PETROLOGICAL STUDY ON THE 1970 ERUPTION OF AKITA-KOMAGATAKE VOLCANO, JAPAN

by

Kenzo YAGI, Hisashi TAKESHITA
and
Yoshio ŌBA

(with 9 Tables and 17 Text-figures)

(Contribution from the Department of Geology and Mineralogy,
Faculty of Science, Hokkaido University, No. 1225)

Introduction

Akita-Komagatake Volcano, Akita Prefecture, Northeastern Japan began to erupt on September 18, 1970 after a repose of thirty eight years. Bombs and lava were emitted intermittently in typical Strombolian eruptions from the top of Medake, a central cone within the northern part of its caldera. This was the first historical activity during which new lavas were produced by this volcano.

One of the authors (K.Y.) visited the volcano soon after the beginning of the activity, made observation in the field and collected samples of bombs and new lavas, with the assistance of two students from Hokkaido University, M. OGAME and K. INABA. Prior to the present study, however, he had made a detailed geological survey of this volcano with Mr. K. SAITO in September, 1956 and August, 1957, under the sponsorship of Nitchitsu Mining Co., Ltd. As a result of this survey the geological structure of the volcano, especially the geology of the sulfur deposits was well documented, and part of this study was published elsewhere (YAGI, 1962). The new lavas collected were studied petrologically by the authors, and chemical analyses were made by one of the authors (Y.Ō.). Based on these recent studies, together with the previous ones, the authors discuss the petrological features of the present activity.

Thanks are due to Mr. N. SATO, and Mr. N. TAGUCHI of TAZAWA town for their help in the recent survey, and to Mr. K. SAITO for his cooperation and to Messrs. WATANABE, M. MATSUTOMI, and N. KONDO, all of Nitchitsu Mining Co. for their help in the previous survey in 1956-57. Thanks are also due to Dr. J.G. Souther, who reviewed this paper and made many helpful suggestions, to Dr. S. ARAMAKI of the University of Tokyo for the chemical analysis of tridymite, to Dr. N. NAKAI of Nagoya University for the isotopic determination of anhydrite, and to Dr. K. ONUMA and Mr. S. TERADA of Hokkaido University for preparation of the diagrams. Part of the present study was financially defrayed by the grant for scientific researches by the Ministry of Education, which is gratefully acknowledged.

Geology and structure of Akita-Komagatake Volcano

Geological study on Akita-Komagatake volcano was initiated many years ago by SAKURAI (1903), and more recent studies were made by one of the authors (YAGI, 1962), HARA (1959) and KAWANO and AOKI (1960).

Akita-Komagatake Volcano is located 10 km to the east of Tazawa Lake, near the border of Akita and Iwate prefectures, and forms the southern extremity of the Towada-Hachimantai National Park. Here the volcanic range, about 12 km long and around 1600 m above sea level, extends from Nyuto on the north to Akita-Komagatake on the south, along the valley of Kakkonda river.

Akita-Komagatake is a complicated, dissected volcano, composed of Katakura-yama on the north and well-developed slopes of Onamedake, Odake, Mitsune-yama, and Medake on the south. The volcano has a shallow horseshoe-shaped caldera, which is 3 km in a NE-SW direction and 1.5 km in a NW-SE direction, surrounded by the ridges of Odake, Byobudake and Yokodake (Fig. 1).

Odake, 1632 m above sea level, is highly dissected, composed of alternate, relatively thin, lava flows of andesite and basalt, and pyroclastic materials. Many dykes cut through these layered rocks around the summit or along the ridge of Gohyaku-Rakan to the south of Odake. Some of them attain 100 m in length and 30 – 40 m in width.

Byobudake forms a ridge extending from Odake eastward. Its southern slope forms part of a steep caldera wall, whilst its northern part forms a nearly flat, swampy field of Midagahara, covered with lava flows and pyroclastic materials ejected later from Onamedake. A shallow pond called Midagaike, 250 m in length, lies in this swamp. Mitsune-yama (1583 m) farther east shows a young topography covered with thick volcanic ejecta.

Katakura-yama to the northeast of Odake is regarded as parasitic cone, and has several lava flows, about 2 – 5 m in thickness, running toward the north and northwest. The crater of Katakura-yama was probably destroyed by explosive activity. A small horseshoe-shaped depression at the head of Katakura river may represent the former explosion crater. There well-laminated alternations of clay and fine sand, about 30 m in total thickness, are associated with sedimentary sulfur deposits (YAGI, 1962). This may indicate the former presence of a crater lake within this explosion crater.

GEOLOGICAL MAP OF AKITA-KOMAGATAKE

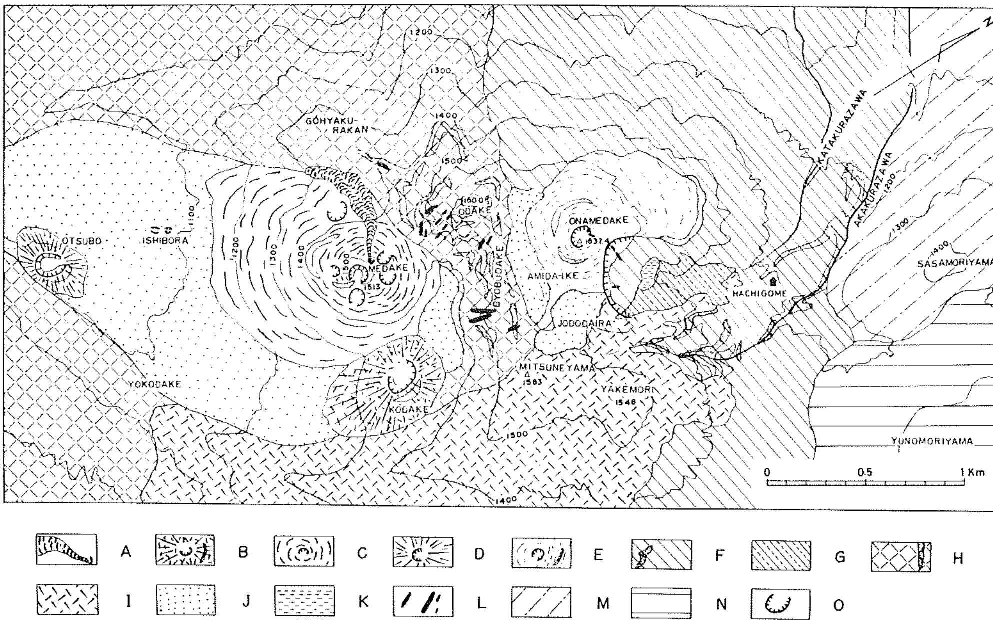


Fig. 1
Geological map of Akita-Komagatake Volcano
(Surveyed by YAGI and SAITO, 1956 – 57).
A 1970 Lava
B Kodake Lava (Scoria)
C Medake Lava
D Otsubo-ike Ejecta (Scoria)
E Onamedake Lava
F Katakura-yama Lava
G ditto: Altered, clayey zone
H Odake Lava
I Scoria Deposits
J Volcanic Ash and Pyroclastic Deposits
K Crater Lake Sediments
L Dykes
M Sasamori-yama Lava
N Yunomori-yama Lava
O Craters and Explosion Craters

Yakemori-yama (1548.8 m) and Mitsune-yama (1580.3 m) to the east of Katakura-yama have gentle slopes covered by fresh, thick scoria beds, but no exposures of lava flows are found there. Similar scoria beds are also observed around the explosion crater, locally resting uncomformably on highly kaolinized or silicified Katakura lava flows. Parts of these scoria beds were derived from Kodake central cone, but most of them may have been supplied from some other large cinder cone. The details, however, are unknown.

Onamedake (1637.4 m), lying on Katakura-yama, is the highest peak in Komagatake Volcano. It has a shallow crater, about 150 m in diameter. Lava flows and volcanic bombs are exposed around the crater, and radial dikes are also observed along the wall of the crater. The lava flows rest unconformably on Katakura-yama lava flows and form a broad lava platform to the north of the summit, whereas to the southeast they form a swampy plain between Odake and Byobudake.

Medake (1513 m), composed of alternations of lava flows and pyroclastic materials, is the largest central cone in the northern part of the caldera. There are about seven small craterlets, about 30 – 70 m in diameter, on or near its top. Some of them are surrounded by lava flows or volcanic ejecta. A small crater in the western foot of Medake is perhaps a parasitic cone. Kodake to the east of Medake is the youngest central cone and is covered only by thick scoria beds. Kodake, though small in size, has a crater about 150 m in diameter, which is further surrounded by a larger cone. Therefore this is a double volcano. From here to Yokodake, the scoria beds are very thick and contain xenolithic fragments of shale and other basement rocks. Otsubo-ike is another small central cone formed at the southwestern part of the caldera and is now covered by thick vegetation. Its summit is now occupied by a small pond. The water in this caldera is shed by the Hinokinai river, which breached the southwestern corner of the caldera.

The basement of this volcano consists of Neogene formations covered by the Tamagawa welded tuff. The Neogene formations are composed mainly of lower to upper Miocene, Green tuff formations. The Tamagawa welded tuff of the Pleistocene is extensively developed in this area, but its origin remains unknown (HAYAKAWA and KITAMURA, 1953).

Former activity of Akita-Komagatake Volcano

The history of activity of Akita-Komagatake Volcano is summarized as follows:

Odake, the main part of the volcano was formed first by alternation of basaltic lava flows and pyroclastic materials which form well developed slopes in the southeast and southwest directions. Then Katakura-yama was formed to the north of Odake, emitting abundant basaltic lava flows toward the northwest.

