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Part I : Basaltic Rocks from Hagi, Western Sanin

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https://hdl.handle.net/2324/1524089

出版情報：九州帝國大學理學部紀要 : Series D, Geology. 1 (3), pp.69-92, 1942-07-20. Faculty of Science, Kyushu Imperial University
バージョン：
権利関係：

Memoirs of the Faculty of Science, Kyūsyū Imperial University,
Ser. D, Vol. 1, No. 3. 1942

PETROLOGICAL STUDIES ON THE BASALTIC ROCKS FROM SANIN AND NORTHERN KYŪSYŪ, SOUTHWESTERN JAPAN

Part I. Basaltic Rocks from Hagi, Western Sanin

By

Ken-ichi Sugi

(Received Sep. 24th, 1941)

Contents

Introduction

Of the leading problems in igneous rocks, it must be the most outstanding one that is concerned to the nature of the primary magmas, from which are derived a series of igneous rocks (or magmas) through differentiation (mainly through fractional crystallization). Although we are yet far from obtaining the final solution, the petrographical literatures so far published suggest us, as emphasized by W. Q. Kennedy(1), the existence of the two contrasted types of basic magmas as parental ones, with respect at least to the effusive rocks. Of the two the one is of the undersaturated, olivine-basaltic magma type, and the other, of the slightly oversaturated, tholeiitic magma type. It seems also certain that the rocks believed to be the desents from these two basaltic

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(1) W. Q. Kennedy, Trends of Differentiation in Basaltic Magmas, Am. Jour. Sci., XXV, 239-256, 1933.

magmas are also mutually contrated in their petrographical characters. While the differentiates from the olivine-basaltic magma include trachyandesite, trachyte and alkalic liparite or trachyte and phonolite, i. e. the alkaline rock series, those from the tholeiitic magma are characterized by the rock series of pyroxene-andesite, dacite and liparite proper, i. e. the subalkaline rock series.

The distinctive features in mineralogy of the basic ends of the above two series were also clearly pointed out by KENNEDY, who layed the most stress on the nature of their pyroxenic components. According to him the pyroxene in olivine-basalt is basaltic augite close to diopside in composition, while in tholeiite it is pigeonite, and the crystallization of diopsidic pyroxene in the one and of pigeonite in the other (this being due to the difference in original composition of the basaltic magmas) determines in the main the trend of crystallization of the magma and favours the development of the alkaline differentiates in the one and the calc-alkaline residual liquids in the other. KENNEDY seems to regard the both types of basaltic magmas as primary ones, indicating, however, the remarkable fact that the olivine-basalt magma occurs both in the continental crust and the oceanic basins, while the tholeiitic magma is absent from the latter areas, apparently being connected in some manner with the presence of the granitic crust. T. TOMITA has concluded, in his elaborate works on the alkaline rocks from Dōgo, Oki Islands as well as from several areas in the Circum-Japan Sea region, that the parent of these alkaline rocks must be undersaturated olivine-basaltic magma. He regarded, in addition, the tholeiitic magma, which is well represented by the siliceous basaltic rock from the well-known Japanese volcanic zones, as a derivative from the olivine-basalt magma through silicification, taking into consideration, among others, the occurrence of "quartz-basalt" in some olivine-basalt areas in Sanin and Northern Kyūsyū.(1) In his recent work, "Die Entstehung der Gesteine, Teil I", T. BARTH also seems to show the sympathetic attitude towards the silicification theory for the tholeiitic magma in orogenic zones, although he still believes, like N. L. BOWEN, its deriva-

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(1) T. TOMITA, Geological and Petrological Study of Dōgo, Oki, 1-20, Jour. Geol. Soc, Tokyō, XXXIV-XXXIX, 1927-1932 (in Japanese), and On the Chemical Composition of the Cenozoic Alkaline Suite of the Circum-Japan Sea Region, Jour. Shanghai Sci. Inst, Sect. II, Vol. I, 227-306, 1935.

tion, on the whole, from the olivine-basaltic magma through fractional crystallization.(1)

But before coming to the conclusion, the more petrographical data are needed from these two types of basaltic rocks, in order to see whether they are really independent, primary magmas or the one, or only a portion of the one, is a derivative from the other through fractional crystallization or by some other way.

As indicated by TOMITA, Sanin and Northern Kyūsyū afford a good example of mixed petrographic province, in which olivine-basalt and quartz-basalt often occur side by side. Since last summer I commenced, therefore, to study the basaltic rocks from this region, and this paper forms the first part of the reports that will be published serially with the progress of the investigations.

The cost of this research has been defrayed from the Scientific Research Expenditure of the Department of Education to whom I express my sincere thanks. I am also indebted to Dr. S. YAMANE for the analysis of a clinopyroxene from olivine-basalt near Hagi, which was done in the chemical laboratory of the Imperial Geological Survey of Japan. Thanks are also to Mr. H. KOIDE of the Faculty of Agriculture, Tokyō Imperial University: through his kindness Mr. S. TAGUTI also analysed a rock specimen of quartz-basalt from Kasayama, Hagi.

Geologic Notes on the Basaltic Rocks

In the neighbourhood of Hagi, a small city bordering the Japan Sea at the western part of the Sanin district, there are many small hills and islets capped with the flows of basaltic rocks.

Of these rocks, those from KASAYAMA, which is built at least of two layers of lava flows, with a small cinder cone at its top, are spotted with small crystals of quartz and have been well known as "quartz-basalt" since the paper by S. KŌZU, who described in some detail the petrography of the rocks together with a chemical analysis.(2) Later these rocks were examined by T. TOMITA, who regarded the quartz crystals as xenocrysts and called special attension, as already mentioned, to their bearing on the problem of the tholeiitic magma. He recorded also the like rocks

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(1) T. BARTH, Die Entstehung der Gesteine, Teil I, 65-80, 1939.
N. L. BOWEN, The Evolution of the Igneous Rocks, 63-91, 1928.

(2) S. KŌZU, Preliminary Notes on Some Igneous Rocks of Japan, II, Jour. Geol, XIX, 561-565, 1911.

from Ōsima, a small island about 5 km due north of Kasayama.⁽¹⁾ Certain lavas of this area that are mapped as basalt in the 1/200,000 map of the Geological Survey are also of the related rocks, although they are more acidic than the above rock type (rather hornblende-andesitic).

The rest of the basaltic rocks belongs to the typical olivine-basalt, with olivine in the groundmass as well as among the phenocrystic constituents, being thus the undersaturated basaltic type. They also appear as mesa-like forms, as seen at Turuedai, Nakanodai, Kitunezima, Uyamamisaki and Sibuki. Excluding the last one, they all show very low elevations (less than 50 m above the sea level) and lie along the coast. With the probable exception of the first two close to Hagi, they seem to be mutually disconnected, not being the erosion relics from the originally much more extended lava flows, since they are more or less distinguished in texture as well as in modal composition. In other words each of them seems to have its own eruptive center near by.

