6. *On Some Lavas of the Volcano Kusatu-Sirané, Kôduke Province, Japan.*

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Introduction.

In 1933, the writer presented a report⁽¹⁾ on the explosive activities of the volcano Kusatu-Sirané during the October of 1932, though little mention was then made of the rocks that compose this volcano. As has been described in that report, the activities of the volcano during historic times differed altogether in their surface manifestations from those of the more southerly volcano Asama.

In view of possible interest, petrologically, in the genetical relationship or otherwise of the rocks composing these two volcanoes, the writer, after describing here some of the rocks from Kusatu-Sirané, compares them with those from Asama, already described in an earlier paper[2].

The rock specimens described in this paper were collected by the writer on his first trip to the volcano on the occasion of its last activity in Oct., 1932. They cover an area forming the eastern flank of the volcano, from the Kusatu spa to the summit of the active Kusatu-Sirané, thus including both the earlier and later products of the volcano.

Rock Sequence of the Kusatu-Sirané Volcano.

In an earlier contribution[3] that appeared in this Bulletin, the writer gave a structural outline of this volcano. It seems desirable however for the sake of convenience to summarize once more the structure and the rock sequence of the volcano, and to take this opportunity of revising some of the names that were given to the rocks at the time on the basis of field observations alone.

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[1] H. TSUYA, *Bull. Earthq. Res. Inst.*, **11** (1933), 82-112.

[2] H. TSUYA, *Bull. Earthq. Res. Inst.*, **11** (1933), 575-594.

[3] *loc. cit.*

About the volcano are of rocks ranging in age from Older Tertiary to Younger. The predominant rock is porphyrite (quartz-bearing augite-hypersthene-porphyrite), which occupies extensive areas to the west, northwest, and northeast of the volcano and, which, according to R. Ohashi,[4] is a hypabyssal intrusive in the Older Tertiary.

Lying directly on the porphyrite mass in the areas east and southeast of the volcano is a series of volcanic rocks (chiefly two-pyroxene-andesite), which are only local lavas fed from ancient volcanoes lying southeast of the volcano, without any direct structural relation to Kusatu-Siranê.

Beds of Younger Tertiary age lie unconformably above the porphyrite and the local andesite lavas. These are largely made up of tuffs, mudstone, clay, sand, gravel, and breccia. At present they are only to be seen on the banks of the river Agatumagawa and its tributaries, which bound the southern foot of the volcano.

While the evidence is admittedly meager, it seems permissible to conclude that the exposed lavas and fragmentary ejecta of volcano Kusatu-Siranê are underlain by the rocks enumerated above, although nothing is known at present as to their thicknesses at the bottom of the volcano nor of the nature of the older rocks lying beneath them.

Volcano Kusatu-Siranê consists of a main body called Moto-Siranêsan and a satellitic one called Siranêsan. The main body is a stratified volcano, built up of various lava-flows and fragmentary ejecta. The lava-flows are for the most part products of later eruptions, while the bulk of the fragmentary ejecta belongs to earlier eruptions. These ejecta form the basal part of the volcano, though some of them occur on the summit of the volcano as final explosion products in the history of its activity. This volcano has long been quiescent, and we have no historic records or any narratives of its eruption.

The satellitic body, Siranêsan proper, which rests on the northern flank near the summit of the main body, is a conical volcano, composed of a few lava-flows and much fragmental material. This volcano has been active eight times during the last fifty years, the activity in Oct., 1932, being the latest. Its activity in historic times consisted in the main of the simple "steam explosion" type, which took place near the earth's surface without the participation of fresh lava flows. The exception however is the explosion of 1902, which took place on the shore

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[4] R. OHASHI, *Report Earthq. Inv. Comm.*, 78 (1913), 1–47, (in Japanese).

of the Yumiiké (an explosion-crater lake on the saddle between Moto-Sirané and Siranésan proper), with recurrent activities at irregular intervals of the Yugama ("hot-water cauldron") crater-bowl at the summit of the volcano.

Of the earliest products of the composite volcano, Moto-Siranésan and Siranésan proper, little can be said now with certainty. As far as the writer's observations go, there appear to be dacitic tuffs, tuff-breccias, and pumices among the earlier products of activity. Possibly some of the lava-flows (chiefly quartz-bearing pyroxene-andesite) were also poured out at this time, though the majority of them were erupted a little later. Thus, the pyroclastic products, which form an important member of the basal part of the volcano, are well developed in the vicinity of the Kusatu spa and downwards to the skirt of the volcano, where they are exposed in the steep cliffs of the valleys that cut deep through their deposits.

Subsequently, various pyroxene-andesites were erupted to form numerous lava-flows, interbedded with which are widespread agglomerates. All the lava-flows are generally thick, sometimes attaining a thickness of 100 m., forming flat-topped and steep-sided ridges, lava-coulée (the Japanese *Butai*), which caused the stepped outline of the upper flank of the volcano. The average slope of the east flank of the volcano is nearly 15°. But this steep slope results not from the actual dip of the lava-flows, which seldom exceed 5°, but results chiefly from the fact that each successive flow extended to a shorter distance from the vents than did the one that preceded it.

The last effusive stage of the volcano was the eruptions of olivine-pyroxene-andesites, which occurred on the flanks near the summit of Moto-Sirané as lava-flows of very youthful morphological aspects, and which are exposed on the surrounding walls of the triple crater at the summit of the satellitic body. At a later stage of activity, fragmentary products, such as volcanic ashes, bread-crust bombs, and blocks, were also ejected.

Thus, although the exact sequence of many of the lava-flows and fragmentary material that form the volcano is still a matter for further detailed field survey, the sequence, as observed on the east flank from the top of the volcano to the Kusatu spa, is roughly as follows, beginning with the youngest products.

1.	Olivine-two-pyroxene-andesite Two-pyroxene-andesite	Explosion products of Siranésan proper.
2.	**Olivine-bearing hypersthene-augite-andesite** (F-lava)	The latest lava-flows of both Moto-Siranésan and Siranésan proper.
3.	Two-pyroxene-andesite (agglomerate)	
4.	Two-pyroxene-andesite (E-lava)	Products of Siranésan proper.
5.	Volcanic ashes, sands, and lapilli	
6.	**Quartz-biotite-olivine-bearing hypersthene-augite-andesite** (D-lava)	
7.	**Biotite-quartz-bearing hypersthene-augite-andesite** (agglomerate-lava)	?
8.	Biotite-bearing two-pyroxene-andesite	Products of Moto-Siranésan.
9.	Two-pyroxene-dacite ? (B-lava)	
10.	Agglomerate	
11.	Volcanic ashes	
12.	**Quartz-bearing hypersthene-augite-andesite** (A-lava)	
13.	Pumice-lapilli	
14.	Agglomerate	
15.	Pumice-blocks	
16.	Volcanic ashes	
17.	Pumice-lapilli	
18.	Pumiceous massive tuff and tuff-breccia	
19.	?	

It will be seen from the foregoing list that the progress of volcanism is from the eruption of lavas of seemingly more acid composition to those less so. But, as will be shown in the following descriptions, the earlier lavas differ but slightly from the later ones in the optical characters of the essential component minerals found in them.[5]

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[5] Of the various lavas that form the volcano, the writer examined microscopically and chemically four specimens taken from the lavas that are printed in thick letters in the foregoing list, the remainder being reserved for further study.

