12. *Geological Investigations on the Zaō Volcanoes.*
II Aoso Volcano.

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Introduction.

The Aoso volcano[1] is included in the Zaō volcanic group and rises at the eastern end of the South Zaō. It is a small composite volcano isolated from the main part of the Zaō volcanoes, being bordered by the Akiyama-zawa, Matsu-kawa and Kosute-gawa. This volcano rests upon the Tertiary formation and is composed of Aoso-yama (799.9 m.),[2] Ōmori-yama (800 m.), Takokura-yama (666.1 m.), Tōmori-yama (564 m.), etc. It is now dissected deeply by Akamatsu-zawa, Dō-zawa, Onashi-zawa, Namin-zawa, Taiko-zawa and Itahashi-zawa. The structure of the Aoso volcano is greatly complicated by its successive eruption, as can be seen along these valleys.

One of the remarkable features observed here is the occurrence of dacite flow[3] which is entirely lacking in other parts of the Zaō volcanoes. It forms central cones represented by Aoso-yama and Ōmori-yama, and its eruption seems to have been investigated by the writer since the autumn of 1947. They are summarized in this paper, with a brief description of lavas and ejecta.

Location.

The Aoso volcano (Figs. 1, 2, 3) is situated near the northern corner of Katta-gun, Miyagi Prefecture. It is easy of access from Shiroishi or Ōgawara of the Tōhoku Railway Line, since there is a bus road between these towns and Aone, going round the eastern or northern periphery of this volcano. The summit of Aoso-yama is accessible from such villages Miya, Teppō-chō, Magatake, Nagano, Kotsumazaka, Tōgatta and Kitahara.

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1) The Aoso volcano was formerly named "Ōgatta volcano" (A. TAKADA, The Zaō Volcanoes, *M. S.*, 1922).

2) Aoso-yama was once called "Ōgatta-dake" (B. KOTŌ, *Jour. Geol. Soc. Japan*, **23** (1926), 34).

3) The eruption of dacite flows is also known in the final activity of the Kurikoma volcanoes and Osore-yama volcanoes which belong to the Nasu volcanic zone.

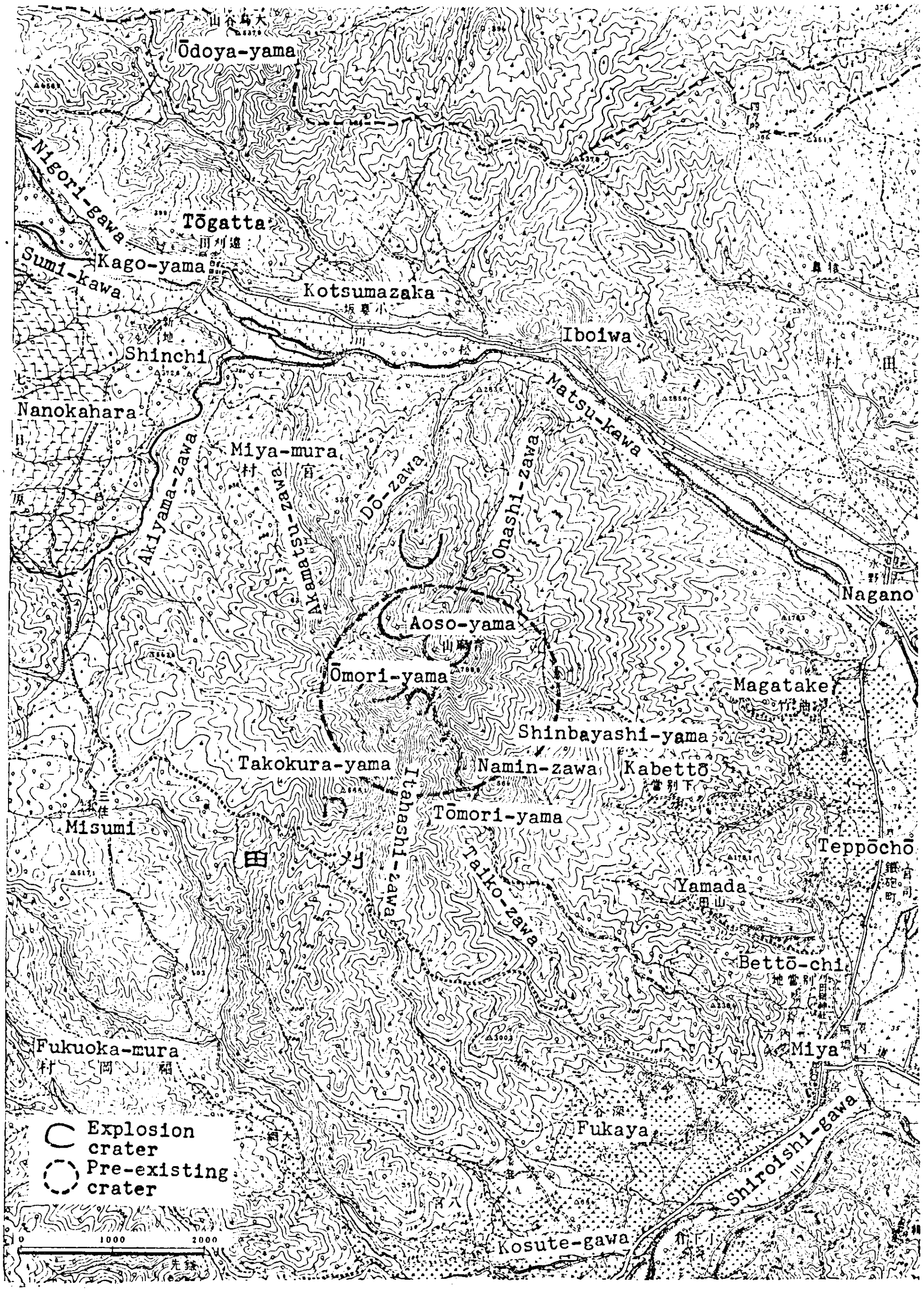

Fig. 1. Topographical map of the Aoso volcano and its vicinity.

Geological Features of Aoso Volcano and Its Adjacent Area.

Besides lavas and ejecta of the Aoso volcano, the area under consideration is composed of Tertiary sediments, agglomerate, andesite, felsite (?) and basalt as well as of Quaternary fluviatile deposits. There is, however, no exposure of granite which can commonly be seen in other parts of the Zaō volcanoes. The Tertiary formation exposed here consists mostly of shale, sandstone and green tuff, but it is represented by alternate beds of sand, clay and gravel in some places. The Aoso volcano rests upon the eroded surface of these Tertiary sediments (Figs. 2, 3).

(1) Shale, sandstone and green tuff beds: In Aoso volcanic area, important base rock are shale, sandstone and green tuff. They are extensively exposed on the hills extending northwards or eastwards from this volcano.

Characteristic exposures of shale and sandstone beds can be seen near Miya and Magatake as well as Tōgatta. In the former case, the eastern extension of shale and sandstone beds disappears beneath the accumulation of volcanic detritus. These beds change their strike and dip from place to place. The shale bed of Tōgatta has a strike of N 70° E to N 80° E and a dip of 5° to 10° N, whereas the shale and sandstone bed exposed near Magatake and Miya indicate respectively a strike of N 20° E or N 10° W to N 45° W and a dip of 70° to 80° ESE or 13° WSW and 10° to 40° NE.

Green tuff is the commonest rock in the area including Tōgatta and Kotsumazaka. Generally, it has a light green color which grades into greyish white in weathered specimens.

The writer has not yet found any fossil in these shale, sandstone and green tuff beds, but they have some lithological similarities to those which has been assigned hitherto to the Miocene in the neighboring districts.

