclase, orthopyroxene and clinopyroxene become the principal constituent. Clinopyroxene is gradually tend to increase with reaction in xenoliths of co-existed ortho-and clinopyroxene. Thus, the process that the original rock is melted and new minerals begin to crystallize out, is clearly recognized in some zoned xenoliths. In xenoliths of this stage when source rock is partly melted and new minerals begin to crystallize in a small amount, traces of vesiculation of xenolith and its contact part are usually weak.

b). Pyroxene type of xenolith

The pyroxene type of xenolith may be subdivided into xenolith consisting of orthopyroxene, orthopyroxene and clinopyroxene, and clinopyroxene. The clinopyroxene is sometimes aegirine augite. Many xenoliths containing both orthopyroxene and clinopyroxene are judged from their texture that orthopyroxene is decomposed and clinopyroxene is newly formed. And in such xenoliths, the modal ratio of clinopyroxene and orthopyroxene becomes higher from the core to the margin. Judging from these, orthopyroxene may be changed into clinopyroxene in these xenoliths as a result of reaction with magma.

The pyroxene type of xenolith has the mosaic texture of plagioclase, pyroxene, and ore mineral. Some xenoliths retain trace of vesiculation all over or partly. Their contact parts are also usually porous as a result of vesiculation. Perfectly opacitized brown hornblende crystals are sometimes distributed in the host rock around the xenolith.

There is no distinct boundary between the pyroxene type and original rock from the mineral assemblage and texture. Therefore, the pyroxene type of xenolith seems to be derived from the original rock type of xenolith through the reaction with magma.

c). Olivine type of xenolith

Xenoliths containing olivine occur sometimes as a single xenolith and sometimes as a part of pyroxene type of xenolith. In the latter case, olivine-rich part often forms the core and rarely lense shaped aggregates in the pyroxene type of xenolith. Thus, the close relation between olivine type and the pyroxene type is recognized from their occurrence. The pyroxene type as stated above, is derived from the sedimentary rocks such as siltstone or fine grained sandstone, therefore the olivine type may be produced from such sedimentary rocks through the reaction with magma.

Olivine type is mainly characterized by the following features; plagioclase is very clear because of its lack of dusty inclusion, and green spinel is often contained. A boundary part are generally very porous.

d). Hornblende type of xenolith

Xenoliths containing hornblende are divided into two sorts from the occurrence of hornblende; in one case, hornblende grows interstitially among minerals such as plagioclase and orthopyroxene and shows the poikilitic texture, in other case, it shows the euhedral form and often occurs in the olivine type of xenolith. Most of hornblende type belong to the latter case, generally contain olivine crystals, and have the similar feature to the olivine type. But this xenolith contains much ore mineral compared with olivine type. Xenolith and its contact part are most porous in all type of xenoliths as a result of vesiculation. Many hornblende crystals are unstable to become opacite and some are perfectly opacitized into aggregates of pyroxene, ore mineral, and plagioclase.

3. Conclusion

As mentioned above, xenoliths are derived from Neogene pelitic or psammitic rocks distributed probably just under the Myoko volcanic cone so far as their source rocks are confirmed. Pyroxene type of xenolith may have been formed from the melted original rock in the magma by the reaction with the magma. Judging from the fact that original rock type of xenolith, pyroxene type of xenolith, olivine type of xenolith, and hornblende type of xenolith are perfectly transitional to each other in mineral assemblage and texture, most of the xenoliths in the Nishikawadani lava may have been formed through the reaction of fragments of the sedimendary rocks with magma. The mechanism of reaction of xenolith with magma is a future problem to study.

Average chemical composition of Neogene pelitic rocks distributed in Niigata and Nagano prefectures is shown in Table 6. The compositions of xenoliths of pyroxene type, olivine type and hornblende type may be far basic in comparison with the average composition of the pelitic rocks. The fact that xenoliths have changed their chemical compositions through the reaction with magma, means

Table 6. Average chemical composition of the basal Neogene pelitic rocks distributed in the Niigata and Nagano prefectures.

SiO_2	65.65
TiO_2	0.42
Al_2O_3	12.92
Fe_2O_3	3.39
FeO*	1.16
MnO*	0.04
MgO	1.91
CaO	1.61
Na_2O	1.54
K_2O	2.14
$H_2O^{(+)}$**	4.64
ΣH_2O	9.00
P_2O_5	0.10

*: mean of 22 analyses. **: mean of 14 analyses.
Others: mean of 26 analyses.
(Using the analyses by SHIBATA, 1968).

that, magma may have been apparently contaminated by xenoliths. Judging from the mineral assemblage of xenolith, most of H_2O and K_2O and some of SiO_2 of original rock should be discharged into magma, and MgO, FeO, CaO and probably Al_2O_3 should be derived from magma into xenolith.

