28. *Geological Investigations on the Zaō Volcanoes. IV Ryū-zan Volcano.*

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Introduction

The Ryū-zan Volcano is included in the North Zaō and occupies the northern end of the Zaō Volcanoes, constructing here one of the centers of activities which are arranged from northeast to southwest in this volcanic area. It is not so extensive as compared with the Kumano Volcano (Zaō Proper) and Byōbu Volcano[1] situated further south, but has very complicated topography and structure due to repeated eruptions and successive openings of explosion craters. Such activities are supposed to have taken place in concert with other parts of the Zaō Volcanoes. Since the present Ryū-zan Volcano is deeply dissected by subsequent erosion and is intensely destructed by explosion, it is very easy to investigate its history of volcanism which seems to be an important key point in making clear the activities of such adjoining volcanoes as Kumano and Gando.

The geological investigations of the Ryū-zan Volcano and its surrounding area were first intended by A. Takada[2] many years ago and recently by the writer's students[3]. The writer's field and laboratory works were also carried on intermittently since 1948, although he unfortunately had an accident in July of 1955, when he was attacked by a big bear on the northern flank of Ryū-zan and was severely injured. The results of these works are summarized in this paper.

Location

The Ryū-zan Volcano is situated at the southeastern corner of Yamagata City where it includes such districts as Takiyama, Zaō and

1) T. ICHIMURA, *Bull. Earthq. Res. Inst.*, **33** (1955), 593-629.
2) A. TAKADA, *Graduation Thesis*, *Tokyo Univ.*, *M.S.* 1922.
3) K. SUGAI, 〃 , *Yamagata Univ.*, *M.S.* 1955.
S. SUTŌ, 〃 , 〃 ., 〃 . 〃 .

Higashizawa. The volcanic area is not far from Yamagata and can easily be approached through several courses. For the purpose of climbing up Ryū-zan and Torikabuto-yama, the Zaō Hot Spring is, however, selected usually as its base, because there are bus roads between Yamagata or Kaminoyama and this place. Each of these summits is directly attainable from here within a short distance. To the summit of Ryū-zan, it is also accessible from Yamagata through Iwanami and Tsuchisaka or Kannō, although both courses are long and steep as compared with others.

Topographical and Geological Features of the Ryū-zan Volcano

The Ryū-zan Volcano is chiefly composed of Ryu-zan (1363.5 m.) and Torikabuto-yama (1401 m.). These two peaks rise up respectively at the northern and southern sides of the Zaō Hot Spring. They are partly forested thickly and have steep or rugged features. The eastern side of this area faces to Gando-san beyond a deep valley dissected by the Mamigasaki-gawa, whereas its western part suddenly lowers down from the steep ridge to slightly undulated table land, which passes gradually into the hilly land westwards, ending at the southern periphery of the Yamagata Basin. The northern end of the table land is bordered by liparitic or dacitic masses of Saruoka-yama, Chitose-yama and Togami-yama close to Yamagata. Of these, Chitose-yama has a beautiful conical form.

The mountainous area mentioned above is watered by the Mamigasaki-gawa, Su-kawa and their tributaries. The Mamigasaki-gawa runs northwestwards and joins such tributaries as Happō-zawa, Gando-zawa, Kote-zawa, Nabekurafudō-zawa, Hanoki-zawa, Nidari-zawa, Mizunashi-zawa, Atera-zawa, Matsudome-zawa, Ōshio-zawa, Koshio-zawa and Hime-sawa on its way. It constructs a typical alluvial fan at the end of its valley, where a part of this gentle slope is occupied by the old town of Yamagata.

The Su-kawa, on the other hand, finds its origin at the bottom of the explosion crater surrounding the Zaō Hot Spring and flows into the Su-kawa of Yamagata Basin* after it gathers the water of the Harai-gawa, Ichido-gawa, Nido-gawa, Sando-gawa and other tributaries. In the case of the Mamigasaki-gawa, the main river and tributaries are

* There is another river called the Su-kawa in the Yamagata Basin, where it runs from south to north and joins to the Mogami-gawa in the vicinity of Nagasaki.

characterized by the predominance of deep gorges with some terraces along them, but the Su-kawa valley is wide and monotonous through its course. It is believed to be due to the occurrence of granitic rocks in the former and the exposure of mud flow in the latter. Besides them, one of noticeable features is the abundance of swamp, large or small, in the area covered by mud flows. They are represented by Haryū-numa, Sanbongi-numa, Sara-numa, Sakazuki-ko, Shiginoyachi-numa and others (Fig. 1).

The area under consideration is geologically intricate, being built up of granite (granodiorite), Neogene sediments and older or younger volcanics as well as of Quaternary fluviatile or talus deposits. The younger volcanics are represented by andesite lavas or other ejecta and rest upon the eroded surface of granite and other base rocks (Fig. 2).

(1) Intrusives and extrusives before the first eruption of the Ryū-zan Volcano:—The most important rock is composed of biotite granite and hornblende biotite granite in which the former is more extensively distributed than the latter, being frequently associated with plagioliparite, felsitic rock and propylite. There are some textural varieties from coarse to fine, and some of these are more or less schistosed. Among them, fine-grained granite is mostly found at the area including the Hime-sawa, Koshio-zawa and Bōbara. In this case, it contains quartz, orthoclase, plagioclase and biotite less than 1 mm. in diameter. The coarse-grained granite is, on the other hand, seen along the Fudō-zawa and Harai-gawa. Its essential components are commonly 5 mm. or more in longer diameter, and biotite-rich varieties have a dark color.

The commonest type of granite is a medium-grained variety which is leaucocratic or melanocratic, and its specimen from the Koshio-zawa is characterized by a warm color.

Under the microscope, such various kinds of granite as mentioned above consist of quartz, orthoclase, microcline, andesine, biotite, hornblende, magnetite, zircon, allanite, apatite, pyrite, titanite in association with leucoxene, epidote, chlorite, sericite, limonite and kaoline.

Moreover, the granites exposed at the Ryū-zan volcanic area contain xenoliths with an ellipsoidal or irregular form, 10 m. or thereabouts in the maximum diameter. They are dioritic or lamprophyric, mineral components being quartz, plagioclase, green biotite, green hornblende, apatite (prismatic or acicular), pyrite, magnetite, titanite, leucoxene, sericite, epidote and chlorite. They are lithologically similar to those in the Gassan granite.

Fig. 1. Topographical map of the Ryū-zan Volcano and its vicinity.
1. Takayu explosion crater, 2. Kannō explosion crater,
3. Akakura explosion crater, 4. Suzuritaki explosion crater.

