29. *Geological Investigations on the Zaō Volcanoes I. Goshiki-dake, a Central Cone of the Zaō Proper.*

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Introduction

In North-East Japan there are still many volcanoes which have long been neglected with no detailed geological investigation. On such volcanoes as explored by some geologists of the Earthquake Investigation Committee many years ago, some re-examination is requested at present. The same may be said of the Zaō volcanic group where no further investigation has been made since that carried out by A. Takada[1] about 30 years ago. There remains, however, various important geological problems to be confirmed, particularly on its structure and volcanic history as well as on the relationship between it and the Funagata or Azuma volcanoes of the same volcanic zone. For this purpose, the writer recently started his field work in the same district, which is yet to be completed. In the beginning, he studied the geological features of the area including Katta-dake and Goshiki-dake, because the area was the chief active center of the Zaō volcanic group in historic time. Of these, Goshiki-dake is a central cone which was formed within the destroyed crater of this area, being characterized by the repeated explosion which has taken place up to the recent. Since the central cone is deeply dissected along the Osawa as well as around a small crater lake generally called "Okama" it would be very fovorable to learn its internal structure and history of the activity which happened here. It is, therefore, desirable to the writer that the result of the geological investigation on Goshiki-dake is first summarized in this paper.

Location

The Zaō volcanic group rises up in the highly mountainous area between the Prefecture of Yamagata and Miyagi. It is situated approximately at the central part of the area enclosed by the parallels 38°0′ and 38°20′ N, and the meridians 140°15′ and 140°45′ E. Goshiki-dake is found in the explosion crater immediately to the east of Umanose which adjoins Kumano-dake in the north and Katta-dake

1) A. TAKADA, *The Zao Volcanoes*, *M. S.* 1922.

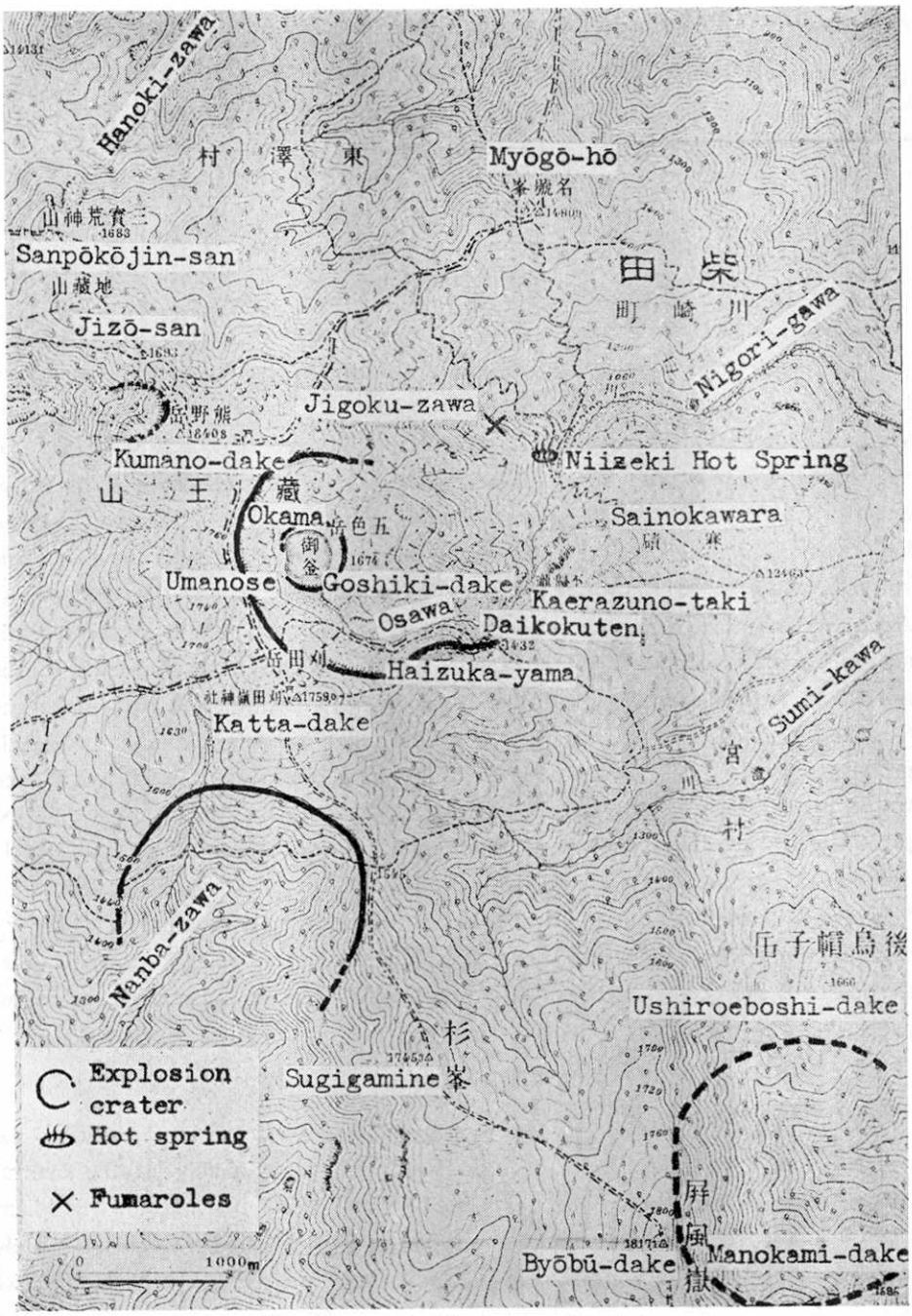

Fig. 1. Map showing the distribution of explosion craters.