The considerably porous circumference as the result of vesiculation around xenolith may show that H_2O has been concentrated there just before eruption, because any significant differences are not recognized in chemical composition between the vesiculated part and other part. In the porous marginal zone of xenolith, relatively large amount of hornblende are often produced. The fact seems to indicate that H_2O-concentration in that part would relate largely to the crystallization of hornblende. At least, a part of H_2O would have been liberated from xenolith.

C. "Large anorthite crystals" from the Myoko volcano

As stated in the general descriptions, the characteristic large plagioclase crystals are included in the Nishikawadani lava and scoria belonging to the IVth stage of the Myoko volcano. These plagioclase crystals are generally 5 to 10 mm in size, and sometimes attain to 30 mm in length. They usually occur as aggregate of several crystals, but sometimes as a single crystal.

Polysynthetic twin after albite and pericline law are most predominant, and twinning of Carlsbad type is also common. The pericline type is common in contrast with the phenocrystic plagioclase included in the same lava. Olivine is common inclusion in the plagioclase, and clinopyroxene and orthopyroxene are rarely. The large crystals have no minute dusty inclusion, and are very clear. A zonal structure is absent or very faint, although there is a very thin rim of more sodic composition.

Anorthite content of the main part determined by the refractive indices n_1 on cleavage flakes ($n_1=1.578$) is 95%, and that of the outermost narrow zone is relatively low. Anorthite content of the main part is larger than that of the common phenocrystic plagioclase of the same rock (about 88%).

Forsterite content of olivine included in the plagioclase is about 80% ($2V(-)=86$–$89°$, $\gamma=1.710$). It is also higher than Fo 72% ($2V(-)=83$–$86°$, $\gamma=1.730$) of olivine contained as a phenocryst of the same rock. Olivine crystals contained as inclusion are often as large as phenocrysts in the same rock, and generally clear, rounded or wedgelike in form. No crystal showing a corroded outline is found.

On the other hand, the phenocrystic plagioclase differ from this plagioclase by small crystal size, scanty pericline twinning, common presence of the crystals with minute dusty inclusions, existence of strong zonal structure, lacking of included olivine, and low anorthite content (Table 7).

The characteristic large plagioclase included in the Nishikawadani lava and scoria agrees perfectly with the large anorthite crystal summarized by ISHIKAWA

(1951, 1969). Therefore, such kind of large plagioclase discovered first from the Myoko volcano is called large anorthite crystal in the present paper.

According to ISHIKAWA (1951, 1969), all known localities of large anorthite crystal are limited only in the outer zone of northeast Japan, ranging from Ketoi to Torishima (Fig. 24). Most of them are included in the Quaternary volcanic

Table 7. Comparison between common plagioclase phenocryst and large anorthite crystal in the Nishikawadani lava and scoria.

	Common plagioclase phenocryst	Large anorthite
Occurrence	Single crystal	Single crystal, aggregate
Size	<2 mm	2 mm~30 mm
Inclusion	Minute dirty material commonly included.	No dust inclusion, very clear. Olivine commonly included.
Zoning	Generally strong	Absent except in very thin rim.
An content of main part	About 88%	95%
Others		Included olivine is higher than common olivine phenocryst in Fo content.

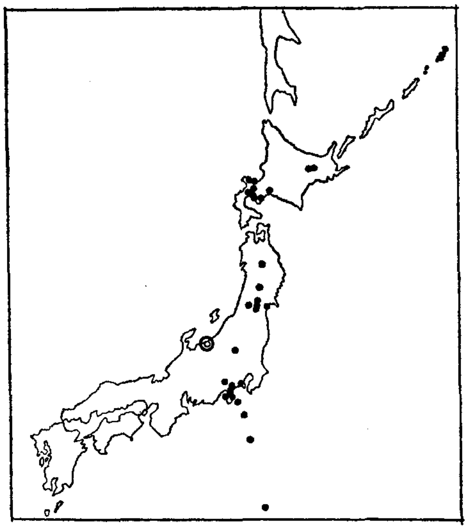

Fig. 24. Distribution of localities of large anorthite crystals (HAYATSU, 1974). Solid circles: already known localities (after ISHIKAWA, 1951). Double circle: new locality, Myoko volcano.

belts; the so-called Chishima, Nasu and southern subbelt of Fuji. But some belong to the Tertiary volcanic area along the above mentioned three volcanic belts. The occurrence of large anorthite has never been reported in the inner zone of northeast Japan and in southwest Japan.