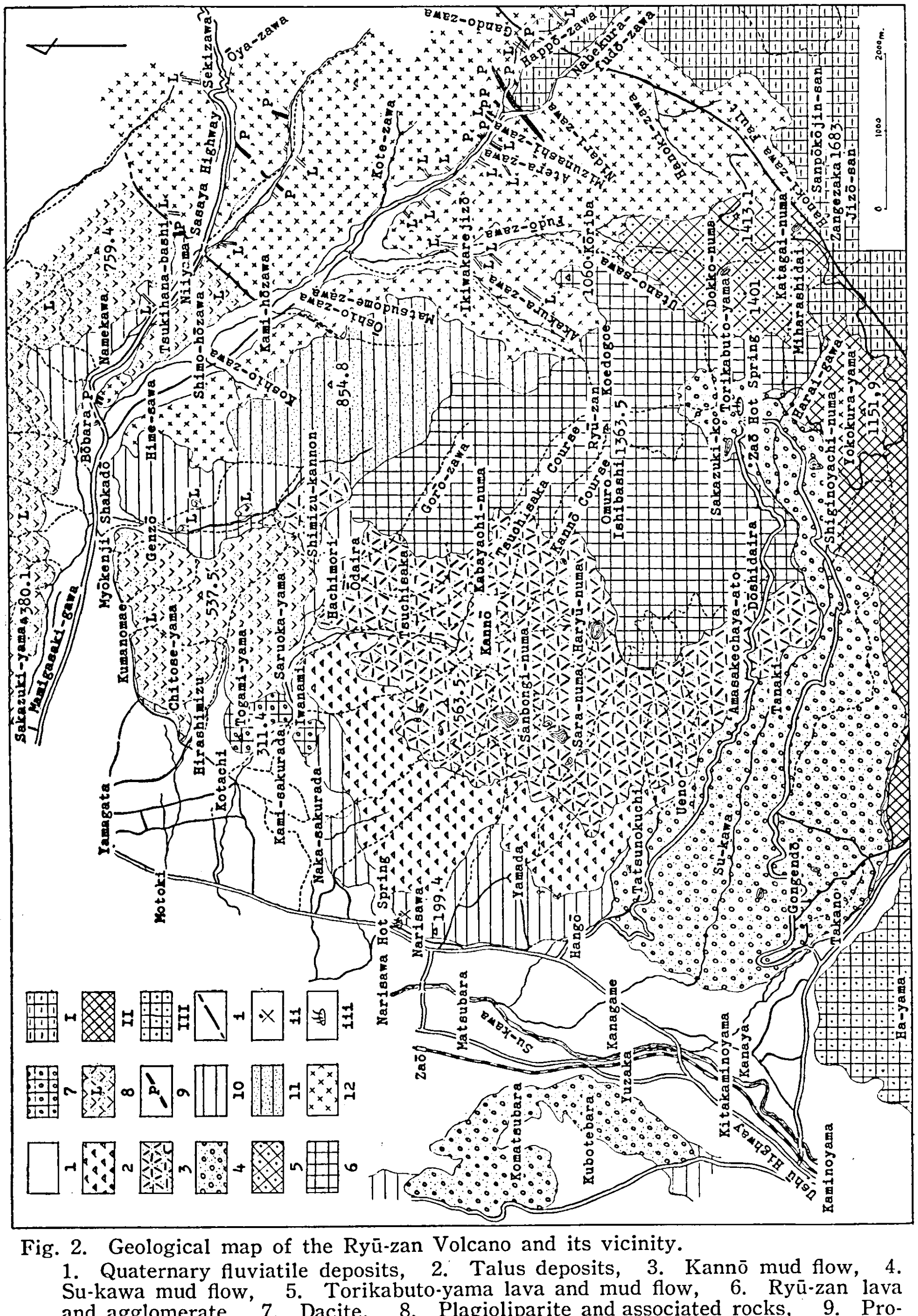

Fig. 2. Geological map of the Ryū-zan Volcano and its vicinity.

1. Quaternary fluviatile deposits, 2. Talus deposits, 3. Kannō mud flow, 4. Su-kawa mud flow, 5. Torikabuto-yama lava and mud flow, 6. Ryū-zan lava and agglomerate, 7. Dacite, 8. Plagioliparite and associated rocks, 9. Propylite, 10. Upper Tuff Formation, 11. Lower Tuff Formation, 12. Granite (granodiorite), I. Jizō-san lava (Kumano Volcano), II. Yokokura-yama lava and agglomerate, (Kumano Volcano), III. Ha-yama lava (Ha-yama Volcano) i. Fault, ii. Fossil localities, iii. Hot spring.

Plagioliparite and felsitic rock are mostly found along the Mamigasaki-gawa and its tributaries, where granitic rocks and Neogene sediments are largely exposed. In this case, plagioliparite shows a high frequency as compared with felsitic rock and occurs as dykes or lava flows of various scales. Of these, the former is very frequently seen at the area which covers the uppermost course of the Mamigasaki-gawa, Niiyama and Sekizawa, showing commonly a trend of NE-SW parallel to the extension of main faults. They are 20 m. or thereabouts in the maximum width. Moreover, some of them are closely associated with propylite dykes, as is indicated by several example obtained near Niiyama and the junction of the Mamigasaki-gawa and Hanoki-zawa.

Its lava flow, on the other hand, rests upon granitic rocks and Neogene sediments exposed along the tributaries of the Mamigasaki-gawa between Namekawa and Niiyama. The eastern end of the exposure is displaced by a fault which is traceable from northeast to southwest and is sharply bordered by a granitic body. Besides it, there is another lava flow of four square kilometers, covering conformably the Neogene formation and spreading over Saruoka-yama, Chitose-yama and Myōkenji. This lava flow seems to extend northwards, although it disappears beneath the Alluvial deposits of the Mamigasaki-gawa. The sporadical occurrence of plagioliparite is furthermore known at the Tertiary area between Myōkenji and Hōzawa. Some of these exposures are probably erosion remnants isolated from the same lava flow.

The palgioliparite mentioned above have such various colors as dark grey, grey, greyish white, etc. In the writer's specimens, quartz phenocrysts, large or small, are sometimes abundant, but they are scarce in other cases. Moreover, intensely silicified or kaolinized examples are to be seen on Chitose-yama. Exclusive of quartz, orthoclase and plagioclase, the rocks are usually composed of pink-colored zircon, magnetite, pyrite, titanite, leucoxene, chlorite and sericite. Microscopically, quartz and feldspar of the groundmass reveal occasionally a spherulitic structure.

Felsitic rock is quite similar to plagioliparite in its mode of occurrence. When the rock takes a dyke form, it cuts granitic rocks at Hōzawa and the upper course of the Mamigasaki-gawa, but its lava flow is extensively distributed on the hilly land beyond the Mamigasaki-gawa, where it is sometimes associated with plagioliparite or andesitic rock with a trachytic texture.

Injected felsitic rock is generally intensely subjected to weathering and attains a grey color. It contains plagioclase and a small amount of orthoclase as phenocrysts, but orthoclase, plagioclase, quartz, magnetite, pyrite, pink zircon, titanite, chlorite, leucoxene and epidote in the matrix. When the rock is exposed as lava flows, it has a dark grey color in fairly fresh specimens, but gets a grey color by weathering. In such a case, phenocrystic components are represented by plagioclase and orthoclase, although the latter is found in a minor amount. They are embedded within the groundmass composed of quartz, orthoclase, plagioclase, apatite, magnetite, calcite, sericite, titanite, leucoxene and limonite.

Dacite is a lava flow which spreads over the area including Togami-yama, Onigoe, Iwanami and Sakurada situated at the northwestern end of the Ryū-zan Volcano. It is supposed to have poured out during the sedimentation of Miocene tuff beds. The erosion remnant of this lava flow are sometimes characterized by such topographical features as Togami-yama and others at present. Some good exposures can be seen on the cutting near the bus station and also on the adjacent stream bed, where they exhibit an indistinct joint structure. The fresh specimen has a black and compact groundmass which contains corroded quartz phenocrysts, 2–4 mm. across, together with such ingredients as plagioclase, hornblende, augite, hypersthene, magnetite and chlorite.

Propylite is frequently found in the granitic mass and Neogene formation exposed largely at the mountainous area which is deeply dissected by the Mamigasaki-gawa and its tributaries. It occurs as dyke or sill; and the former is more predominant than the latter. Of these, the former shows the highest frequency at the upper course of the Mamigasaki-gawa and takes the same trend as plagioliparite with which it is sometimes associated closely. The largest one is to be observed at the entrance of the Hanoki-zawa, and its broadest part is estimated to be 100 m. or thereabouts. Here it is traceable from northeast to southwest across the granitic area watered by the Mamigasaki-gawa and Happō-zawa.

