PETROGRAPHIC NOTES ON THE VOLCANIC ROCKS FROM HARUNA, CENTRAL JAPAN PART I

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PETROGRAPHIC NOTES ON THE VOLCANIC ROCKS FROM HARUNA, CENTRAL JAPAN PART I

By

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Introduction

The writer is now undertaking geological and petrological investigations of the Haruna* volcano on the north of the Kanto Plain, Central Japan. Though the studies hitherto carried have been far from complete, some notable petrographic data were accumulated from the younger volcanic bodies occupying the eastern part of the volcano, and are, therefore, recorded here, as the first part of the papers that are intended to be published serially, according as the progress of the investigations, under the title of "Petrographic Notes on the Volcanic Rocks from Haruna, Central Japan." The data presented would be utilized for or incorporated in full and complete papers that follow. Moreover, the description may render it subject to future revision and supplement.

The investigations were commenced under the guidance of Professor S. TSUBOI and Assistant Professor H. KUNO in the Geological Institute, Tokyo Imperial University. At the present, they are continued in the Geological Institute, Kyūsyū Imperial University by kind encouragements of Professor K. SUGI. The writer must express his hearty thanks to S. TSUBOI, K. SUGI and H. KUNO to whom he owed many valuable suggestions.

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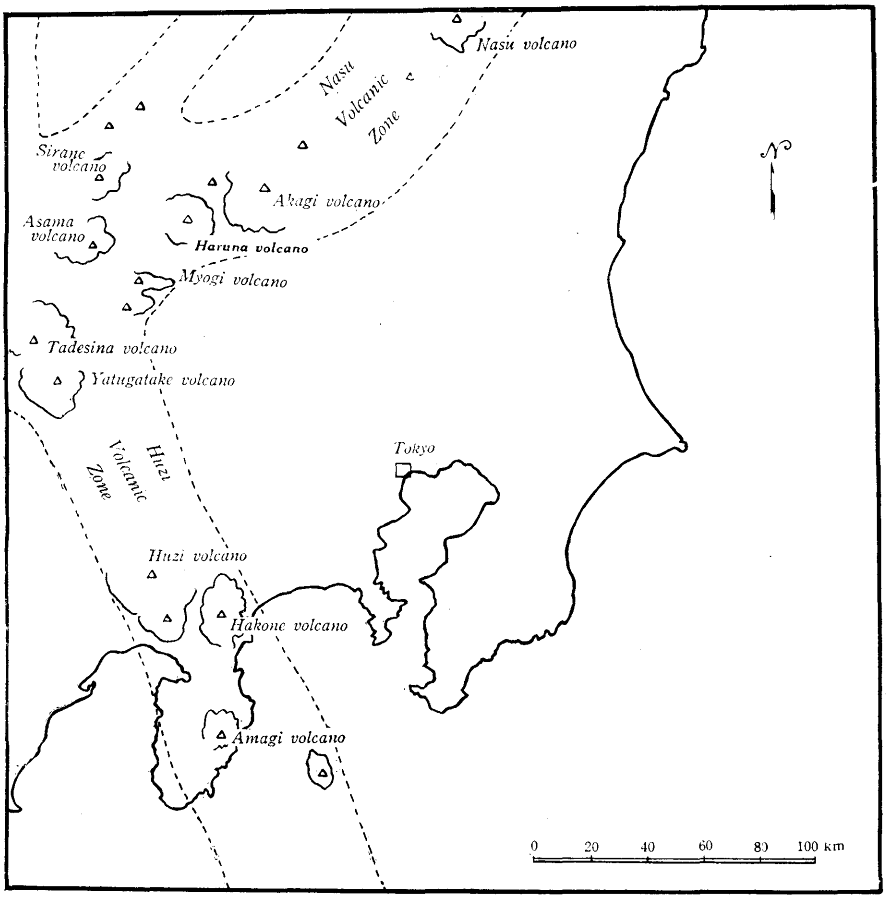


Fig. 1. Map showing the distribution of chief volcanoes adjacent the Haruna volcano.

I. Introductory Remarks on the Geology of Haruna Volcano, Central Japan

As the detailed report on the morphology and geology of the volcano will be published on a later occasion, only a brief account is given in this paper.

The Haruna volcano is an extinct one, standing at the northwestern corner of the Kanto Plain, Central Japan. It is a well shaped conical volcano which is made up of two bodies, the older and the younger.

The older one defines the general form of the volcano and the younger one has modified it on the top and the east flank, and it is a notable fact that while the older body is highly dissected, the younger one is not so eroded. The former is composed of solid lavas and pyroclastics of pyroxene-andesite, together with a few hornblende-andesites. The latter is composed of dome lavas and pyroclastics, i.e. the pumice bed and tuff-breccia, of hornblende-bearing dacitic andesite. In the older body the relation between solid lavas and pyroclastics is still uncertain, but as to the younger body it is clear, that is to say dome lavas of Somasan, Harunahuzi and Mizusawayama are covered by pyroclastics, while the Hutatudake lava dome is not mantled at all. History of the volcanic activity is summarized in the following table.

TABLE I. The eruptive sequence

The Older body:	Somma (eastern part)	Pyroclastics	Pyroxene-andesite (Hornblende-andesite)
		lavas (flow and intrusive)	Pyroxene-andesite
The Younger body:	Somasan	(pyroclastics)	Hornblende-andesite
		dome lava	,,
	↓ Mizusawayama	explosion crater	
		dome lava	,,
	Harunahuzi	dome lava	,,
	Zyagadake	dome lava	,,
	↓ Hutatudake	explosion crater	
		pyroclastics	,,
		dome lava	,,

Rocks

The majority of the rocks that were collected from various parts of the eastern half of the volcano are found to be of two general petrographic types, that is to say one type is hornblendic andesite (dacitic) and the another, pyroxenic andesite.

I. Pyroxene-andesite

1. Olivine-two-pyroxene-andesite.
2. Two-pyroxene-andesite.
3. Olivine-hypersthene-andesite.
4. Hypersthene-andesite.
5. Hornblende-hyperstene-andesite.

II. Hornblende-andesite
1. Augite-bearing hypersthene-hornblende-quartz-andesite.
2. Olivine- and augite-bearing hypersthene-hornblende-andesite (dacitic).
3. Hypersthene-hornblende-quartz-andesite.
4. Hypersthene-hornblende-andesite (dacitic).

Pyroxene-andesite is the product of the older volcanism and hornblende-andesite is largely that of the younger one.

Hornblende-andesite: Hornblende-andesite is rather uniform megascopically as well as microscopically. It carries prisms of lustrous hornblende and hypersthene and large phenocrysts of white plagioclase in the light grey, loose matrix.