The foundation rocks, on the erosion surface of which lie the basalts, are largely made up of quartz-porphyry and granite-porphyry that show the intrusive relation to the porphyrite complex (the Inkstone Series) and seem to belong to the late Mesozoic igneous groups of Tyūgoku. With the exception of the well preserved cinder cone of Kasayama all the basaltic rocks in this area may probably be the products of volcanism of the Pleistocene age, since at Kitunezima, immediate south of Kasayama, agglomerate and ash beds at the base of the olivine-basalt are in alternation with the gravel beds believed to be of the Diluvium (see Figs. 2 and 3)⁽²⁾.

Like the other basalt areas in Sanin and Northern Kyūsyū so far recorded pyroclastic materials are very poorly developed, which are only found locally at the basal part of the basalt at Kitunezima and Nakanodai and at the cinder cone of Kasayama. The explosive activities seem therefore to have been quite subordinate in the eruption of the basalts concerned.

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(1) T. TOMITA, op. cit. 294-302, 1935.

(2) Among the pebbles of the lowest gravel bed, whose pebbles are almost exclusively consisted of granite, granite-porphyry and quartz-porphyry, was found only one specimen of dark greyish aphanite, which was proved in thin section to be typical olivine-basalt. It must be originated from some basalt older than the gravel bed in question, although its source cannot be said with certainty.

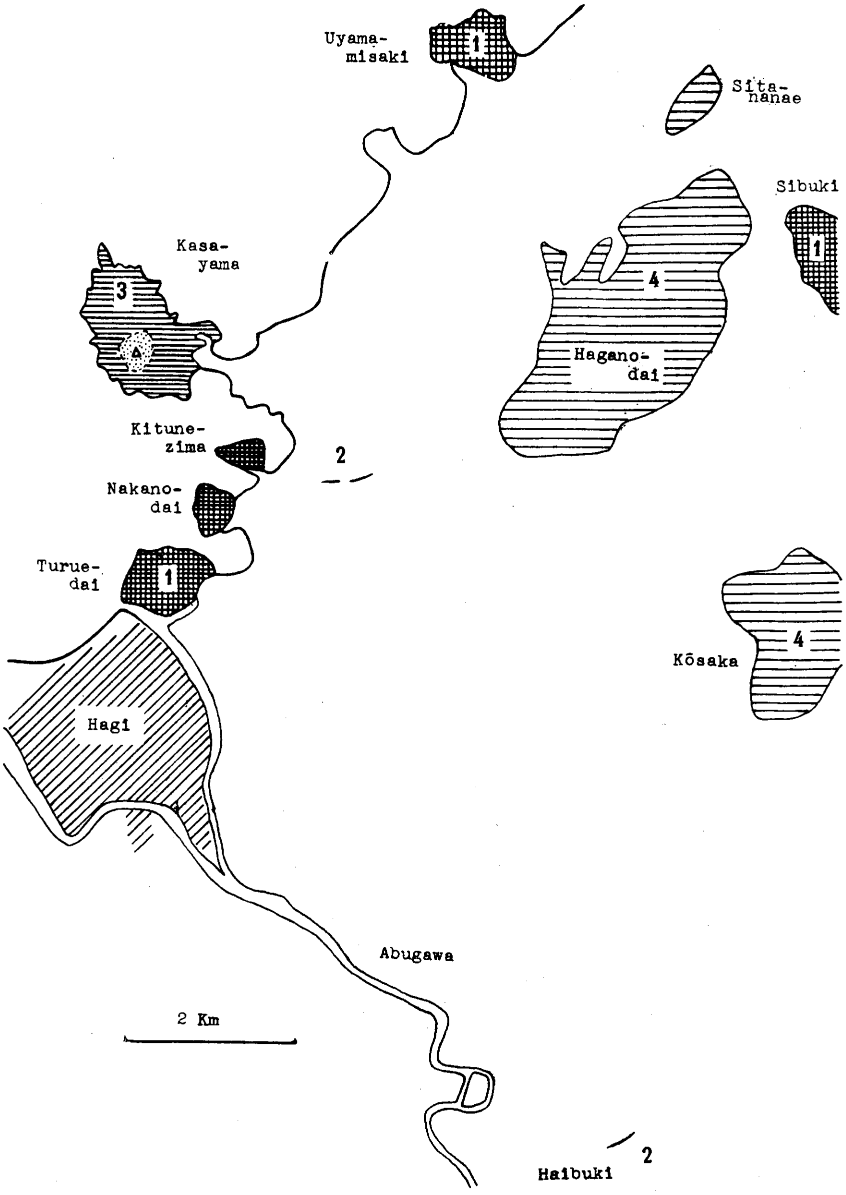

Fig. 1. Map showing the distribution of basaltic rocks near Hagi.

1, Olivine-basalt; 2, Quartz-dolerite; 3, Quartz-basalt; 4, Hornblende-andesitic rock with abundant quartz xenocrysts.

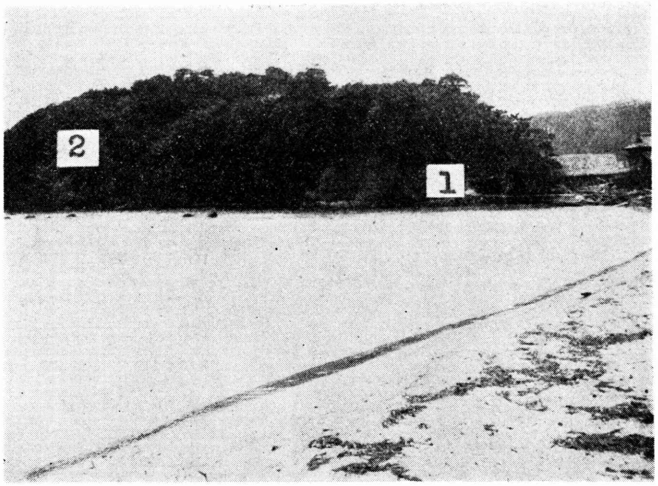

Fig. 2. Kitunezima viewed from the south.
1, Alternation of gravel bed, ash bed and agglomerate;
2, Olivine-basalt.