There are also other remarkable exposures at Namekawa and Nii-yama as well as on the ridge just behind Hōzawa, constructing sill and dykes, large or small, in green tuff beds.

Propylite sills and dykes mentioned above are undoubtedly younger than green tuff, but there are some possibilities of older propylite which are suggested by the presence of its pebbles in the tuffaceous conglomerate. Similarly, propylite is older than plagioliparite, since the former is found as xenolith in the latter. The rock is believed to have mostly been altered from andesite and basalt.

It is a compact rock with a dark green or yellowish green color, being composed of plagioclase, augite, pyrite, magnetite, limonite, hematite, chlorite, calcite, titanite, leucoxene and sericite. The specimen obtained from the Ōshio-zawa, on the other hand, contains some phenocrystic aggregates of chlorite, calcite, hematite, limonite, etc. They are supposed to have been changed from olivine crystals.

(2) Neogene sediments:—These sediments are largely exposed at this volcanic area, being represented by green tuff, sandy tuff, brecciated tuff, conglomerate, sandstone, siltstone and shale. They are divided into two tuff formations, upper and lower. Of these, the Lower Tuff Formation corresponds to the Yoshino Formation[4], whereas the Upper Tuff Formation is similar to the Sugarida Formation[5] in other districts.

The distribution of the Lower Tuff Formation is restricted to the eastern side of the Ryū-zan Volcano. The formation is mainly composed of green tuff beds, and its thickest part is 400 m. or thereabouts. When it rests directly upon granitic rocks, conglomerate is frequently seen at its base. It is used to pass into a brecciated tuff or green tuff upwards, being well exposed at the southeast of Genzō and along the Ōshio-zawa as well as on the river bed near Niiyama. It is rich in boulders, 1 m. in maximum diameter, and contains some pebbles of granitic rocks. Moreover, there are some green tuff beds which are characterized and complicated by the occurrence of propylite fragments and sills. Such a geological feature seems to indicate that propylite has, at least, two different ages of injection or eruption in connection with the sedimentation of green tuff.

In contrast with the formation mentioned above, the Upper Tuff Formation is distributed from north to south at the volcanic area, being intercalated with sandstone, siltstone and shale. It is estimated to be about 300 m. at the thickest part and is closely associated with lava flows of plagioliparite and felsitic rock. The sandy tuff exposed near the Narisawa Hot Spring preserves such Brachiopods as *Terebratalia tenuis*, *Terebratulina crossei*,, etc. Most of the upper tuff formation are, however, covered by ejecta and lava flows of the Ryū-zan Volcano and talus deposits. Its geological structure is, therefore, partly undetermined.

4) S. MINAKAWA, *Bull. Yamagata Univ., Nat. Sc.*, **4** (1957), 244.
5) 〃 , *op. cit.*, (1957), 245.

Since the Upper Tuff Formation was subjected to the strong disturbance, its strike and dip change from place to place. For instance, the alternate beds of black shale and sandstone exposed at Shimizu-kannon reveal a strike of N50°E and a dip of 30°NW, but the siltstone beds of Kabayachi-numa situated near the Tsuchisaka Course are N–S in strike and 50°W in dip. In the case of light green tuff beds stratified behind the Narisawa Hot Spring has a strike of N25°W, inclining 25° east-northeastwards.

(3) Lavas and ejecta from the Ryū-zan Volcano were not so frequently erupted as those of the Byōbu Volcano[6] and Aoso Volcano[7]. They are shown by the eruption of the Ryū-zan lava and agglomerate, Torikabuto-yama lava and mud flow, Su-kawa mud flow and Kannō mud flow.

(i) Ryū-zan lava (olivine two-pyroxene andesite or olivine-bearing two-pyroxene andesite) and agglomerate:—Ryū-zan is built up of the Ryū-zan lava and agglomerate which are elevated to 1363.5 m. above the sea-level at the highest point. These volcanic products rest upon the eroded surface of granitic rocks and the Neogene formation. They are covered by the Torikabuto-yama lava at the southeast and are overlain by the Kannō mud flow at the west, whereas disappears partly beneath the Su-kawa mud flow at the south. The thickest part of lava and agglomerate is estimated to be about 400 m., being well exposed at the northern side of the Zaō Hot Spring.

(ii) Torikabuto-yama lava (olivine two-pyroxene andesite or olivine bearing two-pyroxene andesite) and mud flow:—The volcanic products are exposed on Torikabuto-yama and its surrounding area, but they are found in a small extent as compared with the Ryū-zan lava and mud flow mentioned above.

The lava and agglomerate of this area rest on the surface of granite, palgioliparite, Ryū-zan lava, Yokokura-yama lava and Jizō-san lava, being partly bordered by a big fault from the last one (Fig. 8). The gently sloped area between Momiji-tōge and Zange-zaka seems to be composed of mud flow which passes possibly into the lava flow upwards.

The lava flow here is frequently cliffed, as is indicated at the northeast of Torikabuto-yama where it covers directly granite and on the western flank of the same peak. Its exposure reveals varying

6) T. Ichimura, *op. cit.*, (1955), 627–628.

7) 〃 , *Bull. Earthq. Res. Inst.*, **31** (1953), 147–148.

thickness from place to place, and it is about 200 m. thick in the case of the lava flow exposed on the western flank.

(iii) Su-kawa mud flow:—There are two mud flows on this volcano. One of them is the Su-kawa mud flow erupted from the explosion crater just behind the Zaō Hot Spring (Figs. 3, 4). It extends westwards further down to Shindō, Yuzaka and Kubotebara beyond the Ōu Railway Line, forming here a complicatedly undulated area with several swamps represented by Shiginoyachi-numa, Sakazuki-ko and others.

The mud flow is traceable for a distance of about 11 km. from east to west and shows varying width between 700 m. and 4000 m. Its total area is estimated to be 26 km^2., and the maximum thickness is 100 m. or there-abouts along the Su-kawa where the mud flow is exposed on the Ryū-zan lava.

(iv) Kannō mud flow:—It is widely exposed at the western side of Ryū-zan, extending from Tsuchisaka to Kannō and Dōshidaira southwards (Figs. 5, 6, 7). The area of this mud flow is about 11 km^2. and is suddenly elevated above the Tertiary sediments with some characteristic topographical features of table land. As is indicated by the Su-kawa mud flow, it is about 100 m. in its thickest part and is noticed by the sporadical distribution of such swamp as Haryū-numa, Sanbongi-numa, Sara-numa, etc.

(v) Quaternary sediments:—They are represented by younger or older fluviatile deposits and talus deposits.

(a) Younger or older fluviatile deposits: Fluviatile deposits are accumulated along the Mamigasaki-gawa, Su-kawa and their tributaries, consisting of gravel, sand, and clay beds. The older deposits construct some terraces at the upper course of the Mamigasaki-gawa along its tributaries. There is also a remarkable fan at the lower course of the Mamigasaki-gawa.

(b) Talus deposits:—Neogene sediments are thinly covered by talus deposits on the hilly land including Monzen, Naka-sakurada, Narisawa, Yamada, Hangō, etc. They are composed of andesite blocks or fragments derived from the Kannō mud flow or other detritus.