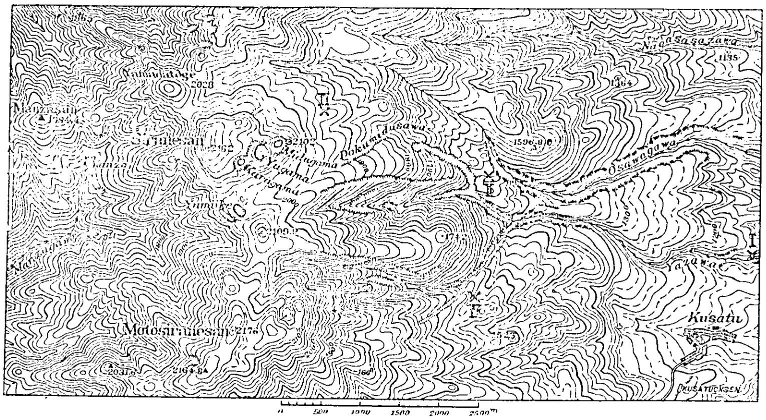

Fig. 1. Index map showing the localities of the rocks described in this paper.

I. Quartz-bearing hypersthene-augite-andesite.
II. Biotite-quartz-bearing hypersthene-augite-andesite.
III. Quartz-biotite-olivine-bearing hypersthene-augite-andesite.
IV. Olivine-bearing hypersthene-augite-andesite.

Petrography.

(I) *Quartz-bearing hypersthene-augite-andesite.* (Fig. 6)

This rock, the earliest of the four described in this paper that erupted, occurs as a lava-flow, about 10 m. thick, in the valley Yazawa[6], 1 km. northeast of the Kusatu spa, where it is exposed in the valley-walls together with overlying volcanic ashes and underlying pumices, ashes, and agglomerate.

Megascopic Characters.—Megascopically, this rock is light gray and non-vesicular. Phenocrysts, which are hardly more than 1·5 mm. in diameter, are plagioclase, pyroxenes, and accessory quartz: they are scattered through an aphanitic, pale gray or rather ash-white groundmass.

Microscopic Characters.—Microscopically, this rock consists of phenocrysts of plagioclase, augite, hypersthene, and accessory magnetite and quartz, the remainder being glass base charged with dust material. Micrometric analysis of the rock gave the result shown in Table I, column I.

The plagioclase phenocrysts, which are euhedral to subhedral, range in size from 2 mm. × 1·5 mm. to 0·2 mm. × 0·1 mm. They show simple

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[6] 谷澤.

and multiple twin-lamellae according to the albite, Carlsbad, and pericline laws. Zonal structure due to chemical difference is faintly exhibited. The range of composition is from $Ab_{37}An_{63}$ to $Ab_{43}An_{57}$, as identified according to the refractive indices—$n_{1D}=1{\cdot}5581\sim1{\cdot}5611$ on (010) or (001)—measured with Tsuboi's dispersion method. The mineral contains inclusions of pyroxene, magnetite, pale brown glass, and dust material.

The augite phenocrysts, which range in diameter from 1 mm. to 0·2 mm., are euhedral to subhedral, and are light greenish brown without perceptible pleochroism. Sometimes the mineral occurs in a rim around the hypersthene in parallel growth. Lamellar intergrowth of augite and hypersthene is also developed, the augite growing parallel to the traces of the (010) and (011) cleavages of the hypersthene, with their c-axes in common and the b-axis of the augite corresponding to the a-axis of the hypersthene. In no case, however, is the augite observed to enclose the hypersthene completely, the ends of the latter always being free. No zonal structure due to chemical difference is observed. The optical properties of the augite are

$$n_{1D}=1{\cdot}6908 \text{ on } (110),$$
$$2V^{7)}=55^\circ(+),$$
$$c\wedge Z'=38{\cdot}5^\circ.$$

Twinning on (100) is often met with. The mineral carries inclusions of plagioclase, magnetite, and pale brown glass.

The hypersthene phenocrysts, which are 1–0·5 mm. long, are euhedral, prismatic, and pale brown with perceptible pleochroism, X–pale brown, Y–pale yellowish brown, Z–pale green. Sometimes the mineral is intergrown with augite: the latter is usually outside, but rarely, as noted above, it may become a multiple lamellar intergrowth with the latter. The optical properties of the mineral are

$$n_{1D}=1{\cdot}7006 \text{ on } (110),\ 2V=64^\circ\ (-), \text{ optical plane parallel to c-axis.}$$

Enclosures of plagioclase, magnetite, and pale brown glass are sparingly present in the mineral.

The quartz crystals, 2 mm. in diameter, are invariably broken or rounded, often indented, resulting in inlets of groundmass. They are entirely free from inclusions.

Magnetite, 0·05–0·3 mm. in diameter, which occurs as euhedral or

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[7] Values given for 2 V for augite, hypersthene, and olivine were measured on the universal stage, using hemispheres of refractive index 1·649.

anhedral grains, is dispersed throughout the rock in isolated crystals or in association with pyroxene phenocrysts.

Apatite occurs very sparsely as prismatic crystals, 0·2 mm., in association with magnetite. It is a colored variety with perceptible pleochroism, X-pale yellowish brown, Z-almost colorless.

The groundmass consists of glass, crowded with dust material and feldspar prismoids, 0·01 mm. in length.

Chemical Composition.—A chemical analysis of the andesite, with its norm, is shown in Table II, column I. According to the C.I.P.W. classification, it belongs in the same subrang as *tonalose* (I)II.4.3.(3)4, transitional into *yellowstonose* or *amiatose*.

(II) *Biotite-quartz-bearing hypersthene-augite-andesite.* (Fig. 7)

This rock, which occurs as an agglomeratic lava-flow, more than a hundred meters in thickness, and which is a little later eruption than the rock described above, lies at a higher horizon than the latter, some agglomerates and pyroclastic beds being sandwitched in between them. It is distributed extensively in the vicinity of the Kakusa[8] hot-spring resort, about 5 km. northwest of the Kusatu spa. It may be seen to best advantage in the cliff, over which hangs the Zyôhu[9] water-fall, because elsewhere it lies concealed by younger ejecta of the volcano. The specimen, which has been analysed, and which will now be described, was taken from a huge lava-block that stands by the roadside, about 500 m. north of the hot-spring resort.

Megascopic Characters.—This rock is generally pumiceous and highly vesicular, but in some places almost compact, the vesicles being less than 1 per cent of the whole. It is pale gray and is rich in porphyritic plagioclase and pyroxenes, with lesser amounts of mica and quartz, set in a glassy matrix.

Microscopic Characters.—Microscopically, this rock is a glassy lava, crowded with phenocrysts of plagioclase, augite, hypersthene, quartz, biotite, and magnetite, but devoid of olivine. Its contents as determined by micrometric analysis are shown in Table I, column II.

The plagioclase phenocrysts, which are euhedral to subhedral, range in size from 2 mm. × 1 mm. to 0·2 mm. × 0·1 mm., and are twinned according to the albite, Carlsbad, and pericline laws. Many of the phenocrysts are faintly zoned, but in general zoning is less pronounced

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[8] 香草. [9] 常布瀧.

than in the rock previously described. The refractive indices measured by the dispersion method are: $n_{1D}=1{\cdot}5565\sim1{\cdot}5594$ on (010) or (001), which correspond to a composition, ranging from acid labradorite ($Ab_{46}An_{54}$) to medium labradorite ($Ab_{41}An_{59}$). The optic axial angle, as measured by the universal stage in an unzoned crystal, is $2V=80°(+)$. The mineral usually carries inclusions of pale brown glass, pyroxene, magnetite, and dust material, which sometimes are arranged roughly parallel to the outline of the host crystal.