Effusion of copious basaltic lavas caused the summit part of the main volcano to collapse, forming a caldera of the Hawaiian type, 3 × 1.5 km in size.

Simultaneously an explosion crater, about 400 m in diameter, was formed north of the summit of Katakura-yama. Later this was covered by a crater lake, depositing well-laminated layers of clay and fine sand, above which sulfur deposits were formed by intense hydrothermal activity. Later the parasitic cone of Onamedake was erupted on the shoulder of Katakura-yama, covering unconformably the lavas of Katakura-yama. This was probably followed by the activity within the caldera that formed the central cones of Medake, Otsubo-ike and Kodake, in that order. Records of historic activity are few. It was reported that rumbling and discharge of ejecta took place at the summit in 1890–91, and also at Yokodake in 1902. The details are unknow. In 1932 explosive activity took place at Ishibora on the southern foot of Medake, forming eleven explosion pits from 10 – 50 m in diameter, and 10 – 15 m in depth. They are arranged in a line trending N 45°E over a distance of 600 m. Along the walls of the pits the alternation of lava flows and pyroclastic materials is well displayed. They are surrounded by deposits of ash and blocks of older lavas, but no juvenile materials were erupted during this activity (OTUKA, 1932; YOSHIKI, 1933).

1970 eruption

After thirty-eight years of quiescence the 1970 eruption occurred on 18 September, 1970 on the summit of Medake central cone. It is worthy of note that recent activity is confined to Medake or its surroundings. It is expected, therefore, that a magma reservoir still exists beneath Medake. The present activity has already been described by many authors. These descriptions are summarized here, supplemented by the present authors' observations.

The activity began with the discharge of vapor and unusual rise of ground temperature on the summit of Medake in late August and early September. The temperature of these newly formed fumaroles attained 95°C at maximum, and sublimation of sulfur on the surrounding rocks was observed. Only three volcanic earthquakes of so-called A type were recorded prior to the eruption, but no earthquakes of B type nor volcanic tremors were observed. The scarcity of volcanic earthquakes immediately before the eruption may be one of the characteristic features of this volcano. (SHIMOZURU et al. 1971, SUZUKI et al. 1971). The first eruption took place at about 8 p.m. at a point slightly lower than the summit of Medake. Thereafter the eruptions were repeated at short intervals, with ejection of volcanic ash, bombs and vapors, followed by effusion of fluid lava from the newly formed crater about 10 m in diameter. The eruptions belonged to the so-called Strombolian type. In fact this was the first record of new lava flows from any of the volcanoes of Northeast Japan since the eruption of Yakebashiri lava flow from Iwate volcano, northeast of Akita-Komagatake, in 1719. The eruption of Medake was splendidly displayed from the summit of Odake, which is 100 m higher than, and 500 m distant from the new crater.

Eruptions occurred at intervals of 2 – 5 min. and lasted for 1 – 1.5 min. Before the eruption the crater was covered with pulsating scoriaceous black lava. With the beginning of the eruption this surface quickly swelled up and radial cracks formed on the top, through which red-hot lava was observed. When the cracks were widely opened, vapor discharged violently, followed by ejection of red-hot volcanic bombs, and ash (Fig. 2). The bombs were usually

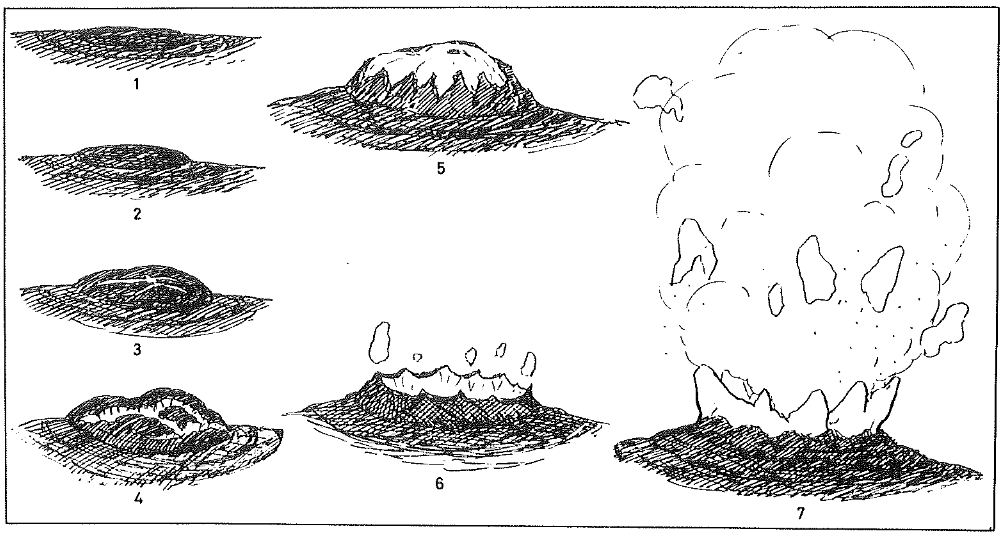


Fig. 2
Change of the crater during the eruption.
1. Prior to eruption. The crater is covered by black scoriaceous surface.
2. Beginning of eruption. Slight swelling of the surface.
3. Formation of radial cracks on the swelled surface.
4. Strong swelling and widening of cracks.
5. Red hot lava is exposed on the surface.
6. Emission of gas after the maximum swelling.
7. Finally fragments of red hot lava are thrown up by strong jet of gases.

irregular in shape, similar to pieces of cloth and sometimes spindle, bread crust, or cow-dung in shape. They were thrown to a maximum height of about 400 m above the crater, and fell down within an area about 700 – 800 m in diameter around the crater. When fallen to the ground, grass and small bushes in this area were burnt by contact with the still hot bombs.

The vapor was usually white, but sometimes denser, dark grey smoke filled

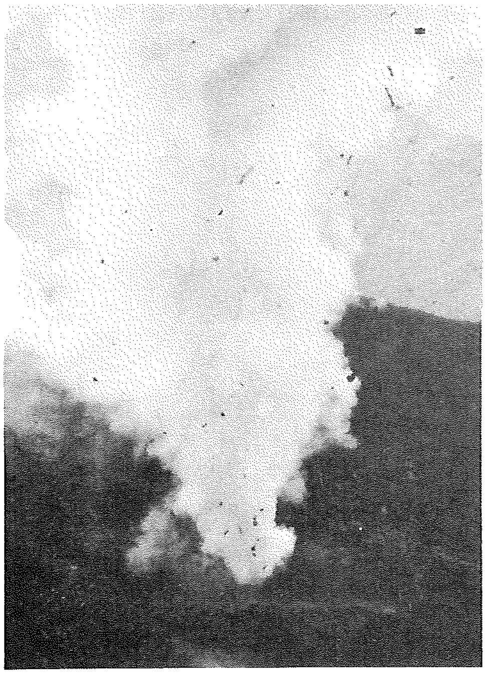


Fig. 3 Weak eruption accompanied by white smoke on 23 Sept. 1970 (INABA photo).

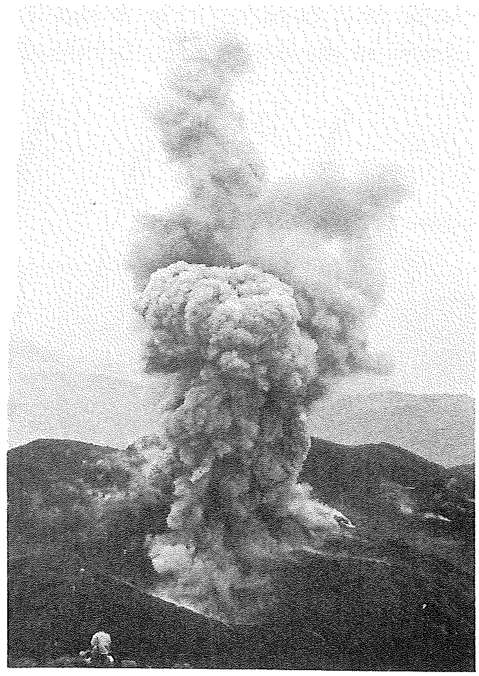


Fig. 4 Strong eruption accompanied by dense grey smoke on 23 Sept. 1970 (INABA photo).