Structure of the Ryū-zan Volcano

The Ryū-zan Volcano is a homate rising up on the northern extension of the weak zone, where the Kumano Volcano and Byōbu Volcano were borned. It is not so large as above-mentioned volcanoes, but is very complicated in its form and structure. The present topography of this volcano depends upon the intense destruction due to repeated eruptions and explosions which took place in connection with other parts of the Zaō Volcanoes. The rugged peak of Ryū-zan was mainly resulted from these volcanic activities.

The relationship between the lava flows, agglomerates and mud flows constructing the Ryū-zan Volcano is well observed at the area surrounding the Zaō Hot Spring, along the Tsuchisaka Course and on Koedogoe as well as along the Gorō-zawa and Akakura-zawa. For instance, the lava flows exposed on the wall of explosion crater near the Zaō Hot Spring and the cliff extending southwestwards from here are piled up with an inclination of about 20°W (Fig. 3), and they are intercalated by agglomerate near the trail of Dōshidaira branching from the bus road.

The lava flow of the crater wall mentioned above seems to be more than 400 m. in its thickness. There is, however, no base rock appearing beneath this lava. The lava flow is also overlapped predominantly on the northern flank of Ryū-zan where it inclines 40°NW along the Tsuchisaka Course, but 20°NW along the Gorō-zawa. In the former case, it is intercalated by a thick agglomerate. The similar rock is found at the lowest part of the lava flow exposed along the Gorō-zawa. Moreover, the inclination of lava flow is 5°–15°E on the flank between Koedogoe and the Akakura-zawa, whereas it is 20°–30°S at Omuro and Ishibashi. These lavas and agglomerates are, therefore, inferred to have been erupted from the crater somewhere near the summit of Ryū-zan. In addition, the steep inclination of the agglomerate bed along the Tsuchisaka Course suggests that there were some disturbances at this area after repeated activities of Ryū-zan Volcano.

Such structures as observed on Ryū-zan are indistinct at its opposite side, viz., Torikabuto-yama. The volcanic products from here are, however, displaced by several faults, large or small, running from the northern side of Sanpōkōjin-san to the Hanoki-zawa and its adjoining area. In this faulting, the side of Torikabuto-yama was thrown down against the Jizō-san lava of Sanpōkōjin-san. Besides them, the Torikabuto-yama lava inclines 10°–20° southwards. It was probably caused by the local subsidence taken place in connection with the explosion of the Ryū-zan Volcano, as is shown by the Kumano-dake lava exposed largely on the wall of the Umanose explosion crater[8].

8) T. ICHIMURA, *Bull. Earthq. Res. Inst.*, **29** (1951), 330-332.

Craters

The Ryū-zan Volcano is now a destruction remnant due to repeated explosions and continuous erosions, but seems to have been a characteristic homate at the earlier stage of its activity. The structure of this volcano also suggests that it was formerly higher than the present altitude and had a large crater on its, summit. Such a crater had still kept its original form, when the Ryū-zan lava and agglomerate were erupted from here and the vicinity, although it was almost obscured later with the formation of the explosion crater surrounding the Zaō Hot Spring.

Explosion craters are well preserved mostly as compared with the pre-existing crater under consideration. They are represented by four semi-circular hollow distributed around Ryū-zan (Fig. 1).

One of these is the Takayu explosion crater which is the largest of all with a diameter of 2500 m. from northwest to southeast and has a steep wall of 250–400 m. high between Ryū-zan and Torikabuto-yama. It is the source of the Su-kawa and Su-kawa mud flow, being characterized by the presence of the Zaō Hot Spring which comes out here and there at its bottom. The crater wall here is frequently highly cliffed at the north, but there are some evidences to suggest a local subsidence at the southeast.

In connection with it, the western side of Ryū-zan is sccoped out downwards by the opening of the Kannō explosion crater. It is, however, found in an extension smaller than the Takayu explosion crater and has a diameter of 1500 m. from northeast to southwest. The original crater wall is more or less deformed and is intricately dissected by subsequent erosion (Figs. 5, 6).

The Kannō mud flow was poured out from here and spreads over the eroded surface of Neogene sediments. It constructs a gently undulated area, where Haryū-numa, Sanbongi-numa, Sara-numa and others are found.

Besides these, two subordinate explosion craters are known at the uppermost course of the Akakura-zawa and just below the summit of Ryū-zan. They are respectively named the Akakura explosion crater and Suzuritaki explosion crater by the writer. In these cases, the Akakura explosion crater opens northeastwards and is about 750 m. in diameter from northwest to southeast. It has no mud flow, and its horse-shoe-shaped hollow is well observed from the summit of Gando-san.

The Suzuritaki explosion crater seems to have exploded northwards close to the summit of Ryū-zan. It is found in very small scale, but has a sharp outline, being closely associated with the Kannō explosion crater.

Mineral Composition of Lavas and Ejecta

(1) Ryū-zan lava and agglomerate:—The Ryū-zan Volcano is mainly composed of the Ryū-zan lava and agglomerate which disappear partly beneath the Torikabuto-yama lava, Su-kawa mud flow and Kannō mud flow. They are exposed here and there at this volcanic area, particularly along the Gorō-zawa, Tsuchisaka Course and bus road of the Zaō Hot Spring as well as on the wall of the Takayu explosion crater.

The Ryū-zan lava and fragments of its agglomerate are almost olivine two-pyroxene andesite and are frequently characterized by the abundance of large plagioclase phenocrysts. They have a black or dark grey color in fresh specimens, but obtain a grey color when decomposed. There is also a reddish variety supposed to have been subjected to reheating. These rocks are compact or porous and consist of plagioclase, augite, hypersthene, olivine, magnetite, tridymite, bowlingite, chlorite and brown glass.

Among them, plagioclase is found as phenocryst or an important ingredient of the groundmass. The phenocrystic plagioclase found here ranges from labradorite to anorthite with a composition of An_{67-90} and is generally anhedral or subhedral, taking a tabular or rectangular form. The largest one examined by the writer is 2.5 cm. in longer diameter. The large phenocryst is abundantly to be seen in the lava exposed along the Gorō-zawa and Tsuchisaka Course as well as on the Takayu crater wall. As is shown by many thin sections, the crystal is distinctly or indistinctly zoned, and some of it encloses augite, magnetite and chlorite in a regular or irregular arrangement. It is also noticed that the phenocryst is often invaded by the groundmass or brown glass which resulted in the formation of a worm-eaten structu re. The turbid part is present in very low frequency and is observed at the central or peripheral part of crystal, being fringed by a narrow clear zone without any enclosure.

In the groundmass, it is more acidic and occurs as a lath-shaped or rectangular crystal, mostly 0.02 mm.—0.2 mm. long. The swarm of such a minute crystal affords a fluidal structure and pilotaxitic texture to the groundmass.

