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History of Tateyama Volcano

Masao YAMASAKI,* Nobuhiro NAKANISHII* and Kin'ichi MIYATA**

**Geological Institute, Faculty of Science, Kanazawa University and*
***Nippon Kôshitsutôki Co. Ltd. (Japan Ironstone China Co. Ltd.)*

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Abstract

Tateyama Volcano situated in the eastern part of Toyama Pref. in central Honshû rests on the west side of the Tateyama Mountains, which are largely composed of gneiss and granite widely exposed in the Hida mountain district. The volcano is now separated mainly into Midagahara Plateau in the northwest and Goshikigahara Plateau in the southeast by a caldera, which was first formed by engulfment and has been enlarged by erosion. The history of the volcano is divided into following four periods :

First Period: Formation of a stratified cone by repeated eruptions of lava and ejecta. Augite–hypersthene andesites with or without hornblende and/or biotite were erupted.

Second Period : Short–lived but violent eruption, which produced a deposit composed of successive layers of pyroclastic flow. The deposit is 500m thick in certain places and strongly welded. Biotite–hornblende–augite–hypersthene dacite pumice was erupted in early stages and augite–hypersthene andesite scoria was erupted later. A collapse caldera was formed on the southwestern flank of the volcano.

Third Period: Repeated eruptions of lava and ejecta took place mainly on the northeast side of the caldera. Lavas erupted were (biotite)–hornblende–hypersthene andesites with or without augite. Biotite–hypersthene–hornblende dacite lava was erupted in the later stage after an eruption of pumice flow. Eruptions of lava took place also within the caldera. At the end of the period, mud flows were issued by explosive activity, which destroyed the post–caldera cone formed in the period.

Fourth Period: Gas explosions, which formed two explosion craters in the northeastern part of Midagahara Plateau. Solfataric activity is still continued in one of the craters. No red–hot materials were erupted.

Six rock samples were chemically analyzed (Table 1). All lavas examined by the writers belong to the calc–alkali rock series, and seem to have been derived from alkali olivine basalt magma by crystallization differentiation and contamination by sialic materials.

Introduction

Tateyama Volcano (Midagahara Volcano) rests on the western slope of the Tateyama Mountains in the eastern Toyama Prefecture, central Japan. This area has been studied geologically by K. SAIKI (1923), H. SHIBATA and H. TOYOSAWA (1957), and T. NOZAWA and T. SAKAMOTO (1962), and the results of the first two works have been summarized by H. KUNO (1962), who named the volcano Midagahara Volcano.

According to the former two works, the volcano has been considered to be a dissected shield volcano with a large erosion caldera, by which the volcanic body is divided into two plateaus, Midagahara in the northwest and Goshikigahara in the southeast. Lava sheets composing the plateaus are underlain by a layer of coarse pyroclastic rocks, which is well exposed along the northern margin of Midagahara. NOZAWA and SAKAMOTO have described lavas and pyroclastic rocks from Midagahara and reported that the pyroclastic rocks were welded in certain places. The area surveyed by them, however, covers only a small part in the west of the volcanic area, and no detail on the geology of Tateyama Volcano has been given in their report.

In 1961, two of the present writers, YAMASAKI and NAKANISHI surveyed Midagahara area with T. IIYAMA, S. FUKAI, and S. FUJII of Toyama University as members of the Scientific Research Group of Tateyama and Shômyô-daki (Shômyô water fall) promoted by the Toyama Shinbun (Toyama Press) (YAMASAKI, NAKANISHI, IIYAMA, and FUJII, 1962). In 1962, one of the present writers, MIYATA, studied the volcano more in detail (MIYATA, 1963). A short survey was made also in 1965 by YAMASAKI and NAKANISHI. Through a series of studies, the writers have come to a conclusion, that the structure as well as the history of the volcano is not so simple as generally accepted. In this paper the writers intend to describe an outline of the geology and history of Tateyama Volcano. No detailed descriptions of gneissose and granitic rocks will be given here, as SHIBATA and TOYOSAWA (1957) have studied mainly on these rocks and described them in detail.