in the south. It is easily accessible from Shiroishi or Ōgawara along the Tōhoku Railway Line and Kaminoyama or Yamagata of the Ōu Railway Line, the former passing through Tōgatta, Aone and Gaga and the latter Osuzu or Takayu.

General Features of Geology in the Adjacent Area

In the beginning, it is necessary to give a short description of the general features of the surrounding area before the writer proceeds to the geological problems of Goshiki-dake.

The Zaō volcanic group is underlain by the Tertiary formation and granite cut by plagioliparite, basalt, etc. In this case, the Tertiary formation covers the eroded surface of biotite granite or hornblende biotite granite, being mostly composed of green tuff, conglomerate and shale. Of these, conglomerate is found at the bottom of this formation and contains many pebbles of granite, aplite and propylite.

The volcanoes here are topographically divided into two subgroups, north and south, along the Sumi-kawa and Nanba-zawa running respectively northeastwards and southwestwards through the central part of this area. The former includes Kumano-dake (1840.8 m.), Katta-dake (1795 m.), Goshiki-dake (1674 m.), Jizō-san (1694 m.), Sanpōkōjin-san (1683 m.), Torikabuto-yama (1401 m.), Yokokura-yama (1151.9 m.), Nakamaru-yama (1557 m.), Sarukura-yama (873 m.), Ryū-zan (1363.5 m.), etc., whereas the latter consists of Sugigamine (1745.3 m.), Byōbu-dake (1817.3 m.), Ushiroeboshi-dake (1655 m.), Maeeboshi-dake (1402.1 m.), Fubō-zan (1705.3 m.), Nyūdō-san (1600 m.), Manokami-dake (1585 m.), Nonomori-yama (733.3 m.), as well as Aoso-yama or Ōkatta-dake (799.9 m.). They are built up of various kinds of ejecta and lava flows represented mainly by two pyroxene andesite, olivine-bearing two pyroxene andesite, and olivine two pyroxene andesite, forming konides or homates with several explosion craters, large or small. Such explosion craters were sometimes the sources of big mud flows, as can be seen at Takayu and Numa.

The ejecta and lavas are very complicatedly distributed and overlapped, because they erupted repeatedly from many centers. They are also subjected to faulting, a remarkable example being traceable from northeast to southwest along the Hanoki-zawa and the northern scarp of Sanpōkōjin-san.

Some of these rest upon such base rocks as the Tertiary sediments and granites exposed along the Nigori-gawa, Sumi-kawa, Yoko-kawa and Zaō-gawa as well as near Takayu where the latter is not so thickly covered by the former as has hitherto been supposed. Moreover, the writer noticed that some of the lavas and

ejecta from Aoso-yama are likely to be underlain by some horizontal beds composed of gravel, sand and clay assigned to the Quarternary.

So far as is known at present the Zaō group seems to have erupted repeatedly even in historic time. Its area is, however, restricted to the Zaō proper[1] which includes Katta-dake, Kumano-dake, Goshiki-dake, Jizō-san and Sanpōkōjin-san, etc. In this case, Goshiki-dake was its active center, and the most recent eruption here took place in 1939.

Large Explosion Crater at the Southern End of North Zaō

There is a large explosion crater at the southern end of North Zaō surrounded by Kumano-dake and Haizuka-yama. (Figs. 4.) The crater is a semicircular hollow with a diameter of about 2 kilometers from northwest to southeast and is opened northeastwards. It was formed by the destruction of a pre-existing crater. Most of its wall is highly cliffed down to the bottom where Goshiki-dake rises up as a central cone characterized by the presence of a small crater lake at its western foot. The Osawa, a branch of the Nigori-gawa, takes its origin here and runs down from east to north, deeply dissecting the eastern or southern foot of the crater wall which is about 200 meters at the highest part.

It is built up of the lavas and ejecta erupted from this pre-existing crater (Fig. 2). Whether younger or older, these volcanic rocks are mainly composed of olivine two pyroxene andesite, agglomerate and lapilli. Of these, the Osawa lava begins to expose itself on the cliff close to Umanose and is traceable down to Daikokuten along the Osawa. The best exposure is seen on the cliff between Haizuka-yama and Daikokuten, where it was intensely subjected to the solfataric action and almost altered into a grey or white rock mottled by a pink or dark grey color. The sulphur-rich part of this rock has once been mined on the steep slope near Daikokuten and also at the bottom of the Osawa.