Augite is the commonest ingredient in all specimens, but its phenocryst is absent in the thin sections of some andesites collected from the cutting of the bus road between Dōshidaira and the Zaō Hot Spring or elsewhere. This mineral is occasionally associated with hypersthene

Table I. Composition and optical characters of plagioclase, augite and hypersthene phenocrysts (measured by F. Hori)

	No. 1. (T.I. 50073104)	No. 2. (T.I. 50080106)	No. 3. (T.I. 51100802)
Plagioclase	$\alpha=1.568\pm0.002$ (n_1 min.) $\gamma=1.582\pm0.002$ (n_2 max.) An_{77-86}	$\alpha=1.564\pm0.002$ (n_1 min.) $\gamma=1.580\pm0.002$ (n_2 max.) An_{67-82}	$\alpha=1.566\pm0.002$ (n_1 min.) $\gamma=1.579\pm0.002$ (n_2 max.) An_{76-81}
Augite	$\alpha=1.694\pm0.002$ $\beta=1.703\pm0.002$ $\gamma=1.719\pm0.002$ $2V(+)=45°$ $Ca_{36}Mg_{35}Fe_{29}$	$\alpha=1.695\pm0.002$ $\beta=1.702\pm0.002$ $\gamma=1.721\pm0.002$ $2V(+)=45°$ $Ca_{36}Mg_{36}Fe_{28}$	$\alpha=1.693\pm0.002$ $\beta=1.701\pm0.002$ $\gamma=1.718\pm0.002$ $2V(+)=46°$ $Ca_{38}Mg_{36}Fe_{26}$
Hypersthene	$\gamma=1.712\pm0.002$ $2V(-)=56°$ $\rho>v$	$\gamma=1.707\pm0.002$ $2V(-)=60°$ $\rho>v$	$\gamma=1.703\pm0.002$ $2V(-)=60°$ $\rho>v$

	No. 4. (T.I. 55073101)	No. 5. (T.I. 56060304)
Plagioclase	$\alpha=1.568\pm0.002$ (n_1 min.) $\gamma=1.585\pm0.002$ (n_2 max.) An_{80-90}	$\alpha=1.566\pm0.002$ (n_1 min.) $\gamma=1.584\pm0.002$ (n_2 max.) An_{75-89}
Augite	$\alpha=1.689\pm0.002$ $\beta=1.692\pm0.002$ $\gamma=1.715\pm0.002$ $2V(+)=50°$ $Ca_{41}Mg_{42}Fe_{17}$	$\alpha=1.689\pm0.002$ $\beta=1.700\pm0.002$ $\gamma=1.703\pm0.002$ $2V(+)=48°$ $Ca_{40}Mg_{40}Fe_{20}$
Hypersthene	$\gamma=1.701\pm0.002$ $2V(-)=63°$ $\rho>v$	$\gamma=1.703\pm0.002$ $2V(-)=48°$ $\rho>v$

To confirm An and CaMgFe ratio the charts devised by F. Chayes [Am. Min. Bowen Volume, (1952)95] and H.H. Hess [Am. Min. 34 (1949), 634] were respectively used.

No. 1.=The Ryū-zan lava from the summit of Ryū-zan.
No. 2.= 〃 Dōshidaira-Haryū-numa.
No. 3.= 〃 near the summit of Ryū-zan.
No. 4.= 〃 the Tsuchisaka Course.
No. 5.= 〃 the Gorō-zawa.

and forms a zonal structure together, the latter being always fringed by the former which is sometimes represented by a crystal aggregate. The extinction angle of phenocrystic augite, $Z \wedge c$, is 38°–40°. When the crystal is zoned, the inner part has a large extinction angle as compared with the periphery. It is subhedral or anhedral, and its largest one is 3.69 mm. long and 1.42 mm. across.

In the groundmass, augite is an important mineral which has a prismatic or granular form, being 0.02 mm.–0.08 mm. long or across in both cases.

The occurrence of hypersthene is restricted only to phenocryst, and its frequency is generally higher than phenocrystic augite. There are, however, several specimens almost free of this mineral, as is shown by those obtained from the southern foot of Ryū-zan and Kannō Course. It is usually a subhedral or anhedral crystal with a long prismatic habit, and the largest one is 2.43 mm. long and 0.83 mm. across. Magnetite is occasionally enclosed in it.

Olivine is not infrequently to be seen in most of thin sections, but is almost or entirely absent in the specimens from the summit of Ryū-zan, Dōshidaira-Haryū-numa, near Dōshidaira and the cutting between Dōshidaira and Zaō Hot Spring. It is commonly found as a subhedral phenocryst, the largest crystal being 3 mm. long and 1.26 mm. across. Generally, this mineral passes into bowlingite or chlorite. Such an alteration begins along the crack or periphery of the crystal and finally spreads over its whole part. Moreover, the crystal encloses magnetite, and it is sometimes fringed by skeleton crystals of the same mineral.

One of the predominant ingredients in the groundmass is magnetite which takes an octahedral or ill-defined form, generally 0.01 mm.–0.08 mm. in diameter. When the crystal has a phenocrystic size, it occurs usually as an irregular grain with the maximum diameter of 0.8 mm. On the contrary, tridymite is a mineral of negligible amount and fills up the interstices of other ingredients in the groundmass. The similar frequency is revealed by the brown glass contained in plagioclase phenocrysts.

In the lava and andesite fragments of agglomerate under consideration, xenoliths are largely represented by a rounded or subangular basaltic rock, large or small. Microscopically, they consist of basic plagioclase, augite, hypersthene, olivine, magnetite, calcite and bowlingite. These xenoliths have no sharp boundary against the groundmass.

The groundmass is an aggregate of labradorite, augite, magnetite, tridymite and chlorite, being mostly characterized by a pilotaxitic or orthophyric texture.

(ii) Torikabuto-yama lava and mud flow:—So far as is known at present, the Torikabuto-yama lava associated with mud flow is exposed on Torikabuto-yama and at its adjacent area. In this case, The lava and fragments of mud flow are olivine two-pyroxene andesite or olivine bearing two-pyroxene andesite with a dark grey or grey or reddish color and porphyritic texture. They are, however, quite free of big plagioclase crystals which are very frequently present in the Ryū-zan lava.

Microscopically, these volcanic products are composed of plagioclase, augite, hypersthene, olivine, magnetite, quartz and xenoliths.

The most important ingredient is plagioclase which is found as phenocryst and in the groundmass. The phenocrystic plagioclase ranges from labradorite to bytownorthite with a composition of An_{51-82}. It is often rich in such enclosures as augite and magnetite. There is also a worm-eaten structure due to the invasion of the groundmass and the light brown glass. Moreover, some of it contains minute fragments of goethite, as can be seen in the specimens from Nanamagari between the Zaō Hot Spring and Dokko-numa.

The phenocrystic plagioclase of Torikabuto-yama lava is distinguishable from that of the Ryū-zan lava in its high frequency of a partly or wholly turbid part. The crystal is euhedral or subhedral, the largest one being 3.06 mm. long and 1.98 mm. across. Mostly it is well zoned with frequent occurrence of zonally enclosed augite and magnetite.

Plagioclase occurs as a lath-shaped crystal in the groundmass, where it is characterized by a fluidal arrangement. The crystal is always elongated and is commonly 0.02 mm.-0.2 mm. in length.

Augite takes a prismatic or granular form. Its phenocryst is subhedral or anhedral and has mostly a small size. Even the largest crystal is 1.56 mm. long and 0.59 mm. across. As is shown by the Ryū-zan lava, the phenocrystic augite is usually zoned with a core of hypersthene, whereas there is another case in which the latter contains the former as irregular patches elongated along c-axis of the mother crystal. It twins simply or complicatedly on (100) or (101), and its extinction angle, $Z \wedge c$, is 40° (±). The frequency of occurrence is high when compared with hypersthene.

In the groundmass, augite is granular or prismatic. It is 0.02 mm. -0.08 mm. across respectively.

The crystal of hypersthene occurs in low frequency and has a long prismatic habit. It is generally euhedral or subhedral, being 1.62 mm. long and 0.93 mm. across in the largest crystal. Magnetite is present as its enclosure.

Table II. Composition and optical characters of plagioclase, augite and hypersthene phenocrysts (measured by F. Hori).