In regard to the genesis of large anorthite, TSUBOI (1920), KOZU and KADOKURA (1927), KOZU (1927), HARADA (1936), ISHIKAWA (1951), and KAWANO and AOKI (1959) gave some considerations. TSUBOI (1920) stated in his petrological study on the Oshima volcano that anorthite exhibiting very faint or no zonal structure was formed by slow cooling under the perfect equilibrium condition and by the movement of crystal in the magma matching with calcic plagioclase in density. KOZU and KADOKURA (1927) and KOZU (1927) considered the large anorthite ejected from the Miyakejima volcano was due to rapid growth in the melt rich in volatile substance and low in viscosity, rather than long duration of crystallization under the equilibrium stage. On the summarization of anorthite which found in the volcanic rocks of Japan, HARADA (1936) suggested that such large anorthite was mixed into the magma from which common plagioclase phenocrysts crystallized out, or that violent mixing of two different magmas including large anorthite and normal phenocrystic plagioclase, respectively, occurred just before effusion. In 1951, ISHIKAWA presumed that large anorthite was formed in close relation with petrographical province. He concluded that the SiO_2-oversaturated magma with poor alkali and rich CaO and Al_2O_3 from which An-rich plagioclase is easy to be crystallized, must have assimilated basal clayey rocks rich in Al_2O_3, and it must have crystallized the large anorthite. Recently, however, ISHIKAWA emphasized the fact that the large anorthite occurs only in the zone of low-alkali magma (ISHIKAWA, 1969). On the basis of modal compositions and groundmass chemical compositions of the large anorthite bearing basic volcanic rocks, KAWANO and AOKI (1959) considered as follows; such rocks should be attributed to the floating up of anorthite crystals with the sinking down of olivine and pyroxene crystals after these crystals have been crystallized out from the tholeiitic magma with high temperature and low viscosity under the perfect equilibrium condition.

The Nishikawadani lava and scoria, as already described, belong to the high-alumina basalt. The alkali content is higher than those of basalts in the outer zone of northeast Japan, and not especially low in comparison with those of any other basalt in MYOKO. It is to be noted that the large anorthite crystal was first discovered in the inner zone of northeast Japan where the rock is rather higher in alkali content than that of the outer zone. The Nishikawadani lava contains microscopically phenocrysts of plagioclase, olivine, augite, hypersthene, and ore mineral, as decreasing order in amount. The groundmass is composed of plagioclase, olivine, clinopyroxene, ore mineral, glass, silica mineral and small amount of hypersthene rimmed by minute clinopyroxene. The mineral assemblage bears a close parallelism

Table 8. Occurrence and properties of large anorthite crystals (ISHIKAWA, 1951).

Localities	Occurrence or mother rocks	Maximum size (cm)	An% of the Main part	An% of the Marginal zone	Inclusions	An % of plagioclase in mother rocks	
						Phenocryst	groundmass
Minamizawa, Ketoi Is.	Placer	3	88	± 80–73	Olivine		
SW of Lake Ketoi	Olivine two pyroxene andesite	1.5	99	±	"		
Shinshirufuji, Shinshiru Is.	"	2.5	88	±	"	70	
Midoriko, Shinshiru Is.	"	2	99	±		80	65
Oakandake, Akan	"	1.8	96	+	Olivine	80–53	45
Fuppushidake, Akan	"	1	96	−	Olivine	77–54	48
Fugoppe, Hokkaidô	Quartz bg, two pyroxene andesitic agglomerate (Tertiary)	1.7	97 (α=1.573 β=1.582, γ=1.587)	±	Olivine	80–57	50
Otaru, Hokkaidô	Tuff (Tertiary)	1.5	93				
Tarumai, Hokkaidô	Crystal lapilli, Two pyroxene andesite (Dome lava, bomb, black compact block)	2	96– (92∼94) 93.6 93	90– (50∼60) 75	Olivine	Dome 90–45 Bomb 66–43 Block 72–47	65–50 45 42
W. side of L. Tôya, Hokkaidô	Olivine two pyroxene andesite and it's agglomerate (Tertiary)	3	95	±		80	68
Nukkibetsu, Hokkaidô	Olivine bearing two pyroxene andesitic agglomerate (Tertary)	3.5	94	88–71		79–54	69–53
Nishi-maruyama, Usu	Olivine two pyroxene andesite	2	96, 97	82	Olivine, augite	80	70
Shôwa-Shinzan, Usu	Olivine two pyroxene andesite	10	89	+		68	
Kuttara, Hokkaidô	Tuff or agglomeratic Tuff	4.5	87∼85	80–65	Olivine, rhombic pyroxene		
Murorandake, Hokkaidô	Two pyroxene andesite (Tertiary)	1	98	65		80–65	65
Dome of Kamabuseyama	Two pyroxene basaltic andesite	1	95∼94, 99	74	Olivine, rhombic pyroxene	75–70, 78	65
East foot of Kamabuseyama	Olivine two pyroxene andesite	3	98∼90	±	Olivine	85–80	