Younger volcanics rest upon the eroded surface of this older lava, and they erupted mostly from the pre-existing crater as well as from Goshiki-dake. Of these, some of the Kumano-dake lavas and ejecta extend eastwards beyond Goshiki-dake. Exclusive of new ejecta supplied from Goshiki-dake, they are quite free of such alterations as mentioned above. It is, therefore, very easy to distinguish them from the Osawa lava.

The pre-existing crater here seems to have largely been destroyed by explo-

1) The term of "Zaō proper" was first used by B. Kotō (B. KOTŌ, *Jour. Geol. Soc. Japan*, **23** (1926), 34-35).

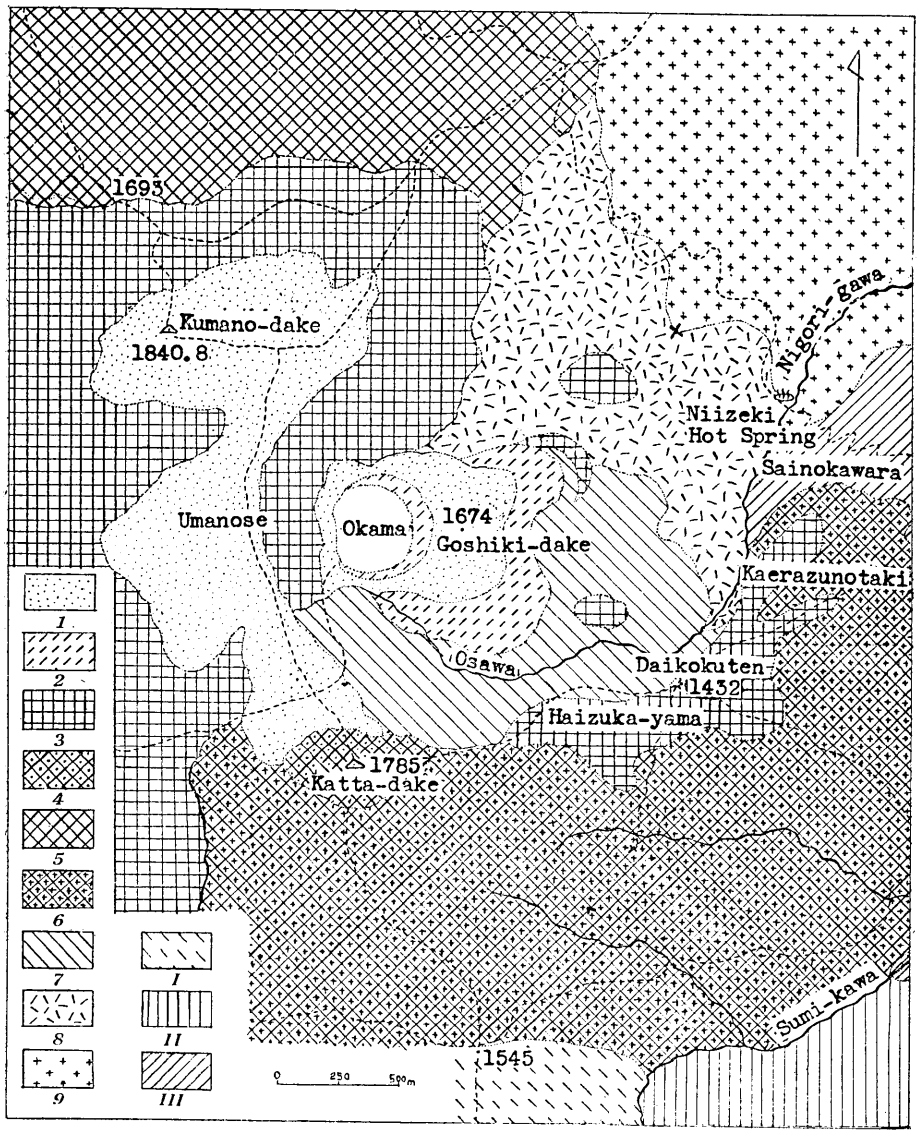

Fig. 2. Geological map of Goshiki-dake and its surrounding area

1. Lapilli and ash (Goshiki-dake), 2. Ash and vol. sand (Goshiki-dake), 3, Kumano-dake lavas (ol. two pyrox. andesite and two pyrox. andesite) and ejecta, 4. Katta-dake lava (ol. two pyrox. andesite), 5. Jizō-san lava (ol. two pyrox. andesite), 6. Nanba-zawa lava (ol. bearing two pyrox. andesite) and ejecta, 7. Osawa lava (two pyrox. andesite), 8. Jigoku-zawa lavas and ejecta, 9. Biotite granite and hornblende biotite granite.

I. Sugigamine lava (ol. two pyrox. andesite), II. Byōbu-dake lava (ol. two pyrox. andesite), III. Sumi-kawa lava (ol. bearing two pyrox. andesite).

tion of the Kumano-dake lavas and ejecta, but the date can not be determined exactly.