Under the microscope, phenocrystic constituents are zoned plagioclase, green or brown hornblende, pleochroic hypersthene and magnetite, sometimes accompanied by a few augite, quartz and apatite. Olivine is almost always absent. Not uncommonly hornblende is opacitized to a more or less degree. Sometimes it is altered to oxyhornblende (pleochroic ruddyred to light yellowish green) in a red part of the rock. Hypersthene shows often zonal structure. Quartz shows an euhedral or corroded form and is surrounded frequently by grains of two kinds of pyroxenes.

The groundmass varies slightly in texture, from a felsitic type to intersertal one. The constituent minerals are plagioclase, pyroxenes, magnetite, alkali feldspar, quartz, tridymite or cristobalite, apatite and glass. Hypersthene is predominating and monoclinic pyroxene is usually absent in the groundmass of rocks that are lacking augite phenocrysts.

Pyroxene-andesite: Pyroxene-andesite is rather variable in relative amounts of phenocrysts, in granularity and in colour, and is distinguished easily from the hornblende-andesite above mentioned by its dark colour, somewhat granular form of phenocrysts or a compact feature.

Microscopically there are phenocrysts of zoned calcic plagioclase, light coloured hypersthene and one or two of olivine and light green augite. Olivine is often resorbed, with formation of corona made up of hypersthene grains or prisms (sometimes up to 1 mm.), occasionally accompanied by vermicular magnetite. Hypersthene is not uncommonly rimed by pigeonitic pyroxene grains. Intergrowth of hypersthene and augite in microphenocryst is not so rare.

The groundmass also varies slightly in texture, from a fine-grained campact type to a medium-grained holocrystalline type. The constituent minerals are plagioclase, pyroxenes, magnetite and alkali feldspar. Pigeonitic pyroxene is predominated and hypersthene disappears in many specimens.

II. Rhombic Pyroxene (I)

It is a remarkable fact that rhombic pyroxene is the most-characteristic mafic constituent and predominates usually in all types of rocks of the Haruna volcano. Consequently the writer's attention has been directed, first of all, to this mineral.

It occurs as phenocrysts, microphenocrysts and coronas around olivine, and in the groundmass also. Optical properties were determined on each of them in many specimens, and some notable data were obtained.

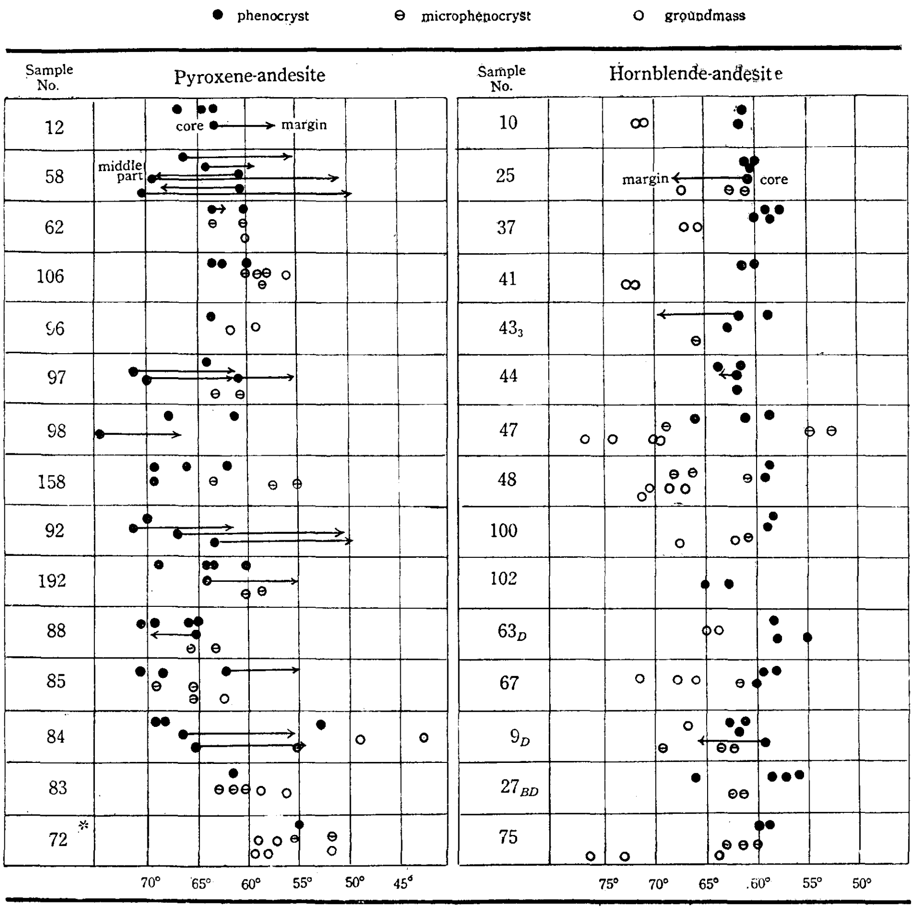
Optic Angle: Optic angle was measured by means of the univeral stage. A systematic difference was found between the mineral from pyroxene-andesite and from hornblende-andesite.

Rhombic Pyroxene in Pyroxene-andesite: Generally saying the phenocrystic rhombic pyroxene has larger optic angle ($(-)\,2\,V$) than the mineral of the groundmass, and the microphenocrystic one is intermediate, in optical angle, between the above two. Not uncommonly the phenocrysts show a zonal structure, in which optic angle ($(-)\,2\,V$) is larger in the core and smaller at the margin. The reverse case, in which the margin of the zoned phenocrysts shows large optic angle ($(-)\,2\,V$) than the core, is rather uncommon. The obtained values of optic angle are shown in Fig. 2.

Rhombic Pyroxene in Hornblende-andesite: So far as the writer's observation goes the phenocrystic pyroxene has smaller optic angle ($(-)\,2\,V$) than the mineral of the groundmass, and the microphenocrystic one is of the intermediate nature between the two. Occasionally a zonal structure is met with in the phenocrysts, in which optic angle ($(-)\,2\,V$) is always smaller at the core and larger at the margin.

The values of optic angle ($(-)\,2\,V$) are also shown in Fig. 2, along with those of the pyroxene-andesite.

Fig. 2. Optic angle (−) $2V$ of rhombic Pyroxene from the Haruna volcano



* Hornblende-hypersthene-andesite belonging to the older lava. This has been reported as hypersthene-hornblende-andesite by the writer(1).

Indices of Refraction: Indices of refraction were measured by means of the immersion method, and the values obtained are shown in Fig. 3, from which some noteworthy facts are mentioned below.

1. There is a tendency that the refractive indices of the rhombic pyroxene of hornblende-andesite are higher than those of pyroxene-andesite.