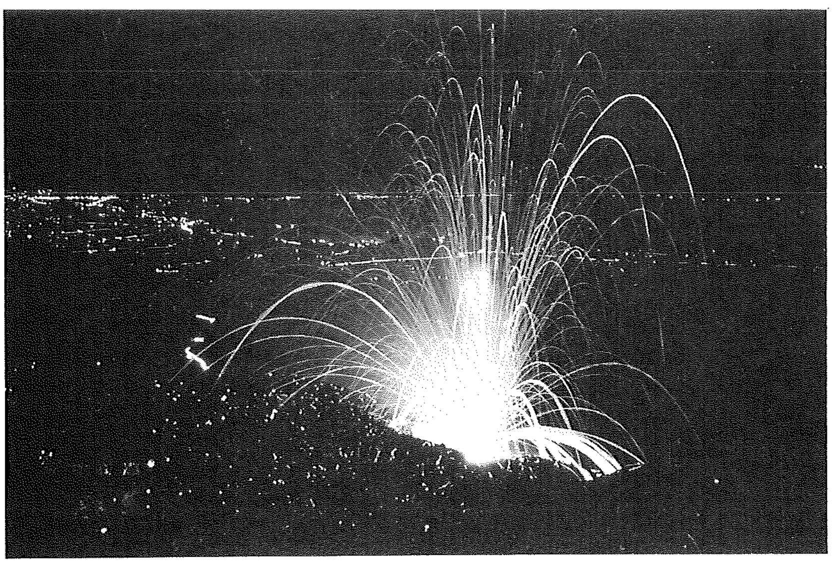
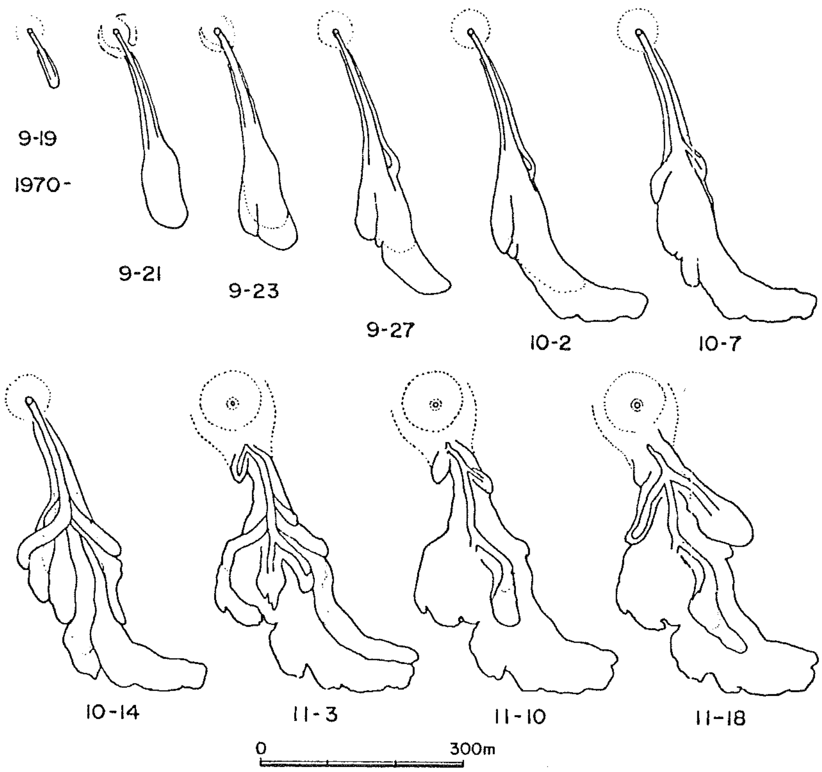
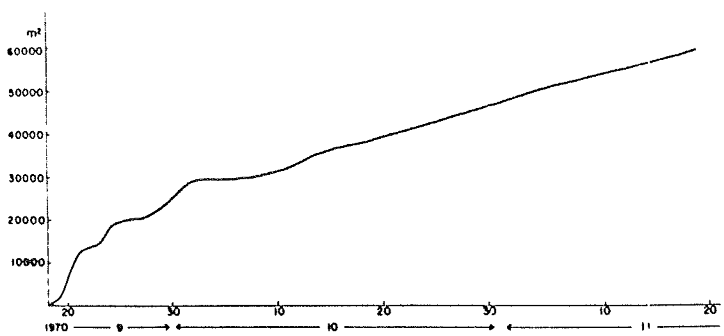


Fig. 5 Night view of an eruption on 23 Sept. 1970. Distant lights are in the town of Tazawako. (Mainichi Press, KOKUBO photo).

with dust occurred (Fig. 3 and 4). At night beautiful parabolic curves were drawn in the sky by these bombs (Fig. 5).



The movement of the lava flow.



The rate of increase of dimensions of the lava flow.

Fig. 6 Changes in the features of the lava flow (after OSSAKA and TAKAHASHI, 1971).

New lava flowed out from the crater almost continuously. The speed of the movement was at first about 100 m/day, but gradually decreased owing to the lesser gradient of the slope and to cooling of the lava flow itself. The rough surface comprised blackened fragments of blocky lavas, but the lava inside was red-hot and had sufficient fluidity to move continuously. The central part of the flow was thinner than either side due to collapse of a rapidly moving lava tunnel in the central part. The lava flow front consisted of thick piles of fragments of aa-type lava common in many lava flows.

The flow ceased to advance when it reached the flat plain between Medake and Gohyaku-rakan ridge. Thereafter the successive lava flows moved in various directions across the already solidified part, increasing the thickness and width of the lava flow. The movement of the lava flow was carefully observed by OSSAKA and TAKAHASHI (1971), whose diagrams are reproduced here in Fig. 6. The total area is estimated at 67,000 m^2, the volume at 1,458,000 m^3, and total weight at 3,198,000 tons according to MIYAZAKI (1971). The maximum temperature, measured by optical pyrometer, at the crater was 1090°C (ARAMAKI and HARAMURA, 1971). From the mode of eruption and the movement of the lava flows, the viscosity of the new lava was estimated to be much lower than that of the andesitic lava flows with similar SiO_2 contents from other volcanoes in Japan. This low viscosity may be ascribed to the enrichment of iron oxide in the groundmass (ARAMAKI and HARAMURA, 1971).

Petrography

For comparison with the new lava, and also for petrogenetic discussions, a brief description will be given of the petrography of the volcanic rocks forming the main part of Komagatake volcano.

*Odake lava; Olivine-bearing augite-hypersthene andesite (Vc)**

The rocks which constitute Odake and its caldera walls are coarse-grained and dark grey in color. Phenocrystic plagioclase (An_{95-63}, mol%**), hypersthene, augite and minor amount of magnetite are always present, while olivine are frequently surrounded by reaction rims of fine-grained clinopyroxene. Glomeroporphyritic aggregates of these phenocrysts are sometimes observed. The groundmass is pilotaxitic in texture, composed mainly of plagioclase and clinopyroxene, accompanied by magnetite, cristobalite, and brown glass.

Katakura-yama lava; Augite-olivine basalt (IVc).

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* In parenthesis rock-type defined by KUNO (1950) is given.

** The compositions of minerals estimated from optics are represented by molecular percentage.

This rock is dark in color and compact. Phenocrystic plagioclase (An_{95-70}), olivine, and augite are present. Olivene is always more abundant than augite, and has no reaction rim of clinopyroxene. Hypersthene is absent. The groundmass is highly crystalline, pilotaxitic in texture, composed of laths of plagioclase, granular clinopyroxene and magnetite, and small amounts of cristobalite.

Onamedake lava; Augite-hypersthene-olivine basalt (Vc).

The rock is rich in phenocrysts, and rather porous. Phenocrysts include plagioclase (An_{95-70}), olivine and hypersthene, both of which are always surrounded by thick reaction rims of clinopyroxene. Rarely olivine also forms parallel intergrowths with hypersthene or augite. The groundmass is highly crystalline, and intergranular in texture, being composed of laths of plagioclase, clinopyroxene, granular magnetite, and a small amount of cristobalite and pale brown glass.

Dikes; Olivine-bearing hypersthen-augite andesite (Vc).

Many dikes are found at Odake and Katakura-yama cutting through the alternation of basalts and pyroclastic materials. They are light brown in color, and more crystalline than the country rocks. Predominant phenocrysts include plagioclase (An_{93-71}), augite, hypersthene and, in some specimens, small amounts of magnetite and olivine. Hypersthene is always surrounded by thick reaction rims of clinopyroxene. The groundmass is pilotaxitic in texture, with distinct flow arrangement of laths of plagioclase. Clinopyroxene is granular or stout prismatic, and twinned on (100). Cristobalite is present as mesostasis, but glass is absent.

Medake lava; Augite-olivine basalt (IVc).

The rock is dark grey and porous, and is conspicuous by the presence of many yellow olivine crystals. Phenocrysts include plagioclase (An_{96-60}), abundant olivine, always surrounded by reaction rim of clinopyroxene, and small amounts of augite. The groundmass is pilotaxitic in texture, composed of plagioclase laths, prismatic or granular clinopyroxene, granular magnetite and small amounts of brown glass. Rarely fine-grained crystals of quartz are found lining the vesicules.

Kodake lava; Pigeonite-bearing augite-olivine basalt (IVc).

Dark grey and porous, with many olivine crystals. Phenocrysts include plagioclase (An_{94-63}), fresh olivine, augite and rarely pigeonite. Augite is sometimes surrounded by aggregates of smaller phenocrystic pigeonite. Olivine is always surrounded by thick reaction rim of clinopyroxene. Hypersthene is always absent. The groundmass is pilotaxitic in texture, composed of plagioclase laths, clinopyroxene, magnetite and small amounts of cristobalite and glass.

Scoria; Olivine-augite basalt (IVc)

Scoria which covers much of Mitsune-yama and Yakemori is dark grey or reddish brown in color and very porous. Phenocrysts include plagioclase (An_{92-71}), augite, and olivine in the pilotaxitic groundmass. Except for the absence of pigeonite phenocrysts, the rock is similar to Kodake lava. It is evident from these descriptions that lavas of Akita-Komagatake volcano are typical of the tholeiitic suite.

Petrography of 1970 lava and its xenoliths

The surfaces of ejected bombs are very spinose and slaggy, and pitch black in color, whereas the interior is usually more dense, although still rich in pores,

Table 1 Modal composition of the new lava, No. 2306.

Phenocrysts	wt %	
Plagioclase	16.4	
Clinopyroxene	2.0	19.9_5
Orthopyroxene	0.5	
Magnetite	1.0_5	
Microphenocrysts		
Plagioclase	8.0	
Clinopyroxene	0.4	10.8_5
Orthopyroxene	1.6	
Magnetite	0.8_5	
Cognate inclusions		
Plagioclase	1.3	
Clinopyroxene	0.1	2.5_9
Orthopyroxene	0.9	
Magnetite	0.2_5	
Deep brown glass	0.0_4	
Groundmass		
Plagioclase	7.0	
Clinopyroxene	4.4	
Orthopyroxene	1.2	66.4
Magnetite	0.6	
Matrix*	53.2	
Total	99.7	
Total of magnetites	2.15	
Porosity	0.32	

* The matrix is composed of brownish glass (n = 1.541), enclosing slender or fibrous microlites of clinopyroxene, very fine laths of plagioclase, and undetermiable dusty materials.

and distinctly porphyritic with abundant plagioclase phenocrysts. The lava flows are petrographically similar to the ejected bombs. A detailed description of the bombs is given below.