	No. 1. (T.I. 48100301)	No. 2. (T.I. 48100302)	No. 3. (T.I. 52100603)
Plagioclase	$\alpha=1.556\pm0.002$ (n_1 min.) $\gamma=1.580\pm0.002$ (n_2 max.) An_{54-82}	$\alpha=1.555\pm0.002$ (n_1 min.) $\gamma=1.577\pm0.002$ (n_2 max.) An_{52-76}	$\alpha=1.554\pm0.002$ (n_1 min.) $\gamma=1.577\pm0.002$ (n_2 max.) An_{51-76}
Augite	$\alpha=1.685\pm0.002$ $\beta=1.694\pm0.002$ $\gamma=1.710\pm0.002$ $2V(+)=48°$ $Ca_{40}Mg_{41}Fe_{19}$	$\alpha=1.691\pm0.002$ $\beta=1.699\pm0.002$ $\gamma=1.718\pm0.002$ $2V(+)=47°$ $Ca_{38}Mg_{37}Fe_{25}$	$\alpha=1.691\pm0.002$ $\beta=1.700\pm0.002$ $\gamma=1.718\pm0.002$ $2V(+)=48°$ $Ca_{39}Mg_{36}Fe_{25}$
Hypersthene	$\gamma=1.708\pm0.002$ $2V(-)=62°$ $\rho>v$	$\gamma=1.705\pm0.002$ $2V(-)=58°$ $\rho>v$	$\gamma=1.702\pm0.002$ $2V(-)=65°$ $\rho>v$

To confirm An and CaMgFe ratio the charts devised by F. Chayes and H. H. Hess were respectively used.

No. 1=The Torikabuto-yama lava from the north of Dokko-numa.
No. 2= 〃 near the summit of Torikabuto-yama.
No. 3= 〃 near Miharashidai.

Olivine is always known only as phenocryst. Its frequency varies in different thin sections. It is conspicuously present in some of them, but is almost or wholly absent in others. The olivine-less example is seen in the specimens collected along the trail between Utanosawa and Fudō-taki. The olivine crystal is commonly anhedral and is sometimes surrounded by the aggregate of augite. It alters partly into goethite or bowlingite and contains magnetite.

Magnetite is a very common mineral in the groundmass, but it is not so abundant as that of the Ryū-zan lava. The octahedral or granular crystal is mostly 0.01 mm.–0.08 mm. in diameter. In the largest one, it is 0.5 mm.

Quartz is a xenocryst with low frequency. It is, however, contained in almost all thin sections. The crystal has a rounded form due to the magmatic corrosion and is occasionally fringed by augite. The largest crystal is 1 mm. (±) in diameter. Besides the ingredients mentioned above, brown glass rarely fills up the interstices of lath-shaped plagioclase and augite in the groundmass.

Xenolith is contained in every thin section and is used to have a distinct border against the mother rock. It is a basaltic rock consisting of plagioclase, augite, magnetite, as well as of olivine.

The groundmass is constructed by plagioclase, augite, magnetite and brown glass. Of these ingredients, plagioclase reveals remarkably a fluidal arrangement. The pilotaxitic or hyalopilitic texture is also to be seen.

(iii) Andesite fragments of the Su-kawa mud flow:—Andesite fragments of this mud flow were almost supplied from the Ryū-zan lava and Torikabuto-yama lava. They are, therefore, composed of olivine two-pyroxene andesite and olivine-bearing two-pyroxene andesite. These andesite fragments have the same mineral compositions and textures as those of the lavas already mentioned.

(iv) Andesite fragments of the Kannō mud flow:—The Ryū-zan lava is the source of the andesite fragments in the Kannō mud flow. These fragments are thus represented by olivine two-pyroxene andesite or olivine-bearing two-pyroxene andesite which is closely associated with a small amount of two-pyroxene andesite. Most of these are remarkably porphyritic with the abundance of phenocrystic plagioclase. In the vicinity of Kannō, the writer collected some specimens characterized by the frequent occurrence of large plagioclase. As is shown by the Ryū-zan lava, such a phenocrystic plagioclase ranges from labradorite to anorthite, euhedral or subhedral, having frequently a worm-eaten structure and being sometimes traversed by veinlets of the light brown glass. In this case, augite, magnetite and goethite as well as chlorite are also found as its enclosures. Moreover, some of it is well zoned and slightly turbid. Minute lath-shaped plagioclase is always a predominant ingredient in the groundmass and constructs a pilotaxitic texture together with augite and magnetite.

The similarities between the andesite fragments of the Kannō mud flow and Ryū-zan lava are equally confirmed on augite and hypersthene in which the latter is usually fringed by the former. The same may be said of olivine crystal, although its frequency is variable in different specimens. Olivine occurs only as phenocryst and is generally less than augite or hypersthene in its amount, but there is an abnormal example in the specimens obtained on the hill about 500 m. north of Kannō and along the Tsuchisaka Course, where it contains noticeably this mineral as compared with augite and hypersthene. When such a crystal is subjected to the alteration, it passes partly or wholly into bowlingite. Besides these, most of octahedral or ill-defined crystals of magnetite are scattered over the groundmass. In addition, brown glass and basaltic xenolith are seen in some specimens.

History of Volcanic Activities

The Ryū-zan Volcano rises up on the eroded surface of biotite granite or hornblende biotite granite (granodiorite) and overlying Neogene sediments exposed together with such extrusives as plagio-liparite, felsitic rock, dacite and propylite. Its volcanism took place on the extension of a weak zone between the Kumano Volcano and Byōbu Volcano with a trend of NW–SE. It seems to have violently been repeated as is indicated by the distribution of various volcanic products.

In the first activity, the Ryū-zan lava are believed to have poured out from the pre-existing crater. Mostly, it flowed westwards down to Dōshidaira on the one hand and Tsuchisaka or Ōdaira on the other. There were also intermittent ejections of agglomerate during its activity. The Ryū-zan lava is, therefore, intercalated with agglomerate here and there. The main body of the volcano is supposed to have been built up at this time. It was probably a homate.

After its formation, the eruption of the Torikabuto-yama lava happened at the southeastern side of the pre-existing crater or on the neighbouring flank. Thus, the lava flow constructed Torikabuto-yama and furthermore extended to the adjacent area, where it covered the Ryū-zan lava and the granite. The lava exposed here is undoubtedly associated with mud flow, but the exact relationship has not yet been confirmed, although the extension of these volcanic products are topographically traceable.

Other remarkable activities resulted in the formation of such explosion craters as Takayu and Kannō which were repeatedly followed by the eruption of the Su-kawa mud flow and Kannō mud flow. They began with the opening of the Takayu explosion crater by which the central part of the volcano was blown off, and the crater lost its original form. In connection with it, the Su-kawa mud flow poured out from this explosion crater opened southwestwards and buried the bottom of the Su-kawa valley, having spread down to Kubotebara, Shindō and

Yuzaka.

The Kannō explosion crater was formed a little later, and the northwestern side of Ryū-zan was largely broken down with the eruption of the Kannō mud flow at its bottom. The mud flow here extends westwards or southwards. It covers the Su-kawa mud flow, Ryū-zan lava or its agglomerate and Neogene sediments at the area including Hachimori, Ōdaira, Tsuchisaka, Kannō, Sanbongi-numa, Dōshidaira, etc. They were succeeded by the explosion taken place at the uppermost course of the Akakura-zawa and near the summit of Ryū-zan. These craters were probably opened at the final stage of activities.

The present Ryū-zan Volcano is, therefore, a destruction remnant in which its original altitude was lowered to some extent, and it remains traces of its former activities only in the frequency of acidic hot spring comming up through the crater bottom.