The augite phenocrysts are euhedral to subhedral, 1–0·2 mm. in diameter, and occur in three different modes: first, isolated crystals; second, glomeroporphyritic crystals in association with plagioclase, hypersthene, and magnetite; and third, reaction-rims surrounding the biotite phenocrysts. Parallel growth of augite and hypersthene is also developed. The augite is light brown, without perceptible pleochroism, having the following optical properties:

$$n_{1D}=1{\cdot}6925 \text{ on } (110),$$
$$2V=52°(+),$$
$$c\wedge Z=42° \text{ on } (010).$$

Although the refractive indices of the mineral surroundiug the biotite were not measured, its optic axial angle and extinction angle are identical with those of the phenocrysts scattered in the rock. The augite, which forms a glomeroporphyritic group, has also the same optical properties as the isolated phenocrysts of the mineral. In the isolated augite phenocrysts, twinning on (100) is often met with. The mineral carries inclusions of brown glass, magnetite, and plagioclase.

The pypersthene phenocrysts are euhedral, prismatic, 1–0·5 mm. in length, and are pale brown with moderate pleochroism, X–pale brown, Y–pale yellowish brown, Z–pale green. The optical properties of the mineral are

$n_{1D}=1{\cdot}7015$ on (110), $2V=62°(-)$, optical plane parallel to c-axis.

Besides being present in the euhedral phenocrysts that occur as isolated individuals or in parallel growth with augite, hypersthene forms a glomeroporphyritic group in association with augite, magnetite, and plagioclase. It is also present as a member of the reaction-rim which surrounds the biotite. It is however identical in optical properties to the isolated phenocrysts. While the mineral is generally free from inclusions, a few carry sporadic granules of magnetite and plagioclase prismoids.

Quartz is always anhedral, rounded, 0·3–0·5 mm. in diameter, and irregularly cracked. It is frequently embayed by inlets of the groundmass, but none of the quartz crystals are surrounded by corona—a frequent occurrence in xenocrystic quartz. The mineral is entirely free from inclusions.

Biotite, which occurs in flakes up to 0·5 mm. in diameter, is always replaced marginally by granular aggregates of augite, hypersthene, magnetite, and plagioclase (Fig. 10). Occasionally it is entirely replaced by the latter, retaining only its original outline. The optical properties of the biotite are

(1) $n_{1D}=1{\cdot}6984$, $n_{2D}>1{\cdot}7020$ on (001), $2V=33°(-)$ for D(590$\mu\mu$),

(2) $n_{1D}=1{\cdot}6784$, $n_{2D}=1{\cdot}6967$ on (001), $2V=43°(-)$ for D(590$\mu\mu$).

Pleochroism: X–yellowish brown, Y–reddish brown, Z–reddish brown.

Dispersion: $\rho>v$ strong.

Absorption: $X<Y<Z$.

As is clear from the data, the biotite has very high refractive indices, and its optic axial angle is greatly widened. An interesting feature of the biotite is that, even in a single specimen of the rock, some flakes of the mineral differ in their optical properties from others. This feature, together with the greater developement of the marginal resorption of the mineral, is explained by the reheating and reaction in contact with the magma-liquid in which the mineral is dispersed. The mineral is entirely free from inclusions.

Magnetite is euhedral or anhedral, 0·5–0·03 mm. in diameter, and occurs as isolated grains or in association with pyroxene. It is also developed as a member of the mineral aggregate forming the reaction-rim which surrounds the biotite.

Apatite is present, though as a minor accessory.

The groundmass is a colorless glass, $n_D=1{\cdot}4905\pm0{\cdot}001$, in which spherulites are sporadically scattered. These spherulites are 0·3–0·1 mm. in diameter, and exhibit a radial structure due to the alignment of colorless or pale gray trichites, while others also display a rough concentric banding as the result of differences in the colors of successive zones. Occasionally, however, the spherulites are devoid of structure, appearing merely as pale gray blotches in the colorless base. Generally, they are either developed outwards from the edges of plagioclase and pyroxene phenocrysts or they grow radially from small nuclei, which are either plagioclase, pyroxene, or magnetite.

Chemical Composition.—A specimen of the rock was chemically analyzed with the result shown in Table II, column II. According to the C. I. P. W. classification, it belongs in the same subrang as *tonalose* ″II. 4. 3. (3) 4, transitional into *yellowstonose* or *amiatose*.

Table I. Modal Composition of the Kusatu-Sirané Rocks.

		I	II	III	IV
Phenocrysts	Quartz	1·11	0·61	0·03	—
	Plagioclase	21·09	26·13	21·41	24·64
	Biotite	—	0·07	0·08	—
	Hypersthene	2·22	3·08	4·30	1·72
	Augite	3·57	5·22	8·53	3·48
	Olivine	—	—	0·16	0·59
	Magnetite	1·49	1·27	0·95	0·90
Groundmass		70·52	63·62	64·54	68·67
Total		100·00	100·00	100·00	100·00
Vesicles		5·28	—	5·67	5·56

I. Quartz-bearing hypersthene-augite-andesite.
II. Biotite-quartz-bearing hypersthene-augite-andesite.
III. Quartz-biotite-olivine-bearing hypersthene-augite-andesite.
IV. Olivine-bearing hypersthene-augite-andesite.

(III) *Quartz-biotite-olivine-bearing hypersthene-augite-andesite.* (Fig. 8)

This rock occurs on the northeast flank, near the summit of Kusatu-Sirané proper, forming a gently sloping lava-plateau. Although this plateau is veneered with ashes erupted from the volcano in 1932 and older times, rock exposures are comparatively plentiful. Further down the slope, the blocky lava-flow terminates abruptly at about 1700 m. above sea-level, forming a sort of terrace. It overlies the preceding agglomerate-lava, but is itself overlain by two-pyroxene-andesite lavas which constitute the northeast side of the Midugama crater-bowl. No reliable estimate of its thickness is possible, but it is probably not less than fifty meters. The specimen here described was taken from a point near Yosigataira,10) where the Sirané trail leaves the highway leading from the Kusatu spa to the Sibu spa11) in the province of Sinano.

Megascopic Characters.—Megascopically, this rock is easily distinguished from the preceding ones by reason of its much darker color. It is non-vesicular, dark gray or almost black, and is porphyritic, both the plagioclase and pyroxene phenocrysts commonly attaining diameters of more than 2 mm.

Microscopic Characters.—Microscopically, this rock contains phenocrysts of plagioclase, augite, hypersthene, olivine, biotite, quartz, and magnetite, scattered through a hyalopilitic groundmass. Micrometric analysis of the rock shows the contents of these phenocrysts and the groundmass to be as listed in Table I, column III.

The plagioclase phenocrysts, which are euhedral to subhedral, stout prismatic, vary in size from 2 mm. × 1·5 mm. to 0·1 mm. × 0·03 mm. They are twinned according to the albite and Carlsbad laws, but rarely to the pericline plan. Among the phenocrysts are distinguished two different types: one which is water-clear, with or without a few inclusions of pale brown glass, pyroxene, and magnetite granules, $n_{1D}=1·5578 \sim 1·5591$ on (010) or (001), $2V=78°(+)$, corresponding to medium labradorite $Ab_{42}An_{58}$, while zonal structure due to chemical difference is less pronounced; whereas the other type exhibits two distinct zones, the core part being densely crowded with dust material and the thin shell part devoid of inclusions. The second type of phenocrysts of the plagioclase are not abundant; the majority of the crystals being of the first type.