(2) Clay, sand and gravel beds: The horizontal beds of clay, sand and gravel are exposed on the cliff which extends from east to west along the southern side of the Akiyama-zawa and Matsu-kawa. Of these. the gravel bed contains such pebbles as granite, propylite, andesite, etc. The almost flat surface of these beds is covered by mud flows, pumice layers and lava flows. The field evidence suggests that they have not been subjected to any strong disturbance since their deposition, and the distribution is restricted to a small extent. Most of them are, furthermore, represented by very loose sediments without any fossil. They are probably Pliocene sediments (Fig. 4).

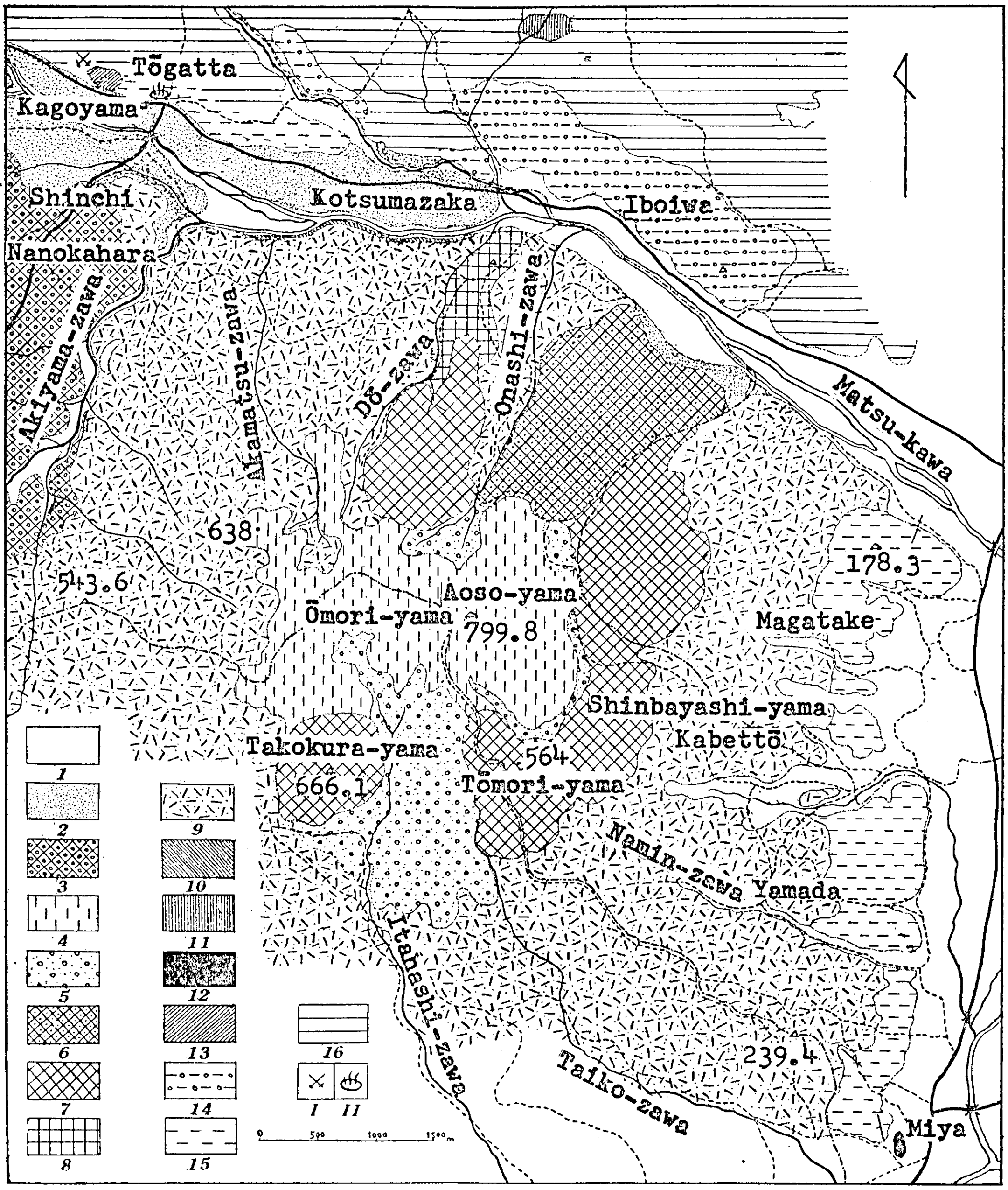

Fig. 2. Geological map of the Aoso volcano and its vicinity. 1. Recent fluviatile deposits, 2. Older fluviatile deposits, 3. Nanokahara mud flow, 4. Ōmori-yama lava (hornb. -bearing two-pyrox. andesite), 5. Itahashi-zawa agglomerate, 6. Onashi-zawa lava (01.-bearing two-pyrox. andesite or two-pyrox. andesite), 7. Tōmori-yama lava (01.-bearing two-pyrox. andesite or 01. two-pyrox. andesite), 8, Dō-zawa lava (two-pyrox. andesite) and agglomerate, 9. Matsu-kawa mud flow covered partly by talus deposits, 10. Clay, sand & gravel (Pliocene?), 11. Two-pyrox. basalt, 12. Aug. andesite, 13. Felsite, 14. Agglomerate, 15. Shale & sandstone, 16. Green tuff, I. Mine abandoned, II. Hot spring.

(3) Agglomerate and some effusive independent of the activities of the Aoso volcano: In association with the green tuff mentioned above, the occurrence of andesitic agglomerate and basalt is a characteristic feature of this district.

The andesitic agglomerate can be seen on the hill behind Kotsumazaka and Iboiwa. In the latter case, it is remarkably exposed along the bus road between Nagano and Tōgatta. The agglomerate here is intercalated with tuff beds, showing a strike of N 45° E to N 60° E and a dip of 30° to 40° NW or NNW. The fragments in agglomerate usually have an angular or subangular form and range mostly from 5 cm. to 20 cm. in diameter. They are olivine two-pyroxene andesite with a dark grey color and porphyritic texture. The similar condition is seen in the agglomerate of Kotsumazaka which contains fragments of two pyroxene andesite or olivine-bearing two-pyroxene andesite and extends from northwest to southeast.

Moreover, the occurrence of basalt in the area of green tuff is to be seen on a hill about 1500 m. north from the bus road near Iboiwa. The exposure of this rock has a nearly circular outline about 400 m. across. It is two-pyroxene olivine basalt which has a black color and is porphyritic in its texture. Under the microscope, the rock consists of plagioclase, olivine, augite, hypersthene, magnetite, goethite, serpentine and brown glass. Of these, phenocrystic minerals are plagioclase, augite, hypersthene and olivine.

It is also noteworthy that the felsitic rock is found together with shale or green tuff bed. An example is shown at the Miya Mine where it projects out as a cliff called "Kago-yama" along the bus road. The felsitic rock here has a white or greyish white color and it frequently stained by iron oxide derived from pyrite. It strongly resembles the silicified shale in its appearance, being composed of fine aggregates of quartz, feldspar and sericite under the microscope.

The small isolated hill behind Miya is an erosion remnant of augite andesite. The fresh specimen has a black color and is indistinctly porphyritic to the naked eye. When it is intensely subjected to weathering, an onion structure is to be seen on the surface. The phenocrystic mineral of this rock are plagioclase and augite. They are embedded in the groundmass consisting of minute crystals of lath-shaped plagioclase, augite and magnetite.