Formation of Goshiki-dake

One of remarkable features in the area of the Zaō proper is indicated by a central cone built up within the large explosion crater already mentioned.

Goshiki-dake is a small but characteristic homate with a gentle slope and an explosion crater which opened westwards at the opposite side of Umanose (Figs. 4–7). It has a diameter of more than 1,000 meters at its base and rises up to about 200 meters above the bottom of the Osawa, forming a double volcano together with its surrounding somma.

This central cone rests upon the eroded surface of lava flows or ejecta which have their sources in the pre-existing crater (Fig. 2). It is deeply disseceted and highly cliffed along the Osawa and in the vicinity, being skirted by a large exposure of the Osama lava subjected intensely to the solfataric action.

The Jigoku-zawa lavas and ejecta are the oldest volcanic rocks of this area and are well exposed at the northeastern foot of the central cone and extend east or northeastwards down to the eastern foot of Kumano-dake, where these rocks are underlain by biotite granite. They are composed of lava flow, agglomerate and lapilli as well as of sand and ash alternately piled up. In these cases, the the Osawa lava rests directly upon a part of the Jigoku-zawa lavas and ejecta as can be seen on the cliff between Daikokuten and Kaerazuno-taki, but is capped with the Kumano-dake lava at the eastern foot of Goshiki-dake.

Structure of Goshiki-dake

As has already been stated, the central cone is so remarkably dissected along the Osawa as well as around Okama that its structure and geology can easily be investigated here and there.

One of the good exposures is to be seen at the opposite side of Haizuka-yama, where the southern flank of the central cone was abruptly cut down by the Osawa and formed a cliff about 70 meters in height. The beds of ash, sand and lapilli exposed on this cliff are well stratified and incline to the west at an angle of 10°–15° (Fig. 4). They are alternately accumulated with no intercalation of lava flows, showing various colors such as grey, brown, dark brown, dark reddish brown, etc. A similar bed is also exposed widely on the crater wall surrounding Okama. The crater wall here is about 50 meters high at its eastern side and

gradually diminishes its height westwards. It is intricately colored from brown to dark reddish brown in good contrast with the beautiful color of lake water. Besides ash and sand beds distorted from place to place, there are agglomerate and scoria layers, 1 meter or thereabouts in thickness, at the top of the wall.

The surface of the cental cone is largely veiled with recent ejecta. Most of these are lapilli and are thinly accumulated, excluding the western periphery of Okama, where they are five meters in the thickest part.

Explosion Crater, "Okama"

An explosion crater, which is now filled up with water, is found at the western side of Goshiki-dake (Figs. 6, 7). It is called "Okama" or "Goshiki-numa" or "Zaō-numa" and has a nearly circular from with a diameter of about 300 meters. This small lake is surrounded by a highly cliffed wall at its eastern half, where thickly accumulated ejecta are well exposed showing various colors differing from place to place.

So far as is known at present, its bottom is deep at the east but shallow at the west. The picture taken by H. Minato in June of 1944 shows that there was still a bar near the western wall, stretching from north to south across the lake. The lake seems to be getting buried year by year by rock fragments crumbling down from the crater wall. It was once, however, 63 meters in depth, when a small explosion took place in 1939.

Volcanic Ejecta of Goshiki-dake

The central cone is built up of such ejecta as agglomerate, lapilli, sand and ash which are well stratified and have varying colors. Of these. agglomerate is exposed on the northern cliff as well as at its opposite side. It is only 1 meter or thereabouts in thickness and contains angular or subangular fragments of two pyroxene andesite, 1–15 centimeters in diameter.

There are two kinds of these fragments. One is black and compact andesite, whereas the other is a scoriaceous variety with the same color. They have a porphyritic texture. The mineral ingredients of the compact specimens are labradorite, bytownite, augite, hypersthene, magnetite and brown glass.

Under the microscope, such phenocrystic minerals as labradorite, bytownite, augite and hypersthene are abundantly found in the groundmass with a hyalopilitic or pilotaxitic texture. In this case, labradorite or bytownite has a fresh appearance and is well zoned. It is often characterized by the presence of turbid zone,

including minute crystals of augite, hypersthene, magnetite and patches of brown glass. These turbid zones and inclosures generally indicate a regular arrangement parallel to the outline of crystals. The crystal mostly takes an anhedral or subhedral form, 2.97 mm.×1.36 mm. in the maximum size.

The phenocrysts of augite and hypersthene are present in almost same amount. They are usually anhedral or subhedral and include magnetite, labradorite, bytownite and brown glass. These minerals are respectively 1.65mm.×1.61mm. (augite) and 2.47 mm.×1.02 mm. (hypersthene) in the maximum size.

The optical characters of phenocrystic minerals are summarized in the following table.