In such cases, the activities took place in concert with those of the Kumano Volcano and Byōbu Volcano. Among them, the lavas and ejecta from the Ryū-zan Volcano are found in a complicated relationship to the Jizō-san lava and Yokokura-yama lava of the Kumano Volcano. Moreover, it can be said that the activities of the Ryū-zan Volcano are likely to have ceased earlier than the Kumano Volcano, although there are still some questions for the Gando Volcano located beyond the Mamigasaki-gawa.

Summary

(i) The Ryū-zan Volcano is located at the northern end of the Zaō Volcanoes and rests upon the eroded surface of base rocks composed of granite (granodiorite) and Neogene sediments as well as such extrusives as plagioliparite, propylite, etc. It is now built up of Ryū-zan and Torikabuto-yama, but is only a destruction remnant of the original volcano.

(ii) Volcanic products are represented by the Ryū-zan lava and agglomerate, Torikabuto-yama lava and mud flow, Su-kawa mud flow and Kannō mud flow. Of these, the Ryū-zan lava, Su-kawa mud flow and Kannō mud flow are extensively exposed.

(iii) The Ryū-zan lava and its agglomerate erupted probably from the pre-existing crater subjected later to the remarkable deformation due to explosion. The Su-kawa mud flow poured out from the Takayu explosion crater formed at the position of pre-existing crater, whereas

Fig. 3. The northwestern wall of the Takayu explosion crater viewed from Nanamagari between the Zaō Hot Spring and Dokko-numa. The lava flow exposed on the southern extension of this wall inclines 20° westwards. 1=The summit of Ryū-zan, 2=Crater wall.

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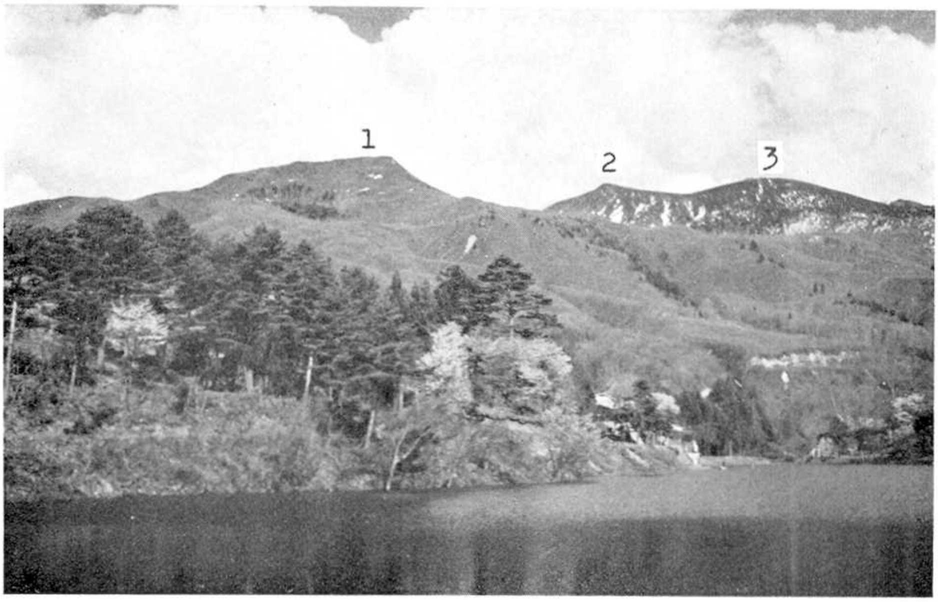

Fig. 4. The southeastern wall of the Takayu explosion crater viewed from Sakazuki-ko which is found on the Su-kawa mud flow. 1=Torikabuto-yama, 2=Sanpōkōjin-san, 3=Jizō-san.

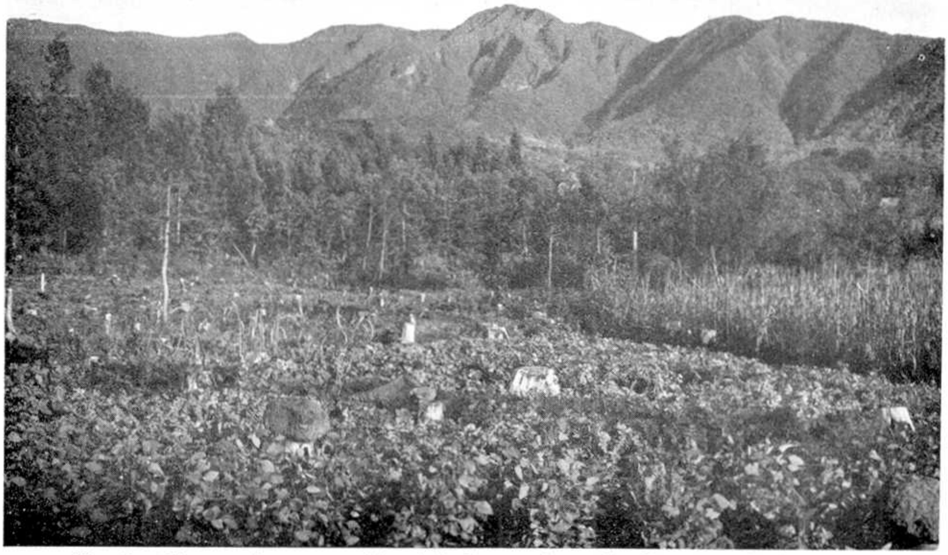

Fig. 5. The northwestern side of Ryū-zan where the Kannō explosion crater was opened northwestwards. The Kannō mud flow poured out from here, and its topographical feature is partly shown in the foreground of this picture.

[Bull. Earthq. Res. Inst., Vol. XXXV, Pl. XXIV.]

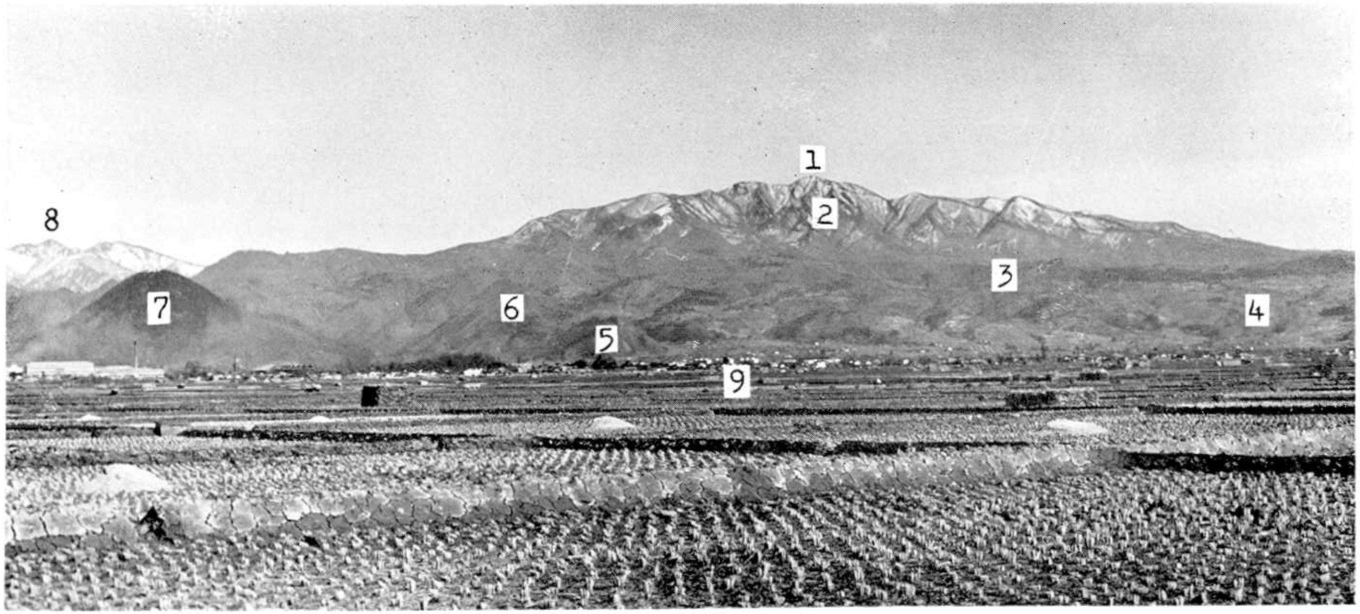

Fig. 6. Ryū-zan viewed from near Iizuka. 1=The summit of Ryū-zan, 2=Kannō explosion crater, 3=The Kannō mud flow resting upon the Neogene formation, 4=The Neogene formation, 5=Togami-yama (dacite), 6=Saruoka-yama (plagioliparite), 7=Chitose-yama (plagioliparite), 8=Gando-san, 9=Yamagata.