2. Refractive index β of the mineral is not, however, above 1.710 even in hornblende-andesite.

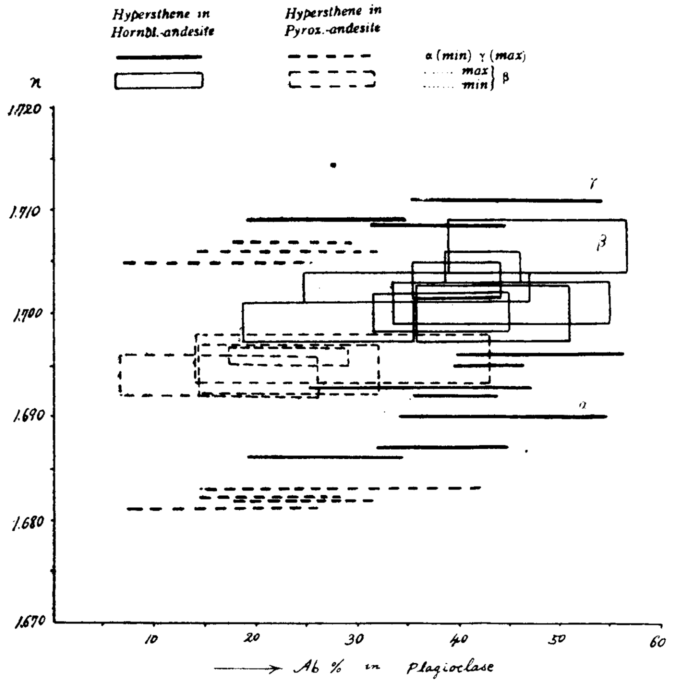


Fig. 3. Paragenesis diagram of hypersthene and plagioclase. Refractive indices of hypersthene vary slightly. α is taken the minimum value and γ the maximum value, while β the whole range.

3. Though the data are yet few, only two from hornblende-andesite (Nos. 48 and 67) and one from pyroxene-andesite (No. 192), it is remarkable that in the hornblende-andesite the phenocrystic rhombic pyroxene has higher refractive indices than the ground-mass pyroxene, while in the pyroxene-andesite the just reverse relation is exhibited*.

4. The difference of refractive indices between the core and the margin of zoned phenocrysts can hardly be discernible in most cases, but in the hornblende-andesite is found rarely porphyritic hypersthene that is surrounded by a narrow marginal zone with distinctly lower refraction*.

Estimation of chemical composition: There is urgent need for more accurate chemical and optical data on common rock-forming minerals, with which the petrologist is concerned. The variations in composition and optic properties in the orthorhombic

* These relations are not shown in Fig. 3.

pyroxenes have been examined by several investigators. A. N. WINCHELL prepared a series of composition-property variation diagrams in 1923[2]. The references given by him have been re-examined and it is found that some of the data are not reliable. N. L. BOWEN and S. F. SCHAIRER showed a diagram of variations of refractive indices (α, β and γ) with ferrosilite content[3]. the data being taken from the literatures, in which appear to be done the most reliable determinations upon the natural minerals. ROBERT WALLS reported "A review of the data for a revision of the enstatite-hypersthene series[4]," and N. F. M. HENRY added some data on the iron rich hypersthenes in 1937[5]. Both authors constructed the variation diagrams independently. S. TSUBOI also compiled a diagram of variation with respect to the principal refractive indices and optic angle of the series[6], based on the data from Japanese (volcanic) rocks. Recently, H. H. HESS and A. H. PHILLIPS collected the exact data of magnesian orthopyroxenes[7].

The diagrams given by these authors differ more or less to each other, and it is hardly decided that which of them is the most reliable.

As for instance, the hypersthene from Odawara-mati, Japan[8], which has the composition approximately *En* 62 *Fs* 38 in weight percentages and *En* 68 *Fs* 32 in molecular percentages, shows $\gamma=1.705$ (average) and $(-)\ 2V \doteqdot 60°$. Hypersthene with this composition is expected to have $\gamma = 1.717$ and $2V = 70°$ according to the diagram prepared by WINEHELL; $\gamma = 1.708$ according to that by N. L. BOWEN and J. F. SCHAIRER; $\gamma = 1.701$, $2V = 66°$, according to that by R. WALLS; and $\gamma = 1.696$, $2V = 70°$, according to that by N. F. M. HENRY.

The relation between the composition and the optical properties of the Odawara hypersthene, according to H. KUNO, agrees fairly well with the diagram by BOWEN and SCHAIRER and that by WALLS, while its deviation from the other diagrams is somewhat prominent.

A peculiarity of Japanese rhombic pyroxenes in their optical properties was already pointed out by S. TSUBOI[9] in his "Petrological Notes[9]." The optical angle $2V$ about X of Japanese rhombic pyroxenes is too small for their refractive indices, if the relation between them by A. N. WINCHELL[10] is taken as normal, as can be seen from the diagram compiled by TSUBOI, which was reproduced in Fig. 4.

At any rate, it seems to be undoubted, at the present, that refractive indices increase with increase in ferrosilite content in the rhombic pyroxenes, and the optic angle about Z also increases with increase in ferrosilite content from enstatite to *En* 55, or thereabouts, and then probably decreases again.

According to the diagram by R. WALLS the maximum value of the optic angle about Z is 128° ((−) 2 *V* ≒ 52°) at *En* 59, with $\gamma \fallingdotseq 1.728$, and according to that by N. F. M. HENRY it is 129.5° ((−) 2 *V* ≒ 50.5°) with $\gamma \fallingdotseq 1.728$ at *En* 55. H. H. HESS and A. H. PHILLIPS have suggested that there may be two types of iron-rich hypersthenes. Hitherto, it is often indicated that a determination

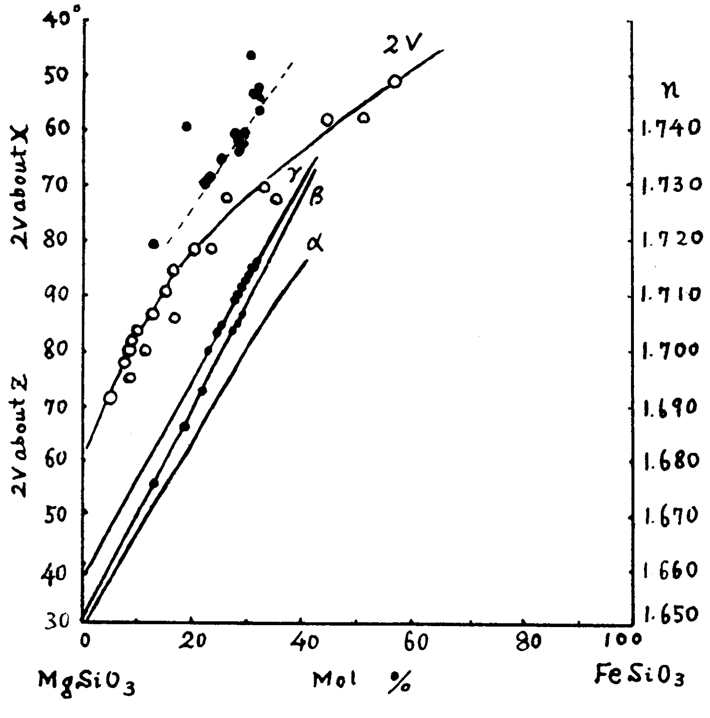


Fig. 4. Diagram showing a peculiarity of rhombic pyroxene from Japan, being taken from "Petrological Note[9]" compiled by S. TSUBOI. The full lines are WINCHELL's and the black dots are for Japanese pyroxenes, the latter being located so that points for either γ or β take their proper positions on the lines for refractive indices. The small open circles in the figure represent the actual values of 2 *V* of foreign rhombic pyroxenes, on which WINCHELL's curve for 2 *V* is based.