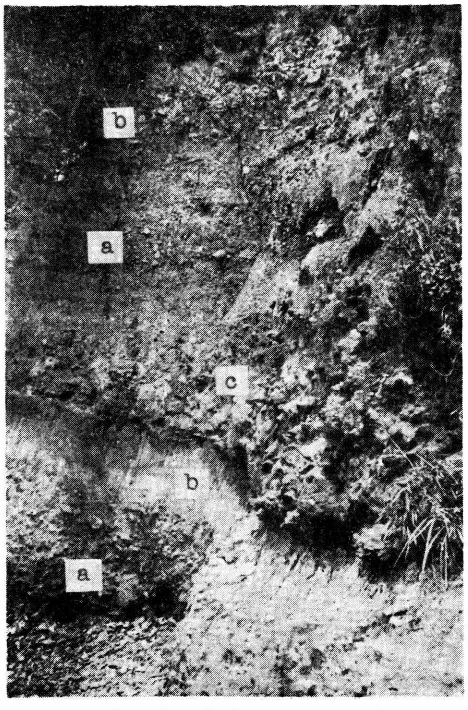

Fig. 3. Details of the part 1 in Fig. 2.
a, Gravel bed; b, Ash bed; c, Agglomerate.

Olivine-Basalt

As just noted olivine-basalt comes from Turuedai, Nakanodai, Kitunezima, Uyamamisaki and Sibuki. The rocks are generally dark greyish and aphanitic, spotted with a few, small crystals of yellowish olivine up to 2 mm in diameter. Very rarely xenocrysts of feldspar and quartz are met with in some lavas and in still rarer cases are found the xenolithic fragments of highly vitrified granitic rocks, which will be accounted in later pages.

In thin sections they are not constant in crystallinity, granularity, and in mineralogical composition. In the basalt from Nakanodai the rocks are rather fine-grained with some interstitial glass, and the optical determination of the constituents, especially of the clinopyroxene, is very difficult, while in that from Uyamamisaki and Kitunezima, and also in part from Turuedai, they are rather coarse-grained.

The notable facts that must be emphasized here with respect to their mineralogical compositions are the absence of rhombic pyroxene and silica minerals(1) and the constant, though not abundant, presence of olivine in the groundmass as well as the variation in the amount of interstitial alkali-feldspar. The proportions of the mafic and the felsic constituents show also slight variation, and about 40 to 45 % in volume of the rocks may be occupied by the former group of minerals. Of these the olivine and titaniferous magnetite respectively form ca. 1/6, and the clinopyroxene, the remaining ca. 4/6, of the mafic minerals. On the other hand, about 5 to 10 %, and sometimes as much as 20 %, of the feldspars may belong to the alkalic variety.

The larger part of the olivine occurs as small phenocrysts and microphenocrysts, mostly in euhedral to subhedral crystals and not showing any close association with the pyroxene. The mineral is almost colourless, without the trace of alteration·except the somewhat weathered rocks, in which it is stained by brownish red colour. The conoscopic observation showed that the optical angle of the mineral seems to be almost 90° or slightly less, with, in the latter case, negative character of mineral. From the highest and lowest refractive indices determined on the mineral from three

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(1) Rhombic pyroxene and cristobalite are found in very small amount in some part of the basalt from Turuedai, which will be accounted in later pages.

specimens, it must be ca. Fa 20 to 25 in molecular percentages (Fa 20–22 in No. 63, Uyamamisaki; Fa 24 in No. 43, Kitunezima; Fa 21–24 in No. 74a, Turuedai).

The clinopyroxene, the most prominent mafic constituent, is almost confined to the groundmass, and even if occurred as phenocrysts, it is very scarce and small in grain size, not exceeding 0.5 mm in length. It is light brownish, with a faint greenish tinge. Larger crystals often show hourglass structure. In order to see whether the mineral belongs to normal diopsidic augite or pigeonite, a preliminary conoscopic observation was done on a large number of grains so far as observable, which showed that the mineral must have moderate optical angle, probably about 50°, with no appreciable variation from grain to grain, either as the microphenocrysts or as the groundmass constituent⑴. This was also verified by the universal stage, the measurement with which was carried on the microphenocrystic to somewhat larger groundmass pyroxene from several specimens, the result being given below together with some data of the refractive index β.

Clinopyroxene from	2V (+)	β
No. 63, Uyamamisaki.	51°–56°, 54°–55°, 52°–55°, 55°.	1.685–1.702
No. 43, Kitunezima.	51°–52°, 50°–53°, 52°.	1.695–1.700
No. 70, Nakanodai.	50°–52°, 50°.	
No. 74a, Turuedai.	50°–51°, 52°, 52°.	1.695–1.700
No. 59, Sibuki.	50°–52°.	(all ± 0.003)

From this the clinopyroxene of the olivine-basalt seems to be diopsidic augite, rather uniform in composition.

The augite in the olivine-basalt from Uyamamisaki (No. 63), in which the finest grains of this mineral are larger than 0.03 mm in diameter, was separated from the rock by means of the magnet, heavy liquids, and centrifuge. From the finest powders passed through the mesh of 0.1 mm, the iron ore was removed by the hand magnet. The rest of the powders were then treated several times by the bromoform and centrifuge, the heavier olivine and pyroxene were thus separated from the lighter feldspars and glass. This heavier portion was then treated also repeatedly by the methylene iodide and centrifuge, the lighter fraction of which was proved to be almost wholly composed of the pyroxene grains.

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(1) The conoscopic method could not, however, be applied to the finest grains of the clinopyroxene in the groundmass, less than ca. 0.03 mm in diameter.

This material was analysed, though alkalies and H_2O being undetermined, in the chemical laboratory of the Imperial Geological Survey of Japan, with the following result.

TABLE I Chemical composition of augite from olivine-basalt, Uyamamisaki, Hagi. Analysed in the chemical laboratory, Imperial Geological Survey of Japan.

		mol. prop.		atom. prop.
SiO_2	49.71	828	Si	828
Al_2O_3	8.05	79	Al	158
Fe_2O_3	2.56	16	Fe'''	32
FeO	6.10	85	Fe''	85
MnO	n. d.			
MgO	14.18	355	Mg	355
CaO	17.07	305	Ca	305
Na_2O	n. d.		Ti	10
K_2O	n. d.		O	2706
H_2O+	n. d.			
TiO_2	0.75	10		
	98.42			

$(Ca, Mg, Fe, Fe''', Ti, Al)_{0.97} (Si, Al)_{1.00} O_{3.00}$;
Wo 41 En 41 Fs 18 in weight %.

$2V (+) = 51° - 56°$,
$\beta = 1.685 - 1.702 \pm 0.003$.

As seen from the chemical data, this mineral is very rich in Al_2O_3, the quantity of which is not, however, uncommon in the basaltic augite hitherto recorded. Apart from this feature it is rather close to diopside in composition, the metasilicatic composition in terms of wo, en, and fs constituting ca. 86 % of the bulk (wo 35.4, en 35.5, and fs 15.4).