The augite phenocrysts are euhedral, prismatic, 0·1–2·0 mm. in length, and pale brown without perceptible pleochroism. Simple and lamellar twinning on (100) are frequently met with. Penetration-twins are rarely observed. Zonal structure due to chemical difference is very faintly exhibited as recognized by the difference of extinction angles in the successive zones, which however does not exceed 2° or 3° on (010). Generally, the extinction angle is somewhat larger in the outer zones than in the inner. The optical properties of the mineral are

$$n_{1D}=1·6920 \text{ on } (110),$$

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10) 芳ケ平. 11) 澁溫泉.

$$2V=49^\circ\ (+),$$
$$c\wedge Z=41{\cdot}4^\circ \text{ on } (010).$$

Besides the isolated phenocrysts, the mineral is intergrown with hypersthene, the latter being usually inside. It also occurs as a reaction-rim, surrounding olivine and biotite. The mineral carries inclusions of brown glass, plagioclase, and magnetite.

The hypersthene phenocrysts are euhedral, prismatic, 1·5–0·2 mm. in length, and pale brown with perceptible pleochroism, X–pale brown, Y–pale yellowish brown, Z–pale green. Contact- and penetration-twins are developed. The optical properties of the mineral are

$$n_{1D}=1{\cdot}7014 \text{ on } (110),$$
$$2V=62^\circ\,(-),$$
Optical plane parallel to c-axis.

The mineral is usually devoid of inclusions, except a few grains of magnetite and plagioclase. Besides the euhedral phenocrysts, which occur either as isolated individuals or in parallel growth with augite, the mineral also occurs as reaction-rim surrounding biotite.

Olivine is always anhedral, 0·3–0·5 mm. in average diameter, and surrounded by augite grains. It is pale brown or almost colorless, and devoid of inclusions, except a few magnetite grains. The refractive indices of the mineral could not be determined; its optic axial angle as determined by the universal stage is $2V=80^\circ\,(-)$, suggesting that the mineral is somewhat ferriferous.

Quartz is anhedral, rounded, 0·5 mm. in average diameter, and is irregularly cracked.

Biotite is anhedral, less than 0·5 mm. in diameter, and is always surrounded by a reaction-rim which consists of closely packed aggregates of plagioclase, augite, hypersthene, and magnetite (Fig. 11). Sometimes the mineral is entirely replaced by these aggregates, leaving only its original crystal outline. There are also occasional glomeroporphyritic clusters of augite and hypersthene, or of these minerals accompanied by plagioclase and much magnetite, which hint at the former plentiful existence of that biotite. Little need be said of the optical properties of the biotite; for it resembles in all respects the biotite described from the preceding rock.

Magnetite is euhedral to anhedral, and varies in diameter from 0·5 mm. to 0·01 mm. The larger crystals occur as isolated grains or in association with pyroxene phenocrysts. Smaller crystals are dispersed through the groundmass.

The groundmass consists of pale brown glass, sprinkled with microlites, 0·02 mm. in length, of plagioclase, and granules of magnetite.

Chemical Composition.—A specimen of the rock was chemically analyzed with the result shown in Table II, column III. It is poorer in silica than the preceding rocks, notwithstanding its quartz and biotite contents. But, according to the C. I. P. W. classification, it also belongs in the same subrang as *tonalose* II. 4.3(4).4, transitional to *bandose*.

(IV) *Olivine-bearing hypersthene-augite-andesite.* (Fig. 9)

This rock occurs as a blocky lava-flow at Sessyôgawara, a solfatarized region east of the main body Moto-Siranêsan. The source of this rock doubtless lies in a region beyond that comprised in the present activities of Siranêsan. Nothing regarding its source is yet known, but it appears to be merely a tongue-shaped lava-flow that poured out from a parasitic (?) crater on the east side of the main body in a northeasterly direction toward Sessyôgawara. It is clear that a deep valley had existed on the present site of Sessyôgawara prior to the eruption of the lava now under discussion, and that the lava poured into the steep sided valley northeastward from a steep slope half way up the flank of the main body. That the lava is at least younger than the agglomeratic lava (No. II), described in the preceding pages, is evident from the fact that the former flowed along a valley which cut into the latter, but what its relation is to the lava exposed on the walls of the active crater of Siranêsan proper remains unknown. They may both be about the same age, since the two resemble each other in petrographic characters. Thus, it is supposed that the lava here described may be one of the latest lavas of the Kusatu-Siranê volcano.

Megascopic Characters.—Megascopically, this rock most closely resembles the preceding one. It is slightly vesicular, dark gray to almost black, and studded with prominent, white phenocrysts of plagioclase and also with less conspicuous granules of greenish pyroxenes. Olivine is scarcely visible.

Microscopic Characters.—Microscopically, this rock is rich in porphyritic plagioclase, augite, and hypersthene, with lesser amounts of olivine and magnetite, all set in a hyalopilitic groundmass. Micro-

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12) 殺生河原.

metric analysis of the rock shows the contents of these phenocrysts and the groundmass to be as listed in Table I, column IV.

The plagioclase phenocrysts are euhedral to subhedral, reaching in size up to 2 mm. × 1 mm. Twinning is on the albite, and less commonly, on the Carlsbad, but rarely on the pericline law. Many of the phenocrysts are very faintly zoned. The refractive indices are $n_{1D}=1{\cdot}5593 \sim 1{\cdot}5603$ on (010) or (001), according to which the mineral is identified as medium labradorite $Ab_{51}An_{49} \sim Ab_{39}An_{61}$. The mineral carries inclusions of pale brown glass, pyroxene, magnetite, and dust material.

Augite occurs as euhedral and subhedral phenocrysts, averaging 0·5 mm. in diameter. Twinning after (100) is often met with. The mineral, which is of the pale brown variety, without perceptible pleochroism, and not zonally built, has the following optical properties:

$$n_{1D}=1{\cdot}6929 \text{ on } (110),$$
$$2V=50^\circ (+),$$
$$c \wedge Z=42{\cdot}5^\circ \text{ on } (010).$$

This mineral carries inclusions of plagioclase, magnetite, and pale brown glass. Besides being present as isolated phenocrysts, it occurs in a rim around the hypersthene phenocrysts in parallel growth. There are also occasional glomeroporphyritic clusters of augite grains, accompanied by plagioclase and magnetite.

Hypersthene occurs as euhedral phenocrysts of prismatic form, measuring 0·2–1·5 mm. along the longest direction. It is a pale brown variety with pleochroism, X-brown, Y-brown, Z-pale green. $n_{1D}=1{\cdot}7007$ on (110), $2V=62^\circ(-)$, optical plane parallel to c-axis. The mineral has inclusions of plagioclase, magnetite, and pale brown glass.

Olivine is anhedral, 0·3–1·0 mm. in diameter, and almost colorless. Marginal conversion of the mineral into aggregates of augite grains is always developed. The refractive indices of the olivine could not be determined. Its optic axial angle as determined by the universal stage is $2V=88^\circ(+)$, suggesting that the mineral is poor in fayalite molecules.

Magnetite is euhedral to anhedral, reaching up to 0·5 mm. in diameter. It occurs as isolated crystals or in close association with pyroxenes. Smaller magnetite grains are dispersed through the groundmass.

The groundmass is hyalopilitic, and consists of pale brown glass, densely crowded with rod-like crystallites and minute granules which are too small for accurate identification, but which appear to be plagio-

Table II. Bulk Composition (Wt. %) of the Kusatu-Siranė Rocks.