Localities	Occurrence or mother rocks	Maximum size (cm)	An% of the Main part	An% of the Marginal zone	Inc usions	An % of plagioclase in mother rocks: Phenocryst	An % of plagioclase in mother rocks: ground-mass
Yakushidake, Iwatesan	Crystal in lapilli bed		$Nm \fallingdotseq 1.572$				
Mitaki, Sendai	Andesitic basalt (Tertiary)	3	95	74.9	Pyroxene	92.9, 76.9	68.2
Nyudoyama, Zaôsan	Two pyroxene andesite	1	$1.572 < Nm < 1.582$				
Kôshinzan, Tochigi	Pyroxene andesite	1.5	Anorthite				
Volcano Fuji	Two pyroxene bg. olivine basalt	1	95			84	74
	Augite bg. olivine basalt		95			83	78
Keshôzaka, Kamakura	Two pyroxene andesitic agglomerate and tuff	2	Anorthite				
Tônosawa, Hakone	Andesite (dyke)	1	95				
Hedaohama, Shizuoka	Olivine andesite	3	Anorthite				
Chigasaki, Ôshima	Two pyroxene olivine anorthite basalt	2	95		Olivine	95	
Miyakejima	Crystal lapilli	5	96, 95.4 94	90–64	Olivine	Lapilli 80	
Dôrinzawa, Hachijôjima	Placer	3	97				
Torishima	Two pyroxene andesite	1	94			91	

to those of other basalts in the present area. It should be noted that fragments of the basal sedimentary rocks are commonly included as xenolith in the Nishikawadani lava, and many of them are changed into the aggregates of plagioclase, olivine and others through the reaction with magma as mentioned above (Section IV-B).

Between such aggregates derived from accidental xenolith and large anorthite crystal, varias intermediates are found by naked eye in field and also microscopically in laboratory. Namely, a continuous transition is traced in texture and mineral assemblage from the aggregate of plagioclase, olivine, and others derived from clearly accidental xenolith to the large anorthite (HAYATSU, 1974, for details). The fact shows that the large anorthite must have been formed from the accidental xenolith through the reaction with magma.

The spaces between such aggregate derived from xenolith and the host rock, and the aggregate itself are always very porous as the result of vesiculation at the eruption, and the xenolith containing olivine often involves hornblende (see IV-B). This fact leads us to the assumption that H_2O included in xenolith may be one of the most important factors in forming a large anorthite. Namely the high P_{H_2O} in the part of xenolith may allow crystallizing anorthite at low temperature and may expedite to built the large crystal (ISHIKAWA, 1969). The geological evidence that the large anorthite is often ejected as crystal lapilli or pyroclastic fall, characteristic for explosive eruption, in the Miyakejima volcano (1874, 1940), Tarumae volcano, and many others (Table 8) may support the above-mentioned assumption.

ISHIKAWA (1951) stated that olivine included in large anorthite has crystallized surely earlier than anorthite. But olivine is involved by anorthite because the latter may grow more rapidly, although both began to crystallize nearly at the same stage (HAYATSU, 1974). Included olivine of inclusion is richer in forsterite content than the phenocryst in the same rock. It agrees very well with the fact that forsterite content of olivine and enstatite content of orthopyroxene included in the other aggregates derived from the accidental xenolith are higher than those of host rock, Nishikawadani lava. The following three may be considered as the main reasons. (a) Selective transfer of Mg from magma to xenolith. (b) Magnetite crystallization under high P_{O_2} condition derived from high P_{H_2O} condition enriches Mg relatively in the residual material. (c) High P_{H_2O} condition makes fall down the crystallization temperature, and accelerates the crystallization of Mg-rich olivine and orthopyroxene.

From the facts described above, it may be concluded that the large anorthite included in the Nishikawadani lava belonging to the IVth stage of the Myoko volcano must have been formed as the result of reaction of the accidental xenolith such as pelitic or psammitic rocks with magma under high P_{H_2O} condition. The reaction with magma may be a sort of metasomatism in a broad sense.

The distribution of the large anorthite is restricted to a certain zones and rocks

(ISHIKAWA, 1951). It suggests that the large anorthite requires in its genesis not only the host magma taking the wall rocks rich in H_2O and probably Al_2O_3 as xenolith but also having the limited composition as considered by ISHIKAWA (1951). A mechanical process concerning the reaction between xenolith and magma, and also concerning the growth of the large anorthite is to get an important and interesting problem to be studied.

D. Inclusions in the hornblende andesites

Many inclusions are found in lavas and fragments composing pyroclastic flow deposits of andesite, especially hornblende andesite, from MYOKO. They are generally round shaped, and several centimetres long in diameter. Under the microscope, they are characteristically very porous, and consist of euhedral phenocrysts and/or microphenocrysts of plagioclase, hornblende, hypersthene, olivine, and small amount of augite and ore mineral. Interstitial glass, plagioclase, hypersthene, and ore mineral occur usually and augite, apatite, silica minerals such as cristobalite, and alkali feldspar occur sometimes as groundmass constituent.

Such inclusions are often found in other volcanic rocks in Japan. They have been called as autolith, cognate inclusion, or cognate xenolith, and have been interpreted as fragment of rock crystallized at the earlier stage in the same evolutional series as the host rock. Those in MYOKO have also been called as cognate xenolith or cognate inclusion by previous workers (YAGI et al., 1958; SUZUKI, 1961; YAMASAKI et al., 1961). The inclusions stated above are contained mainly in intermediate to acidic andesite (dacite), especially in hornblende andesite, but rather rarely in basalt and rhyolite.