The clinopyroxene of our olivine-basalt may generally be similar in composition to the analysed one, judged from the data of the optical constants above given.

As to the other mafic constituents much needs not be stated. The black iron ore is always conspicuous, being sometimes isometric and sometimes also tabular in form. The presence of ilmenite could not be ascertained, and the opaque mineral in this basalt may probably be titaniferous magnetite. Dark brown picotite is found occasionally, the larger grains tending to be associated with the phenocrystic olivine. Minute needles of apatite are also observed, being included in the interstitial plagioclase.

The plagioclase is also excluded from the phenocrysts. It forms small laths and somewhat larger and rudely tabular, interstitial crystals. The former is calcic labradorite, ca. An 70 to An 60, and the greater part of the latter is sodic labradorite to calcic andesine as sodic as An 40. But in some rocks, especially in those from Kitunezima, the more sodic one, probably oligoclase, is also found. Among the interstitial plagioclase is encountered the one apparently with small optical angle and showing just the same features as recorded by me shortly before(1). Such plagioclase is also quite common in other basaltic rocks of this area. Closely associated with such interstitial plagioclase and often forming its margin, occurs always the alkali feldspar, though quite variable in amount. It seems to be moderately sodic variety (anorthoclase), the highest index of the mineral from the olivine-basalt, Uyamamisaki (No. 63), being determined to be 1.529.

Quartz-Dolerite

Though there could not be found any dike connected with the flows of the basaltic rocks, either of the olivine-basalt or of the quartz-basalt, dikes of the doleritic rocks were observed at two localities, the one near Kitunezima, and the other near Haibuki, about 8 km southeast of Hagi, rather remote from any basalt flow in this area.

The former intrudes into the granite porphyry, and the latter, into the sedimentaries believed to be of the Palaeozoic Formation, the both occurring as small dikes with only 1 to 2 m in width. The rocks from these two dikes are megascopically fine-grained and dark grey with more or less a greenish tinge, and petrographically not like the olivine-basalt above described, but are much allied to the quartz-basalt to be accounted.

Under the microscope olivine seems to be absent, though there is some green, serpentinous material as interstitial matter, which may probably be altered glass. Colour index of the rock is also somewhat (ca. 10 %) lower than that of the olivine-basalt.

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(1) K. SUGI, On the Nature of Some Plagioclase apparently with Small Optical Angle etc., Mem. Fac. Sci. Kyûsyû Imp. Univ, Ser. D, Vol. I, No. 1,1940.

Clinopyroxene forms the bulk of the mafic constituents. As shown below, it has distinctly smaller optical angle than the augite of the olivine-basalt, and may properly be called pigeonitic augite.

Pigeonitic augite from (1)	2V (+)	β
(a), near Kitunezima	40° −47°, 40°− 47°, 40°− 33°	1.690−1.700
(b), near Haibuki	37°− 38°, 38°− 44°, 42°	(±0.003)

The other mafic ingredients are titaniferous magnetite, little actinolitic amphibole, reddish brown biotite and apatite, besides the interstitial serpentinous material (from the glass).

As to the felsic minerals, calcic labradorite forms laths, and less calcic one, i. e. sodic labradorite to calcic andesine, forms the interstitial matter. Some of the plagioclase from Haibuki is in part altered to albite. It must be specially noted that in these rocks quartz occurs, though little in quantity, interstitially together with the potash feldspar.

Quartz-Basalt

As already remarked, the lavas from Kasayama, immediate north of Kitunezima, have been well known as "quartz-basalt". Here we have at least two layers of lava flows, the lower and the upper, which are further overlain by a small cinder cone, with a craterlet at the summit and consisting of scoriaceous ejecta of the dark grey to blackish rocks as well as the oxidized, reddish ones.

The upper lava is more vesiculated and very dark grey to almost black, while the lower one is somewhat lighter in colour like the usual olivine-basalt, from which is distinguished megascopically by the constant presence of the clear quartz crystals, commonly 2 to 3 mm in diameter and rather uniformly distributed. They are more prominent in the upper lava, but even in this their quantity is not large, being estimated, in the mean, to be about 2 %. Xenocrysts of vitrified feldspar that looks like the fragments of white porcelain are also associated, though of very rare occurrence.

Under the microscope the lower lava is higher in crystallinity and shows more variation in its modal composition than the upper

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(1) The both specimens were collected by H. Kuroda, now student of the 3rd year course, of our institute.

lava, which bears always abundant brownish glass in mesostasis of the rock. Colour index of the rocks seems also to be somewhat lower than in the olivine-basalt.

All the rocks have a few small phenocrysts of olivine, usually in anhedral development and being surrounded by the small prisms or grains of both the rhombic and monoclinic pyroxenes. The olivine seems to be slightly higher in fayalite molecules than that from the olivine-basalt (Fa 28 mol. % in No. 7, the lower lava).

One of the most distinctive features of the quartz-basalt is the constant presence, as an essential mafic mineral, of the rhombic pyroxene, though it is variable in amount, and in some part of the lower lava it becomes indeed very scarce, the rock approaching mineralogically to the usual olivine-basalt. But in the greater part of the lavas the ratio of the clinopyroxene to the rhombic one was estimated to be about 3:1 to 1:1.

The rhombic pyroxene, as well as the monoclinic one, occurs mostly as the groundmass making mineral, and very rarely as small phenocrystic to microphenocrystic one. This mineral is not markedly pleochroic except certain small phenocrysts. The porphyritic one usually shows parallel growth, on its (100) plane, with the clinopyroxene. Of the two small phenocrysts examined with the universal stage, the one from the upper lava (No. 66) shows the zonal structure in which the core is optically positive with $2V=88^\circ$ and the margin is negative with $2V=74^\circ$, while the other from the lower lava (No. 7) shows the reverse relation, the core being negative with $2V=80^\circ$ and the margin, positive with $2V=84^\circ$. In the latter rock refractive index γ of the rhombic pyroxene was measured to be 1.690 to 1.695 ± 0.003. It must be poor in ferrosilite molecules, being about Fs 20 in mol. %.

The clinopyroxene also occurs largely in the groundmass, and is optically almost identical with that from the olivine-basalt, as seen from the following data.

		2V (+)
Augite from lower lava	No. 4	52°
	No. 5	50°
	No. 7	52°, 52°
upper lava	No. 2	54° – 55°
	No. 8	52°

Black iron ore (probably titaniferous magnetite) is also conspicuous in the groundmass, and occurs as small grains and dusts (globulites), being included in the brownish glass, in which are scattered minute needles of apatite as well.

The plagioclase is confined to the groundmass, as small laths and interstitial crystals, often intimately interwoven with the glassy base and thickly clouded with the opaque globulites. The former is intermediate labradorite, mostly about An 60 or slightly more sodic, while the latter is intermediate andesine, about An 40 or slightly more sodic(1).