Form and Structure

The Tateyama Mountains occupy the northern part of Hida mountain district and the main ridge of the mountains lies from north to south. Following peaks are standing on the main ridge from north to south: Tsurugi-dake (3003m), Tsurugagozen, Masago-dake, Ônanji (3015m), Oyama (2992m), Jôdosan (2872m), Ryûôdake, Onidake, Shishidake, Washidake, and Tonbiyama. The east side of the main ridge is deeply cut by the Kurobe Valley. A ridge named Dainichi Mountain projects from Tsurugagozen toward west. These ridges are largely composed of gneissose rocks of Hida metamorphic rocks and granitic rocks. The latter rocks have been divided into two types, Tateyama type formed at the time of Hida metamorphism, and Takase type formed in Cretaceous, by SHIBATA and TOYOSAWA (1957). Granite of the latter type is exposed in the vicinity of Masago-dake, and in the southern part of the main ridge. A quartz porphyry mass exposed in the vicinity of Zara Pass on the main ridge is intruded by this granite.

Tateyama Volcano rests mainly on the west side of the main ridge and its northern margin abuts on the south slope of Dainichi Mountain. Lavas and ejecta are also found in a small area on the eastern slope of the main ridge, and the total area occupied by the volcano is about 80 km². The volcanic body is now separated into parts, Midagahara Plateau in the northwest and Goshikigahara Plateau in the southeast, by a caldera, which is drained westward by the Yukawa River. (Plate II, Fig. B)

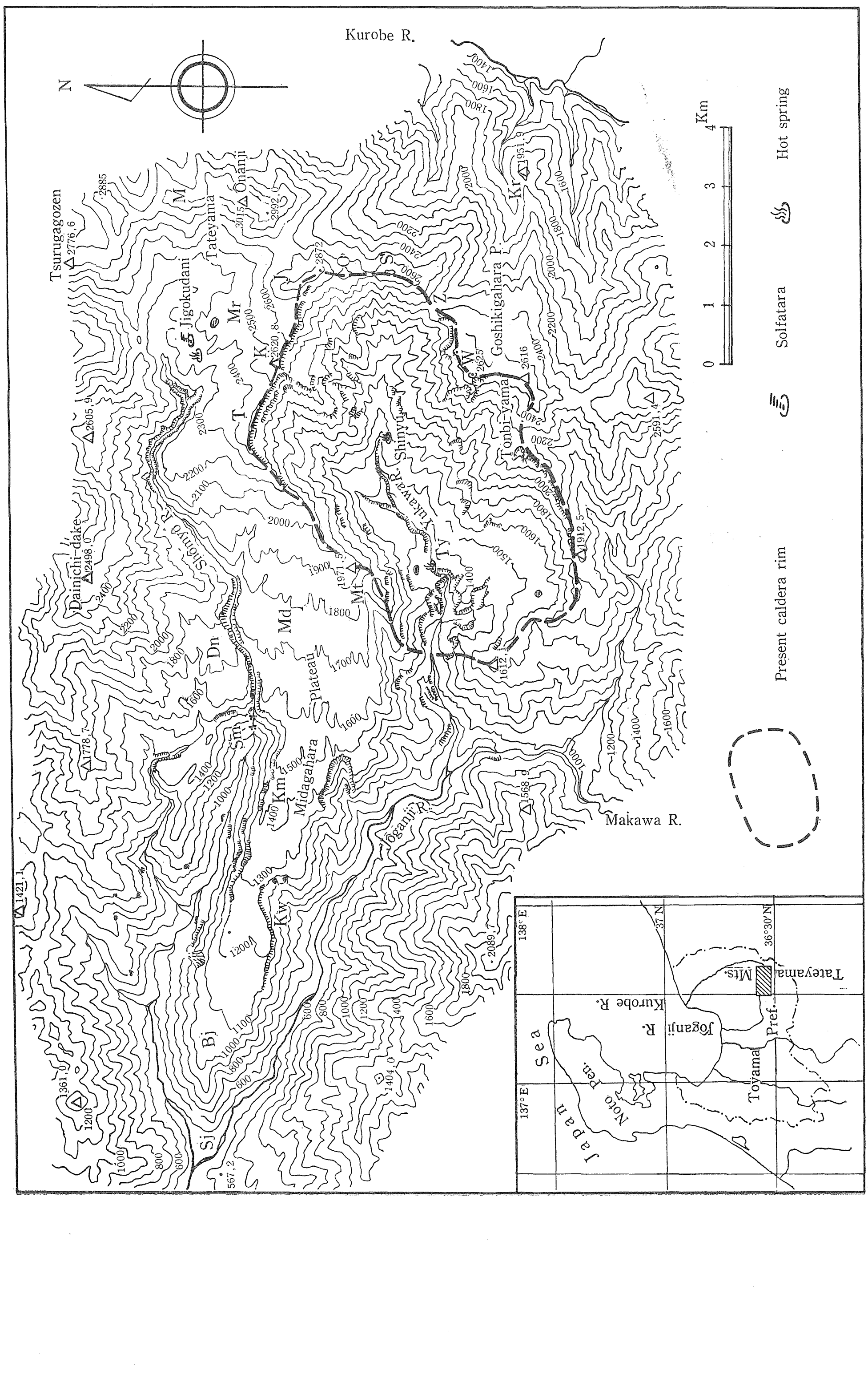
The shape of the caldera is elongated in the direction from southwest to northeast, being about 6 km long and 3 km wide. The caldera is surrounded by steep walls about 600 m high, which are breached on the west side by the Yukawa Valley, which joins with the Makawa River to the west of the caldera rim. The stream below the junction is called the Jôganji River.