	I	II	III	IV	V
SiO_2	64·35	64·90	59·52	60·80	62·66
Al_2O_3	15·75	15·34	16·19	16·39	15·91
Fe_2O_3	2·24	1·76	2·02	2·12	5·91
FeO	3·26	3·67	5·32	4·71	2·11
MgO	2·39	2·30	3·75	3·27	3·52
CaO	5·21	5·03	6·93	6·69	6·70
Na_2O	2·93	2·92	2·77	2·82	0·17
K_2O	2·38	2·60	1·71	1·87	0·36
H_2O+	0·57	0·52	0·56	0·46	1·32
$-$	0·27	0·18	0·17	0·15	
TiO_2	0·57	0·53	0·60	0·64	—
P_2O_5	0·06	0·08	0·11	0·11	0·31
MnO	0·10	0·12	0·17	0·14	—
Total	100·08	99·95	99·82	100·17	99·97
Norms					
Q	22·76	22·64	14·90	16·94	41·20
Or	13·91	15·58	10·12	11·13	2·23
Ab	24·64	24·64	23·59	23·59	1·57
An	23·09	20·86	26·70	26·70	31·43
C	—	—	—	—	3·67
Di	2·26	2·72	5·69	4·55	—
Hy	8·12	9·01	13.80	12·10	8·93
Mt	3·24	2·55	3·01	3·01	6·71
Ap	–	0·31	0·31	0·31	0·62
Il	1·06	1·06	1·21	1·21	— Hm 1·28
C. I. P. W. Symbols	(II)I.4.3.(3)4 *Tonalose*	II.4.3(3).4 *Tonalose*	II.4.3(4).4 *Tonalose*	II.4.3(4).4 *Tonalose*	"II.3.5." 3 ×

I. Quartz-bearing hypersthene-augite-andesite. S. Tanaka anal.
II. Biotite-quartz-bearing hypersthene-augite-andesite. S. Tanaka anal.
III. Quartz-biotite-olivine-bearing hypersthene-augite-andesite. S. Tanaka anal.
IV. Olivine-bearing hypersthene-augite-andesite S. Tanaka anal.
V. Olivine-bearing hypersthene-augite-andesite. Imp. Geol. Surv. anal.

clase prismoids, pyroxene, and magnetite grains.

Chemical Composition.—The chemical analysis of this rock is shown in Table II, column IV. It will be seen from the table that this rock is slightly more acid than the preceding one (No. III), even though the latter carries phenocrystic quartz. But, compared with the first two rocks (Nos. I and II), it is more basic, the rock most closely resembling it being the preceding one. According to the C. I. P. W. classification, the present rock belongs in the same subrang as *tonalose* II. 4.3(4).4, transitional to *bandose*.

Genetical Relationship.

From the foregoing petrographic descriptions, it will be seen that the lavas of volcano Kusatu-Siranê are, roughly speaking, pyroxene-andesites, but that the mineral association in them is far from regular, the principal feature being the appearance of biotite or quartz, or of both in all the lavas except the last (No. IV). A discussion of the genetical relationship of the rocks examined follows.

Paragenic relations.—For convenience, the optical data of the porphyritic minerals found in the rocks are reproduced in tabular form, see Table III. The porphyritic minerals found in all the rocks examined are plagioclase and pyroxenes. The composition-range of the plagioclase, so far as the most sodic parts of the mineral are concerned, is only from $Ab_{46}An_{54}$ in rock No. II to $Ab_{41}An_{59}$ in No. IV, that is from acid to medium labradorite. The composition-variations of the pyroxenes are also very small as inferred from their optical constants.[13] But one feature that calls for special notice is that the pyroxenes, especially augite in rock No. I, is distinctly lower in refractive indices than the same minerals in the remaining rocks, and that, accordingly, the former appears to be a variety poorer in iron than the latter. The actual paragenic relations between the plagioclase and the pyroxenes are graphically represented in Fig. 2. As will be seen from the figure, there is no regular variation in these component minerals to indicate that pyro-

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[13] The hypersthene is markedly smaller in the optic axial angle than that expected from its refractive indices by using Winchell's diagram (N. H. Winchell and A. N. Winchell, *Optical Mineralogy*, II (1927), 177). This is a fact that calls for further notice, suggesting that Winchell's diagram may not be generally applicable for estimating the composition of hypersthene. The augite is also a little smaller in the optic axial angle than any of the common augites listed in the text-book by the same author.

Table III. Optical Data of the Porphyritic Minerals in the Kusatu-Sirané Lavas.

		I	II	III	IV
Plagioclase (on 010 or 001)	n_{1D}	1·5581–1·5611	1·5565–1·5594	1·5578–1·5591	1·5593–1·5603
	Ab%	37–43	41–46	41–42	39–41
Biotite (on 001)	n_{1D}	—	1·6784 1·6984	n.d.	—
	n_{2D}	—	1·6967 1·7020	n.d.	—
	2V	—	43°(−) 33°(−)	n.d.	—
Hypersthene (on 110)	n_{1D}	1·7006	1·7015	1·7014	1·7007
	2V	64(−)	62°(−)	64°(−)	62°(−)
Augite (on 110)	n_{1D}	1·6908	1·6925	1·6920	1·6929
	2V	55°(+)	52°(+)	49°(+)	50°(+)
	$c \wedge Z$	38·5°	42°	41°	42·5°
Olivine	2V	—	—	80°(−)	88°(+)

I. Quartz-bearing hypersthene-augite-andesite.
II. Biotite-quartz-bearing hypersthene-augite-andesite.
III. Quartz-biotite-olivine-bearing hypersthene-augite-andesite.
IV. Olivine-bearing hypersthene-augite-andesite.

xene increases its refractive indices as the associating plagioclase increases its Ab content. There is however a tendency in the pyroxenes in rocks Nos. III and IV to become higher in their refractive indices than those in rocks Nos. I and II, while the associating plagioclases are more sodic (Ab rich) in the latter rocks than in the former. This tendency is naturally expected, since rocks Nos. III and IV contain olivine relics covered by a corona of pyroxene.

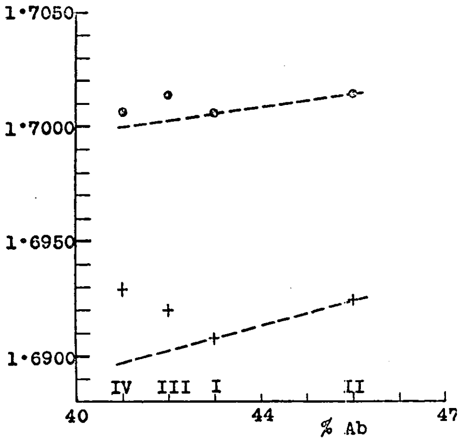

Fig. 2. Actual paragenic relations of plagioclases and pyroxenes in the lavas of Kusatu-Sirané (●: hypersthene, +: augite).

The normative plagioclases

are generally slightly richer in Ab than the modal plagioclase phenocrysts (Table IV), varying from calcic andesine $Ab_{51}An_{46}$ in rock No. II to sodic labradorite $Ab_{47}An_{53}$ in rocks Nos. III and IV. The normative pyroxenes in rocks Nos. II, III, and IV closely agree in composition, while the same mineral in rock No. I is much poorer in FeO(+MnO) content than these (Table IV). The composition-relation of normative plagioclase and normative pyroxene is graphically represented in Fig. 3. It will readily be seen from this figure that the actual paragenic relations of plagioclase and pyroxene are clearly reflected in the composition-relation of normative plagioclase and normative pyroxene. Compared with rocks Nos. II, III, and IV, rock No. I has less ferrous normative pyroxene, the FeO(+MnO) content being 30% as against 37-38% FeO (+MnO) in the normative pyroxenes of the former (Table IV).

Table IV. Compositiods of Normative Plagioclase and Pyroxene.

		I	II	III	IV
Norm plagioclase Ab%		52	54	47	47
Norm pyroxene :					
$\frac{FeO(+MnO)\times 100}{FeO(+MnO)+MgO}$		30	38	37	37
Mol.%	FeO(+MnO)	27	34	32	32
	MgO..................	63	55	54	55
	CaO	10	11	14	13

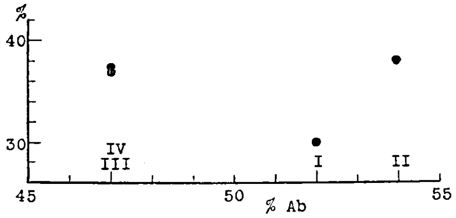

Fig. 3. Composition-relation of normative plagioclase and normative pyroxene in the rocks of Kusatu-Siranė.