Though not always found, alkali feldspar is met with in the rocks with higher crystallinity. It is very remarkable that the mineral cristobalite, foreign to the olivine-basalt, is found in most of the slices examined, though small and not constant in amount.

The quartz xenocrysts, not abundant but universally present, are in most cases roughly circular in outline, more or less corroded, and are surrounded by the small prisms or grains of clinopyroxene (with 2V estimated to be about 50°) that are intermingled with the brownish glass. Xenocrysts of feldspar are very rare, being observed only a few grains under the microscope. They belong to the plagioclase of andesine-oligoclase and are also highly affected, with a honeycomb like structure due to the partial vitrification that is especially marked at the peripheral part, as already described by me in the granitic xenoliths and xenocrysts in sanukite and related volcanic rocks from Northern Sikoku(2), and also as reported by Larsen and Switzer in the partially vitrified granodiorite xenolith in andesite from California(3).

Chemical analysis of a rock specimen from the upper lava (No. 8), which is nearly aphyric excepting the quartz-xenocrysts (ca. 2 %) and rather rich in the glass mesostasis, was done by S. TAGUTI, with the following result.

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(1) Some of the interstitial plagioclase is apparently very low in retardation and looks as if it shows gradual transition to the surrounding glass, just as the feldspar-like mineral in Cascade andesite of Oregon recently reported by Bogue and Hodge (Am. Min. XXV, 630-631, 1940).

(2) K. SUGI, On the Sanukites at the Environs of Takamatu, Sikoku, Bull. Volc. Soc. Japan, IV, 17-33, 1938 (in Japanese).

(3) E. S. LARSEN and G. SWITZER, An Obsidian-like Rock formed from a Melting of a Granodiorite, Am. Jour. Sci., Vol. 237, 562-568, 1939.

TABLE II. Chemical composition of the quartz-basalt from Kasayama (the upper lava), Hagi. Anal. S. TAGUTI.

SiO_2	55.90	Norm	
Al_2O_3	16.00	Q	6.48
Fe_2O_3	0.92	or	8.90
FeO	6.10	ab	29.87
MnO	0.12	an	23.35
MgO	4.84	wo	4.29
CaO	7.32	en	12.10
Na_2O	3.56	fs	7.92
K_2O	1.52	mt	1.39
H_2O+	0.98	il	3.04
H_2O-	0.14	ap	1.01
TiO_2	1.56		98.35
P_2O_5	0.37	Or 14 Ab 48 An 38;	
	99.33	Wo 17 En 50 Fs 33.	

In its rather high silica percentages as well as in its normative composition, i. e. rather low normative colour index (about 30) and sodic nature of the normative plagioclase (An 44 Ab 56), this rock is more andesitic than basaltic and may properly be called olivine-bearing two pyroxene andesite with xenocrystic quartz, though the name quartz-basalt is here still used.

Comparing to the andesitic rocks (aphyric ones) with the corresponding amount of SiO_2, say those from the Huzi volcanic zone, this rock is, however, much lower in iron oxides and higher in magnesia and alkalies, especially in potash. These distinctive features are also clearly seen from the norm of the respective rock, but it is remarkable that the normative pyroxene either in our quartz basalt or in the typical Japanese pyroxene andesite shows nearly the same amount of $CaSiO_3$, as seen from the tables II and III.

Basalt with xenocrystic quartz was recorded by E. Sakai from Daikonzima, near Matue, Central Sanin. According to him this rock is markedly porphyritic (dopatic to sempatic) with phenocrysts of labradorite and olivine (Fa 20) besides the quartz xenocrysts, and the groundmass consists of calcic andesine, pigeonite ($2V=30°-38°$), magnetite, ilmenite, cristobalite, and glass. Though the chemical composition of the rock is more basic (with yet very little normative olivine) than the quartz-basalt from Hagi, it may be said that it is mineralogically much related to the latter.

TABLE III.

	1	2	3
SiO_2	56.62	56.70	52.39
Al_2O_3	15.49	15.90	15.62
Fe_2O_3	4.58	2.94	1.50
FeO	7.09	7.74	8.06
MnO	0.22	0.18	0.13
MgO	3.00	3.34	6.92
CaO	7.33	7.77	8.68
Na_2O	2.95	3.13	3.43
K_2O	0.55	0.74	0.79
H_2O+	0.35	0.36	0.22
H_2O-	0.72	0.09	0.24
TiO_2	0.96	1.24	1.47
P_2O_5	0.08	0.16	0.33
	99.94	100.29	99.78

Norm	1	2	3
Q	15.48	11.82	
or	3.34	4.45	5.00
ab	25.15	26.72	28.82
an	27.24	26.97	24.74
wo	3.48	4.52	6.96
en	7.50	8.40	16.40
fs	8.06	10.16	10.56
fo			0.63
fa			0.51
mt	6.73	4.18	2.09
il	1.82	2.43	2.89
ap	0.34	0.34	0.67
	99.14	99.99	99.27
Wo	18	20	20
En	40	36	49
Fs	42	44	31

1, Aphyric andesite, Aziro, North Izu (after H. Kuno)(1).
2, Aphyric andesite, Hakone (after H. Kuno).
3, Basalt with xenocrystic quartz, Daikonzima, near Matue (after E. Sakai)(2).

The rocks, with much similarity to the quartz-basalt above described, but with more acidic compositions, are developed in the northern and eastern parts of the area investigated. They come from the lava plateaus of Haganodai and Kōsaka and a lava flow at Sitananae.

They are megascopically characterized by the porphyritic hornblende in black, lustrous prisms up to 1 cm in length and also by the xenocrystic quartz and feldspar that are much more abundant than in the previous rocks (see the annexed photograph). The rocks from the former two localities are almost black and

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(1) H. Kuno, On the Chemical Compositions of Volcanic Rocks in Izu and Hakone Districts, Bull. Volc. Soc. Jap. III, 53-71, 1936 (in Japanese).

(2) E. Sakai, Geology of Daikonzima, with Special Reference to the Basalt with Xenocrystic Quartz, Jour. Geol. Soc. Jap. XLVI, 275-277, 1939 (in Japanese).

compact and very low in crystallinity and granularity of the groundmass, while those from the last locality is light grey in colour and somewhat higher in crystallinity.

Fig. 4. A xenolith of granitic rock (a) and numerous xenocrysts of quartz and feldspar in the hornblende-andesitic rock from Sitananae.