The rock is very porphyritic with phenocrysts of plagioclase, augite, hypersthene, and magnetite set in the groundmass (Table 1).

Plagioclase: Zoning is well-developed, especially oscillatory zoning in the outer part. The composition varies from An_{70} to An_{56}, (α_{min} = 1.556, γ_{max} = 1.574). In order to obtain the composition of the main portion of phenocrysts, some measurements of the acute side of the Köhler (010) twin angle, XX and YY are plotted on Uruno's chart (URUNO, 1963) as shown in Table 2.

Pyroxenes; Pyroxene phenocrysts are dominantly augite and hypersthene, and subordinately pigeonite.

Table 2 Some measurements of the acute side of the Köhler (010) twin angles.

Number	XX	YY	ZZ	θ	ϵ	MP	$2V_\gamma$	Size*	An mol. %/o.d.
2301-1	48.0	56.0	78.2	1.0	300	39.5	–	0.45mm	$An_{70.5}$
2301-2	48.0	58.2	79.2	0.8	240	37.7	85	0.3	$An_{69/0.37}$
2302-1	57.8	58.8	85.7	0.8	240	40.5	77.6	0.42	An_{78}
2306-1	46.2	53.5	71.0	0.2	60	37.8	–	0.32	$An_{70.5}$

* The size is measured along (010) trace.

Optical data are as follow:

Augite min	Augite Max	Hypersthene
α = 1.683	–	α = 1.686
β = 1.687	– 1.702	γ = 1.704
γ = 1.711	– 1.719	Fs = 29–34

Optic axial angles of porphyritic pyroxenes are shown in Table 3.

There seems to be no difference in composition between phenocrystic and microphenocrystic hypersthenes. Often hypersthene phenocrysts are surrounded by minute crystals of clinopyroxene (Fig. 7) and sometimes are sandwitched by thick or thin lamellae of phenocrystic or microphenocrystic clinopyroxenes. The relation is similar in the case of microphenocrystic hypersthene. Nearly all groundmass pyroxenes also show the same mode of intergrowth (Fig. 8). On the contrary single groundmass orthopyroxene crystals are rarely observed.

Table 3 Optic angles of the phenocrystic pyroxenes.

Phenocrystic clinopyroxene (Augite)

Size (mm)	0.5	0.4	0.38	0.3	0.3	0.25	0.2	
$2V_\gamma$	56	52	54	55	52	54	51	
					CZ=42°			
					~43°			

Phenocrystic orthopyroxene (Hypersthene)

Size (mm)	1.6	0.8	0.6	0.5	0.45	0.4	0.35	0.3
$2V_\alpha$	62	65	60	63	62	64	64	59
Size (mm)	0.3	0.25	0.25	0.24	0.08			
$2V_\alpha$	64	62	66	62	64			

Microphenocrystic pyroxene

Size (mm)	0.09	0.09	0.15	0.2	0.12
$2V_\gamma$	25*	–	–	–	–
$2V_\alpha$	–	67	66	65	60

* Optic plane is parallel to (010).
The size is measured along c-axis or along (010) twin plane in clinopyroxene.

Table 4 shows the results of microscopic count analysis of groundmass pyroxenes identified by conoscopic figure observed on randomly selected single crystal grains smaller than 0.05 mm in length along the prism. Zonal structure of groundmass clinopyroxene is commonly observed, as shown in Fig. 9. The refractive indices of groundmass clinopyroxenes are given below, and the optical axial angles in Table 5.

α min = 1.685

β = 1.687 – 1.688

γ max = 1.715 $(En_{55\text{-}60}Wo_{12\text{-}22}Fs_{23\text{-}28})$

Morphology of groundmass pigeonite can also be recognized (Figs. 10 and 11). Seen under the high-power objective (x100) single crystals of orthopyroxene in the groundmass appear to be composed of hypersthene, accompanied by very thin lamellae of clinopyroxene (Figs. 11-e, f). Therefore the lamellae of clinopyroxene are considered to be translation lamellae from orthopyroxene, and the symbol of the rock-type, should be Vd → c, which type has been frequently found among the later differentiates of the tholeiitic rock series.

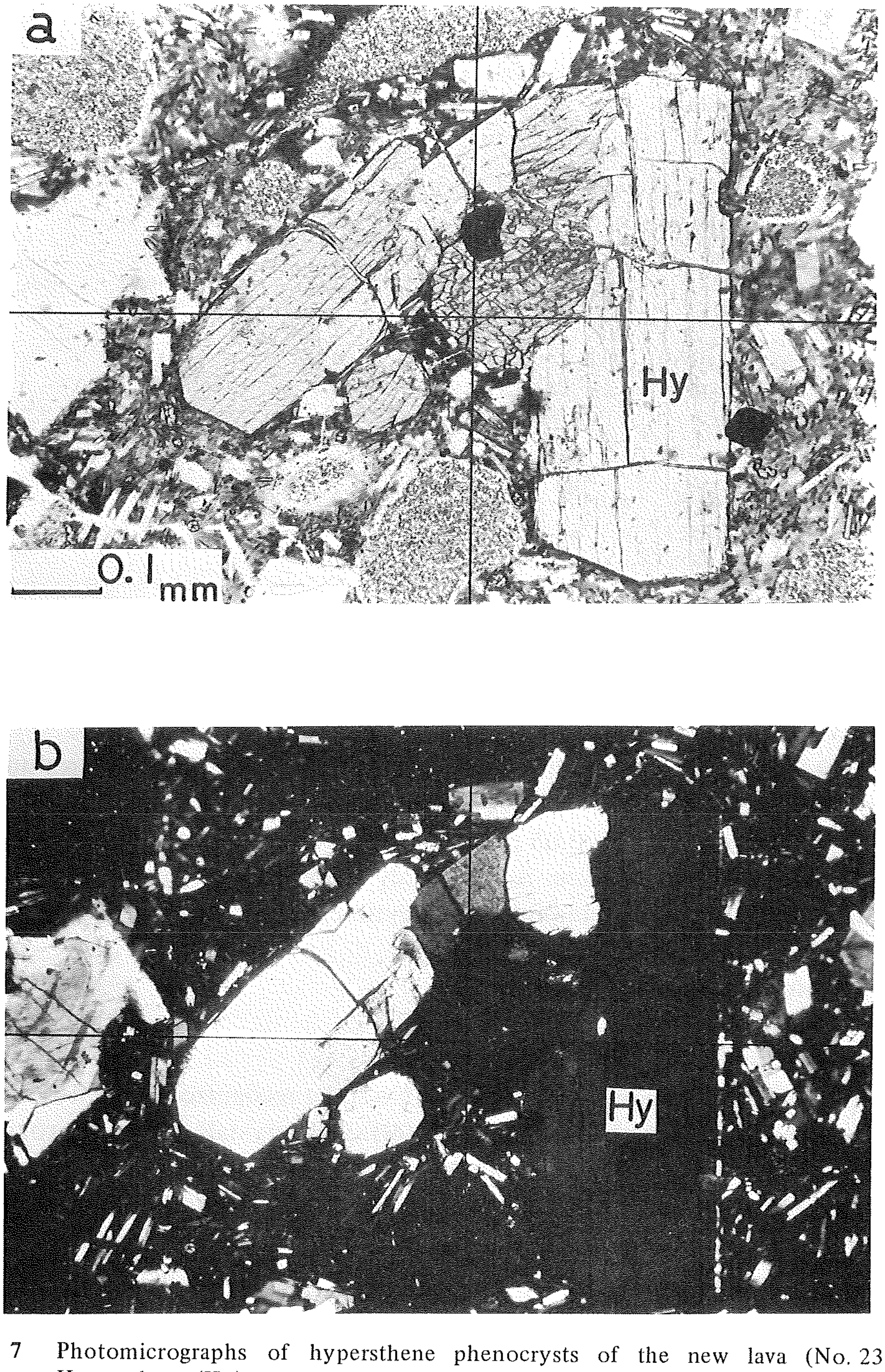

Fig. 7 Photomicrographs of hypersthene phenocrysts of the new lava (No. 2306): Hypersthene (Hy) is surrounded by minute crystals of clinopyroxene.
a: Open nicols b: Crossed nicols.