(4) Lavas and ejecta erupted from the Aoso volcano: The Aoso volcano is composed of lava flows and various kinds of ejecta which rest

upon the Tertiary formation. They are the Matsu-kawa mud flow, Dō-zawa lava and agglomerate, Tōmori-yama lava, Onashi-zawa lava, Itahashi-zawa agglomerate and Ōmori-yama lava in the order of eruption.

(i) Matsu-kawa mud flow. The Aoso volcano is skirted with the exposures of the Matsu-kawa mud flow which is supposed to have poured out from its pre-existing crater or its neighboring Byōbu volcano[4] at the earliest stage of activity. The northern end of this mud flow is highly cliffed along the Matsu-kawa and the lower course of the Akiyama-zawa where it is underlain by nearly horizontal beds of clay, sand and gravel (Fig. 4).

The mud flow exposed here is intercalated with several ash beds, pumice layers and thin lava flows. Such a mud flow is also seen along the Akamatsu-zawa, Dō-zawa and Itahashi-zawa, but it has some different appearance in the area including the lower course of the Taiko-zawa, Yamada, Kabettō, etc. In the latter case, it is extensively covered by talus deposits and is underlain by shale and sandstone beds.

The repeated occurrence of pumice layer is also found in this place. It is generally 30 cm. to 1 m. and consists of pumice fragments with a grey or light grey color. Lava flows associated with this mud flow are seen on the cliff of the Akiyama-zawa. They are mostly two-pyroxene andesite.

(ii) Dō-zawa lava (olivine-bearing two-pyroxene andesite) and agglomerate: The Matsu-kawa mud flow was followed by the eruption of the Dō-zawa lava and agglomerate. They extend from south to north, forming a narrow ridge between the Dō-zawa and Onashi-zawa. The northern end of this lava flow and agglomerate is highly cliffed along the Matsu-kawa, but they disappear beneath the Tōmori-yama lava southwards and are supposed to have been supplied from the pre-existing crater.

(iii) Tōmori-yama lava (olivine two-pyroxene andesite or olivine-bearing two-pyroxene andesite): It is widely exposed around the central cones of the Aoso volcano and forms a part of somma which is now dissected deeply by the Akamatsu-zawa, Dō-zawa, Onashi-zawa, Namin-zawa, Taiko-zawa, Itahashi-zawa, etc. The lava is amply exposed on Tōmori-yama, Takokura-yama and Shinbayashi-yama. Of these, Tōmori-yama rises as a small but characteristic cone which is easily distinguishable from other parts of the Aoso volcano. The Tōmori-yama lava is partly covered by the Onashi-zawa lava, Itahashi-zawa agglomerate, Ōmori-yama lava and talus deposits, but is underlain by the Matsu-kawa mud flow.

4) The Byōbu volcano belongs to the South Zaō.

(iv) Onashi-zawa lava (olivine-bearing two-pyroxene andesite or two-pyroxene andesite): The lava flow poured out from the same crater as mentioned above. It is underlain by the Tōmori-yama, but is covered by the Ōmori-yama lava. The lava exposed here seems to have run down northeastwards, and its terminal is now cut off by the Matsu-kawa.

(v) Itahashi-zawa agglomerate: It is amply exposed along the Itahashi-zawa and at the uppermost course of the Onashi-zawa in close association with the Ōmori-yama lava. It contains abundant fragments, large or small, of hornblende-bearing two-pyroxene dacite. In this case, this agglomerate is covered by the Ōmori-yama lava and seems to have been the forerunner of the lava which formed the central cones.

(vi) Ōmori-yama lava (hornblende-bearing two-pyroxene dacite): A different type of lava can be observed on Ōmori-yama and Aoso-yama which were deformed by the presence of explosion craters. It rests directly upon the Itahashi-zawa agglomerate and Tōmori-yama lava. The relationship between this and the Itahashi-zawa agglomerate can be seen on the northern cliff of Ōmori-yama and the uppermost course of the Itahashi-zawa and Taiko-zawa. In this case, the lava eruption took place within the crater surrounded by the Tōmori-yama lava.

(5) Quaternary fluviatile deposits: Younger or older fluviatile deposits are found along the present river course where they are composed of clay, sand and gravel.

(6) Talus deposits: The eastern or western flank and foot of the Aoso volcano is widely covered by talus deposits supplied from various kinds of lava flow and agglomerate. In such a case, the andesite fragments derived from the Tōmori-yama lava are more predominant than others.

Structure of the Aoso Volcano and Its Pre-existing Crater.

The present Aoso volcano is composed of somma and central cones, but it seems to have been a characteristic homate in the earlier stage of its activity. Such cones as Takokura-yama (Figs. 6, 7), Tōmori-yama (Figs. 5, 6), Shinbayashi-yama, etc. seem to have been formed on the peripheral part of the crater which is supposed to be 2.5 km. or thereabouts in diameter. The original form of this crater was subsequently destructed by the eruption of the Onashi-zawa lava, Itahashi-zawa agglomerate and Ōmori-yama lava.

As has already been stated, the Aoso volcano is constructed by mud flow, two-pyroxene andesite, olivine-bearing two-pyroxene andesite, olivine two-pyroxene andesite, hornblende-bearing two-pyroxene dacite and agglomerate. It rests upon the Tertiary formation, and there is an evidence that the mud flow directly covers the flat surface of horizontal beds composed of sand, clay and gravel assigned to Pliocene (?). Of these, the Tōmori-yama lava is most extensively distributed and almost surrounds the Ōmori-yama lava, although it partly disappears beneath the Ōmori-yama lava, Onashi-zawa lava and Itahashi-zawa agglomerate. The structure of this volcano can be confirmed along several valleys to some extent, but lavas and ejecta are poorly exposed within the crater where it is thickly forested. The crater here is almost filled up with the Itahashi-zawa agglomerate and Ōmori-yama lava.

Central Cones.

There are two central cones called Ōmori-yama and Aoso-yama in the crater mentioned above (Figs. 3. 5). These central cones stand side by side with a narrow watershed of the Onashi-zawa and Itahashi-zawa between them. They are composed of the Ōmori-yama lava underlain by the Itahashi-zawa agglomerate. Such a feature can be observed at the uppermost course of the Onashi-zawa, Taiko-zawa and Itahashi-zawa, where the Ōmori-yama lava directly covers the Itahashi-zawa agglomerate. Ōmori-yama and Aoso-yama seem to have been formed almost simultaneously on the fissure running from east to west. The present topographical features of these cones are much affected subsequently by the formation of explosion craters here and there.

Explosion Craters.

The presence of 6 explosion craters have been hitherto known on the Aoso volcano. They are respectively found on the northern or southern side of central cones and the southern flank of Takokura-yama as well as on the northern side of a cone situated about 1 km. northwest from the summit of Aoso-yama. Of these, two are characteristic explosion craters opened semicircularly northwards and northeastwards at the source of the Onashi-zawa and its branch. They are highly cliffed and are walled by a thick accumlation of the Ōmori-yama lava and Itahashi-zawa agglomerate.

Other explosion craters of these central cones can be seen at the opposite side, but are of a small scale as compared with those of the northern flank. They open westwards or southwards, passing downwards into the valleys of the Itahashi-zawa and Taiko-zawa.

The explosion craters of Takokura-yama and the cone 1 km. northwest from the summit of Aoso-yama are smaller and older than those of the central cones. The former exploded southwards on the southern flank of Takokura-yama, but it has been more or less obscured by the subsequent erosion. The latter is, on the other hand, still preserved as a horse-shoe-shaped hollow on the northern slope of the cone. This topographical feature can be observed fully from the opposite side near Kotsumazaka.

Mineral Composition of Lavas and Ejecta.