They are all rather poor in the mafic constituents in their groundmass, in which the coloured minerals are almost confined to the minute prisms of rhombic pyroxene (also poor in ferrosilite molecules, γ of the mineral in a specimem from Kōsaka being determined to be 1.695 ± 0.003) and little magnetite. It is also noticiable that in the rocks from Sitananae cristobalite becomes a prominent constituent of the groundmass besides the one developed on the margin or along the cracks of the xenocrystic quartz (see Fig. 4, Pl. IV)

Phenocrysts are much more abundant than in the rocks from Kasayama. The most prominent ones are the brownish hornblende, mostly and often completely altered to the black opacite associated with the grains (rather large) of augite. The latter mineral occurs also as isolated, sporadic microphenocrysts, with somewhat larger optical angle than the augite in the basalts of this area, 2 V (+) ranging from 53° to 60°. On the contrary rhombic pyroxene is not found among the phenocrysts, in which olivine is noticed, however, very rarely in the rocks from Haganodai. Lath-shaped to tabular crystals of labradorite are also conspicuous as microphenocrysts.

Mineralogically these rocks must therefore be hornblende-andesitic, certainly being more acidic than the quartz-basalt from Kasayama.

Genetical Relation of the Quartz-Basalt to the Olivine-Basalt

From the petrographical description given in the foregoing pages we see some distinctive features between the olivine-basalt and the quartz-basalt, although these two types of rocks are also closely related geologically as well as in certain mineralogical aspects. It must be stressed here that in the olivine-basalt magnesian olivine and augite seem to be in parallel crystallization and quartz and other silica minerals are excluded from the constituents, while in the quartz-dolerite olivine is absent and the pyroxene is pigeonitic augite, with moreover the interstitial quartz, and in the quartz-basalt very little phenocrystic olivine seems to be in reaction relation with the pyroxenes, being surrounded by the rims consisting of both the rhombic and monoclinic pyroxenes, and the latter two minerals, though variable in their relative proportions, are also the characteristic constituents of the rock, together with the cristobalite and the resorbed quartz xenocrysts universally present.

Thus apart from the undersaturated nature of the olivine-basalt and the slightly oversaturated nature of the quartz-basalt, these two groups of rocks are distinguished in their bulk pyroxenic composition, which must be augitic (diopsidic) in the former and rather pigeonitic in the latter.

On the other hand there is some connecting link between these two rock types. Some part of the quartz-basalt investigated is indeed poor in the rhombic pyroxene, resembling more to the olivine-basalt. As already noted the xenocrysts of quartz, and much less those of feldspar, are not confined to the quartz-basalt, but are sometimes met with in the olivine-basalt. At two localities (the one at Nakanodai, and the other at Turuedai) were observed the xenoliths from granitic rocks that are irregularly shaped, often streaky in appearance, and are highly vitrified.

They show just the same microscopical features as the granitic xenoliths in sanukites from Northern Sikoku and the granodiorite xenolith in andesite from California already cited, and need not be described in detail here.

All the mafic minerals of the original rocks have been completely altered to the opaque material and feldspar and quartz are also in part vitrified, the glass (usually slightly brownish) or its devitrification product forming irregular networks or patches through the rock and sometimes looking like the glassy base of the effusive rocks, with newly crystallized prisms of hypersthene and augite (see Fig. 4, Pl. III). At Turuedai some olivine-basalt near the xenoliths is also mineralogically distinguished from the normal type in that it contains, though very small in amount, magnesian hypersthene (Fs 20—24) and cristobalite in the more or less leucocratic groundmass along with the augite, magnetite, andesine, and alkali-feldspar (see Fig. 3, Pl. III). Of the two specimens, whose augite was examined with the universal stage, the one has the augite with slightly smaller optical angle than in the usual rocks ($2V=48°$, $47°$, $47°$ in No. 77; $2V=51°$, $51°$, $50°$ in No. 78). Thus the hypersthene and cristobalite-bearing facies of the olivine-basalt shows the affinity to the quartz-basalt.

It is therefore beyond doubt that the latter group of rocks has been derived from some olivine-basaltic magma through the incorporation of the granitic materials, either wholly or differentially.

Although the analysis of our olivine-basalt has not yet been undertaken, but the probable composition of the rock, and accordingly that of the basaltic magma, can be calculated, if the mode of the rock is appropriately taken, since in such rock the compositions of its constituents must be rather simple except the clinopyroxene, the most important mafic mineral of the rock. As to the latter, however, chemical composition of the analysed augite already given may well be adopted. Assuming now the modal composition to be 7 % Or 50 Ab 50, 48 % An 50 Ab 50, 8 % olivine with 30 Fa in weight %, 30 % augite with the composition of the analysed one, and 7 % iron ores (4 % magnetite and 3 % ilmenite), we have the chemical composition of the basalt shown in column 1 in Table IV.

It is in composition much more alike the Tomita's East-Asiatic basalt than the typical Japanese basalt with excess silica. It is only distinguished from the former by its lower potash (ca. 1.5 % lower) and higher magnesia (ca. 2 % higher), as seen from the data shown in Table IV (see 1, 5, 6 and 7).

TABLE IV

	1	2	3	4	5	6	7
SiO_2	49.8	56.3	71.5	53.0	49.6	49.60	51.25
Al_2O_3	17.3	16.6	14.9	16.9	17.0	16.96	14.73
Fe_2O_3	3.6	1.0	0.3	2.0	3.2	5.40	3.82
FeO	6.2	6.4	1.4	6.6	7.0	6.65	10.22
MnO						0.21	0.28
MgO	7.5	5.2	0.1	6.3	5.3	5.92	5.47
CaO	10.0	7.6	2.0	8.8	10.0	10.03	11.73
Na_2O	3.2	3.7	4.9	3.5	3.6	2.48	1.85
K_2O	0.6	1.6	3.8	1.1	2.2	0.58	0.26
TiO_2	1.8	1.6	1.0	1.7	2.1	1.40	0.81
P_2O_5						0.20	0.13
	100.0	100.0	99.9	100.0	100.0	99.43	100.55
Q		3.7	24.5	0.2	4.3 (ne)	3.78	5.41
or	3.3	9.5	22.2	6.7	12.8	3.34	1.67
ab	27.3	31.4	41.4	29.3	22.5	20.97	15.73
an	31.1	23.9	7.5	27.2	23.9	33.38	30.88
wo	7.8	5.8	1.0	6.8	10.8	6.50	11.03
en	12.8	13.0	0.3	15.8	6.7	14.76	13.65
fs	3.4	8.3	0.5	7.7	3.4	5.80	14.77
fo	4.3				4.6		
fa	1.4				2.5		
il	3.5	3.0	2.0	3.2	4.0	2.73	1.52
mt	5.3	1.4	0.5	3.0	4.6	7.87	5.56
ap						0.33	0.33
	100.1	100.0	99.9	99.9	100.1	99.46	100.55
Wo	33	21		22	51	24	28
En	53	48		52	32	55	35
Fs	14	31		26	17	21	37

1, Composition of the olivine-basaltic magma assumed.
2, Quartz-basalt from Kasayama being modified and recalculated to 100.
3, Composition of the material added to the olivine-basaltic magma (1).
4, Composition of the basaltic magma produced from the olivine-basaltic magma (1) by the contamination of granitic material shown under 3.
5, Composition of some East-Asiatic basalt computed from the data given by Tomita(1).
6, Olivine-basalt (almost aphyric) from Hōeisan; Huzi; and 7, Aphyric basalt from Ōsima (after H. Tsuya)(2).