	No. 1 (T. I., 48092201)	No. 2 (T. I., 48092204)
Plagioclase	An_{54-78}	An_{76-77}
Augite	$\beta_D = 1.692\pm0.002$ $2V=50°$ $c\wedge Z=40°$ $Ca_{41}Mg_{41}Fe_{18}$ (atom.%)	$\beta_D = 1.693\pm0.002$ $2V=48°$ $Ca_{40}Mg_{41}Fe_{19}$ (atom.%)
Hypersthene	$\alpha_D = 1.688\pm0.002$ $\beta_D = 1.699\pm0.002$ $\gamma_D = 1.703\pm0.002$ $\gamma-\alpha=0.015$ $(-)\ 2V=58°$ $\rho>\upsilon$ about X $Mg_{73}Fe_{27}$ (atom. %)	$\alpha_D = 1.988\pm0.002$ $\beta_D = 1.700\pm0.002$ $\gamma_D = 1.703\pm0.002$ $\gamma-\alpha=0.015$ $(-)\ 2V=56°$ $\rho>\upsilon$ about X $Mg_{72}Fe_{28}$ (atom. %)

The optical properties of augite and hypersthene in this table were mainly investigated by R. Morimoto and F. Hori. Of these, indices of refraction were determined by Hori. To confirm 2V and the composition of augite and hypersthene the charts devised by H. H. Hess[1] and G. C. Kennedy[2] were respectively used.

The groundmass is composed of bytownite, augite, hypersthene, magnetite and glass.

Such mineral components as mentioned above are also to be seen in the scoriaceous variety.

1) H. H. HESS, *Amer. Min.*, **34** (1949), 634.
2) G. C. KENNEDY, *Amer. Min.*, **32** (1947), 564.

Sand and ash are the most important ejecta of this area, being well exposed on the cliff and the summit. They consist of plagioclase, augite, hypersthene, magnetite as well as of tuffaceous substance and minute fragments of two pyroxene andesite.

Recent ejecta are widely accumulated on the surface of the central cone and its surrounding area. The occurrence of such ejecta can easily be recognized at a distance, because the area has a white or grey color similar to that of the intensely altered Osawa lava. They are composed of ash and lapilli. The latter is represented by angular fragments of two pyroxene andesite, commonly 0.5 cm.—5 cm. in diameter. Most of these fragments have a light grey color, but there are frequently porous or compact andesites with a dark grey or grey color. Light grey or grey colored fragments are intensely subjected to the solfataric action and are reprensented by opalized andesites. This fact suggests that some of these have undoubtedly been teared off from the altered Osawa lava in the explosion of this central cone.

Fumaroles Formed in Association with the Recent Eruption of the Central Cone

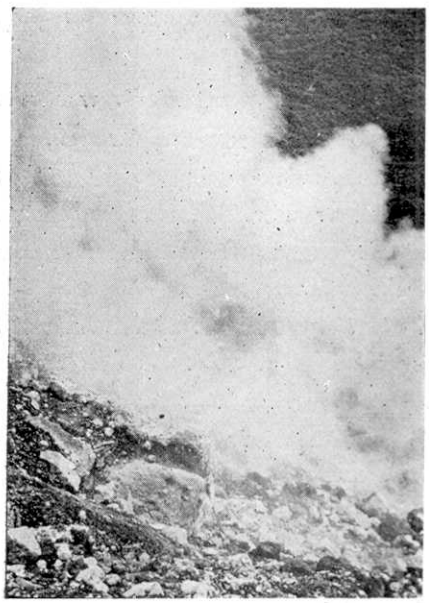

Fig. 3. Fumaroles on the slope about 1500 meters northeast from Goshiki-dake.

Several small fumaroles are found on the slope near the entrance of the Jigokuzawa tending eastwards from Kumano-dake, being situated about 2 kilometers northeast from the summit of Goshiki-dake and are accessible from the junction of trails for Kumano-dake and Hōzawa as well as from the Niizeki hot spring resort which is now desolate.

They are opened in the granite near the high cliff of volcanic rocks exposed on the slope about 100 meters above the valley bottom, emitting superheated steam with a minor amount of SO_2 (Fig. 3). The activity of these fumaroles started in the middle of April, 1940 after a small eruption took place within the crater of Goshiki-dake. In the beginning, it is said that they have

intensely exhaled poisonous gases here and there. The fumaroles show, even at present, a temperature of about 90°C at their mouth, where they are beautifully adorned with sulphur incrustation. The ground near the fumaroles is remarkably altered by solfataric action and is traversed by small fissures out of which hot sulphur spring is abundantly flowing out. The surface of the ground is thinly veiled with sulphur and halotrichite.

Volcanic Activities in Historic Time

It is unknown how many times volcanic activity took place in the area of Goshiki-dake since its first eruption. This may be also said of the volcanic activities in historic time, because it is partly obscured by insufficient data.

So far as is shown by the historic records compiled by F. Ōmori[1] T. Kochibe[2] and T. Anzai[3], it took place in 884, 1230, 1331–1333, 1623 (May), 1624, 1669, 1821 (January 27), 1857 (October 21), 1873 (August—September), 1894 (July 3), 1895 (February 15, August 22 and September 27), 1897 (January 14), 1906 (?), 1918 (January—August), 1927 and 1939. They are mostly of little importance, but several of them requires a short description here.