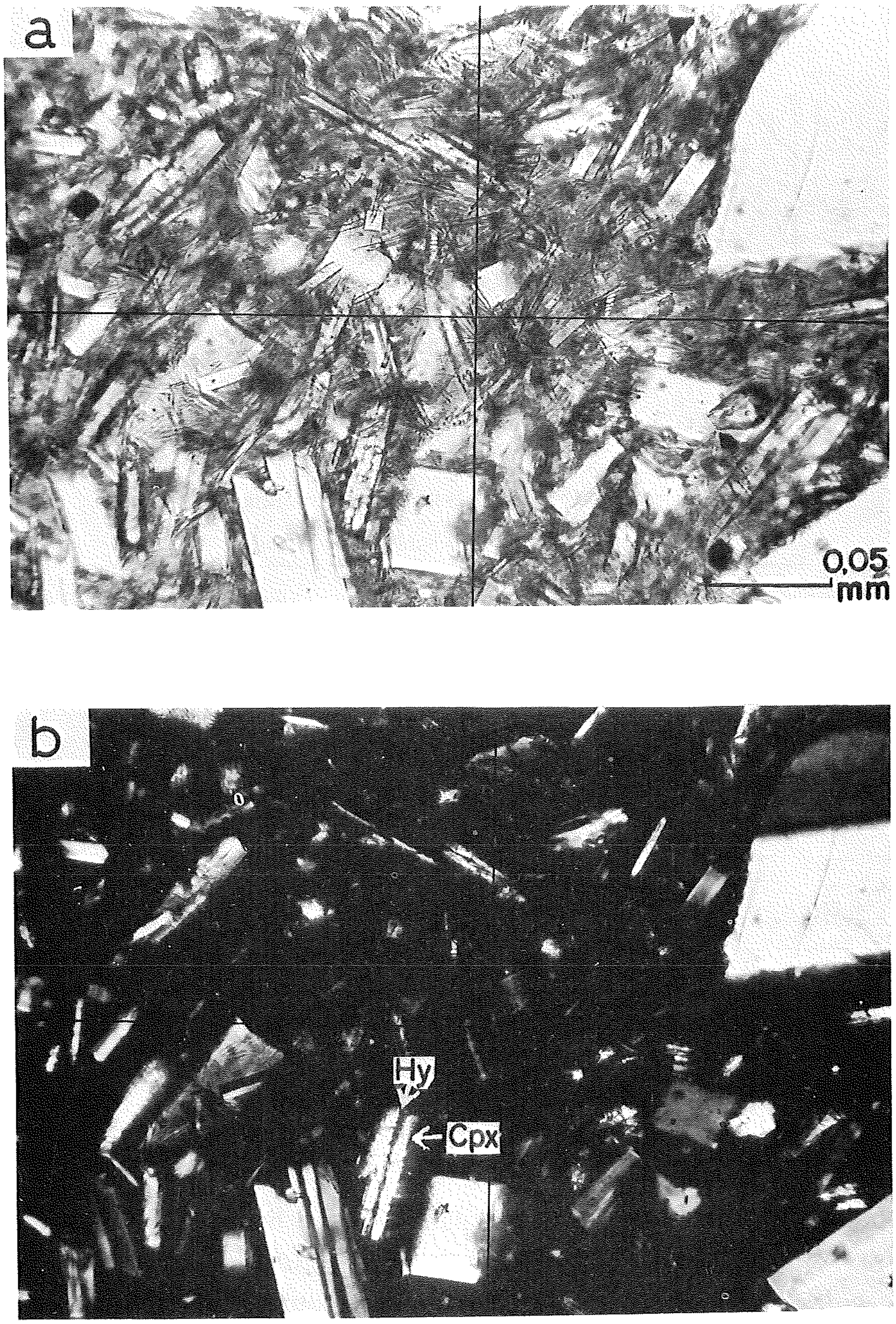

Fig. 8 Photomicrographs of groundmass pyroxenes of the new lava (No. 2306). Hypersthene (Hy) is sandwitched by clinopyroxene (Cpx).
a: Open nicols b: Crossed nicols.

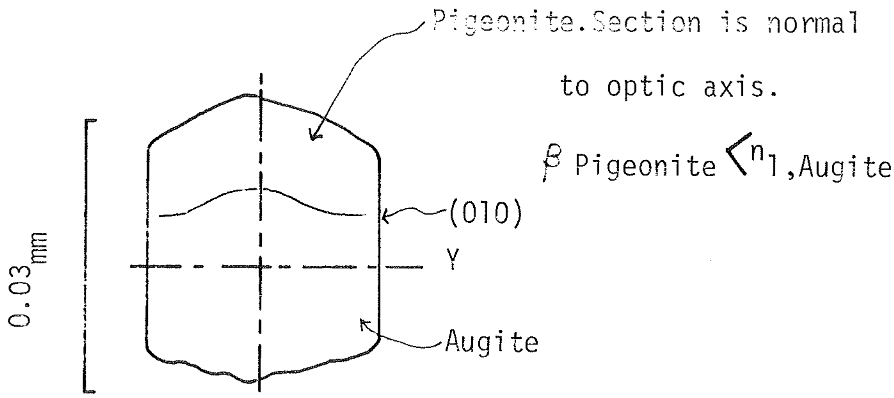

Fig. 9 Zonal structure of a groundmass pyroxene.

Table 4 Microscopic count analyses of the groundmass pyroxenes.

	Number of individuals			
	Ejecta		Lava	Sum
	2306	2301		
Augite	8	2	3	13
Pigeonitic augite	10	4	5	19
Pigeonite	11	14	17	42
Hypersthene	1	1	–	2
Total	30	21	25	76

Table 5 Optical axial angles of groundmass pyroxenes.

	Pigeonite					Hypersthene	
$2V_\alpha$	–						67°
$2V_\gamma$	19°	8°	0°	23°	20°	–	
Size (mm)						0.07	0.08_5
Optic plane	⊥ (010)	// (010)		⊥ (010)	// (010)		
Fig.	11a	11c	11d	11b	11c	11e	11f

Magnetite: According to EPMA determination by ARAMAKI (ARAMAKI and HAYAKAWA, 1971) the magnetite contains TiO_2 up to 12.3 wt %. In this respect it is worthy of note that no ilmenite has been found in the groundmass. The modal magnetite of the present rock is much less than the normative one. Probably part of the normative magnetite may be occult in the brown glass of the groundmass, whose refractive index is as high as 1.541. This clearly

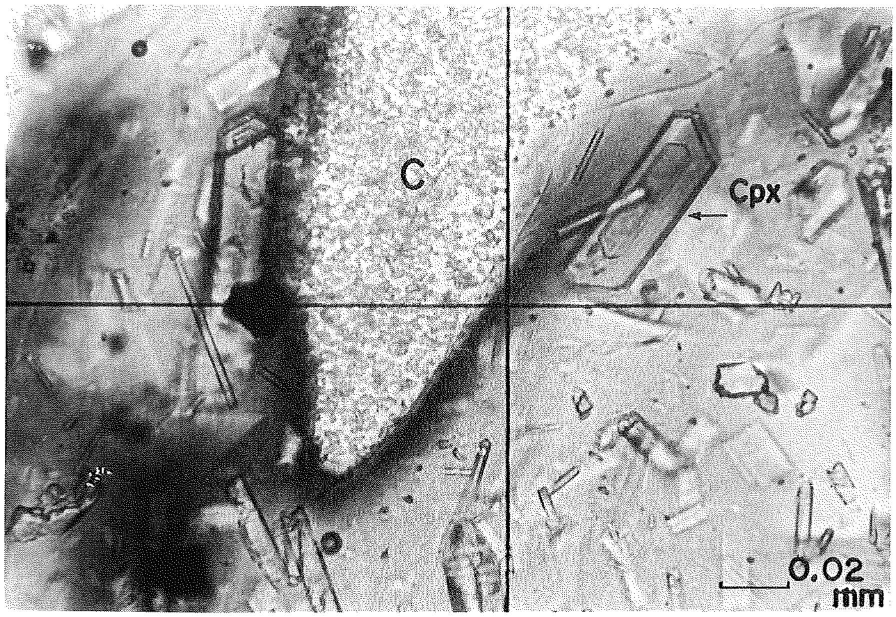

Fig. 10 Photomicrograph of groundmass pigeonites of the new lava (No. 2302). Open nicols. C: cavity.

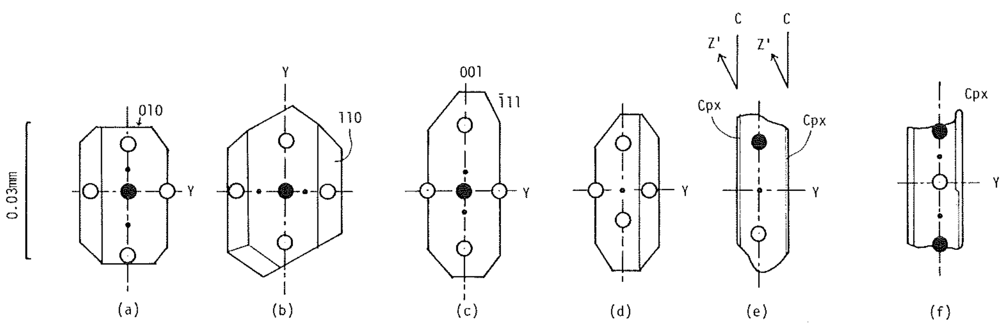

Fig. 11 The relation between optic orientation and morphology of groundmass pyroxenes.
Solid circles: Additive resultant retardation by gypsum plate.
Open circles: Subtractive resultant retardation.
Small dots: Optic axes.
a and d: Crystals twinned on (100).
b: Crystal showing tabular habit parallel to (100).
c: Single crystal.
e and f: Intergrowths of hypersthene and clinopyroxene.

indicates enrichment of iron in the residual glass. The paucity of phenocrystic magnetite is worthy of note, considering that calc-alkalic rocks of other volcanoes in northeastern Japan are rich in phenocrystic magnetite. Cognate