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(1) T. Tomita, op. cit. 262-263, 1935.

(2) H. Tsuya, On the Volcanism of the Huzi Volcanic Zone, with Special Reference to the Geology and Petrology of Izu and the Southern Islands, Bull. Earthq. Res. Inst., XV, 307 and 298-299, 1937.

If the analysed quartz-basalt from Kasayama is taken, for a while, to have been derived from this olivine-basaltic magma through the contamination by some granitic material, the probable composition of the latter can easily be determined graphically.

In doing so was subtracted, however, ca. 2 % SiO_2, corresponding to the xenocrystic quartz present, from the bulk composition, as well as removing such oxides as MnO, P_2O_5, and H_2O, and the rest was recalculated to 100. From the diagram shown in Fig. 5. it must be granitic rather rich in soda, the composition of which is also given in column 3, Table IV. But this diagram indicates at the same time that 100 parts of the basaltic magma must resolve 43 parts of the granitic material, which seems to be almost impossible unless the enormous quantity of heat be available from some sources.

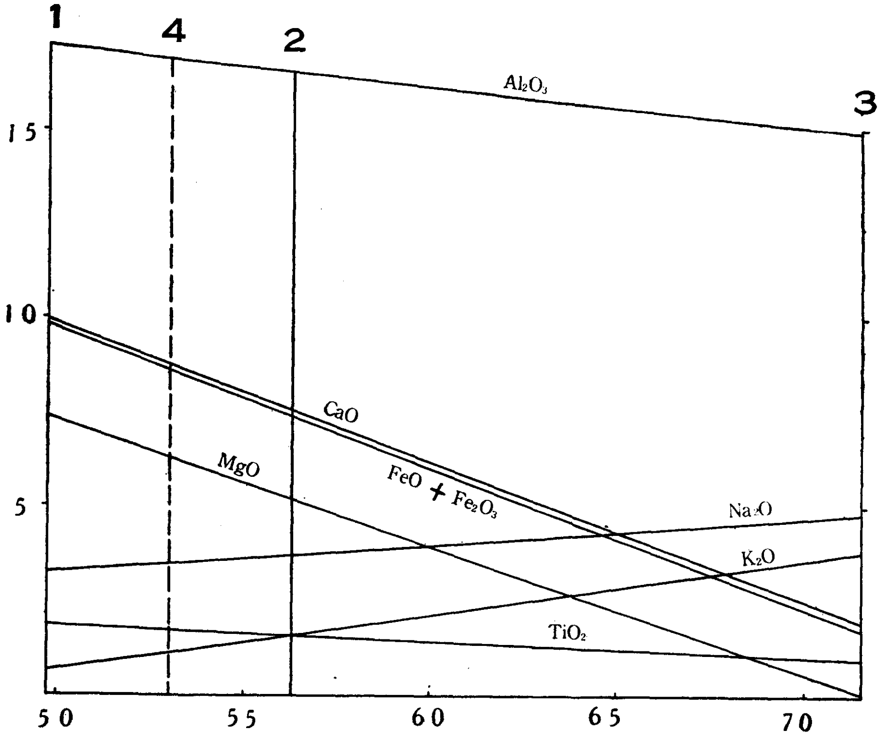

Fig. 5. The diagram to show the derivation of the quartz-basalt (2) or the more basic basaltic magma (4) from the olivine-basaltic magma (1) and the granitic material (3).

It is a very remarkable fact that in those parts of the variation diagrams of the subalkaline rock series, in which silica percentages are higher than 52 or 53, the variation curve for every oxide is not markedly deviated from the straight line. It can be taken, therefore, that the magma produced from the olivine-basaltic one through the contamination may well be more basic than the quartz-basalt from Kasayama, say it is just saturated with SiO_2, as shown in the diagram in Fig. 5 and also in Table IV (4), from which the more acidic quartz-basalt was derived mainly through the fractional crystallization(1). In this must be assimilated only 17 parts of the granitic material which may be accomplished without much difficulties, although the complete resorption may still be hard unless accompanying the precipitation of certain amounts of the minerals like olivine and others.

It may be unnecessary here to state that the pure fractional crystallization of our olivine-basaltic magma would not produce the rocks under consideration, but may probably form such alkaline rocks (say trachyandesitic ones) as treated by T. TOMITA(2).

While in the TOMITA'S East-Asiatic basalt with the corresponding silica the normative pyroxene must be diopsidic (with little hedenbergite) because of the existence of little normative nepheline (see column 5 in Table IV), in our olivine-basalt it is somewhat poor in $CaSiO_3$, with Wo 33 En 53 Fs 14, which is, however, more diopsidic than in the typical Japanese basalt, say the aphyric basalts from Huzi and Ōsima (see columns 6 and 7 in Table IV). As emphasized by Kennedy, and later shown by Kuno, Benson and Turner(3), and also seen from the data in this paper, it seems to be the rule that the clinopyroxene (the bulk pyroxene) of the olivine-basalt is diopsidic, in contrast to the pigeonitic pyroxene of the tholeiitic rocks. The more or less pigeonitic composition of the normative pyroxene in our olivine-basalt is indeed due to the very aluminous nature (ca. 8% Al_2O_3) of the augite, that was taken to enter into the constituents, the metasilicatic composition of which is, however, Wo 41 En 41 Fs 18, i. e. rather diopsidic in composition. On the other hand the modal pyroxenic composi-

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(1) This basaltic magma(4) is rather close in composition to the basalt with xenocrystic quartz from Daikonzima already cited. The derivation of the latter rock from the olivine-basaltic magma much allied to the one just assumed can be done by postulating the contamination of the granitic material with similar composition, though not shown here.

tion of the Japanese basaltic rocks with excess silica may probably be rather pigeonitic, as the clinopyroxene from the latter rocks seems to be not so rich in Al_2O_3(4).

But in the basaltic magma assumed to have been produced through the contamination, and also in the related, but more acidic quartz-basalt, their normative pyroxene is decidedly poor in $CaSiO_3$ (with Wo 22 En 52 Fs 26 in the former and Wo 21 En 48 Fs 31 in the latter), much resembling in this respect to the rocks from the Huzi volcanic zone (see also Table III).