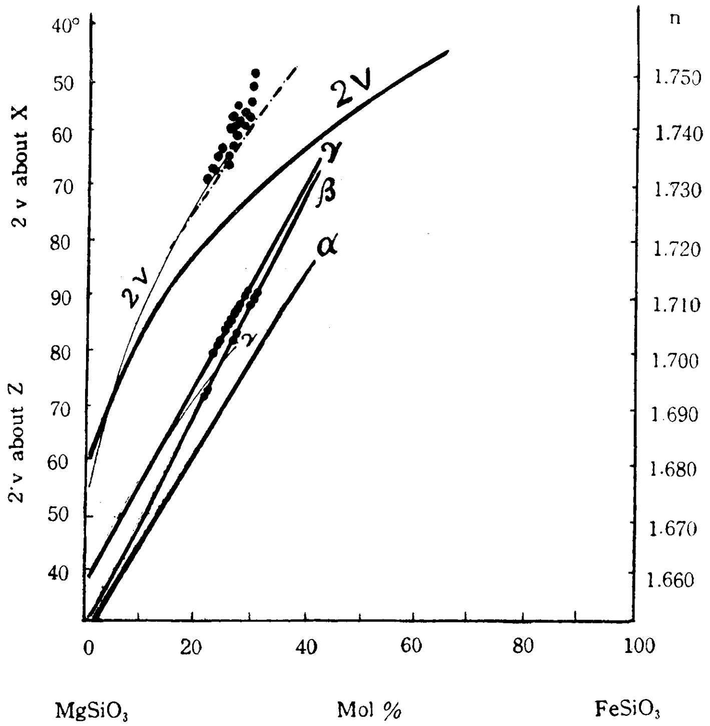


Fig. 5. Optic angle of Haruna's rhombic pyroxenes based on the curves for refractive indices by WINCHELL.
WINCHELL's diagram.
HESS and PHILLIPS' diagram.
Average $2V$ of Japanese rhombic pyroxenes (From Fig. 4).
Haruna's rhombic pyroxenes.

of the *En*: *Fs* ratio can be made with a high accuracy by measuring the refractive indices, especially γ. The determination of optic angle can easily be done, though the data being unreliable occasionally due perhaps to some variation caused by the presence of other constituents (CaO, MnO, TiO_2, etc.) or by the mechanical conditions, as strain[(7)].

In order to see whether Haruna's rhombic pyroxenes are normal or not in their optical properties, their optic angle was plotted, along with their corresponding refractive index γ or β, on the WINCHELL's diagram as shown in Fig. 5. It is clearly seen that they show the same feature as the general Japanese pyroxenes.

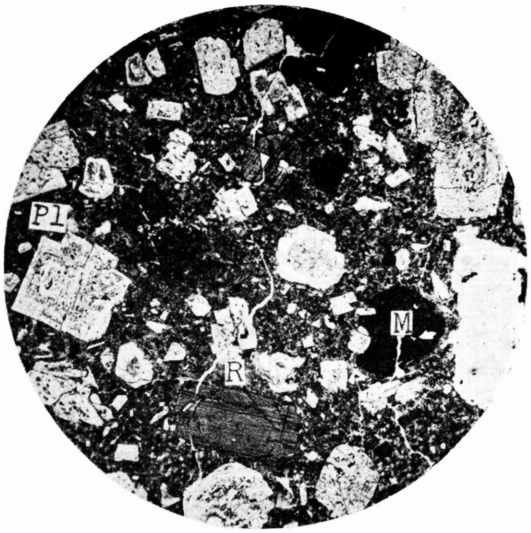


Fig. 6. Olivine- and augite-bearing hypersthene hornblende andesite from Hutatudake, a dome of the the younger bodies.
Pl–plagioclase, *M*–magnetite, *R*–hypersthene, showing the reversed zonal stracture. (X 16)

Consulting to the available data (both chemical and optical) of rhombic pyroxenes above mentioned, the estimated compositions of Haruna's pyroxenes may range from *Fs* 20 to *Fs* 40. the minerals from hornblende-andesite being, as a whole, slightly more *Fs* rich than those from pyroxene-andesite. In hornblende-andesite, hypersthene in the groundmass is always more *En* rich than the porphyritic hypersthene, while in pyroxene-andesite, hypersthene in the groundmass is usually more *Fs* rich than the porphyritic hypersthene. Zoning of hypersthene is reversal, without exception, in hornblende-andesite, but it is usually normal in pyroxene-andesite.

III. Hornblende (I)

This mineral occurs as phenocrysts in the dome lavas and pyroclastics of the younger bodies of the volcano.

There are three distinct mineral varieties, i.e. green, brown and red-brown types, and they are of great petrological interest. In size the crystals range from 3 or 4 mm. down to 0.2 mm., and exceptionally they become as large as 10 mm. in length. Usually

they are euhedral with well-defined prismatic, pinacoidal, and pyramidal crystal faces, but sometimes they are irregularly embayed with or without an opacite zone. In the latter case, they are closely associated with the granules or microphenocrysts of magnetite and hypersthene. They often enclose small laths or rods of plagioclase, grains of magnetite and microphenocrystic hypersthene. In some instances the hornblede is attached to hypersthene in such a manner as shown in Fig. 7.
Both the green and the brown hornblendes show not uncommonly such zonal structure as several zones of deeper colour and higher refraction being developed within a crystal or a layer of lighter colour and lower refraction forming the margin (Fig. 8). Twined crystals after 100 are not also rare.