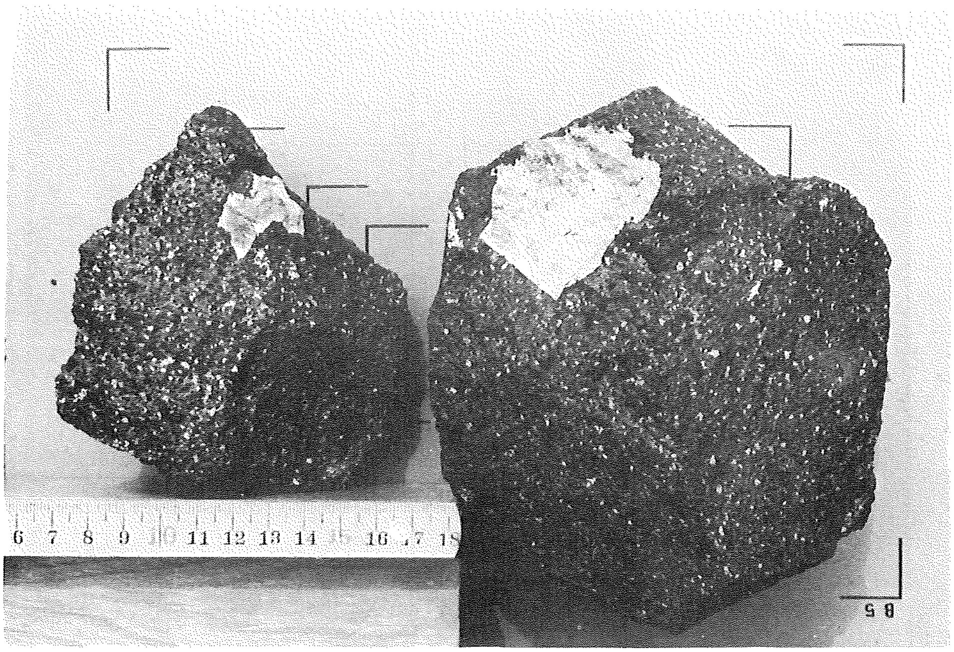

Fig. 12 Angular anhydrite-bearing xenoliths in the new lava (Collected by K. INABA).

Table 6 Chemical composition of a xenolith included in the 1970 lava, Akita-Komagatake

		Norm		
SiO_2	84.53		Q	70.19
TiO_2	0.22	Fel	or	2.11
Al_2O_3	3.93		ab	7.45
Fe_2O_3	1.25		an	5.40
FeO	1.33	Px	wo	5.45
MnO	n.d.		en	2.89
MgO	1.15		fs	1.04
CaO	4.63		mt	1.81
Na_2O	0.88		il	0.42
K_2O	0.36		Anhydrite	1.04
P_2O_5	n.d.			
$H_2O(+)$	0.27			
$H_2O(-)$	0.00			
SO_3	0.61			
Total	99.16*		Analyst Y. ŌBA n.d.: not determined	

*This value seems a little too small. When powdered rock sample was decomposed with hot HCl, H_2S gas was liberated; the xenolith contains an undetermined amount of free S.

inclusions, composed mainly of plagioclase and hypersthene associated with small amounts of augite and magnetite, are sporadically distributed in the

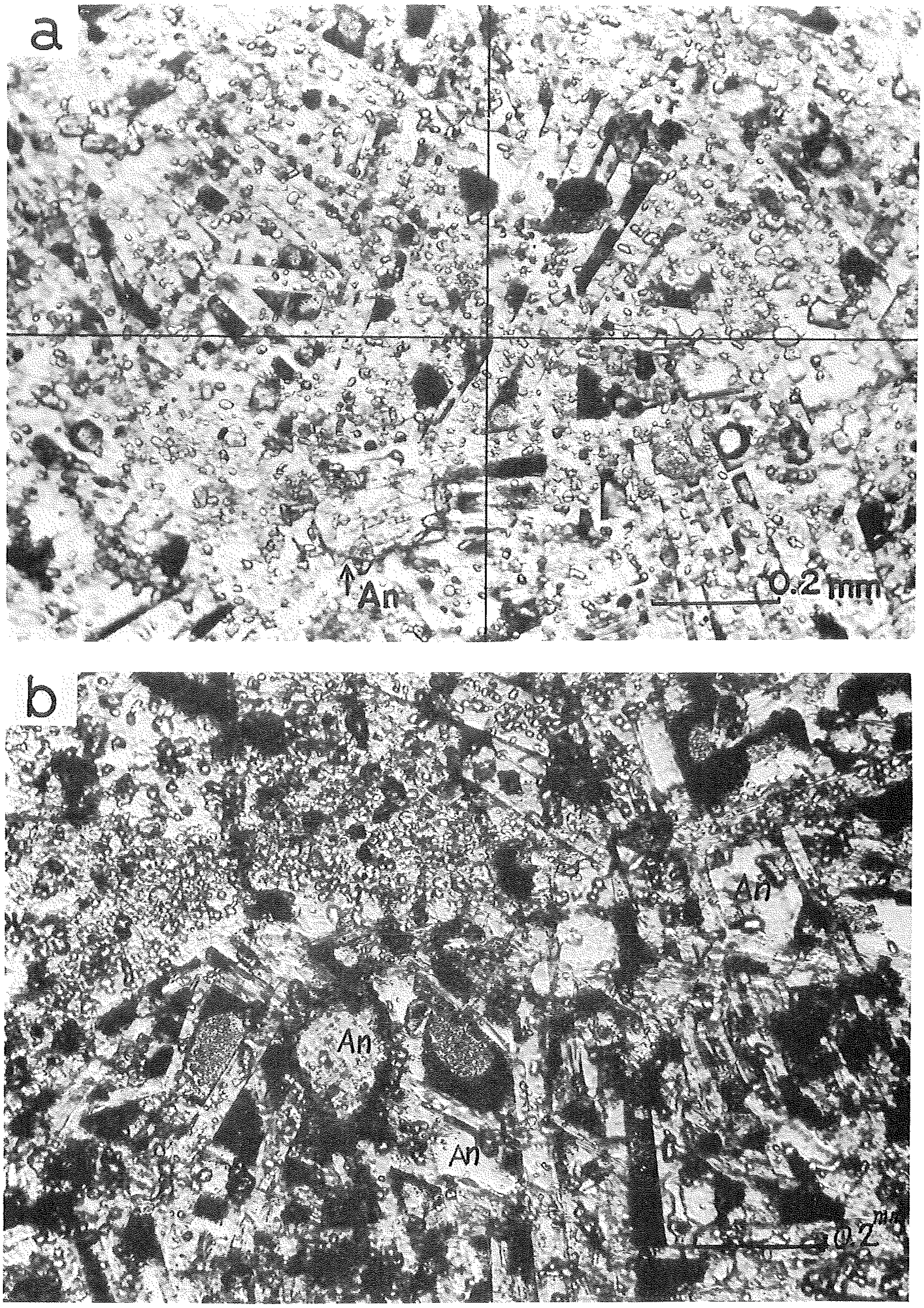

Fig. 13 Photomicrographs of a xenolith in the new lava. Numerous fine-grained clinopyroxenes are scattered in the network of prismatic crystals of tridymite.
An: anhydrite a: white part, open nicols b: grey part, open nicols.

groundmass. They probably represent crystalline aggregates of the earlier crystallized minerals.

Anhydrite-bearing xenoliths

Rarely angular xenoliths up to 5 cm in diameter are found in the bombs (Fig. 12). They are pale greenish white or bluish grey in color, and very fine-grained. The boundary between the xenoliths and the host rocks is loose, and the xenoliths can be easily separated. Under the microscope the xenolith is seen to comprise mainly tridymite and nearly colorless glass, accompanied by anhydrite and small crystals of clinopyroxene (Fig. 13). Bulk chemical composition of the xenolith is presented in Table 6.

Tridymite: Usually forms subparallel bundles of prismatic crystals or rarely narrow plates, 0.5 – 1.5 mm in length and 0.05 – 0.2 mm in width. Owing to the low refractive indices, prismatic tridymite crystals give conspicuously contrasted outlines within the colorless glass. The optic axial angle can easily be measured on a section parallel to the (001) plane (Fig. 14).

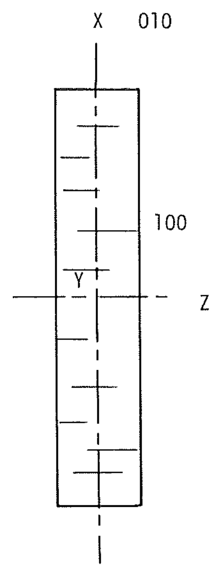

Fig. 14 Optic orientation of tridymite.

Optical properties are given below:

$\alpha = 1.472$ $\beta = 1.473\text{-}4$ $\gamma = 1.476$ $2V\gamma = 45°$

The unit cell dimensions are

a = 9.93 Å c = 81.8 Å

From these values it is evident that the tridymite forms super-cell structure.

Chemical analysis of tridymite in the xenoliths was made by EMPA by

Dr. S. ARAMAKI of the University of Tokyo, with the results shown in Table 7 (personal comm.). It is noticed that an appreciable amount of Al_2O_3 is present in the tridymite. Although quantitative determination of alkalis was not made, they are present in small amount. It is evident, therefore, that small amounts of nepheline (Na, K) $AlSiO_4$ molecule are present as solid solution in this tridymite, as is usually the case with tridymite.

Table 7 Chemical composition of tridymite

	1	2
SiO_2	97.85	99.1
Al_2O_3	0.47	0.35
FeO	0.00	0.02
CaO	0.01	0.00
Na_2O	n.d.	n.d.
K_2O	n.d.	n.d.