The source of biotite and quartz.—In the Kusatu-Siranė lavas the chief ferromagnesian constituents are the pyroxenes, augite always in larger amount than hypersthene. Besides these, biotite is sparingly developed in rocks Nos. II and III. In describing these rocks, the writer remarked that the biotite contained in them suffered from reheating and reaction with the magma-liquid in which the mineral is dispersed. Thermal transformation (widening of optic axial angle, increasing of refractive indices, etc.) is not uncommon, according to reports on the rocks of various volcanoes[14], but in the present case the transformation of the mineral is not merely thermal. The mineral is always resorbed marginally, resulting in aggregates of augite, hypersthene, magnetite, and plagioclase. Sometimes it is entirely replaced by the latter, leaving only its original outline. As to the cause of the resorption of the biotite, two possibilities suggest themselves: either it was resorbed owing to inability to support its own composition by temperature-pressure change or, more probably, it was resorbed owing to reaction during the crystallization of the enclosing magma-liquid.

The optical properties of the minerals which surround the biotite flakes are identical to those of the respective phenocrystic minerals that are scattered in the lavas in which the biotite occurs. The groundmasses of these lavas contain none of the minerals which may be identified with those that surround the biotite. It is therefore inferred that the biotite flakes were already present before the lavas, in which they are found, were saturated with phenocrysts of plagioclase and pyroxenes now found in these lavas, and that the remarkable resorption of the biotite flakes occurred under conditions in which slow cooling of the lavas prevailed, solidification (eruption) taking place after the resorption of the biotite had proceeded to a great extent.

Since the remarkable resorption of the biotite cannot be explained by the breaking down of the mineral due to sudden change of temperature-pressure conditions consequent upon its transport to the earth's surface, we must seek some other explanation. The only one available is that the biotite might have been resorbed owing to a *reactive solution process* during the crystallization of the lava in which it occurs. Such a process may be readily expected, provided the biotite is not a phenocryst that crystallized out where it is now found, but a xenocryst picked up from a certain acidic differentiate by the lava when the latter was saturated with plagioclase and pyroxenes. It is worth noting in this connection that lavas (II and III), in which the biotite occurs, carry phenocrystic quartz crystals. They are always anhedral, irregularly cracked, and rounded or indented as if they were highly corroded. In rock No. III, they are accompanied by olivine, besides pyroxenes. Although the co-existence of quartz and olivine may be explained by some special manner in which the crystallization-dif-

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[14] H. TSUYA, *Bull. Earthq Res. Inst.*, 7 (1929), 269—334.

ferentiation of basaltic magma occurred,[15] the quartz crystals under discussion may be regarded as xenocrysts. While there is no visible evidence that the biotite and quartz are xenocrysts derived from a common source, the possibility cannot be denied. If such be the case, then the source of these xenocrysts may be an acid differentiate (either granite or quartz-diorite, or an effusive rock equivalent to these) lying beneath the volcano. This subject will be discussed again later from the chemical standpoint.

Variation diagram.—In Table II are listed four recent analyses of rocks from this volcano, (I–IV, analyst S. Tanaka) and an old analysis (V, Imp. Geol. Surv.). Although rocks IV and V closely resemble each other both petrographically and in respect to age, their chemical compositions show notable differences. Compared with IV, V shows lower alkali and FeO content, and higher Fe_2O_3 and H_2O content. It is probable that analysis V does not represent very accurately the composition of the fresh rock, since microscopic examination shows that even the freshest specimens of the rock undergo certain alteration. Indeed, the wall of the Yugama crater-bowl, whence rock V was collected by K. Nakajima,[16] is characterised by intense solfataric alterations of the lavas composing the wall.

In Figure 4 are plotted the analyses of the lavas from the volcano, analysis V being excluded for the reason just mentioned. The most siliceous rock among them is rock II with 64·90 % SiO_2, and the least siliceous one rock III with 59·52 % SiO_2. Rock I closely approaches the former and rock IV the latter. The salient feature of the variation diagram is that the courses of the oxides, except of Al_2O_3, are represented as straight lines. The trends of all the lines accord with the tendency that we would expect from the crystallization-differentiation. But since the actual paragenic relation of the porphyritic minerals held in the analyzed rocks does not imply such a pronounced differentiation as would be expected from the variation diagram, it behooves us to know what it is that causes these rocks to show such variation in their chemical composition as is indicated by the diagram (Fig. 4). In this quest the addition and subtraction diagram (Fig. 5) is very suggestive and helpful.

In Fig. 5, A and B represent the averages of analyses I–II and

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[15] M. ICHIKI, *Bull. Earthq. Res. Inst.*, 7 (1929), 335–380.

[16] K. NAKAJIMA, Expl. Text, Geol. Map. "Nagano" sheet (1:200000), (1888), 25, (in Japanese).

III–IV respectively. The curve for K_2O falls to zero at S (about 48·85 % SiO_2) and the curve for MgO falls to zero at R (about 73·50 % SiO_2). The substance of composition represented by the ordinate at S is therefore the least siliceous material and that of composition represented by the ordinate at R the most siliceous material that could control the change from A to B, or from B to A. The composition at S and R are shown in Table V.

Material S is normatively a mixture of a basic labradorite ($Ab_{34}An_{64}$) with pyroxenes, some olivine, and a little magnetite. All these are minerals found in the less acid rock type (III and IV). The required change from

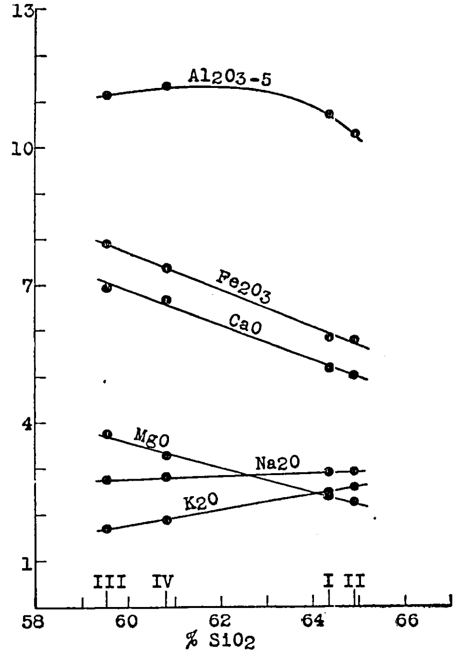

Fig. 4. Variation diagram of the rocks of Kusatu-Sirané. All iron oxide calculated as Fe_2O_3. I, II, III, and IV at the bottom of the figure correspond with those at the top of Table II.