Their optical properties are shown in the following tables (TABLE II (a) and (b)). The refractive indices were measured by means of the immersion method and the optic angle, with the uni-

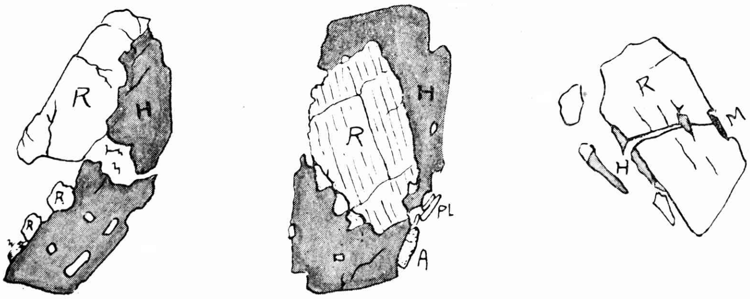


Fig. 7. The relation between hypersthene and hornblende in the thin section. *R*-hypersthene, *H*-hornblende, *M*-magnetite, *Pl*-plagioclase, *A*-apatite.

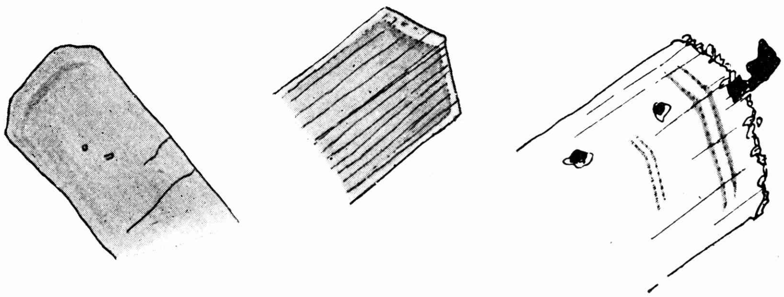


Fig. 8. Zoning in hornblende, shown by difference in colour and refraction.

versal stage. The red-brown hornblende shows strong absorption and more over not uncommonly undulatory extinction, consequently the optic angle being hardly determined.

TABLE IIa

Type		Pleochroism X	Pleochroism Y	Pleochroism Z	Refractive Indices α (min.)	β (min.)	β (max.)	γ (max.)	Optic Angle (−) 2 V	Absorption	Rock	
Green hornblende	1	Light orange green	Greenish yellow	Green	1.652	1.663	1.665	1.678	79–77°	Y≧Z≫X	The Hutatudake pumice	1
	2	Slightly greenish yellow	Deep chrysolite green *	Rinneman's green *	1.653	1.663	1.665	1.678	75–73°	Y≧Z≫X	A part of the Harunahuzi lava	2
	3	Greenish yellow	Yellowish green	Green	1.651	1.662	1.664	1.677	75–70°	Y≒Z≫X	A pumice fragment in tuff breccia	3
	4	Greenish yellow	Biscay * green	Green	1.652	1.664	1.665	1.679	71–68°	Y≒Z≫X	A bread crust bomb (core)	4
	5	Greenish yellow	Mignonette * green	Slightly smoky green	1.653	1.665	1.666	1.679	-71°-	Y≧Z≫X	A bread crust bomb (crust)	5
Brown hornblende	6	Dark yellow	Mignonette * green	Biscay * green	1.652	1.664	1.665	1.679	76–70°	Y>Z≫X	A block in tuff breccia	6
	7	Primose * yellow	Greenish dark orange	Slightly brownioh green	1.652	1.664	1.665	1.679	73-71°	Y≒Z≫X	A part of the Somasan lava	7
	8	Dark orange yellow	Greenish orange	Greenish brown	1.653	1.667	1.672	1.687	-64°-	Z>Y≫X	A block in tuff breccia	8
	9	Dark yellow	Greenish dark brown	Deep greenish brown	1.654	1.669	1.676	1.691	70-69°	Z>Y≫X	A part of the Hutatudake lava	9
Red-brown hornblende	10	Deep chrome-* Primose yellow	Zinc orange-* Red orange	Deep ruddy brown Flame scarlet *	1.684	1.700	1.711	1.735	60° ± ?	Z>Y≫X	A red part of the Hutatudake lava	10

* Colour name after S. Wada's "Colour Nomenclature"

TABLE IIb

Type	Optic Angle (−) 2 V	Approximating C∧Z
Green hornblende	70°,71°,72°,72°,67° (margin)-74° (core), 74°,75°, 75°,75°,76°,77°,77°,77°,78°,78°,79°,79°,80°,	22°-15°
Brown hornblende	64°,67°,68°,68°,69°,69°,70°,71°,71°,73°,73°,75°,77°,	20°-12°
Red-brown hornblende	(54°,57°,62°,40°-80°,67°,80°,)?	0°±

The red-brown hornblende occurs usually in rocks that are reddened and oxidized to some extent. In such rocks phenocrystic and microphenocrystic hypersthene are surrounded by the iron oxide rims, and magnetite grains (especially large ones) also show mantles of an oxidation product. These facts are clear sign of oxidation from the external sources. There are, however, some red-brown hornblende-bearing rocks which are megascopically not reddened at all and also microscopically show hardly any evidence that they were oxidized by the external sources.

The green hornblende is confined to pumice fragments, bread-crust bombs, and a part of the lavas, of which the groundmass is glassy or semiglassy.

The brown hornblende often occurs in holocrystalline or slightly vitreous rocks, as in blocks in the hornblende-andesitic tuff breccia and in the dome lava. A number of slices indicates that in the hornblende there are gradations in colour between green and brown, as well as brown and red-brown. Besides such intermediate varieties, there are some crystals that are partially green and partially brown or rarely partially brown and partially red-brown.

The writer therefore inferred that the red-brown type of hornblende from Haruna has been produced by oxidation from the green hornblende, and the brown varieties also by partial oxidation. The red-brown type must be a variety belonging to "oxyhornblende"(11)*.

It is wellknown that the green hornblende is altered to the red-brown hornblende (oxyhornblende) by oxidation and it will be well to refer the process as "auto-oxidation."

Experimental researches on the production of oxyhornblende

* "Lamprobolite" proposed by A. F. ROGERS (Amer. Min., vol. 25, 1940).

were done by KOZU[12], BARNES[13], KENNEDY and DIXON[14], etc[15]. KOZU found that the extinction angles in heated hornblendes remained unaffected until about 650°–700°C, but thereafter fell very rapidly, becoming almost zero at 800°, and zero at 900°. BARNES restored the heated hornblendes to its original colour and optical condition by reheating it in hydrogen.

MAGGREGOR's[16] recent opinion on the formation of oxyhornblende in comformity with experimental results is as follows.

Under magmatic conditions, and at a higher temperature, slight relief of pressure produces a colour change from green to brown because of partial auto-oxidation of ferrous iron, due to loss of some hydrogen or water. It is thought that the change is less likely to be caused by reheating of a semi consolidated or consolidated rock during a period of rising temperature in the preliminary stage of an eruption.