Therefore, the inclusions may give one important clue to consider the genetic problem of some hornblende andesites. Such inclusicons in the rocks of MYOKO has already described in detail (HAYATSU, 1975). The abstract will be described in this section.

All rocks of the Myoko IVth stage represented by the Otagirigawa pyroclastic flow deposit (hornblende andesite), Tsubame lava (pyroxene andesite), and Nishikawadani lava (basalt) contain many xenoliths and xenolith-like inclusions.

The inclusions are abundantly contained in the essential blocks of the Otagirigawa pyroclastic flow deposit. Ten blocks, whose total section is about 6 m^2 wide, are selected at randam in order to examine the modal composition of these inclusions. The volume ratio of inclusions over 1 cm diameter to a whole rock is about 2%. Their size is mostly less than 5 cm and those of 2 to 3 cm size are especially predominated. The largest one is 20 cm long in diameter. They are almost always rounded in shape, commonly oval or globe-like, and occasionally irregular. The contact part of inclusion with host rock is in general considerably porous, and often numberless pores are arranged radially from inclusion as nucleus. Without doubt, it may have been produced by vesiculation at the eruption. Any fragment of basal Neogene sedimentary rocks has not been found out in the essential blocks of the Otagirigawa pyroclastic flow deposit.

Under the microscope, the inclusions have several mineral assemblages. For convenience, they are tentatively distinguished as follows: the olivine type, containing olivine and no hornblende; the hornblende-olivine type, containing hornblende in addition to the olivine type, whereas olivine is higher than hornblende in modal composition; the olivine-hornblende type, resembling to the type mentioned just obove, but hornblende is higher than olivine; the hornblende type, containing much hornblende and no olivine; and the opacite type, containing relatively much opacite. The inclusion except for the opacite type sometimes contains the aggregate of green spinel and plagioclase which is almost identical with a certain part of some xenoliths in the Nishikawadani lava (see Section IV-B). The mineral assemblage, characteristic features of each mineral, mutual relation to each mineral, and texture change continuously from the olivine type, via the hornblende-olivine type and olivine-hornblende type, to the hornblende type, and useful sharp boundary is not recognized (Table 9, Fig. 25). This fact strongly indicates that the hornblende type of inclusion may have been derived from the olivine type of inclusion.

The inclusions in the Tsubame lava show apparently intermediate features between accidental xenoliths in the Nishikawadani lava and inclusions in the Otagirigawa pyroclastic flow deposit. They are about 2% in volume to the whole rock with 4 m^2 in section. They are generally similar in form and size to the inclusions in the Otagirigawa pyroclastic flow deposit, namely rounded or oval and commomly a few cm's in size. But the fine grained inclusions (several mm's in diammer) which are often found out in the pyroclastic flow deposit are rather rare. Some contact parts of the inclusion are very porous in many cases.

The main types of inclusion in the Tsubame lava contain much olivine crystals (olivine type) or much opacite (opacite type). The inclusion containing pyroxene as main clored mineral is also subordinately present (pyroxene type).

The olivine type of inclusion in the Tsubame lava changes gradually the characteristic features such as mineral assemblage, texture, and features of each mineral, between the olivine type of xenolith of the Nishikawadani lava and the olivine type of inclusion of the Otagirigawa pyroclastic flow deposit (Table 9, Fig. 25). From this fact, it is considered that the olivine type of inclusion in the pyroclastic flow deposit may have been derived from the xenolith similar to the olivine type of xenolith in the Nishikawadani lava.

The opacite type of inclusion in the Tsubame lava is completely continuous in the characteristic features from the opacite type of inclusion in the above-mentioned

Table 9. Characteristic features of the minerals of the inclusions in the Nishikawadani lava, the Tsubame lava, and the Otagirigawa pyroclastic flow deposit. —: Free, +(Present) <++ <+++ (Rich), Opx: Orthopyroxene, Cpx: Clinopyroxene, Mt: Magnetite, br: Brown, pbr.: Pale brown, cl: Colorless, *: Numbers of measured crystal, Gm: Groundmass.