(1) Andesite fragments of the Matsu-kawa mud flow: Andesite fragments, large or small, are abundantly contained in the Matsu-kawa mud flow. Most of these are two-pyroxene andesite, but they are sometimes represented by olivine-bearing two-pyroxene andesite. The writer collected such specimens along the Matsu-kawa, Akamatsu-zawa, Akiyama-zawa, etc., where this mud flow is well exposed. The specimens thus obtained show features differing from place to place. They, however, have a porphyritic texture and black or dark grey color, being composed of such ingredients as plagioclase, augite, hypersthene, olivine, magnetite, tridymite, apatite and brown or colorless glass. Of these, the occurrence of olivine is restricted to some specimens obtained from the middle course of the Akamatsu-zawa.

Plagioclase is the most predominant mineral as phenocryst and also in the groundmass. The phenocryst of this mineral has a tabular or rectangular form and is 2.04 mm. × 1.16 mm. in its maximum size. It ranges from labradorite to bytownite with a composition between An_{65} and An_{80}. Moreover, the crystal is always characterized by the frequency of zonal structure and turbid zone. In such a case, the turbid zone is generally found in the central part or periphery of the crystal. It sometimes contains augite, hypersthene, magnetite and brown glass.

The minute crystals of lath-shaped or rectangular labradorite are abundantly found in the groundmass together with augite and magnetite as well as glass. Such crystals are mostly 0.03 mm.∼0.2 mm. in length.

In several specimens collected along the Akiyama-zawa, Matsu-kawa and Akamatsu-zawa, augite is always an important ingredient. It takes an euhedral or suhhedral form, being 2.04 mm. × 0.68 mm. in its maximum size. It sometimes shows that the extinction angle, $Z \wedge c$, is 38°∼40° and twins on (100) or (101). The crystal is closely associated with hypersthene in parallel intergrowth or granular aggregation. It contains magnetite as an enclosure. Small prismatic or granular augite crystals are commonly seen in the groundmass where they are 0.01 mm.$\sim$0.03 mm. in length or longer diameter.

The occurrence of hypersthene is known in all specimens. It is frequently more abundant than the phenocrystic augite. This mineral usually occurs as subhedral or anhedral phenocrysts, but well-defined crystals are not rare in the specimens of the Akamatsu-zawa. The largest one is 2.14 mm. $\times$ 0.81 mm. in size. Such crystals often include magnetite, apatite and plagioclase. When hypersthene and augite occur together in parallel intergrowth, the former is always fringed by the latter.

Olivine is rarely present as a phenocrystic mineral, and its occurrence is only known in the andesite fragments from the Akamatsu-zawa. It has a granular form. Octahedral or granular magnetite is a common accessory mineral in the groundmass. In most cases. it is shorter than 0.01 mm. in diameter, although there are some large crystals whose diameter is more than 0.5 mm.

Besides the ingredients mentioned above, chlorite is an alteration product derived from hypersthene. Tridymite and brown or colorless glass are sometimes found in the groundmass where they fill up the interstices of other ingredients. Moreover, some xenoliths of basaltic or noritic character are contained in the specimens obtained from the mud flow exposed along the Matsu-kawa, the lower course of the Akiyama-zawa and the middle course of the Akamatsu-zawa.

(2) Dō-zawa lava and agglomerate: The Dō-zawa lava and the fragments of its agglomerate have similar characters megascopically and microscopically. They are olivine-bearing two-pyroxene andesite with a black color and porphyritic texture. The andesite specimens collected by the writer on the cliff of the Matsu-kawa is a compact and hard rock composed of plagioclase, augite, hypersthene, olivine, magnetite and brown glass. Of these, plagioclase, augite, hypersthene and olivine are found as phenocrysts and ingredients of groundmass.

The phenocrystic plagioclase is usually euhedral or subhedral and takes a tabular or rectangular form. The largest crystal is 7 mm. in longer diameter. Some of it is well zoned and remarkably turbid, containing small grains of augite and magnetite as well as irregular patches of brown glass. The indices of refraction measured on (010) indicate that this plagioclase ranges from labradorite to bytownite and is $An_{72}\sim An_{81}$ in composition.

The plagioclase in the groundmass mostly occur as minute lath-shaped crystals, 0.03 mm.$\sim$0.2 mm. in length, and is more acidic than the phenocrystic one. In some specimens, the parallel arrangement of this mineral in the brown glass gives a hyalopilitic texture to the groundmass.

Augite is one of remarkable ingredients, and most of phenocrysts have a subhedral or anhedral form. Among them, the largest one is 2.5 mm. long and 1.05 mm. across. Such phenocrysts are occasionally twinned on (100) or (101), and the maximum extinction angle, $Z \wedge c$, is 40°. In these crystals, hypersthene and magnetite are always contained. Moreover, small prismatic or granular augite is abundantly found in the groundmass together with plagioclase, magnetite and brown glass. In this case, the length of prismatic crystals is less than 0.05 mm.

Hypersthene is also an important mineral as augite in all of the specimens collected by the writer. The amount of this mineral is, however, variable in different specimens. Thus, andesite fragments of Dō-zawa agglomerate contain hypersthene less abundantly than augite. The large phenocryst is 1.2 mm. or more in length, and it is sometimes associated with augite in parallel intergrowth, the former passing suddenly outwards into the latter.

The composition of phenocrystic plagioclase and the optical characters of phenocrystic augite and hypersthene are summarized in the following table.

	No. 1 (T.I. 47110101)	No. 2 (T.I. 47110102)
Plagioclase	Core: $(-)2V=86°$, An_{78}; Margin: $(-)2V=88°$, An_{72}	$An_{72\sim81}$
Augite	$\alpha=1.685\pm0.002$ $\beta=1.694\pm0.002$ $\gamma=1.711\pm0.002$ $\gamma\sim\alpha=0.028$ $(+)2V=50°$	$\alpha=1.681\pm0.002$ $\beta=1.692\pm0.002$ $\gamma=1.709\pm0.002$ $\gamma\sim\alpha=0.028$ $(+)2V=52°$
Hypersthene	$\alpha=1.693\pm0.002$ $\beta=1.700\pm0.002$ $\gamma=1.705\pm0.002$ $\gamma\sim\alpha=0.012$ $(-)2V=64°$ $\rho>v$	$\alpha=1.696\pm0.002$ $\beta=1.705\pm0.002$ $\gamma=1.709\pm0.002$ $\gamma\sim\alpha=0.013$ $(-)2V=62°$ $\rho>v$

No. 1.=Andesite frgment in the Dō-zawa agglomerate.
No. 2.=The Dō-zawa lava. (Measured by F. Hori)

Olivine is an important phenocrystic mineral, 2.12 mm. × 1.11 mm. in its maximum size. It is subhedral or anhedral and partly or entirely alters into serpentine. The crystal encloses magnetite like other phenocrysts.

Magnetite is either octahedral, granular or skeletal in form. The crystal contained in plagioclase, augite. hypersthene and olivine are larger than those in the groundmass. It is 0.51 mm. by 0.34 mm. in the biggest crystal, but its diameter is mostly shorter than 0.02 mm. in the latter case.

Brown glass fills up the interstices of all other ingredients. It is less abundant in the Dō-zawa lava.