According to him, in Montserrat, however, red-brown type of hornblende occurs only in rocks that show clear signs of oxidation from external sources, and can not be fully elucidated by his hypothesis as has been recognized by himself.

As above mentioned, the oxyhornblende of Haruna occurs in some non reddened rocks as well as reddened ones and in the latter case it shows evidence of oxidation by outer sources at a still later stage than that which MAGGREGOR assigned. At the present, it is quite propable that while auto-oxidation under magmatic conditions is a principal factor of producing the oxyhornblende, oxidation by air plays also a part in the change under volcanic conditions, during a period of simmering under slight pressure in the throat of the volcano and of consolidation after an eruption.

Moreover it is easily considerable that in glassy rocks the sudden freezing of the hornblende crystals would render them immune to alteration. This hypothesis implies that the pumice and bread crust bombs represent the more deep-seated, gas charged, and less viscous part of the magma, in which the volcanic explosion originated. This hypothesis is favourable to the rocks from Haruna, since the phenocrystic plagioclase of pumice (green hornblende andesitic) is more *An* rich than that of more crystalline andesite with brownish hornblende, while there is a tendency that plagioclase of the hornblende-andesite is more *Ab* rich than that of the pyroxene-annesite.

The hornblende of Haruna shows two distinct types of "opacitization" phenomena.

(1) A "black" type in which the hornblende is wholly or partly replaced by a very fine grained aggregate, composed of minute granules of magnetite and pyroxenes and being predominantly black and opaque.

(2) A "pyroxenic" type in which the hornblende is replaced wholly or partly by a much less fine grained aggregate, with more or less parallel arrangenent of pyroxene and with some plagioclase and magnetite. Sometimes these crystals have been grown up to a considerable size.

In almost every case apatite appears to be subordinate to magneitite and hypersthene.

The green hornblende is generally unaltered in the most glassy rocks. A few crystals in a certain compact ejecta in a pumice bed show the "pyroxenic" opacitization. In one case the marginal part of prismatic green hornblende has been altered to the "pyroxenic" opacites in two zones, of which the inner part is composed of monoclinic pyroxene and the marginal zone of hypersthene. Although the both minerals are in parallel growth to the original hornblende, the former is rather granular and the latter is prismatic and eveloping the hornblende, partly filling the interstices of the former (Fig. 9, a).

The "black" opacitization occurs very slightly at the margin of the green hornblende with somewhat brownish tint in certain holocrystalline rocks (Fig. 9, b).

Usually the green hornblende has well-defined crystal faces, but such opacitized one shows an irregular outline with shallow embayments (Fig. 9, c). There are also few hornblendes with no "black" rim, in spite of its irregular form.

The brown hornblende has suffered both types of opacitization, which are developing not uncormmonly side by side even in a crystal. In such case a "black" core with some patches of the original crystal is succeeded outwards by a "pyroxenic" margin, the line of junction being irregular (Fig. 9, d–g). Sometimes the hornblende is completely replaced by dense aggregates of minute granules of magnetite, hypersthene and augite, together with a few feldspars. Although the core of the aggregate is rich in magnetite, the periphery is free from this mineral (Fig. 9, h). In some instances the core of the pseudomorph is coarse in grain size and the margin is fine grained and dark in spite of its less magnetite grains. The coarse-grained part is often hardly distinguishable from the "pyroxenic" type (Fig. 9, i).

Sometimes the whole crystal of a hornblende is replaced by well shaped crystals of hypersthene (up to 1 mm. in length) which are arranged in subparallel position with subordinate magnetite and feldspar (Fig. 9, j–l).

In some instances the inner part of the hornblende has been altered partially to the aggregate of pyroxene (usually hypersthene only) with or without few magnetites and feldspars. It may be one case of reaction occurring first along the cracks and fractures of the crystal.

In some slices are found the basal sections of the hornblende showing a peculiar feature of opacitization (Fig. 9, m and n). In these they are surrounded by a chain or aggregates that are composed of the rods of monoclinic and rhombic pyroxenes, with some magnetite grains and arranged diversely inwards. Rather large crystals of plagioclase and hypersthene are also found close by it. The hornblende is replaced by plagioclase, tridymite and glass, this occurring along the cleavage cracks and fractures. In another case, irregular shaped magnetite grains gather around the hornblende core, with interstices of glass and tridymite (?), small grains or rods of apatite being also associated with these minerals. In a certain case, minute grains of magnetite only replace the hornblende wholly. This phenomenon may be happened related with the opacitization, but it is not very likely all of the minerals are derived from the opacitization alone (Fig. 9, o).

The optical properties of the hypersthene replacing the hornblende in the "pyroxenic" opacitization are rather variable. For instance, in the Somasan lava, the optic angle of such hypersthene ranges from 50° to 64°, while that of phenocrystic hypersthene is from 58° to 62°, that of microphenocrystic one is 60° to 69°, and that of the groundmass hypersthene is from 65° to 72°. The refractive index (γ) of the hypersthene replacing the hornblende was measured on a slice by the immersion method, the obtained values are $\gamma = 1.700$–1.702, while phenocrystic hypersthene shows $\gamma = 1.704$–

1.709. In a part of the Hutatudake lava, optic angle of the hypersthene replacing the hornblende is intermediate between that of the phenocrystic hypersthene and that of the groundmass hypersthene. These relations are shown in the following table.

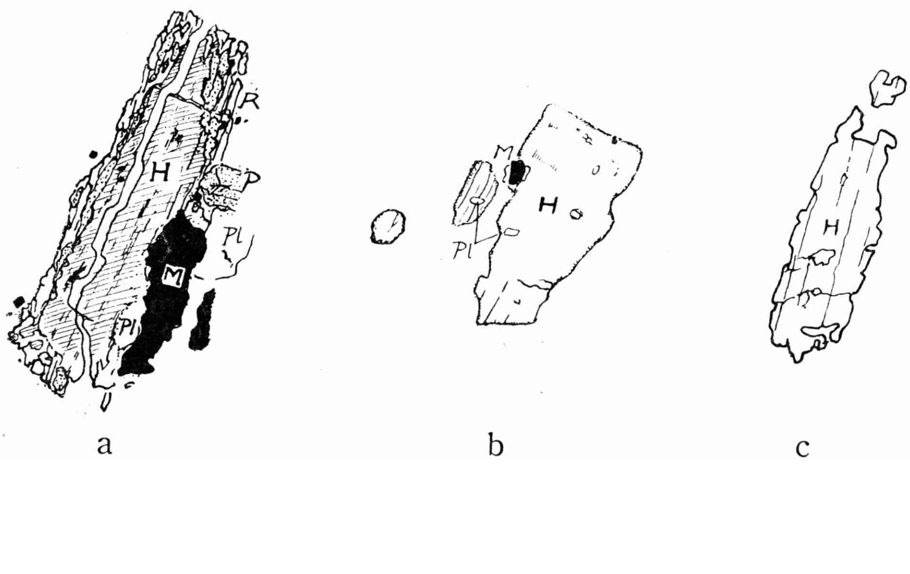
TABLE III

	Phenocryst	Microphenocryst	Groundmass
A part of the Somasan lava	59°,59°,62°, 60°,	61°,67°,68°,69°, 50°,61°,63°64°,	65°,67°,68°,69°,71°,71°,72°,
Apart of the Hutatudake lava	59°,60°,61°,	63°, 59°,60°,61°,70°,	69°,72°,73°,