Analyst: S. ARAMAKI
1. Tridymite in the xenolith collected by Inaba (this study)
2. Tridymite in the xenolith collectef by O. Oshima

Clinopyroxene: Minute, euhedral or slightly rounded crystals of clinopyroxene are distributed heterogeneously in the matrix of tridymite and glass. They are colorless and non-pleochroic. The optical properties are:

$\alpha = 1.682$ $\beta = 1.688$ $\gamma = 1.704$ $2V\gamma = 51°, 53°, 55°$

Average composition: $Wo_{44}En_{42}Fs_{14}$

Anhydrite: The crystals are elongated or platy in shape, usually less than 0.5 mm, but sometimes up to 1.5 mm in length. Usually the margins are ragged, and often are decomposed into aggregates of minute grains of undetermined minerals. They usually include small rounded grains of clinopyroxene. Anhydrite often truncates the prismatic crystals of tridymite, indicating nearly simultaneous crystallization. Cleavages are perfect in two directions, (001) and (010), and are distinct in the (100) direction. Twinned crystals are rarely found. Both relief and birefringence are characteristically high. Optical properties are:

$\alpha = 1.569$ $\beta = 1.578$ $\gamma = 1.614$

$\gamma - \alpha = 0.045$ $2V\gamma = 40°$

Opaque minerals: A very small amount of opaque minerals is seen under higher magnification. Though exact determination was not possible, magnetite may be present among them.

Glass: Two kinds of glass are noticed in the xenolith; one is clear and the other is filled with a brownish dusty substance. The refractive indices are:

Pale brownish dusty glass $n = 1.520$

Colorless glass $n = 1.516 - 1.520$

It is to be noted that the refractive indices of the colorless glass are much higher than the ordinary glass in dacitic or rhyolitic rocks. However, the brownish clear glass of the host rock has an even higher index of 1.541. This suggests different origins for glass in the xenolith and that in the host rock. The glass in the xenolith was not formed by rapid impregnation of andesitic magma into the xenolith, but was formed by melting of some components in the xenolith itself.

Genetic consideration on anhydrite

Though anhydrite is very rare in volcanic rocks, its occurrence has been described from some localities in Japan. YOSHIKI (1932) found anhydrite associated with cordierite, hypersthene, augite, anorthite and pyrrhotite in the xenoliths enclosed in the 1929 pumice of Komagatake volcano, Hokkaido, and concluded that the anhydrite was formed at about 1150°C after the formation of silicate minerals by pyrometasomatic effects on the pre-existing rocks enclosed in the new lava. According to KAWANO (1948) large crystals of anhydrite in the glassy rhyolite from Himeshima, Oita Prefecture are true phenocrysts crystallized out in the early stage. The same anhydrite crystals were, however, interpreted later by TANEDA (1949) to represent crystallization in the dueteric stage. In spite of their large crystal sizes he considered they had formed by replacing groundmass glass or phenocrystic minerals, such as hornblende. A similar occurrence of anhydrite in the groundmass of alkali olivine basalt from Rishiri volcano, Hokkaido was also reported by KATSUI (1958). MORIMOTO and OSSAKA (1951) described quite a different mode of occurrence of anhydrite in the 1950–51 lavas of Oshima volcano, Izu. There anhydrite was found associated with opal in sublimates on the surface of the new lavas. Locally beautiful crystals of gypsum were also present. This occurrence suggests an interpretation of formation of anhydrite in the present case.

Gypsum has been found by the authors as a secondary mineral in the vesicules of sandstones and shales in Nagano district (YAGI and YAGI 1958). Similar occurrences of gypsum are also well-known from many other places. It is tempting, therefore, to regard the anhydrite in the present case as the product of a pyrometasomatic effect on the gypsum-bearing sandstone enclosed in the new lava. It is quite unlikely, however, that well-developed crystals of tridymite, with lengths up to 1 – 2 mm could have formed by replacing the original quartz grains. Probably they represent the product of crystallization from a vapor phase or recrystallization from amorphous silica.

As mentioned previously both anhydrite and tridymite are probably of simultaneous crystallization, enclosing abundant small grains of clinopyroxene. Since the xenoliths form solid rock fragments they can not represent the sublimation products themselves, but may be regarded as metasomatised fragments of such pre-existing sublimation products, or they may have been derived from pre-existing siliceous rocks, very rich in opaline or amorphous silica.

Tridymite and anhydrite were formed during the violent fumarolic action of the deuteric stage when the solid rock fragments incorporated in the new lava reacted with volcanic gases rich in sulfuric acid. Since no other metamorphic minerals are present, the temperature of formation of anhydrite was not as high as 1150°C as in the case of Komagatake of Hokkaido.

The sulfur isotope of this anhydrite was determined by a mass spectrograph by Dr. N. NAKAI of Nagoya University. He got a value of ^{34}S = +2.3‰, as compared with the standard of the troilite of Canon Diablo meteorite. From this value, NAKAI suggests that the anhydrite in question may be originally magmatic, or that if it was captured in the lava on the way to the surface, it should have been in isotopic equilibrium with sulfide at temperatures higher than 600°C (personal comm.). The present authors' conclusion does not conflict with his estimation.

Petrochemistry

The chemical composition of the new lavas is given in Table 8, together with the composition of the older lavas of Akita-Komagatake reported by KAWANO and AOKI (1960). It is evident that the range of SiO_2 is narrow, from 49 to 59%. It is noted that the new lavas are andesitic, while the older ones are basalts or mafic andesites.

The new lavas are rather high in Na_2O, while poor in K_2O, when compared with the average volcanic rocks of Japan. This relation is evident in the (Na_2O + K_2O) – SiO_2 and K_2O/Na_2O – SiO_2 diagrams (Figs. 15, A & B). The new lavas plot on the elongation of the older lavas of Akita-komagatake in the former diagram, whereas they are shown in distinctly lower positions than the other lavas in the latter diagram. The same trend is more obvious when the new lavas are compared with the historic andesite lavas (58–60% SiO_2) of other volcanoes in Japan (Table 9). The reason for this drastic change in alkali content has not yet been clarified.

The content of total iron is fairly high, while the ratio Fe_2O_3/FeO is low. However, this ratio is higher in the more porous bombs than in more dense bombs, owing to the ease for oxidation during the flight of the former.

When chemical composition is plotted on an MgO – (FeO + Fe_2O_3) -- (Na_2O + K_2O) diagram, it is noted that most of the older lavas fall in the central part of the tholeiite field of the Iwate-Hachimantai volcanic district

Table 8 Chemical and normative compositions of the lavas of Akita-Komagatake

	1	2	3	4	5	6	7	8
SiO_2	58.42	59.01	49.98	51.24	51.61	52.96	55.01	55.82
TiO_2	1.08	1.08	0.64	1.09	0.76	0.88	0.82	1.16
Al_2O_3	16.59	16.14	19.71	19.58	17.18	16.17	17.07	16.15
Fe_2O_3	2.68	1.69	2.86	2.52	3.77	2.68	3.75	4.37
FeO	5.63	6.53	7.52	7.03	7.72	9.06	7.28	6.49
MnO	0.17	0.17	0.11	0.12	0.13	0.18	0.12	0.17
MgO	3.17	2.96	4.65	3.69	5.20	5.01	3.87	3.29
CaO	6.95	6.91	11.77	11.26	9.68	9.93	7.92	7.66
Na_2O	3.63	3.68	1.79	2.16	2.56	2.28	2.82	2.82
K_2O	0.46	0.48	0.21	0.28	0.27	0.32	0.46	0.49
H_2O+	0.27	0.48	0.50	0.46	0.77	0.52	0.65	0.81
H_2O-	0.18	0.16	0.14	0.37	0.18	0.35	0.46	0.92
P_2O_5	0.22	0.17	0.12	0.12	0.12	0.13	0.12	0.12
Total	99.45	99.46	100.00	99.92	99.95	100.47	100.35	100.27
Anal.	Y.ŌBA	Y.ŌBA	K.AOKI	K.AOKI	K.AOKI	K.AOKI	K.AOKI	K.AOKI
Q	14.69	14.39	4.67	6.74	5.68	7.39	11.56	15.08
Or	2.72	2.84	1.22	1.67	1.61	1.89	2.72	2.89
Ab	30.65	31.13	15.14	18.24	21.64	19.28	23.84	23.84
An	27.58	26.05	45.06	42.87	34.53	32.89	32.53	29.91
Wo	2.36	3.02	5.58	5.14	5.35	6.50	2.53	3.09
En	1.25	1.35	2.86	2.52	2.92	3.29	1.27	1.65
Fs	1.04	1.66	2.60	2.53	2.25	3.06	1.20	1.34
En	6.67	6.05	8.76	6.70	10.08	9.23	8.40	6.57
Fs	5.60	7.44	7.96	6.71	7.77	8.61	8.70	5.35
Mt	3.90	2.46	4.15	3.64	5.48	3.87	5.43	6.33
Il	2.05	2.05	1.22	3.07	1.44	1.67	1.55	2.20
Ap	0.50	0.40	0.27	0.27	0.27	0.30	0.27	0.27

New lavas
1. Porous volcanic bomb (No. 2301).
2. More dence volcanic bomb (No. 2306).

Old lavas
3. Augite-olivine basalt, Medake central cone. KAWANO et al. (1960).
4. Augite-hypersthene-olivine basalt, summit of Onamedake. KAWANO et al. (1960).
5. Augite-olivine basalt, Yokodake. KAWANO et al. (1960).
6. Pigeonite-bearing augite-olivine basalt, Kodake central cone. KAWANO et al. (1960).
7. Olivine-augite-hypersthene andesite, Odake. KAWANO et al. (1960).
8. Olivine-augite-hypersthene andesite, western caldera wall of Komagatake (Gohyakurakan). KAWANO et al. (1960).