		Nishikawadani lava		Tsubame lava		Otagirigawa pyroclastic flow deposit			
		Olivine type		Olivine type		Olivine type	Horn-blende-olivine type	Olivine-horn-blende type	Horn-blende type
		Massive	Porous	Gm-poor	Gm-rich				
Gas cavity		—	+++	+++	++	++	++	+	+
Glass		—	—~+	—~+	—~+	+ br~pbr.	+ pbr. or cl.	++ colorless	++ colorless
Olivine	Reaction rim	—	—or+ Cpx	—or+ Cpx, Opx	—or+ Opx+Mt, Cpx	—or+ Cpx, Opx	+ Opx+Mt >Cpx	+ Opx+Mt	Mt+Opx aggregate only —
Olivine	2V (—) (γ) [Fo]	86.6(3)* (1.710) [80]	86.9(3)	86.2(3) (1.710) [80]	87.1(1)	86.5(4) (1.710) [80]	86.9(9)	86.3(1)	
Plagioclase	Zoning	—	Very thin rim(±)	Very thin rim	Oscillatory thin rim	Oscillatory rim	Thick oscillatory rim	Thick oscillatory rim	Oscillatory zoning
Plagioclase	Crystal with irregular calcic core	—	—	—	—	—	+	+	++
Plagioclase	Olivine as inclusion	+	+	+	+	+	+	+~—	—
Plagioclase	Crystal with dust inclusion	—	—	—	+	+	+	—	—
Plagioclase	Glass spots as inclusion	—	—	—	+	+	+	++	++
Plagioclase	Crystal with corroded margin	—	—	—	+	+	+	+	+~—
Opx (2V —) [En]	Phenocryst					65.7 [70]	61.8 [66]	60.2 [65]	55.5 [60]
Opx (2V —) [En]	Groundmass				59.6 [65]	65.9 [70]	68.4 [74]	59.7 [65]	59.3 [65]
Aggregate of plagioclase and olivine		+++	+++	+++	++	++	+	+	—

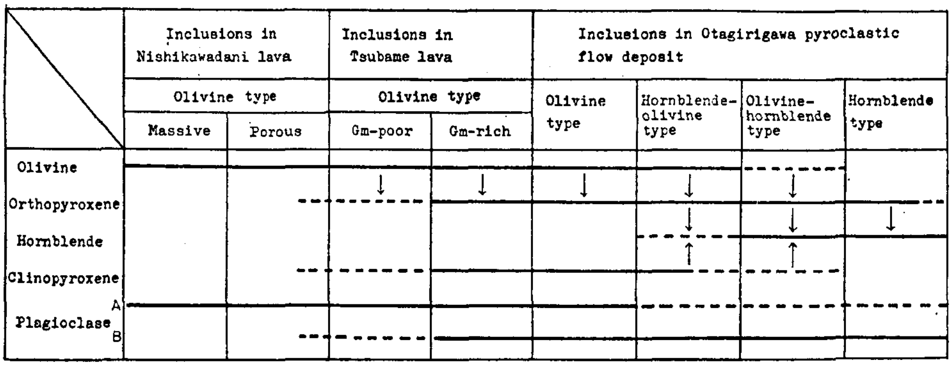

Fig. 25. Successive change of mineral assemblage from xenolith to the so-called cognate inclusion.
Arrow shows the observed order of crystallization.

pyroclastic flow deposit to the hornblende type of xenolith in the Nishikawadani lava, therefore the opacite type of inclusion may have been derived from the hornblende type of xenolith.

The pyroxene type of inclusion in the Tsubame lava partly maintains the same texture and mineral assemblage as the pyroxene type of xenolith in the Nishikawadani lava. The former may have been derived from the latter.

From the facts mentioned above, it may be considered that the inclusion which has been called cognate inclusion in the Otagirigawa pyroclastic flow deposit has been produced as the result of reaction of accidental xenolith with magma.

The following eruptives in MYOKO are also characterized by hornblende andesite; all rocks of the Yakeyama volcano, most rocks of the Myoko volcano Ist stage, rocks of upper part of the Myoko IInd stage, essential fragments of the Shibutamigawa pyroclastic flow deposit of the Myoko IIIrd stage, most rocks of the central cone of the Myoko IVth stage, rocks composing lapilli fall deposit (Sc-3) of the Kurohime volcano, many rocks of the Iizuna volcano Ist stage, and essential fragments of the Morozawa pyroclastic flow deposit, and most rocks of lava domes of the Iizuna IInd stage. All those hornblende andesites, contain a large amount of inclusions. Hitherto, these inclusions have been generally called cognate inclusion, and understood as rock fragments crystallized at the earlier stage in the same evolutional series as the host rock. But these resemble closely to those in the Otagirigawa pyroclastic flow deposit described above in mineral assemblage and especially in characteristic texture. This fact may indicate that the inclusions are also of the accidental xenolith origin as well as those in the Myoko IVth stage.

The microscopic observation on the inclusions of the Hakusan, Dainichidake, Daisen, Shirouma-Oike, Yatsugatake, Ontake*, and Yakedake* volcanoes, show similar petrographic characteristics especially in their texture to those of MYOKO. This fact may suggest that these inclusions are originated from the accidental xenolith, although we cannot obtain a conclusive point of evidence on its genesis for the present. Some differences concerning mineral assemblage in each inclusion may be caused by the original rock of xenolith, original magma, and degree of reaction of these two. If such inclusions were the fragments from the large mass crystallized at the eary stage, or formed by the accumulation of the eary crystals, some of intrusive body should be commonly provided such mass with the same texture as the inclusion.

The inclusion which derived from accidental xenolith by reaction with magma should not be called cognate inclusion.