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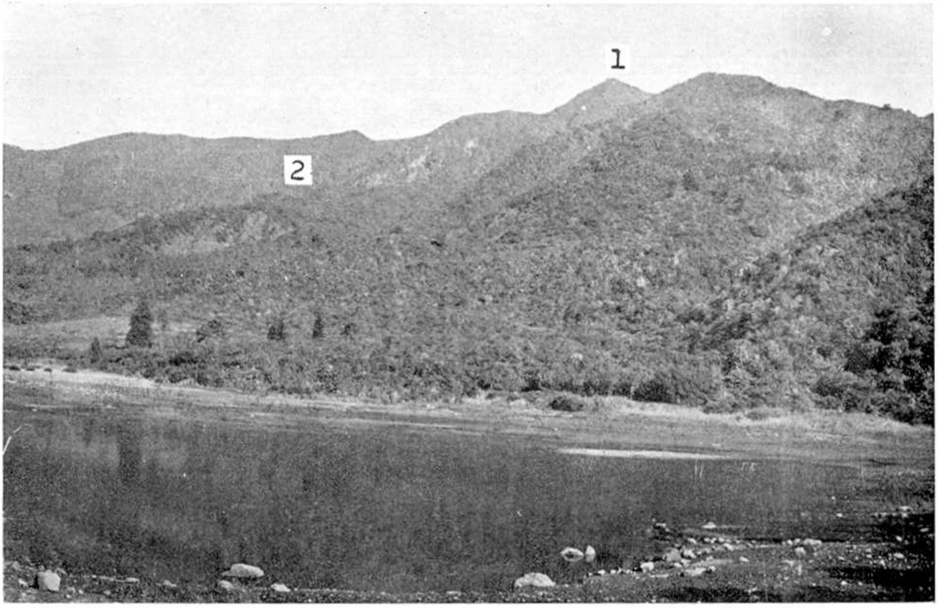

Fig. 7. Haryū-numa on the Kannō mud flow. The Kannō explosion crater is seen in the background. 1=The summit of Ryū-san, 2=A part of crater wall.

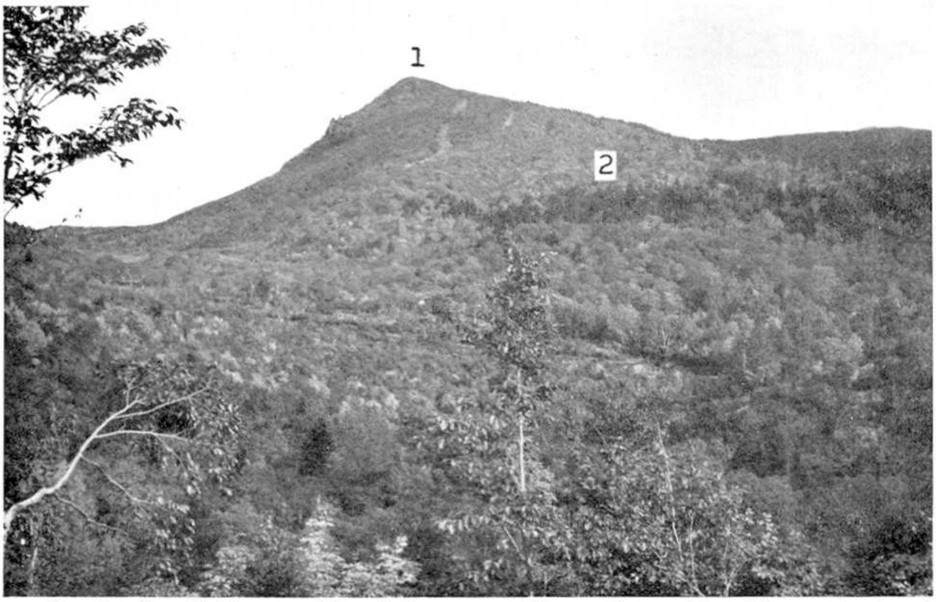

Fig. 8. Sanpōkōjin-san with a fault scarp at its northern side. The gently sloped area is built up of the Mud flow associated with the Torikabuto-yama lava and is displaced down against the Jizō-san lava exposed on Sanpōkōjin-san. The Hanoki-zawa fault runs along the northern foot of this peak and Jizō-san. 1=Sanpōkōjin-san, 2=Zangezaka.

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the Kannō mud flow ejected in the formation of the Kannō explosion crater. In connection with these activities, the Akakura explosion crater and Suzuritaki explosion crater were opened. The present topography of the Ryū-zan Volcano, therefore, depends on such eruptions and explosions as well as on the subsequent erosions.

(iv) The activities of the Ryū-zan Volcano are likely to have successively repeated in the pre-historic time in concert with other parts of the Zaō Volcanoes. The first activity is supposed to have started in the beginning of the Quaternary, as can be inferred from those of the Aoso Volcano and Byōbu Volcano. There is, however, still no exact evidence to confirm the relationship between the Ryū-zan Volcano and Gando Volcano rising up within a short distance, although they erupted on the eroded surface of similar base rocks.

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28. 蔵王火山の地質学的研究 (第 4 報)

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蔵王火山群の北端には竜山火山がある．この火山は竜山と鳥兜山とよりなり，花崗岩（花崗閃緑岩），新第三系，これ等を貫く火山岩または新第三系に伴う各種熔岩などを基盤岩として，その上に盛上り，火山体は竜山熔岩（橄欖石複輝石安山岩または含橄欖石複輝石安山岩）及びその集塊岩，鳥兜山熔岩（橄欖石複輝石安山岩または含橄欖石複輝石安山岩）及びその泥流，酢川泥流，神尾泥流などにより構成されている．

火山活動は，竜山熔岩及び集塊岩の噴出に始まり，竜山火山の主要なる部分は，このとき築き上げられたものと思われる．これに続いて，鳥兜山熔岩や泥流が旧噴火口の南東側或は側面から供給され，その後，高湯爆裂火口，神尾爆裂火口が生ずるに当つて，酢川泥流と神尾泥流とを順次に流出したもののようである。その他，赤倉爆裂火口や硯滝爆裂火口も引続き生じたが，これらには，泥流を伴わない。こうした相次ぐ爆発と爆裂火口生成のために，竜山火山は破壊されて旧態を失い，現在見られるような山容を呈するに至つたのである．竜山火山の活動は，隣接する熊野火山や屏風火山などのそれらと第四紀に入つてから，相呼応して行かれたものであり，有史以後の活動は，知られていない．活動の名残りとしては，高湯爆裂火口底から，蔵王温泉に見られるように，強酸性の温泉が多量に湧出している．