Though the basaltic magma here postulated is not a product of the mere addition of silica to the olivine-basaltic magma, it can be regarded, so far as concerned to the derivation of the pigeonitic composition of the pyroxene, as the silicification of olivine molecules, as is well illustrated in their normative compositions, in which the olivine-basalt shows 7.8 wo, 12.8 en, 3.4 fs, 4.3 fo, and 1.4 fa (total 29.7), while the modified basalt, 6.8 wo, 15.8 en, and 7.7 fs with no olivine (total 30.3).

Thus it is almost beyond doubt that the quartz-basalt under consideration must have been derived from the undersaturated, olivine-basaltic magma through the resorption of certain granitic material, probably followed by the fractional crystallization as well.

Summary

Near Hagi in Western Sanin, undersaturated olivine-basalt and slightly oversaturated quartz-basalt are closely associated. From the petrographical studies on these two groups of rocks it was found that they are much distinguished mineralogically, especially in their pyroxenic compositions, but it became also highly probable that they should not be mutually independent and the latter rock type must have been derived from the olivine-basaltic magma through the assimilation of granitic material, accompanied also by the fractional crystallization.

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(2) T. TOMITA, op. cit., 262–294, 1935.

(3) W. Q. KENNEDY, op. cit.

H. KUNO, Petrology of Alaid Volcano, North Kurile, Jap. Jour. Geol. Geog., XII, 153–162, 1935.

W. N. BENSON and F. J. TURNER, Mineralogical Notes from the Univ. of Otago, No. 2, Trans. Roy. Soc. New Zeal. Vol. 69, Part 1, 56–72, 1939.

(4) H. KUNO and M. SAWATARI, On the Augites from Wadaki, Izu, and from Yoneyama, Etigo, Japan, Jap. Jour. Geol. Geog., XI, 327–343, 1934.

PLATE

Explanation of Plates.

Pl. III.

Fig. 1. Olivine-basalt from Uyamamisaki. × 60.
ol olivine, au augite.

Fig. 2. Olivine-basalt from Turuedai. × 66.
ol olivine, au augite.

Fig. 3. Olivine-basalt with hypersthene and cristobalite in the groundmass. × 66.
ol olivine, au augite, hy hypersthene,
cr cristobalite.

Fig. 4. Vitrified granite xenolith in olivine-basalt from Turuedai. × 66.
pl oligoclase, q quartz, hy hypersthene.

Pl. IV.

Fig. 1. Quartz-dolerite near Kitunezima. × 66.
pa pigeonitic augite, q quartz.

Fig. 2. Quartz-basalt from Kasayama (lower lava). × 66.
ol olivine, au augite, hy hypersthene.

Fig. 3. Quartz-basalt from Kasayama (upper lava). × 66.
Core of a porphyritic hypersthene (hy) is markedly pleochroic.
ol olivine, au augite.

Fig. 4. Hornblende-andesitic rock from Sitananae. × 66.
op opacite, q quartz, cr cristobalite.

Fig. 1.

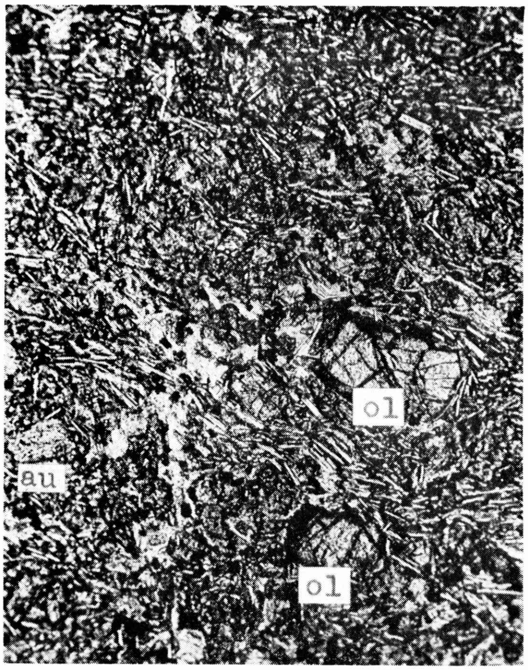

Fig. 2.

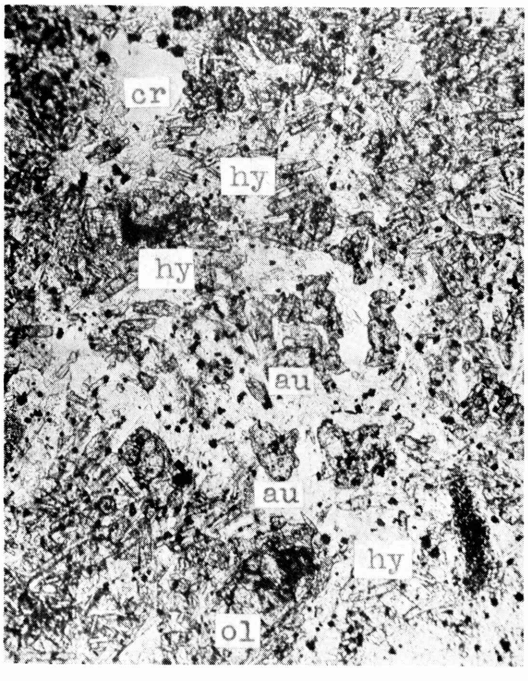

Fig. 3.

Fig. 4.

Fig. 1.

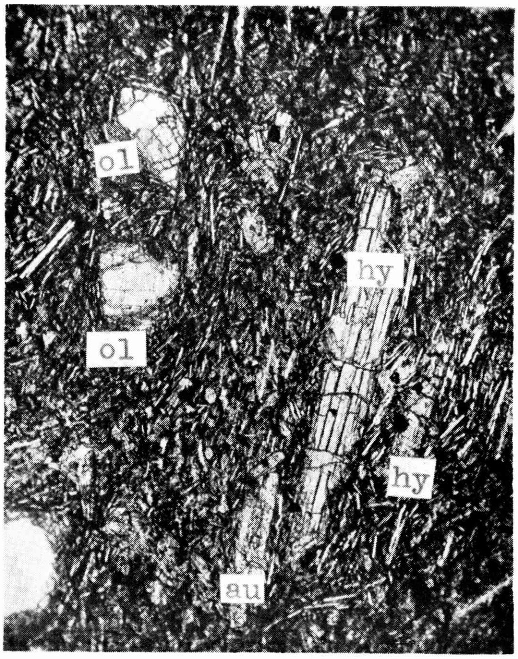

Fig. 2.

Fig. 3.

Fig. 4.