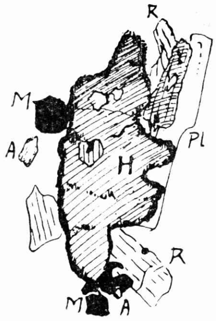
※ The upper rows show (−) 2 V of the normally crystallized hypersthene, while the lower ones are concerned with the hypersthene replacing the hornblende.

Fig. 9. Modes of opacitization.

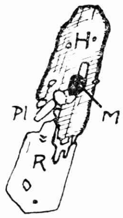
a–c, concerned with the green hornblende; *d–o*, concerned with the brown hornblende; and *p–s*, concerned with the oxyhornblende. *H*-hornblende, *R*-hypersthene, *P*-monoclinic pyroxene, *M*-magnetite, *Pl*-plagioclase, *A*-apatite, *G*-glass and *T*-tridymite.



a b c



d



e

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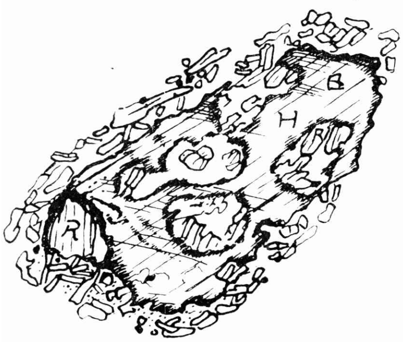

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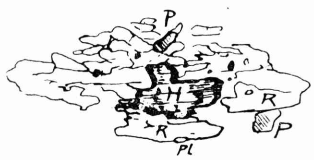

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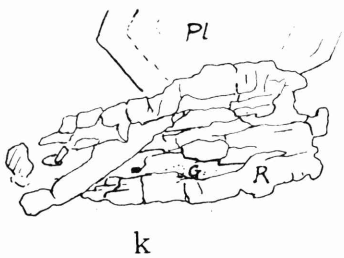

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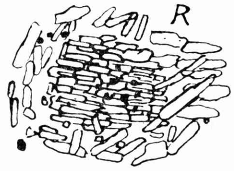
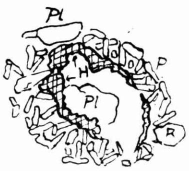
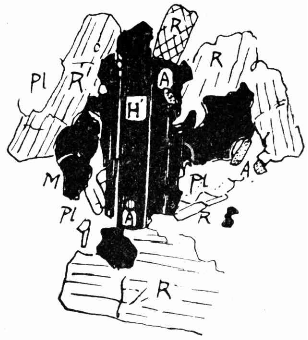


l


Pl
H
Pl
P
R

m


R
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Pl
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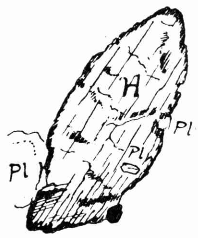
H
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R
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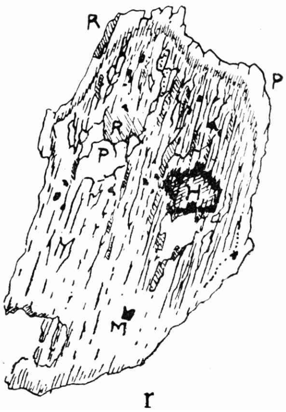
M

q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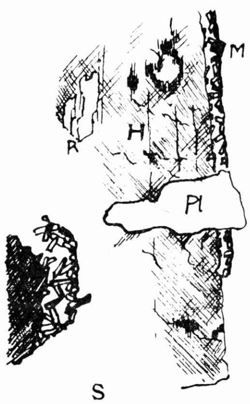
P
R
P
H
M
M

r


M
H
R
Pl

s

The oxyhornblende also shows both types of opacitization, the "black" and the "pyroxenic" ones (Fig. 9, p–r). The former is composed, however, of minute grains of pyroxene, magnetite and hematite which predominates specially in the reddened rocks. When the both types are developed side by side in a crystal, the latter prefers to take the outer position, that is to say the "black" zone around the original crystal is succeeded outwards by the broad "pyroxenic" margin. The "pyroxenic" type is composed of one or both of monoclinic and rhombic pyroxenes, associated with more or less magnetite and plagioclase as seen in the green and brown hornblendes (Fig. 9, r).

In some instance "the pyroxenic" zone is developed extensively and the monoclinic and rhombic pyroxenes are often in the form of close-set little prisms with parallel orientation (Fig. 9, q). Not infrequently, hypersthene (?) prisms, usually 0.02 mm. in length, stained to red-brown and being arranged diversely inwards, surround the oxyhornblende of somewhat ragged shape (Fig. 9, s).

The "black" type of opacitization was fully discussed long ago by WASHINGTON(17). He stressed the fact that these pseudsmorphs are much more common in crystalline than in glassy rocks, and concluded that the alteration is not due to reaction with the magma, but takes place when the mineral becomes unstable under conditions of diminished pressure and slow cooling from a relatively high temperature. He considered that the instability of hornblende compared with pyroxene is due to its much more complex chemical composition, and the alteration is simply a molecular rearrangement. On heating brown hornblende in nitrogen at one atmospheric pressure to a temperature between 1040° and 1100°C KOZU and YOSHIKI(18) found that it dissociates into a black opaque substance and expands enormously along the c-axis; at 1200°C rhombic pyroxene (?) and magnetite were seen in the aggregate.

The "pyroxenic" type of the opacitization was considered by MAGGREGOR(16) recently to be formed at greater depth than the "black" type. He pointed that the hornblende of the most glassy rocks including cognate xenoliths not uncommonly shows the "pyroxenic" type of alteration, and moreover the aggregate chemical composition must differs considerably. He suggested that the "pyroxenic" type may be due to a magmatic reaction.

So far as the writer's observation goes, both process of alteration of hornblende above mentioned seem to have occurred in the rocks of Haruna. At present he thinks that in Haruna's rocks some crystals of hornblende were reacted with the magma under certain conditions and produced the "pyroxenic" type, and then the relict parts surrounded by the "pyroxenic" rim became unstable owing to the diminished pressure and reheating under volcanic conditions, and dissociated to produce the "black" type.