(i) The activity in 1624, according to a local tradition, seems to have started with a rumbling noise which continued day and night, being followed by some minor explosions.

(ii) In 1669, a large amount of volcanic ashes was blown off eastwards to Shibata-gun and Katta-gun, where it caused a serious damage to the farming.

(iii) When the explosion took place in 1821, a muddy water flowed out from Okama down to the Nigori-gawa. It was preceded by a sudden rumbling noise. The lower course including the Shiroishi-gawa was thus visited by inundation, but fortunately no harm was done to men or beasts at that time.

(iv) A similar accident was repeated on October 21, 1857. An unexpected inundation due to the overflow of muddy water from Okama took place along the Nigori-gawa and killed three men who had stayed to take bath in the hot spring near the eastern foot of Goshiki-dake, In this case, the river rose more than 6 meters.

The exhalation of steam and occasional emission of black smoke lasted to rise

1) F. OMORI, *Rep. Earthq. Inv. Comm.*, **86** (1918), 150–153.
〃 , *Tōyōgakugeizasshi*, **35** (1918), 565–574.
2) T. KOCHIBE, *Geol. Mem. Geol. Surv.*, **1** (1896), 23–32.
3) Personal communication by T. ANZAI.

up from Okama for several months even after the explosion ceased.

(v) On February 15, 1895, Okama broke out in a remarkable explosion soon after a rumbling noise took place. It was 9.30 in the morning, when the weather was exceedingly fine. In this volcanic activity, ash, lapilli and scoria were abundantly blown off northeastwards. As has repeatedly been indicated in previous explosions, the muddy water overflowed from Okama rushed down along the Matsukawa and Shiroishi-gawa, where many fishes were killed by the poisonous water.

An inundation due to the explosion of Okama also happened on September 27 of the same year and caused considerable damage to the district mentioned above. As a result of the explosion in 1895, the volcanic products thrown out from Okama accumulated extensively on the slope of the central cone and its surrounding area.

(vi) The most recent activity is represented by that which took place in 1939. Anzai[1] states that the water of Okama presented an extraordinary sight in July. According to his observation, the green colored water here was first mottled with many white spots due to the presence of innumerable sulphur grains which came up from the bottom. These grains had a hollow structure and are 1 millimeter or thereabouts in diameter.

When the lake changed its color, the temperature of water was 25°C on the surface, but 128°C at the bottom. Moreover, Okama increased its depth to 63 meters in October.

In connection with this volcanic activity, several fumaroles opened on the slope situated about 1.5 kilometers northeast from Okama. They were formed in the middle of April, 1940 and exhaled some poisonous gases which once rised to 100 meters in height. Simultaneously, the activity of some fumaroles started near the high cliff called "Keisei-iwa" at the bottom of the Zaō-gawa. Poisonous gases emitted here were SO_2 or H_2S and killed animals, birds and insects. The exhalation of these gases, however, has almost ceased at present.

Summary

(i) Goshiki-dake is a central cone of the Zaō proper and rises up to 1674 meter above the sea level. It is formed within the semi-circular explosion crater surrounded by Kumano-dake, Umanose, Katta-dake and Haizuka-yama.

(ii) This central cone rests upon the eroded surface of lava flows and ejecta which have their sources in the pre-existing crater destroyed largely by later ex-

1) Personal Communication by T. ANZAI.

plosions, being deeply dissected and highly cliffed along the Osawa and at the eastern side of Okama. It has a diameter of more than 1000 meters at its base and is about 200 meters high above the bottom of the Osawa.

(iii) The central cone is chracterized by the presence of explosion crater-called generally "Okama" which is found at its western side. It is a nearly circular depression about 300 meters in diameter, being now filled with beautifully-colored water.

(iv) The internal structure is well shown along the crater wall and high cliff dissected deeply by the Osawa. The cone is built up of ash, sand, lapilli and agglomerate which are distinctly stratified and incline to the west at an angle of 10° —15°. They have accumulated alternately with no intercalation of lava flows. The surface of the central cone and its surrounding area are largely veiled with recent ejecta thrown out from Okama. They are composed of ash and lapilli, the prevailing color being light grey or grey.

(v) Volcanic sand and ash here consist of plagioclase, augite, hypersthene and magnetite as well as of tuffaceous substances and minute fragments of two pyroxene andesite. The recent lapilli is, however, represented by two pyroxene andesite subjected mostly to solfataric action. Agglomerate contains angular or subangular fragments of two pyroxene andesite with such component minerals as labradorite, bytownite, augite, hypersthene, magnetite and brown glass.

(vi) The volcanic activities of the central cone are recorded since 884. The most recent one took place in 1939. So far as is shown by historic records, these activities always took place in Okama, and the explosion was frequently followed by the inundation of lake water which caused a serious damage to the district along the Nigori-gawa, Matsu-kawa, Shiroishi-gawa, etc. The fumaroles newly opened in 1940 are still active at present, their exhalation being composed mainly of superheated steam with a small amount of SO_2.