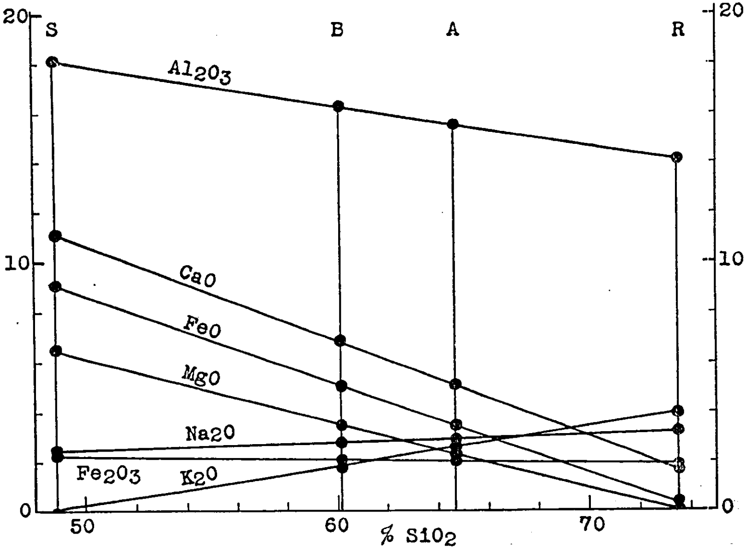

Fig. 5. Addition and subtraction diagram, showing relation between acid rock type A (average of analyses I and II) and the less acid rock type B, (average of analyses III and IV) of Kusatu-Sirané.

Table V. Composition of Added and Subtracted Material required to change the Composition of the Kusatu-Sirané Rocks.

	S	R		S	R
SiO_2	48·85	73·50	Q	—	35·74
Al_2O_3	18·15	14·15	Or	—	23·37
Fe_2O_3	2·22	1·90	Ab	20·45	27·26
FeO	9·05	0·34	An	38·66	8·90
MgO	6·50	—	C	—	1·33
CaO	11·05	1·80	Di	13·31	—
Na_2O	2·43	3·22	Hy	17·54	—
K_2O	—	3·96	Ol	5·01	—
			Mt	3·24	1·16
			Hm	—	1·12

B to A may be effected by subtracting from B these mineral mixtures (S) to the extent of about 30 % of B. But, as already mentioned, fractional crystallization alone will not make the change so satisfactorily that it will not conflict with the observed facts.

We discussed, in the preceding pages, the source of the biotite and quartz found in the present rocks. Should they be xenocrysts, as there supposed, they must have affected the chemical composition of the rocks in which they are found. Referring again to Fig. 5 and Table V, we see that the most siliceous possible material R has a very remarkable

Table V. Average Composition of the Japanese Granstes (average of 94 analyses)

	Wt. %	Norm			Wt. %	Norm
SiO_2	72·25	Q	32·79	K_2O	3·17	
Al_2O_3	14·04	Or	18·92	H_2O	0·85	
Fe_2O_3	0·38	Ab	28·84	TiO_2	0·35	
FeO	2·32	An	10·57	P_2O_5	0·22	
MgO	0·67	C	1·12	MnO	0·19	
CaO	2·13	Hy	5·66			
Na_2O	3·43	Mt	0·46	Total	100·00	

composition, similar to that of certain granitic rocks. The marked similarity is brought out very strikingly in Table VI, which gives the average composition of the Japanese granites as calculated by J. Suzuki and T. Nemoto from 94 analyses.[17]

The added material R does not, of course, correspond exactly with the composition of the average Japanese granite; it is a remarkably near approach. The former is a mixture of quartz, orthoclase, sodic plagioclase ($Ab_{75}An_{25}$), with lesser amounts of corrundum, magnetite, and hematite; while the latter consists of quartz, orthoclase, sodic plagioclase ($Ab_{73}An_{27}$), with some hypersthene and lesser amounts of corrundum and magnetite. Since the assumption that no MgO is present in the added material is not warranted, we may assume the material to be a little less siliceous than R. If the norm be worked out for such an added material as represented by, for example, 72 % SiO_2 in Fig. 5, it will be found that the norm of the material approaches more nearly that of average granite. In this connection it is to be noted that even the most siliceous material R must be added to the extent of 41 % of B in order to produce the required change, that is, the change from B to A, and that any less siliceous material would have to be added in still greater amount. But, we can avoid the necessity of having to add so much by assuming that the required change is the result of both crystallization (subtraction) of a mixture represented by S and assimilation (addition) of a granitic material represented by R. On this hypothesis, the biotite and quartz in the analysed rocks are constituents of the assimilated granitic rock, and the wholesale resorption of the biotite is attributed to the reactive solution by magma that is saturated with plagioclase and pyroxenes. It is possible that some of the plagioclase crystals in the analysed rocks are xenocrysts that have been derived from the assimilated granitic rock.

Bowen has discussed in detail the effects of assimilation.[18] We quote the following from his discussion:

"Saturated basaltic magma can react with inclusions of igneous rocks later in the reaction series (in general more acid) in such a way that the inclusions become part of the liquid, crystals of the phases with which the basalt is saturated being precipitated at the same time".

Unfortunately, there is no visible field evidence that the biotite and

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[17] J. SUZUKI and T. NEMOTO, *Jour. Geol. Soc., Tokyo*, 39 (1932), 294-296, (in Japanese).

[18] N. L. BOWEN, "The Evolution of Igneous Rocks," Princeton, (1928).

quartz in the rocks under discussion are xenocrysts, torn away from certain granitic rocks beneath the Kusatu-Sirané volcano. Exposures of such granitic mass are nowhere to be seen in the observed area. Neither ejecta nor xenoliths of such rock have been found among the products of the volcano. It is possible, however, that the quartz-diorite[19] of the Mikuni mountains,[20] northeast of Kusatu-Sirané, continues beneath the latter region. The discovery in future of such a rock in this region may add further weight to this supposition.

Genetically speaking, assimilated granitic rock needs not necessarily be unrelated to the lavas in which it is incorporated. The former may be an acid differentiate of the magma from which the latter have been derived. If such be the case, it may be deduced that since the magma underneath the Kusatu-Sirané volcano must have crystallized in the presence of much volatile matter, it should yield a granitic or quartz-dioritic crust, beneath which lay hotter and more fluid material capable of forming olivine, pyroxenes, and plagioclase, and that immediately before the eruption, the underlying hotter part of the magma assimilated the granitic roof of the reservoir.[21]

It is a notable fact that many of the Japanese volcanoes which are directly underlain by granite or allied rocks, for example, the volcanoes (Ontaké,[22], Norikura,[23] Iwodaké,[24] etc.) in the Hida Mountains,[25] and the volcanoes (Hakusan,[26] Daisen[27], Sambé,[28] etc.) in the so-called Endoperipheric Volcanic Chain of Southwest Japan,[29] consist of rocks in which quartz and biotite or hornblende occur frequently as dominant phenocrysts, besides those of plagioclase and pyroxenes. In these rocks the biotite is sometimes of anomite type, and the hornblende occasionally of basaltic variety. What is the explanation of these facts? While they obviously do not prove that such minerals are xenocrysts, derived from

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19) This mass is correlated with the quartz-diorite mass of the Tanzawa (丹澤) mountainland, in Sagami Province (相模國), which has intruded into the Misaka series (御坂層), a Japanese Lower Miocene formation. According to Toyoda, the quartz-diorite exposed at the Simizu Tunnel (淸水隧道) consists of quartz, orthoclase, plagioclase (Ab 35-60%), hypersthene ($n_1 = 1{\cdot}697$), augite ($n_1 = 1{\cdot}687$), hornblende ($n_1 = 1{\cdot}649$, $n_2 = 1{\cdot}656$), biotite ($\gamma \doteqdot 1{\cdot}650$), with accessory magnetite, zircon, and apatite. H. Toyoda, *Jour. Geogr., Tokyo Geogr. Soc.*, **43** (1931), 528, (in Japanese).

20) 三國山脈.

21) H. A. Brower, *Zeit. f. Vulk.*, **6** (1921), 37-46.

22) 御嶽. 23) 乘鞍嶽. 24) 硫黃嶽. 25) 飛彈山脈. 26) 白山.

27) 大山. 28) 三瓶山.