Midagahara Plateau is elongated in shape and surrounded by steep cliffs. Its flat top is narrower in the west and slopes down stepwise toward west, forming a series of plains or gentle slopes. From east to west, the plains and the mean altitude of each of them are as follows: Murodô-daira (2430 m), Tengu-bira (2320 m), Kagamiishi daira (2180 m), Mimatsu-daira (2095 m), Shishigahana-daira (1980 m), Midagahara (1910 m), Oiwake-daira (1800 m), Kôbô-daira (1645 m), Kaminoko-daira (1465 m), Shimonoko-daira (1320 m), Buna-daira (1160 m), and Bijo-daira (1020 m). (Plate II. Fig. A)

The Shômyô River flows westward between Midagahara Plateau and Dainichi Mountain, forming a deep gorge, and joins with the Jôganji at Senjugahara to the west of Bijo-daira. The well-known water fall, Shômyô-daki, is about 8 km upstream from the junction. The water fall is 350 m high being separated into four steps. A water fall named Hannoki-daki hanging on the south side cliff of Shômyô-daki is 500 m high. The cliff is composed of a welded pyroclastic flow deposit. Gentle slopes on the south flank of Dainichi Mountain, Dainichi-daira and Zakuro-daira, are the northren extention of Midagahara Plateau, from which they are separated by the Shômyô Valley.

In the eastern part of Midagahara Plateau, a series of small mountains, Murodô-yama, Kunimidake, and Tenguyama, from east to west, stand along the south margin of the plateau, and the south side of each of the mountains is cut by the north wall of the caldera. Two explosion craters, Mikurigaike and Jigoku-dani (Hell-like Valley), are in the northern part of Murodô-daira. The former is now occupied by a crater lake and the latter by active solfatara. (Plate III, Fig. B)

Goshikigahara Plateau rests on the main ridge, gently sloping down toward east,


Kurobe R.
N
Tsurugagozen
Tateyama
Ōnanji
Jigokudani
Dainichi-dake
Shōmyō R.
Midagahara Plateau
Yukawa R.
Shinyu
Goshikigahara P.
Tonbi-yama
Makawa R.
Jōganji R.
Km
Solfatara
Hot spring
Present caldera rim
Japan Sea
Noto Pen.
Toyama Pref.
Tateyama Mts.
Kurobe R.
Jōganji R.
137° E
138° E
37° N
36°30′N