(3) Tōmori-yama lava: Of various lavas and agglomerates exposed on the Aoso volcano, the most remarkable one is the Tōmori-yama lava, which has a wide area of distribution including Tōmori-yama, Takokura-yama, Shinbayashi-yama and others. It is a compact and porphyritic rock with a grey color. In weathered specimens, the porphyritic texture is shown more distinctly than in fresh ones. The mineral ingredients of this lava is represented by plagioclase, augite, hypersthene, olivine, magnetite, tridymite, apatite, hematite and brown glass. Of these, phenocrystic minerals are plagioclase, augite, hypersthene and olivine. There are, however, some mineralogical differences even in the same lava. In certain specimens, olivine is abundantly present, but it is lacking in others, although the lava has a quite similar texture in the groundmass. Hence, the lavas from Tōmori-yama and Shinbayashi-yama are olivine two-pyroxene andesite or olivine-bearing two-pyroxene andesite,. whereas those of Takokura-yama or elsewhere are composed of two-pyroxene andesite.

In such cases, various features are indicated by plagioclase, which takes an euhedral or subhedral form. It is well zoned and turbid in the inner or outer part, although each shows a fresh appearance. The largest phenocryst is 3.14 mm. × 2.38 mm. in size. Some of its crystal has a worm-eaten structure due to the abundance of irregular patches of brown glass. Besides brown glass, it encloses augite, hypersthene, magnetite, actinolite (?) needles and biotite which are often found in the turbid zone. Some of these are often arranged parallel to the periphery of plagioclase phenocrysts. Indices of refraction measured on (010) suggest that this plagioclase belongs to labradorite or bytownite with a composition ranging from An_{58} to An_{78}.

In the gronndmass, abundant lath-shaped crystals, mostly 0.025 mm.～0.2 mm. in length, generally takes a fluidal arrangement between phenocrystic minerals.

Augite and hypersthene are common ingredients of this rock. Hypersthene is sometimes more abundant than augite or *vice versa*. The augite phenocryst is generally subhedral or anhedral, but it is euhedral in some specimens. The largest phenocryst is 1.78 mm. × 1.07 mm. When the crystal is euhedral or subhedral, it has a stout prismatic form. It is sometimes found in parallel intergrowth with hypersthene. In this case, the latter is always fringed by the former. In zoned crystals, the inner part has a large extinction angle as compared with the periphery. It twins on (100) or (101), and its maximum extinction angle, $Z\wedge c$, is 41°. In the groundmass, augite is abundant and occurs as a prismatic or irregular form.

Hypersthene is a characteristic mineral with a distinctly pleochroic scheme. It is frequently found as an euhedral or subhedral crystal with a long prismatic form, 4.59 mm. × 0.93 mm. in its maximum size. This mineral contains mostly magnetite as enclosure.

The composition of phenocrystic plagioclase and the optical characters of phenocrystic augite and hypersthene are summarized in the following table.

	No. 1 (T.I. 47110201)	No. 2 (T.I. 51040101)	No. 3 (T.I. 51040106)	No. 4 (T.I. 51040201)	No. 5 (T.I. 51033106)
Plagioclase		$An_{60\sim74}$	$An_{70\sim78}$	$An_{58\sim75}$	
Augite	$\alpha=1.683 \pm0.002$	$\alpha=1.686 \pm0.002$	$\alpha=1.690 \pm0.002$	$\alpha=1.683 \pm0.002$	$\alpha=1.686 \pm0.002$
	$\beta=1.695 \pm0.002$	$\beta=1.693 \pm0.002$	$\beta=1.695 \pm0.002$	$\beta=1.690 \pm0.002$	$\beta=1.692 \pm0.002$
	$\gamma=1.711 \pm0.002$	$\gamma=1.708 \pm0.002$	$\gamma\doteqdot1.710$	$\gamma=1.710 \pm0.002$	$\gamma=1.712 \pm0.002$
	$\gamma\sim\alpha=0.028$	$\gamma\sim\alpha=0.028$	?	$\gamma\sim\alpha=0.027$	$\gamma\sim\alpha=0.026$
	$(+)2V=50°$	$(+)2V=51°$	$(+)2V=49°$	$(+)2V=50°$	$(+)2V=49°$
Hypersthene	$\alpha=1.700 \pm0.002$	$\alpha=1.691 \pm0.002$	$\alpha=1.689 \pm0.002$	$\alpha=1.689 \pm0.002$	$\alpha=1.693 \pm0.002$
	$\beta=1.708 \pm0.002$	$\beta=1.700 \pm0.002$	$\beta=1.699 \pm0.002$	$\beta=1.700 \pm0.002$	$\beta=1.699 \pm0.002$
	$\gamma=1.713 \pm0.002$	$\gamma=1.704 \pm0.002$	$\gamma=1.704 \pm0.002$	$\gamma=1.703 \pm0.002$	$\gamma=1.705 \pm0.002$
	$\gamma\sim\alpha=0.013$	$\gamma\sim\alpha=0.013$	$\gamma\sim\alpha=0.015$	$\gamma\sim\alpha=0.014$	$\gamma\sim\alpha=0.012$
	$(-)2V=59°$	$(-)2V=59°$	$(-)2V=60°$	$(-)2V=60°$	$(-)2V=58°$

No. 1. = The Tōmori-yama lava from the upper course of the Dō-zawa.
No. 2. = The Tōmori-yama lava from the Namin-zawa.
No. 3. = The Tōmori-yama lava from the hill at the north of Shinbayashi-yama.
No. 4. = The Tōmori-yama lava from the hill at the north of Shinbayashi-yama.
No. 5. = The Tōmori-yama lava from Takokura-yama. (Measured by F. Hori)

The occurrence of olivine is not so important when compared with other phenocrystic minerals, although it is frequently seen in the specimens collected from the lower course of the Akamatsu-zawa. The crystal of this mineral usually takes a subhedral or anhedral form, and its maximum size is 0.88 mm. × 0.59 mm. Part of it changes into bowlingite along the peripheries and cracks. Commonly, it contains magnetite.

One of characteristic features of this rock is the abundance of small magnetite crystals or grains in the groundmass together with minute lath-shaped plagioclase and augite. They are frequently represented by octahedral crystals. In some cases, these crystals are contained in the aggregate of granular augite. The crystal is 0.06 mm. in its maximum diameter, but it is mostly 0.01 mm.–0.05 mm. across.

There are rarely apatite crystals which have a dark brown color due to decomposition, being 0.39 mm. × 0.05 mm. in the maximum size. Tridymite fills up the interstices of various ingredients of the groundmass. It is not a rare mineral in the specimens from the Namin-zawa and the east flank of Takokura-yama. Long prismatic actinolite (?) occurs as an enclosure of plagioclase phenocrysts. The mineral shows a weak pleochroism and a small extinction angle, $Z \wedge c$, of 16° or thereabouts.

Besides these, doleritic, noritic or gabboic inclusions are found in most specimens. They are composed of plagioclase, augite, hypersthene and magnetite.

(4) Onashi-zawa lava: The ridge extending northeastwards along the eastern side of the Onashi-zawa is formed of two-pyroxene andesite or olivine-bearing two-pyroxene andesite with a remarkable porphyritic texture. The lava exposed here has a dark grey color, but it usually assumes a grey or reddish color by alteration.

The specimens collected by the writer are composed of plagioclase, augite, hypersthene, olivine, magnetite, hematite, tridymite, apatite, brown glass and actinolitic mineral.

Under the microscope, the phenocrystic plagioclase mostly has an euhedral or subhedral form, being 3.16 mm. × 2.15 mm. at its maximum size. It is well-zoned and occasionally turbid. It is sometimes characterized by a worm-eaten structure and includes such minerals as augite, magnetite and brown glass which occur as irregular patches. The indices of refraction on (010) suggest that the phenocrystic plagioclase ranges from labradorite to bytownite with a composition between An_{63} and An_{70}.

In the groundmass, lath-shaped or rectangular crystals are abundantly present. The former is 0.02 mm. ∼ 0.05 mm. long and occasionally shows a fluidal arrangement around phenocrystic minerals. It belongs to labradorite.