Although, not uncommonly, oxidation and opacitization occur side by side in Haruna's rocks, both phenomena might have happened (rather) independently.

It is almost true without farther comments that the "pyroxenic" opacitization took place prior to the oxidation and the "black" opacitization, though the time relation between the latter two phenomena can not easily be decided. All of the reddened and oxidized rocks contain the oxyhornblende, but the mineral occurs also in some rocks that show no evidence of the oxidation by outer sources.

At the present it is likely that the auto-oxidation of hornblende begun at a rather earlier period than the "black" opacitization and continued to the stage of the latter, and moreover the partial oxidation by certain outer sources took place about contemporaneously or succeedingly to the latter period.

Summary

From the descriptions given above, the natures of Haruna's hornblendes are summarized below.

The green hornblende is confined to more or less vitreous rocks, and usually free from "opacitization." Although the "pyroxenic" alteration is found in one slice prepared from the essential ejecta, the "black" type is never found.

The brown- and oxy-hornblendes occur in much less vitreous rocks such as compact ejecta and dome lavas, and are never found in pumice and pumiceous rocks.

The brown hornblende is a transitional variety between the green hornblende and the oxyhornblende.

The brown hornblendes and oxyhornblendes show two distinct types of opacitization, the "black" and the "pyroxenic" types. Sometimes the both types are found not only in the one and same slice but also in the same crystal. In the latter case, the "pyroxenic" type forms a marginal zone.

Apatite shows also the interesting modes of occurence close by the opacitized hornblende.

Oxidation and opacitization occur side by side but rather independently. Oxidation may be of a post "pyroxenic" opacitization, and of a pre- and syn-"black" opacitization.

While under a certain depth green hornblende crystallized out in a magma, the condition of the magma changed succeedingly by some external or internal agencies and the hornblende was forced to react with the magma. In this period the magma was at rather high temperatures and heterogeous and the reaction type of opacitization was taken place to some extent. And then auto-oxidation of the hornblende due to slight relief of pressure happened partially. Through a period of rising temperature in the preliminary stage of an eruption and of consolidation succeeding to it, the hornblende was suffered to the dissociation type of opacitization and oxidation, not only auto- but also "allo-oxidation." These processes took place under the condition of slow cooling and low pressure and easily occurred at the periphery or along the cracks and fractures of the hornblende crystals.

IV. Apatite

This mineral is a minor accessory constituent of hornblende-andesite of the Haruna volcano.

Usually it occurs with magnetite side by side, sometimes as rods or grains, usually less than 0.2 mm. in length, and sometimes as well developed crystals, adhering to the magnetite, or being enclosed in or surrounded by the grains of the latter mineral. At the contact of the two minerals the apatite shows usually euhedral form against the magnetite, and such apatite is not rare to be more or less smokey. Rarely minute crystals of apatite are also scattered through the groundmass. Besides the apatite above mentioned, there is a porphyritic one. It is prismatic, up to 1 mm. length and with well-defined prismatic, pyramidal or basal faces.

A basal cleavage and indistinct vertical striae are developed, the smoky part often extending along the latter.

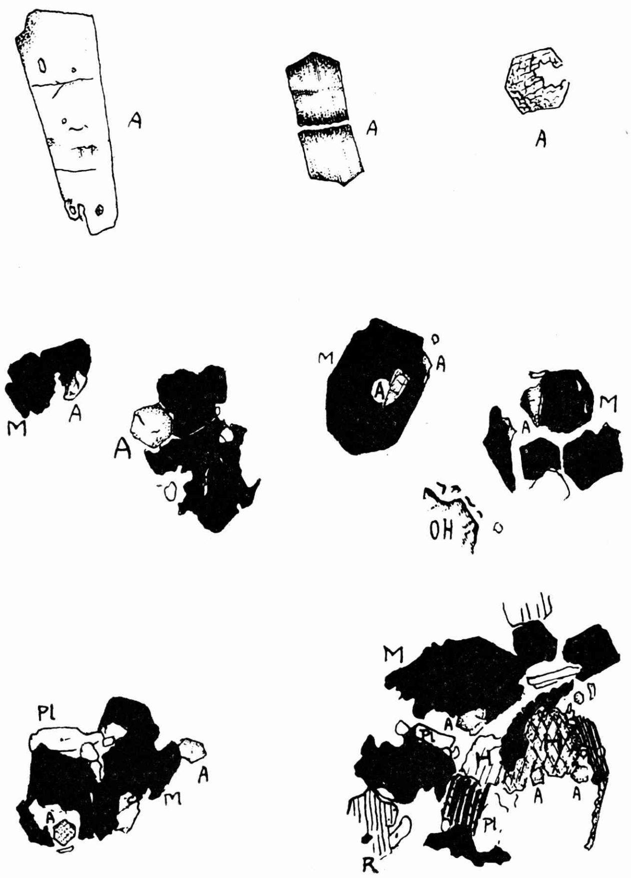


Fig. 10. Mode of occurrece of apatite in hornblende-andesite from Haruna. *A*-apatite, *Pl*-plagioclase, *R*-hypersthene, *M*-magnetite, *H*-hornblende, *OH*-oxyhornblende.

It is wellknown that in the form of minute microscopic crystals apatite is universally distributed as an accessory rock-forming mineral. It is found in all kinds of igneous rocks, especially abundant in basic type, and is supposed to be one of the earliest products of the original crystallization. An interesting fact that attracts the writer's attention is that in Haruna the mineral is almost limited to the hornblende-andesite and is hardly found in the pyroxene-andesite. And moreover it is notable that the mineral is characteristically associated with the magnetite. From the mode of occurrence of the apatite above mentioned, it seems to the writer at the present that the formation of this mineral is related not only to pure magmatic crystallization but also to opacitization, and if necessary, any other processes.

It appears to be conclusive that a part of the apatite and magnetite occurring side by side was formed at the stage of volatile concentration in a magma during or succeeding to the "pyroxenic" alteration of the hornblende.

The important role which the volatile constituents play during contamination in acid magmas has been emphasized by S. R. NOCKOLDS(19), who expressed an opinion that there was a preferential absorption of the volatile constituents by the xenolith. This conclusion was based partly on the relative abundance of apatite found in xenoliths and more contaminated portions of the magma when compared with the amount present in the invaded or invading rock. There are many examples that apatite is abundant in hybrid rocks, mixed rocks or altered xenoliths(20). GRANTHAM(21), in his paper on the Shap granite, mentioned the abundance of apatite needles in the andesitic inclusions and in the early basic granite (a hybrid).

In conclusion, the writer wishes to take this opportunity of offering his cordial thanks to Professor Kenichi SUGI of this Institute for his kindness in reviewing this manuscript.

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