V. GENETIC PROBLEMS OF THE ANDESITE, ESPECIALLY HORNBLENDE ANDESITE OF THE MYOKO VOLCANOES IN A VIEW POINT OF FIELD OCCURRENCE

The rocks constituting MYOKO are characterized by the andesite, especially hornblende andesite. Andesite characterizes the volcanic rocks in the island arc-orogenic belt, and its origin seems to be closely related to the problem of island arc. Recently, it has become one of the most interesting and important problems on earth science.

Many schools have different opinion concerning the boundary with basalt, but here is adopted 52.5 percent of silica content as boundary between the two. Andesite occurring in orogenic belt belongs to the rock series in which silica and alkali are generally increasing with the crystallization of magma, and a total iron oxides are decreasing and does not show an enrichment at the middle stage of the crystallization (KUNO, 1965). Such andesite is called calc-alkaline andesite or orogenic andesite, and almost coincides with andesite belonging to the hypersthenic rock series of KUNO (KUNO, 1965).

About the origin of calc-alkaline andesite, two groups of the hypotheses have largely been published. One is the hypothesis that andesite may be derived from basalt through some mechanism (BOWEN, 1928; KUNO, 1950; YODER, 1958; OSBORN, 1959), and the other is the hypothesis that the primary andesite magma may be produced directly in mantle or lower crust (WATERS, 1955; YODER, 1969; GREEN and RINGWOOD, 1968).

In MYOKO, hornblende andesite is generally common rock, and often occurs together with basalt and pyroxene andesite. It suggests that hornblende andesite may genetically related with basalt and pyroxene andesite. A definite

* Mr. T. KOBAYASHI kindly permitted the writer to use his many thin sections.

regularity between the growth history of the volcano and its petrography is observed in each volcano.

Iizuna volcano
The Ist stage: pyroxene andesite and hornblende andesite
The IInd stage: high alumina basalt→pyroxene andesite of the pigeonitic rock series*→hornblende andesite
Kurohime volcano: high alumina basalt→pyroxene andesite of the pigeonitic rock series→pyroxene andesite and hornblende andesite of the hypersthenic rock series*
Myoko volcano
The Ist stage: pyroxene andesite and hornblende andesite
The IInd stage: high alumina basalt→pyroxene andesite of the pigeonitic rock series→pyroxene andesite of the hypersthenic rock series→hornblende andesite
The IIIrd stage: high alumina basalt→pyroxene andesite of the pigeonitic rock series→hornblende andesite
The IVth stage: high alumina basalt→hornblende andesite→pyroxene andesite of the hypersthenic rock series→hornblende andesite
Yakeyama volcano: hornblende andesite

As above-mentioned examples in MYOKO, hornblende andesite appears always after the eruption of basalt or pyroxene andesite belonging to the pigeonitic rock series. From this fact, it is reasonable to assume that the hornblende andesite of this area is generated from basaltic magma through pyroxene andesitic magma by a certain mechanism. Bulk chemical composition mentioned above and new data of K, Rb, and Sr (ISHIZAKA, YANAGI and HAYATSU, unpublished) show fairiy good continuity from basalt to hornblende andesite in each basalt-andesite series.

In the xenolith which is commonly included in the hornblende andesite of MYOKO, the olivine crystals generally richer in forsterite content than those crystals of the basalt belonging to the same group are often included. As far as observed in the present area, the fragments of the pelitic or psammitic rocks taken in the basaltic magma can crystallize olivine in the certain stage of the reaction with magma. It is already mentioned that the olivine in the xenolith of the hornblened andesite of the Myoko IVth stage is the relict of the olivine which has crystallized by the reaction of the fragments of the pelitic or psammitic rocks with basaltic magma. Most of olivine crystals of the other hornblende andesite of MYOKO may be

* According to KUNO's definition (KUNO, 1954).

also the relict as well as those of the Myoko IVth stage.* It strongly supports the assumption stated abobe that the hornblende andesite of MYOKO may be derived from basaltic magma.

But it was proved by observation of many other intrusive bodies and many silicate melt studies that no calc-alkaline andesite such as hornblende andesite is derived from any basalt magma through simple fractional crystallization.

Then, special attention should be paid to the following fact. Namely, in each basalt-andesite series of MYOKO, a large amount of xenoliths are generally contained in basalt and/or pyroxene andesite, and indicate the reaction with magma. For example, fragments of siltstone or fine grained sandstone are changed into the aggregate of plagioclase and pyroxene, or plagioclase and olivine. This indicates that the primary chemical composition of xenolith was changed by the reaction with magma, and at the same time, that the chemical composition of magma itself was also changed by influence of xenolith. Nonmetamorphosed accidental xenolith is generally rare and hitherto called cognate inclusion or autolith occurs in a large amount in hornblende andesite of MYOKO. As described in the previous Section, such inclusions are originated from accidental xenolith. The fact that basalt or pyroxene andesite erupted before hornblende andesite in each basalt-andesite series includes a large amount of xenoliths, and hornblende andesite also contains those, of which reaction with magma has more progressed in comparison with the former, cannot be interpreted as simply accidental. It is reasonable to assume that the contamination of basaltic or pyroxene andesitic magma by the xenoliths are intimately related with genesis of hornblende andesite. The rapid increase of the ratio of K_2O and Na_2O in the rocks of MYOKO as shown in Fig. 22 may be the result of the contamination (YAMASAKI, 1956).