Augite is found as phenocryst and is an important ingredient in the groundmass. The phenocrystic augite is, however, less abundant than hypersthene and commonly takes a subhedral or anhedral form, twinning on (100) or (101). In this case, the largest crystal is 1.75 mm. × 0.49 mm. in size, and the maximum extinction angle, Z∧c, 14°. Moreover, most phenocrysts contain magnetite as enclosure. The augite crystals of the groundmass have a granular or stout prismatic form, being 0.03 mm.～0.08 mm. in the latter case.

Hypersthene with an euhedral or subhedral form is usually characterized by a long prismatic habit. The crystal is 2.75 mm. in its maximum lengh and includes magnetite. It is sometimes intergrown with augite in parallel position, the former passing outwards into the latter. In the andesite with a reddish color, it is intensely affected and segregates hematite.

The composition of phenocrystic plagioclase and the optical characters of phenocrystic augite and hypersthene are shown in the following table.

Olivine is a rare ingredient in the Onashi-zawa lava as compared with hypersthene and augite. The occurrence of this mineral is only known in several specimens. It has a very irregular form and partly changes into bowlingite along its periphery and crack.

	(T.I. 51040301)*
Plagioclase	$An_{63\sim70}$
Augite	$\alpha=1.684\pm0.002$ $\beta=1.693\pm0.002$ $\gamma=1.709\pm0.002$ $\gamma\sim\alpha=0.025$ $(+)2V=51°$
Hypersthene	$\alpha=1.690$ $\beta=1.699$ $\gamma=1.703$ $\gamma\sim\alpha=0.013$ $(-)2V=60°$

* The Onashi-zawa lava from the Onashi-zawa. (Measured by F. Hori)

Magnetite is always a very common mineral in the groundmass where it abundantly occurs in a granular or octahedral form. Most of magnetite crystals have a diameter ranging from 0.01 mm. to 0.05 mm., although there are some large crystals more than 0.4 mm. across. It passes into hematite in the specimens subjected to reheating.

The interstices of the minute ingredients in the groundmass is occasionally filled up by tridymite which is characterized by its irregular form and exceedingly low birefringence.

The occurrence of apatite is very rare. Its prismatic crystal is usually traversed by cracks and is somewhat decomposed in its inner part and obtains a dark brown color. Actinolitic mineral is only found as an enclosure of phenocrystic plagioclase. This mineral occurs as minute prismatic or acicular crystal traversed by cracks. It is always colorless and has a small extinction angle. The frequent occurrence of brown glass is noticed in the phenocrystic plagioclase and also in the groundmass of almost all specimens.

The groundmass consists of plagioclase, augite, magnetite, apatite and brown glass and reveals a hyalopilitic or pilotaxitic texture.

Besides the various ingredients mentioned above, there are some xenoliths with noritic or doleritic character. They are composed of plagioclase, hypersthene, augite, magnetite and brown glass.

(5) Dacite fragments of the Itahashi-zawa agglomerate: In this agglomerate many angular or subangular fragments of hornblende-bearing two-pyroxene andesite are cemented by tuffaceous or sandy matrix. These dacite fragments, large or small, have an appearance quite similar to the Ōmori-yama lava, being characterized by the abundance of phenocrystic quartz and the presence of hornblende. They are dark grey in fresh specimens and grey or light grey in weathered ones. Moreover, some of these obtain a reddish color by reheating.

Exclusive of quartz and hornblende, the dacite fragments under consideration consist of plagioclase, hypersthene, augite, magnetite, olivine and tridymite.

Of these, the phenocrystic quartz is generally subjected to magmatic corrosion and takes a more or less rounded form, 1.5 mm, in its maximum diameter. It is traversed by many cracks, and there are some crystals with liquid inclusions. Occasionally, the crystal shows a wavy extinction and, accordingly, a biaxial character. Quartz is also an important ingredient in the groundmass which shows a micrograniti texture.

The coarse porphyritic texture of dacite fragments in the Itahashi-zawa agglomerate is due to the frequent occurrence of fairly large phenocrystic plagioclase which is 3.91 mm. $\times$ 1.95 mm. in its maximum size. Euhedral, subhedral or anhedral phenocrysts of this mineral are always well-zoned and sometimes turbid, frequently containing magnetite, augite and hypersthene. Indices of refraction measured on (010) indicate that the phenocrystic plagioclase ranges from acidic labradorite to basic labradorite with such a composition as $An_{55\sim73}$. Minute lath-shaped or granular plagioclase is a remarkable constituent in the groundmass. In the former case, it is 0.08 mm. $\sim$ 0.25 mm. in length and belongs to andesine.

Phenocrystic augite, subhedral or anhedral, is usually less abundant than hypersthene. The crystal generally twins on (100), and its extinction angle, $Z \wedge c$, is 41°, being 2.2 mm. $\times$ 1.7 mm. in its maximum size. Magnetite is generally found as its enclosure. Augite is also a common ingredient in the groundmass. When it has a long prismatic form, the crystal is 0.08 mm.~0.02 mm. in length.

All specimens collected by the writer contain varying amount of hypersthene with a long primatic form. The largest phenocryst is 1.87 mm.×0.54 mm. in size, and the prismatic crystals of this mineral in the groundmass is 0.1 mm.~0.3 mm. in length.

The composition of phenocrystic plagioclase and the optical characters of phenocrystic hypersthene and augite is as follows.

	(T.I. 51033107)*
Plagioclase	$An_{55\sim73}$
Augite	$\alpha=1.682\pm0.002$ $\beta=1.695\pm0.002$ $\gamma=1.710\pm0.002$ $\gamma\sim\alpha=0.028$ $(+)2V=49°$
Hypersthene	$\alpha=1.695\pm0.002$ $\beta=1.703\pm0.002$ $\gamma=1.708\pm0.002$ $\gamma\sim\alpha=0.013$ $(-)2V=55°$

* Dacite fragment of the Itahashi-zawa agglomerate from the upper course of the Itahashi-zawa. (Measured by F. Hori)

Hornblende is one of characteristic minerals in this rock. It has a long prismatic form, and is characterized by a strongly pleochroic scheme, viz., X=amber yellow, Y=yellowish brown, Z=reddish brown. The color probably resulted from the oxidation due to reheating. Some of it twins on (100), and the largest crystal is 1.27 mm. long. It is partly opacitized.

Octahedral or granular magnetite is always found as an enclosure in other minerals and in the groundmass, where the largest crystal is 0.56 mm. in diameter. Besides these ingredients, the rock contains basaltic xenoliths consisting of plagioclase, augite, hypersthene, magnetite and olivine.

The groundmass indicates a microgranitic texture and contains plagioclase, augite. hypersthene, magnetite and tridymite.

(6) Ōmori-yama lava: The Ōmori-yama lava is underlain by the Itahashi-zawa agglomerate, both of which seem to have been erupted successively. Therefore, the Ōmori-yama lava and dacite fragments of the Itahashi-zawa agglomerate have some similar petrographic characters, as is shown by the presence of phenocrystic quartz and hornblende.

The phenocrystic quartz with a rounded form is always abundant in all specimens. It is traversed by many cracks, and the occurrence of liquid inclusions is known in many specimens. The crystal occasionally reveals a wavy extinction, and its maximum diameter is estimated at 1.44 mm.