In conclusion, the writer's thanks are due to Dr. H. Tsuya who allowed him to continue his work in the Earthquake Research Institute of Tokyo University. The writer is also deeply indebted to Mr. R. Morimoto and Mr. F. Hori for their co-operation in his laboratory work.

The expense of this research was defrayed from the fund for the Scientific Research of the Educational Ministry.

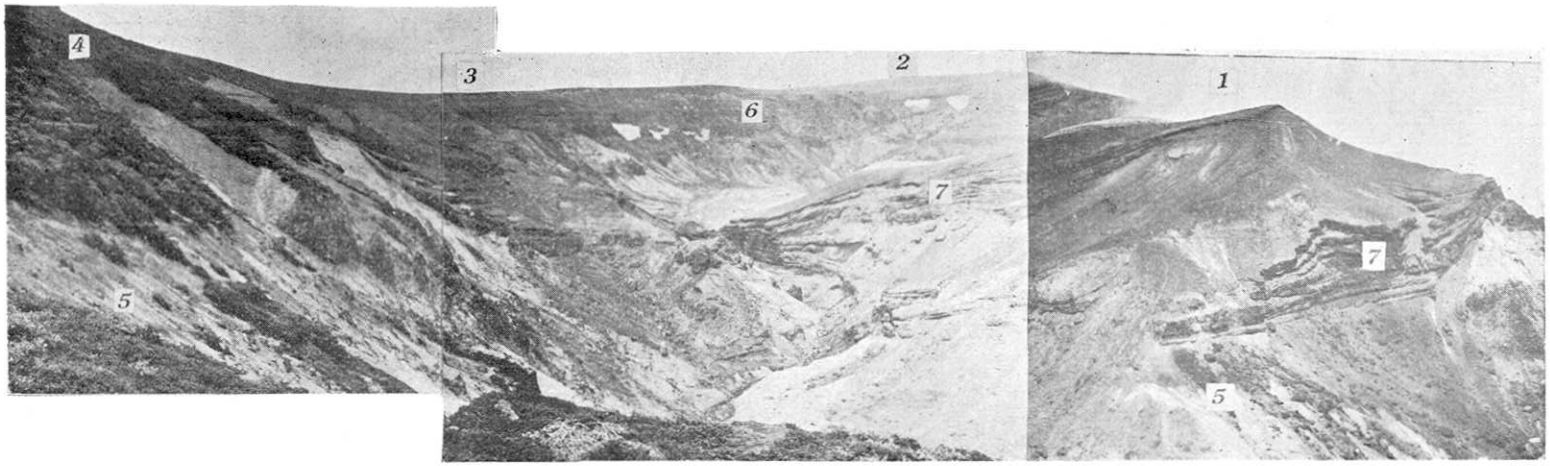

Fig. 4. Goshiki-dake viewed from the cliff between Katta-dake and Haizuka-yama. It is highly cliffed along the Osawa, being surrounded by a large explosion crater which extends to Kumano-dake in the north and Haizuka-yama in the south.

1 = Goshiki-dake, *2* = Kumano-dake, *3* = Umanose, *4* = Katta-dake,
5 = Osawa lava, *6* = Kumano-dake lavas and ejecta, *7* = Ash and volcanic sand.

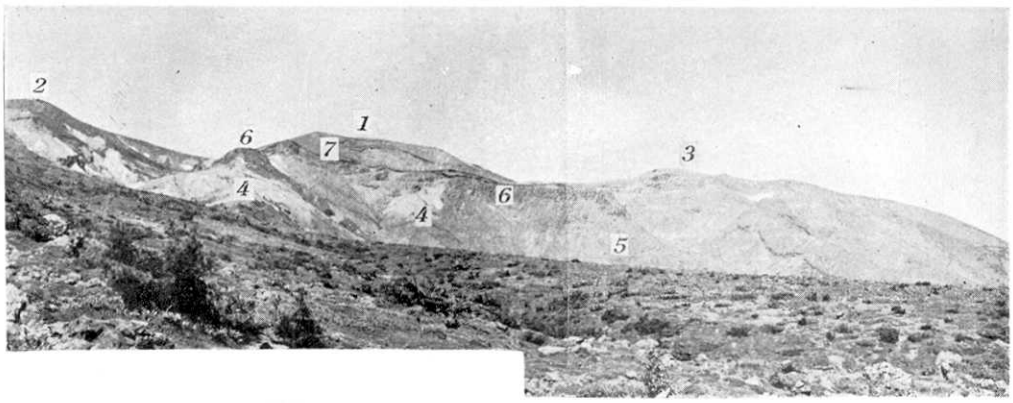

Fig. 5. Goshiki-dake viewed from the hill between Atomizaka and Daikokuten.
1 = Goshiki-dake, *2* = Katta-dake, *3* = Kumano-dake, *4* = Osawa lava,
5 = Jigoku-zawa lavas and ejecta, *6* = Kumano-dake lava,
7 = Ash and volcanic sand from Goshiki-dake.