29) B. Koto, *Jour. Geol. Soc., Tokyo*, **23** (1916), 9-13.

the underlying granite or allied rocks, the possibility is not to be denied. According to S. Tsuboi,[30] the quariz, biotite, and some of the feldspar crystals, with garnet, found in the andesites that form the volcano Nizyô, Yamato Province,[31] are supposed to be xenocrysts derived from the rock (gneiss) underneath the volcano.

Petrographic and chemical comparison of the Kusatu-Sirané rocks and the Asama rocks.—Unlike the rocks of the nearby volcano Asama, those of the volcano Kusatu-Sirané contain xenocrysts, possibly suggesting an underlying granitic rock. The paragenic relation among the component minerals in the rocks of Kusatu-Sirané shows some difference when compared with that in the rocks of Asama. Generally speaking, the pyroxene phenocrysts, in the Kusatsu-Sirané rocks have lower refractive indices than those in the Asama rocks (hornblende-two-pyroxene-dacite being excluded). Chemically, the Kusatu-Sirané rocks are characterized by a much higher content of potash than the Asama andesites.

In brief, it may be concluded that the volcano Kusatu-Sirané has its own magma-reservoir, within which both crystallization-differentiation and assimilation of some granitic material took place, resulting in the various rocks with which the volcano has been built up.

6. 草津白根火山の二三の熔岩に就いて

地震研究所　津屋弘逵

草津白根山は多種多様の安山岩質熔岩及び火山碎屑物に依つて構成せられ，岩石學的に見て其代表的なものとして，舊新の順序に，次の 4 種の岩石を擧げることが出來る．卽ち，

I. 含石英-紫蘇輝石・普通輝石安山岩
II. 含黑雲母・石英-紫蘇輝石・普通輝石安山岩
III. 含石英・黑雲母・橄欖石-紫蘇輝石・普通輝石安山岩
IV. 含橄欖石-紫蘇輝石・普通輝石安山岩

本文では先づ，之等の 4 種の岩石の産狀，肉眼的性質，顯微鏡的性質，及び化學成分を記載し，次に之等の岩石相互の岩石學的關係を光學分析の結果より考察し，更に II 及び III に含まれてゐる石英及び黑雲母が外來結晶なることを之等の鑛物の顯微鏡的性質及び之等を含む岩石の化學成分の變化より推論し，最後に本火山と之に隣接する淺間山とは，夫々の噴出物の岩石學的諸性質を比較して，少くとも岩漿的には無關係の狀態にあることを述べた．

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[30] S. Tsuboi, *Jour. Geol. Soc., Tokyo*, **36** (1929), 30-31, (in Japanese).

[31] 大和二上山.

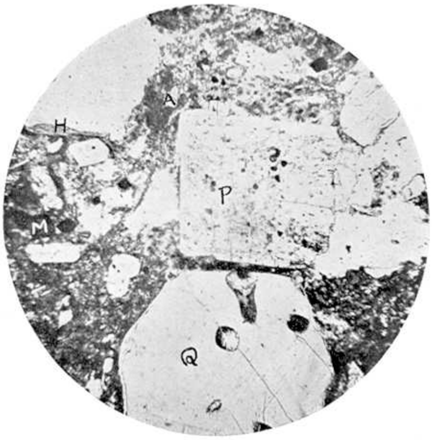

Fig. 6. Quartz-bearing hypersthene-augite-andesite. ×15. See p. 6. P····labradorite, Q····quartz, A····augite, H····hypersthene, M····magnetite.

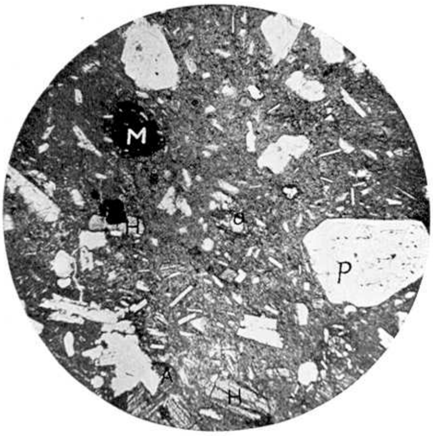

Fig. 9. Olivine-bearing hypersthene-augite-andesite. ×15. See p. 20. P··· labradorite, A····augite, H····hypersthene, O····olivine, M····magnetite.

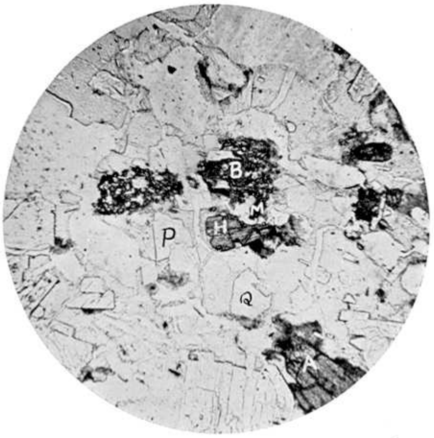

Fig. 7. Biotite-quartz-bearing hypersthene-augite-andesite. ×15. See p. 8. P····labradorite, A····augite, H····hypersthene, Q···· quartz, B····biotite, M····magnetite.

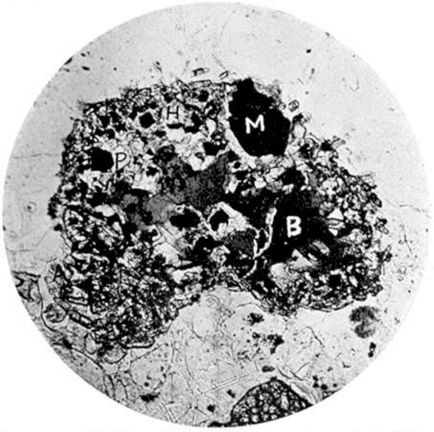

Fig. 10. Biotite (B) with reaction-rim (P····labradorite, A····augite, H····hypersthene, M····magnetite) in the biotite-quartz-bearing hypersthene-augite-andesite (Fig. 6). ×45.

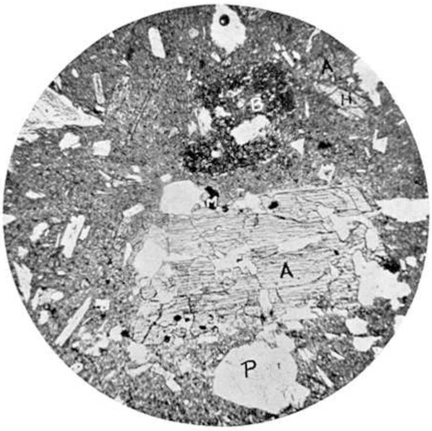

Fig. 8. Quartz-biotite-olivine-bearing hypersthene-augite-andesite. ×15. See p. 15. P····labradorite, A····augite, H····hypersthene, B····biotite, M····magnetite.

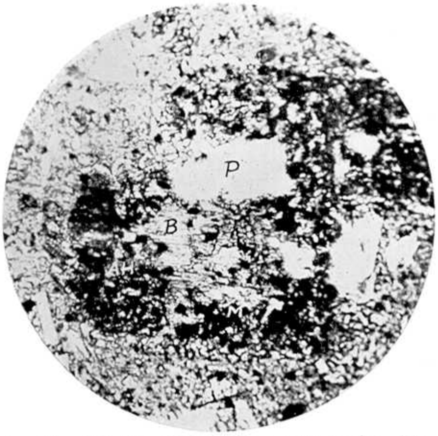

Fig 11. Biotite (B) with reaction-rim (P····labradorite, AH····augite and hypersthene, M····magnetite) in the quartz-biotite-olivine-bearing hypersthene-augite-andesite (Fig. 7). ×50.

Microphotographs of the Rocks of Kusatu-Sirané.

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