One of the important ingredients is the phenocrystic plagioclase with an euhedral, subhedral or anhedral form which is 2.41 mm. × 1.70 mm. in its maximum sixe. It ranges from acidic labradorite to basic labradorite with such a composition as $An_{55\sim68}$. It mostly includes augite, magnetite and apatite, partly passing into a light brown glass. The crystal is well-zoned, and it is rarely not frequently turbid along the periphery or in the inner part of crystals. When plagioclase occurs as an ingredient in the groundmass, it is mostly represented by minute lath-shaped crystals, 0.02 mm.∼0.18 mm. in length. Augite and hypersthene are found in almost the same amount as those of the Itahashi-zawa agglomerate. Both minerals include magnetite grains and sometimes pass into one another, showing a parallel intergrowth in which hypersthene is always fringed by augite.

The prismatic hypersthene crystal is 1.57 mm. in its maximum length as phenocryst and 0.086 mm.∼0.18 mm. long as an ingredient of the groundmass.

Augite often twins on (100) or (101), and its extinction angle, $Z\wedge c$, is 40°. It has a subhedral or anhedral form, the phenocrysts being 0.81 mm × 0.25 mm. in the maximum size, and the minute crystals in the groundmass 0.01 mm.∼0.15 mm. long.

The following table shows the composition of phenocrystic plagioclase and the optical characters of augite and hypersthene.

	(T.I. 4711015)*
Plagioclase	$An_{55}\sim An_{68}$
Augite	$\alpha=1.689\pm0.002$ $\beta=1.695\pm0.002$ $\gamma=1.710\pm0.002$ $\gamma\sim\alpha=$? $(+)2V=50°$
Hypersthene	$\alpha=1.695\pm0.002$ $\beta=1.704\pm0.002$ $\gamma=1.709\pm0.002$ $\gamma\sim\alpha=0.014$ $(-)2V=57°$

* The Ōmori-yama lava from near the summit of Ōmori-yama.
(Measured by F. Hori)

Long prismatic hornblende is mostly of an oxidized type with a strong pleochroism changing from amber yellow (X) to yellowish brown (Y) or reddish brown (Z). In several specimens, there is also basaltic hornblende which shows the following pleochroic scheme viz., X=light yellow, Y=browish green, Z=greenish brown. The absorption is Z>Y>X in both cases. These two kinds of hornblende are subhedral or anhedral, and they are sometimes opacitized entirely. The maximum size of such crystals are 1.71 mm. × 0.17 mm.

Magnetite is the commonest mineral in the groundmass. It is generally

0.01 mm.~0.08 mm. in diameter, although there are some crystals with a diameter exceeding 0.42 mm.

Tridymite fills up the interstices of the ingredient minerals in the groundmass, and olivine is only found in xenolith. The groundmass is composed of such minerals as quartz, plagioclase, augite, hypersthene, magnetite and tridymite. Of these, lath-shaped plagioclase crystals often exhibit a fluidal arrangement, but the characteristic microgranitic texture is also known. In this rock, the occurrence of xenolith is not rate. They are basaltic rocks, consisting of plagioclase, augite, hypersthene, olivine and magnetite.

History of Volcanic Activities.

The activies of the Zaō volcanoes are supposed to have repeated many times on the upheaved area composed of the Tertiary formation and such intrusives or extrusives as granite, propylite, basalt, etc. Some of these abundantly supplied lavas and ejecta to construct the Aoso volcano at the eastern end of the South Zaō.

The first eruption seems to have taken place through the Tertiary formation exposed now in the district surrounding the Aoso volcano and is supposed to have began by pouring forth the Matsu-kawa mud flow. This mud flow was first considered by Takada to be the youngest ejecta in the South Zaō, but several field evidences here suggest that it may have been the forerunner of activities which happened in the Aoso or Byōbu volcanic area. Moreover, the Matsu-kawa mud flow is believed to have been ejected in the Pleistocene, since it partly rests upon the eroded surface of nearly horizontal beds assigned to the Pliocene (?).

The next activity is indicated by the eruption of the Dō-zawa lava and agglomerate which are always associated with each other. It was, however, restricted to a small area.

The central cone of the Aoso volcano is surrounded by the Tōmori-yama lava poured out later than the Dō-zawa lava and agglomerate. Its way of distribution suggests that there was formerly a large crater at the central part of this volcano occupied now by Aoso-yama and Ōmori-yama. The lava seems to have flowed out from here or from the fissures on the flank and to have rushed down in several directions. Tōmori-yama may be a parastic cone formed in connection with this eruption. After intensely subjected to erosion, the Onashi-zawa lava was ejected from the same crater and filled up the hollow between the Tōmori-yama lava and Matsu-kawa mud flow extending northeastwards.

The final activity is represented by the eruption of the Itahashi-zawa agglomerate and Ōmori-yama lava, the latter following the former. The Ōmori-yama lava is, therefore, underlain by the Itahashi-zawa agglomerate everywhere they are exposed. Both kinds of volcanic products resulted in the formation of central cones within the crater mentioned above. They are Ōmori-yama and Aoso-yama which rise as the two main peaks of the Aoso volcano.

In these repeated activities, the remarkable feature is the occurrence of hornblende-bearing two-pyroxene dacite. This rock is the final product in the activities of the Aoso volcano and suggests that it was probably derived from the magma which had captured such acidic rocks as granite and plagioliparite.

Summary.

(i) The Aoso volcano is isolated from the main part of the Zaō volcanoes, rising at the eastern end of the South Zaō. It is a small but characteristic volcano with central cones and several explosion craters as well as a large dissected crater which is about 2500 m. across.

(ii) This volcano rests upon the eroded surface of two different Tertiary formations. They are assigned to the Miocene and Pliocene (?) respectively, the former consisting of green tuff, shale, sandstone and andesitic agglomerate, whereas the latter is represented by clay, sand and gravel. In these cases, the Miocene sediments are sometimes intruded by felstic rock, andesite and basalt.

(iii) The volcano is formed of several lavas and ejecta, viz., the Matsu-kawa mud flow, Dō-zawa lava and agglomerate, Tōmori-yama lava, Onashi-zawa lava, Itahashi-zawa agglomerate and Ōmori-yama lava.

(iv) These lava flows and ejecta are supposed to have been supplied mainly from the pre-existing crater which were largely destroyed later by repeated eruption.

(v) The volcanic activities of this area probably started with the eruption of the Matsu-kawa mud flow and were closed by the formation of central cones constructed by hornblende-bearing two-pyroxene dacite.

(vi) The first eruption here seems to have taken place in the Pleistocene. It is shown on the cliff of the Matsu-kawa near Tōgatta, where the Matsu-kawa mud flow is underlain by alternate beds of clay, sand and gravel assigned to the Pliocene (?).

Fig. 3. The Aoso volcano from near Kotsumazaka. 1=Aoso-yama, 2=Ōmori-yama (Ōmori-yama and Aoso-yama are built up of Ōmori-yama lava underlain by the Itahashi-zawa agglomerate), 3=The Matsu-kawa, 4=The Onashi-zawa, 5=The Dō-zawa, 6=The Akamatsu-zawa, 7=Itahashi-zawa agglomerate, 8=Onashi-zawa lava, 9=Tōmori-yama lava, 10=Dō-zawa lava and agglomerate, 11=Matsu-kawa mud flow, 12=Alternate beds of clay, sand and gravel assigned to the Pliocene (?). ×=Explosion crater.