However, the amount of xenolith is several percent and is not over 10 percent of the whole rock, so far as observed in field. Therefore, relatively acidic hornblende andesite does not seem to be directly derived by simple contamination only (s. st.). It is already made clear by the investigation of TAYLOR on minor elements that calk-alkaline andesite can not be produced by such contamination from basalt (TAYLOR, 1969).

The hornblende is generally found as phenocrystic mineral, and extremely

* The rocks of the Shirouma-Oike volcano, situating just west of MYOKO and belonging to the volcanoes of the Southwest Japan, are also contained olivine-bearing xenoliths having very similar texture and mineral assemblage to those of the hornblende andesite of MYOKO (SAKUYAMA, 1975).

The rocks of this volcano are characterized by the common occurrence of the biotite phenocryst together with hornblende phenocryst as well as many other Quaternary calc-alkaline volcanic rocks of the Southwest Japan. If the olivine crystals in their xenoliths are same in genetic process as those of MYOKO, the biotite bearing andesites widely distributed in the Southwest Japan should be closely related with basaltic magma in their genesis.

rare as the groundmass constituent. It is never formed as the groundmass constituent even in the hornblende-rich reacted xenolith. In such xenolith, microphenocrystic hornblende is often rimmed by scale or needle-like clinopyroxene crystals of groundmass stage. From the above facts, the following assumption may be possible. Though hornblende has been crystallizing in the magma reservoir or the vent in the underground under condition of high water-concentration, it has been far from the condition to crystallize after eruption as the result that most of water in the magma escaped to atomosphere. Still more, as mentioned already, some amount of hornblende crystals are often produced at the very porous part (assumed to be formed by vesiculation at the eruption) of xenolith of the Nishikawadani lava (basalt). It may suggest that one necessary condition for crystallization of hornblende is high water-enrichment in magma. The following fact may also support the above-mentioned assumption. The later stage of basalt-andesite series is characterized by the explosive eruption of pyroclastic flow and by the formation of volcanic mud flow of violent steam explosion as the result of high pressure of water in magma. Among rocks which are the same as each other in solidification index or silica content, and similar to each other in other components except for water, some rocks contain hornblende, or others don't. The crystallization of hornblende is assumed to be largely controlled by water content in magma whose composition except for water is limited within a certain variation. TANEDA (1949) also concluded that the most important factor of the hornblende andesite genesis is the accumulation of the volatile matters.

The high concentration of water in basaltic magma may be also favorable for the genesis of other calc-alkaline (hypersthenic) series rocks (KUNO, 1965). The mineralogy and chemistry of the rocks of MYOKO are consistent with the KUNO's opinion for the genesis of the hypersthenic rock series (Figs. 8~10, 23).

It was already mentioned that xenolith seems to be closely related to the genesis of hornblende andesite. Now the xenolith seems to have played one of the most important roles to produce the hornblende andesite as transporter of water from wall rocks to magma. The magma in the present area has undoubtedly taken water from xenolith (chapter IV-B). Apart from the problem whether the parental magma of MYOKO have been originally rich in water or not, water from xenoliths, at least, must have promoted the crystallization of hornblende.

SUMMARY

1. Most of the rocks of MYOKO are pyroxene andesite and hornblende andesite, and the rest of the rocks are basalt (high-alumina basalt). Generally, the rocks tend to change from lower to upper in each group as follows: basalt→pyroxene andesite→hornblende andesite. The chemical composition and the mineral

assemblage of the rocks have well resemblance to those of the Chokai volcanic belt, and are different from those of the Nasu volcanic belt. The rocks may be distinguished from the Quaternary volcanic rocks just east of the MYOKO in common occurrence of hornblende phenocryst, and from those of Southwest Japan in absense of biotite phenocryst.

2. The K_2O content of the rocks tends to increase northward, namely from the Iizuna through Kurohime and Myoko to Yakeyama volcanoes. This tendency is keeping with the increase of K_2O content from the Pacific Ocean side to the Japan Sea side.
3. The "large anorthite crystals" were discovered in the Myoko volcano. They may have been formed through the reaction between the xenolith of the basal Neogene sedimentary rocks and the host magma under the condition of high concentration of water.
4. The inclusions which have been called "cognate inclusion" in MYOKO are considered to be accidental xenoliths which have remarkably reacted with magma.
5. The hornblende andesite of MYOKO may have been generated from basaltic magma. In producing the hornblende andesite, xenoliths seem to have played one of the most important roles as water transporter from wall rocks to magma.

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