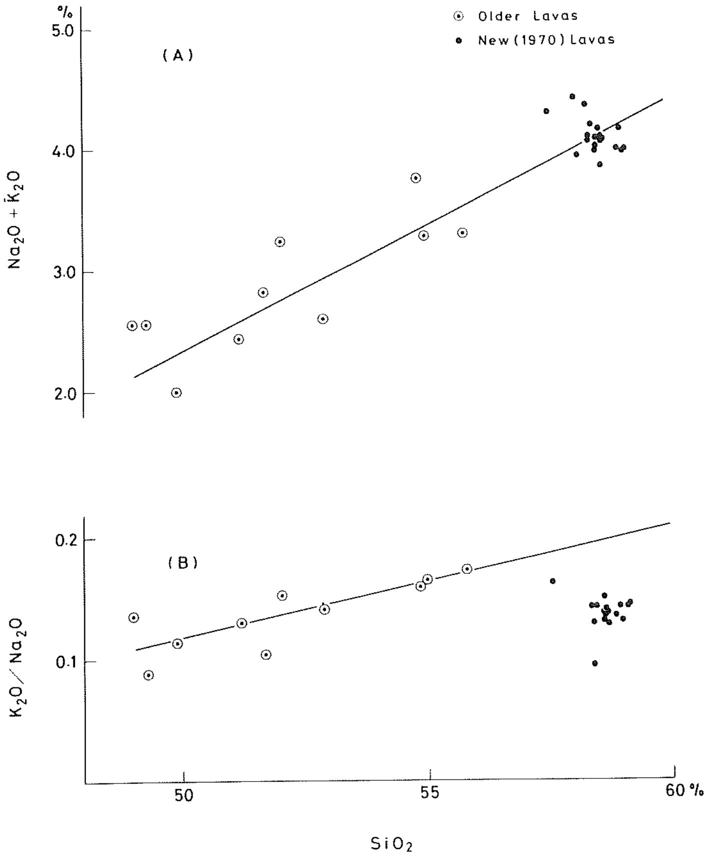

Fig. 15 Relation between SiO_2 and alkali contents of the Akita-Komagatake lavas.
Double circles: older lavas
Solid circles: new lavas
Fig. 15-A ($Na_2O + K_2O$) – SiO_2 diagram.
Fig. 15-B K_2O/Na_2O – SiO_2 diagram.

Table 9 Chemical comparison of the new lava with some historical andesite lavas from Japan

Lava or bomb	SiO_2	Na_2O	K_2O	K_2O/Na_2O	Reference
1952 bomb, Ontake, Suwanose Island.	58.38	3.20	1.49	0.47	MATSUMOTO, 1956.
1946 lava, Sakura-jima.	61.24	2.81	1.49	0.53	MORIMOTO, 1948.
1926 or 1936 bomb, Asama.	59.82	3.07	1.00	0.33	IWASAKI, 1936.
1929 bomb, Hokkaido Komagatake.	59.35	3.25	0.88	0.27	TSUYA, 1930.
1909 bomb, Tarumai.*	57.88	2.22	1.00	0.45	ISHIKAWA, 1952.
1970 bomb, Akita-Komagatake.**	58.72	3.65	0.47	0.13	

* Average value of three compositions of bombs.
** Average value of two compositions of bombs.

(KAWANO and AOKI, 1960), whereas the new lavas plot near or on the boundary between the tholeiite and calc-calkalic rock fields of the same district (Fig. 16). This is in agreement with the microscopic observation that all the older lavas belong to the tholeiitic series of Vc or IVc type, whereas the new lavas belong to the Vd → c type, indicating that the new lavas have intermediate features between calc-alkalic and tholeiitic rock series. The new lavas probably represent a transitional phase between the two series.

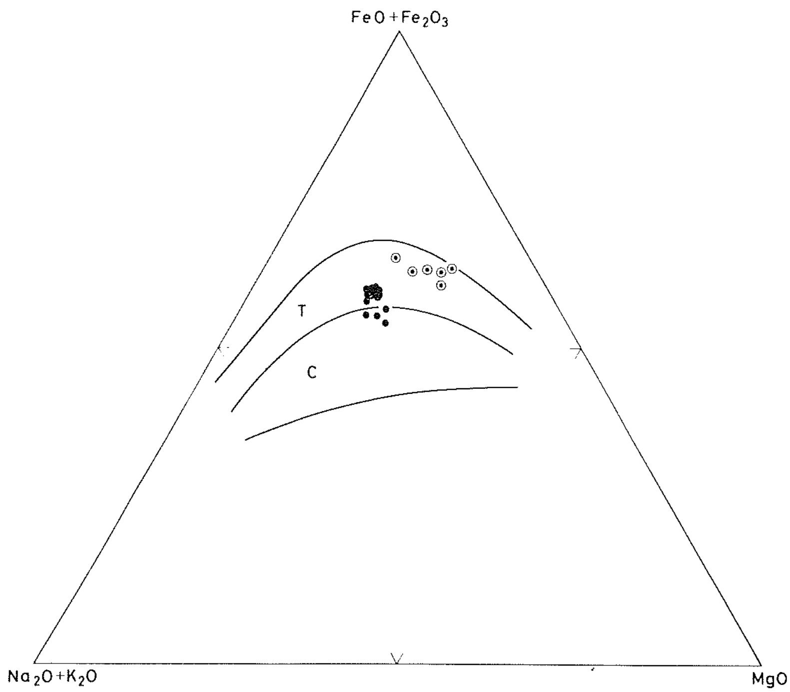

Fig. 16 MgO – ($FeO + Fe_2O_3$) – ($Na_2O + K_2O$)diagram of the Akita-Komagatake lavas.
Double circles: Older lavas.
Solid circles: New lavas.
T: Tholeiite field of Iwate-Hachimantai volcanic district.
C: Calc-alkalic rock field of the same district (KAWANO and AOKI 1960).

Petrogenetic consideration

When compared with the older lavas of Akita-Komagatake the new lavas present several points of interest to us. These are extremely low ratio of K_2O/Na_2O, higher SiO_2 content, and their transitional position between tholeiite and calc-alkalic rock series. In order to clarify these points, an $FeO + Fe_2O_3/FeO + Fe_2O_3 + MgO$ -- SiO_2 diagram is shown in Fig. 17.

Nockolds' averages of the tholeiite and calc-alkali rock series are used in this diagram for comparison. As OSBORN (1959) has pointed out, iron enrichment takes place under conditions of low pO_2, following the course of tholeiite, whereas enrichment in SiO_2 takes place with increasing pO_2, following the course of calc-alkalic rocks series (Cascade lavas).

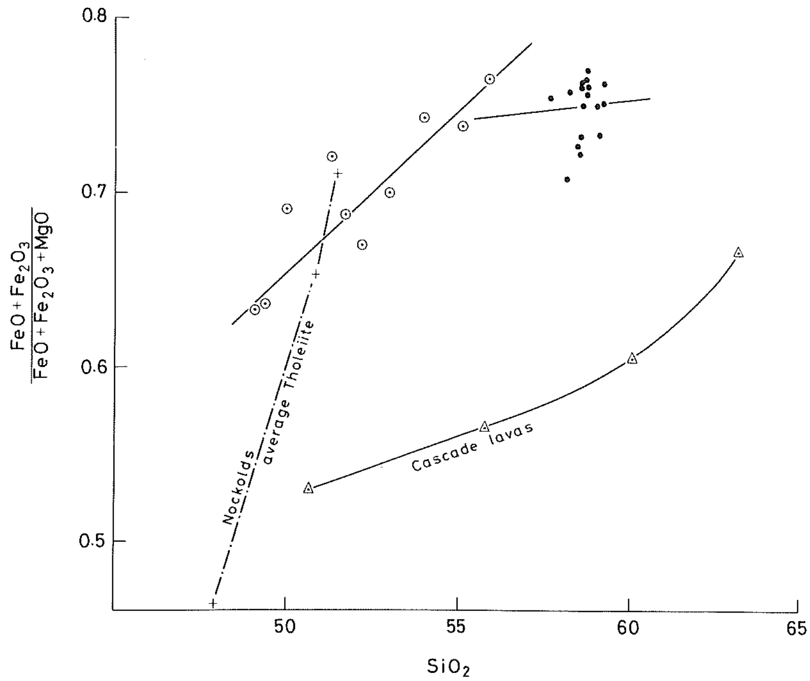

Fig. 17 $FeO + Fe_2O_3/FeO + Fe_2O_3 + MgO - SiO_2$ diagram of the Akita-Komagatake lavas.
Double circles: older lavas.
Solid circles: new lavas.
Crosses: Average tholeiite series of Nockolds.
Triangles: Average calc-alkalic rocks of the Cascades.

With some prejudice, it may be possible to draw two different trends for the old and new lavas of Akita-Komagatake as shown in the diagram. If this is the case, it may indicate that there have been some changes in the trend of differentiation in the Akita-Komagatake magma from tholeiitic to calc-alkalic trend. What can be the reason for this change?

Although the new lavas have a few xenoliths their amount is too small to have had any profound influence on the course of crystallization of the magma.

As mentioned before the older lavas of Akita-Komagatake are usually poor in phenocrystic magnetite, especially the basalts of Medake and Kodake which are quite free from them. On the contrary the new lavas have considerable amounts of phenocrystic magnetite. This may indicate that the pO_2 has recently been increased in the magma reservoir of Akita-Komagatake.

The present authors have observed in the dyke at Mujina-goro, Nagano

City, that crystallization differentiation within a single volcanic rock mass may give rise to calc-alkalic rock series from tholeiite series (TAKESHITA and YAGI, 1961). It is well-known that small amounts of calc-alkalic rocks are formed in the later stage of tholeiitic volcanoes in northeastern Japan (KAWANO et al. 1961 YAGI et al. 1963).

From these considerations the authors are lead to the conclusion that the drastic change in the petrological features in Akita-Komagatake may be due to the change of pO_2 in the magma reservoir. If this trend goes further it may be expected that calc-alkalic andesite of Vd type possibly with about 60% SiO_2 might be produced in future activity of Akita-Komagatake.

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