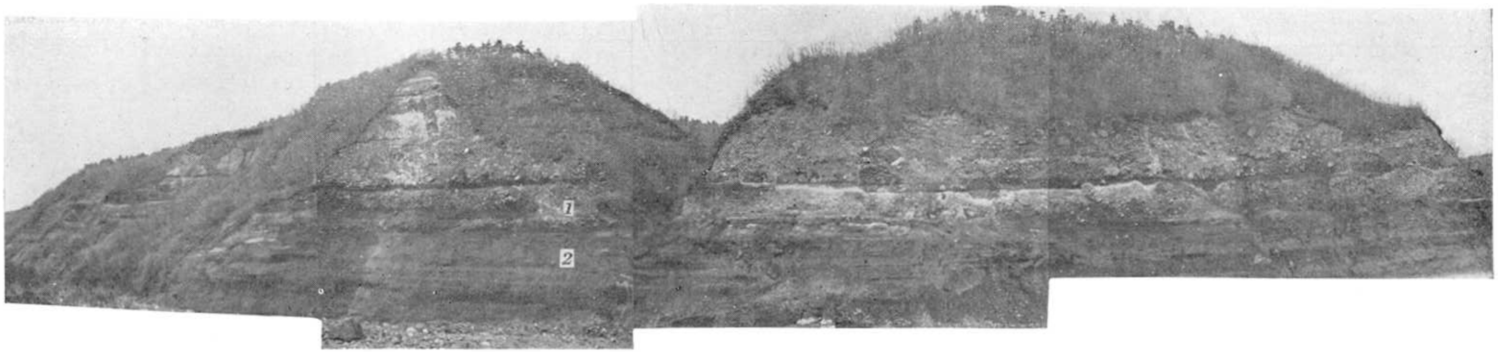

Fig. 4. The Matsu-kawa mud flow underlain by alternate beds of clay, sand and gravel assigned to the Pliocene (?). 1=The Matsu-kawa mud flow with pumice beds, 2=Alternate beds of clay, sand and gravel.

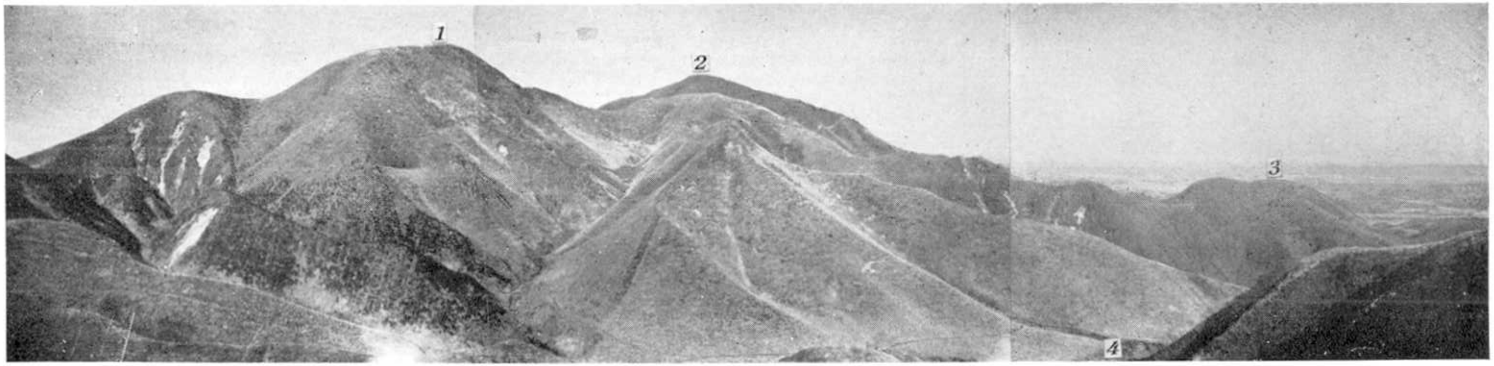

Fig. 5. Ōmori-yama and Aoso-yama, central cones of the Aoso volcano viewed from northeast.

1 = Ōmori-yama, 2 = Aoso-yama, 3 = Tōmori-yama.

Ōmori-yama and Aoso-yama are built up of hornblende-bearing two-pyroxene dacite underlain by the Itahashi-zawa agglomerate.

4 = The Itahashi-zawa.

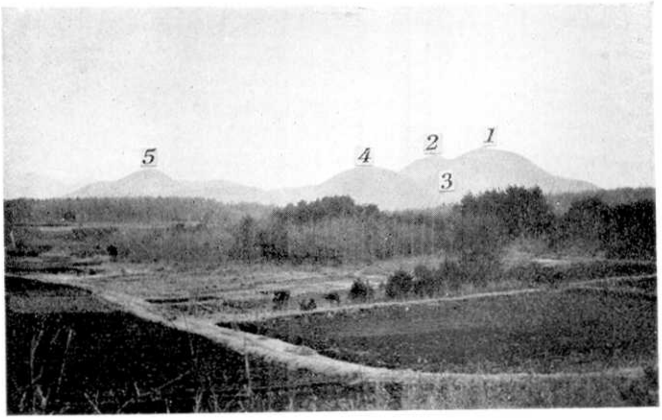

Fig. 6. The Aoso volcano from near Yamada.
1 = Aoso-yama, 2 = Ōmori-yama, 3 = Shinbayashi-yama, 4 = Tōmori-yama, 5 = Takokura-yama.

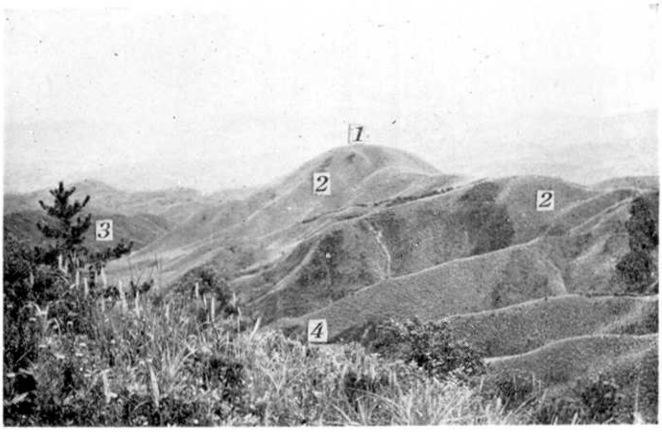

Fig. 7. Takokura-yama from near Ōmori-yama.
1 = Takokura-yama (Tōmori-yama lava), 2 = Ōmori-yama lava, 3 = Itahashi-zawa agglomerate, 4 = The Itahashi-zawa.

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12. 藏王火山の地質学的研究 (第二報)

地震研究所 市 村 毅

東北線の白石驛又は大河原驛から遠刈田溫泉へ行く途中，先づ目につくのは，道路の左側に根を張る青麻火山の姿である．此火山は，高さこそ約 800 米に過ぎないが，爆発や浸蝕作用のために変貌した外輪山とその內側に生じた中央火口丘よりなり，小さいながらも，纒つた火山の形態を見せている．然も藏王火山群の他の火山と異なり，何処からでも容易に近づけるので，その研究には極く都合の良い火山である．

青麻火山は，第三系とこれを貫く各種の火成岩を基盤として盛上り，松川泥流，ドー沢熔岩とその集塊岩，遠森山熔岩，オナシ沢熔岩，イタハシ沢集塊岩，大森山熔岩から構成されている．殊に最後に噴出した大森山熔岩とその直ぐ下位を占めるイタハシ沢集塊岩とは，他の噴出物が複輝石安山岩，含橄欖石複輝石安山岩又は橄欖石複輝石安山質なのに比べ，角閃石を含む複輝石石英安山岩なる点に特徴を有する．又最初の火山活動は，その基盤岩との関係が示す様に，第四紀に入つてから開始されたものであり，これは屛風火山の活動と相呼応して行われたものと見做される．

本文には，これ等の地質的事項と各噴出物の內容に就ての概略が纒められてある．但し熔岩や火山碎屑物に関する詳しい岩石学的研究結果の報告は化学分析が完了した後に譲ることにする．