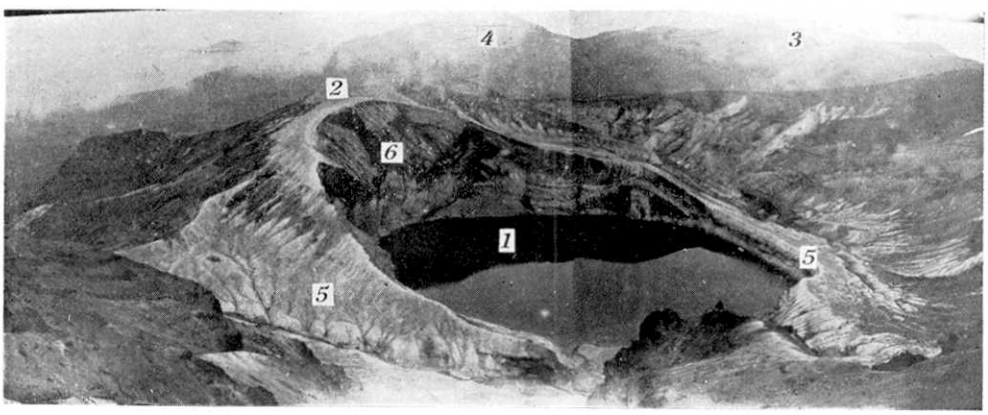

Fig. 6. Goshiki-dake and its explosion crater called generally "Okama" viewed from Kumano-dake.
1 = Okama, *2* = Goshiki-dake, *3* = Byōbu-dake, *4* = Ushiroeboshi-dake,
5 = Recent lapilli and ash, *6* = Ash and volcanic sand.

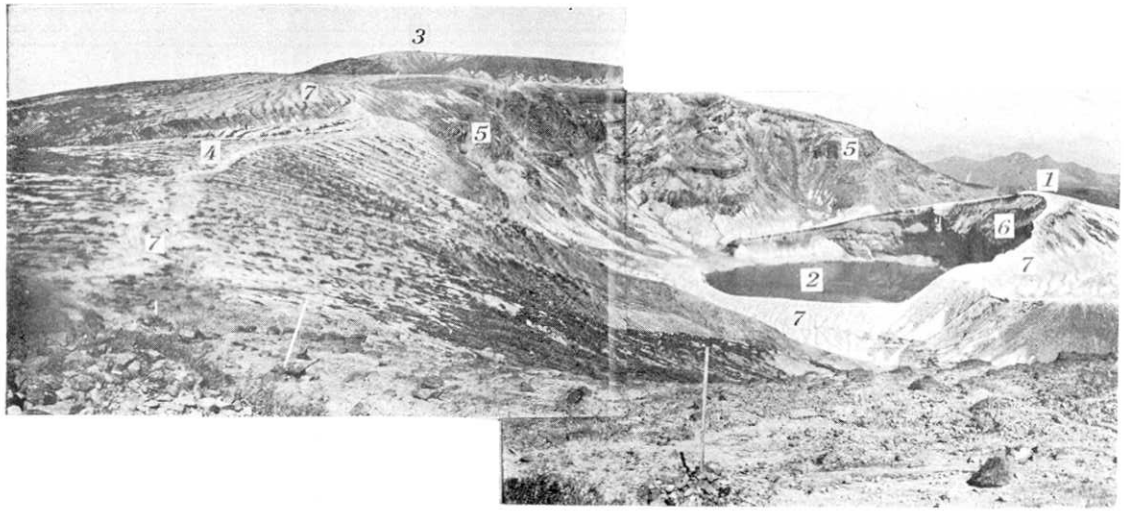

Fig. 7. Goshiki-dake and its explosion crater, "Okama", viewed from the summit of Katta-dake.
1 = Goshiki-dake, *2* = Okama, *3* = Kumano-dake, *4* = Umanose,
5 = Kumano-dake lava, *6* = Ash and volcanic sand, *7* = Recent lapilli and ash.
The surface of Goshiki-dake, Umanose and Kumano-dake is thinly covered with recent lapilli and ash from Goshiki-dake.

29. 藏王火山の地質學的研究（第 1 報）

地震研究所　市　村　毅

藏王火山に關する地質學的研究の結果を報告するに當り，先づその中心に位する五色岳から始めて逐次他の部分に及ぶことにした．

五色岳は藏王火山群の中でも最も新しい火山であり，所謂馬ノ脊大爆裂火口の内部に生じた中央火口丘である．少くとも有史以後の活動は皆此火口丘を中心として行われ，その活動は最近にまで及んでいる．新しい火山なのにも拘らず，開析の程度が著しいために，火山の構造が御澤と御釜の緣に沿うて明かに認められる．從つて藏王火山に登る人々にとつては御釜爆裂火口の存在と共に此場所が最も興味を覺える處である．本文には此五色岳を取卷く馬ノ脊大爆裂火口，五色岳の生成及其地質構造，御釜爆裂火口，五色岳を構成する火山噴出物，最近の活動に際して生じた噴氣孔，五色岳の活動等に關する事項が纒められている．