The upper portion of the plateau is composed of a deposit of pyroclastic flow, while Washidake and Tonbiyama peaks standing on the plateau are largely composed of lava. The lower portion of the plateau is occupied by lava layers. All these layers dip toward southeast. The north side of the plateau is steeply cut by the caldera wall. (Plate III, Fig. A)

The basement rocks are widely exposed in the lowest portion of the western Midagahara Plateau, while on the caldera bottom they are exposed in small areas. They are usually covered by layers of lava and ejecta, which are the products of the first period of the history of the volcano. Also the lava layers occupying the lower portion of Goshikigahara Plateau mentioned above were erupted in the same period. The deposits of ejecta of this period are especially thick and widely exposed in the northeastern half of the caldera, where the ejected materials are altered considerably. This fact strongly suggests, that the center of eruption of this period was located near the center of the northeastern half of the caldera.

The deposits of lava and ejecta of the first period are covered by a deposit of pyroclastic flow, which is composed of layers of pyroclastic rocks usually strongly welded. Midagahara Plateau is mainly composed of this deposit, and it is well exposed on the surrounding cliffs of the plateau. The thickness of the deposit differs from place to place, and in the vicinity of Shômyô-daki, it is as large as about 500 m. At certain localities on the both sides of the Jôganji downstream from Senjuga hara, separated masses of the same deposit are found. Therefore, some of the pyroclastic flows seem to have reached Toyama plain. The second period of the history of Tateyama Volcano is represented by the eruptions of these pyroclastic flows. The deposit of pyroclastic flow occupying the upper portion of Goshikigahara Plateau, too, was formed in the same period. The short-lived activity, which outpoured a large amount of pyroclastic materials, was followed by a formation of caldera. The southwestern half of the area occupied by the present caldera was collapsed forming a depression on the southwestern flank of the ancestral cone. The deposit of pyroclastic flows is covered by layers of lava and ejecta in the eastern part of Midagahara Plateau.

The plains from Murodô-daira to Mimatsu-daira, as well as the mountains Murodô-yama, Kunimi-dake, and Tenguyama, are largely composed of lava layers, which dip to the northwest and head into the present caldera rim. Consequently, these lavas must have come

Fig. 1 Topographic Map of Tateyama Volcano and surrounding Areas (Contour line interval : 100m)

Bj : Bijo-daira, Dn : Dainichi-daira, J : Jôdosan, K : Kunimi-dake, Km : Kaminoko-daira, Kr : Kariyasu Pass, Kw : Kuwatani, M : Masago-dake, Md : Midagahara, Mr : Murodô-daira, Mt : Matsuo Pass, O : Ônidake, S : Shishidake, Sj : Senjugahara, Sm : Shômyô-daki, T : Tenguyama, Ty : Tateyama-onsen, W : Washidake, Z : Zara Pass down from a vent or vents located in an area now occupied by the northeastern part of the caldera.

These lava as well as the lavas of Washidake and Tonbiyama standing on Goshiki-gahara Plateau represent the products of the third period of the volcanic history of Tateyama. A pumice flow deposit is found in Mimatsu-daira, lying on a lava bed, of which the plain is composed. The pumice flow deposit is, in turn, covered by a thick lava mass of Tenguyama. Successive eruptions of the pumice flow and Tenguyama lava took place in the later stage of this period. Through repeated eruptions of lava and pyroclastic materials, a post-caldera cone seems to have been built on the northeast side of the collapse caldera. The major part of the cone, however, has been removed by erosion together with the underlying portion of the pre-caldera cone.

Eruptions of lava took place also within the collapse caldera. Thus, a mass being composed of lava beds rests on the caldera floor at the foot of the northwestern caldera wall.

Thin layers of mud flow deposit cover the surface of Midagahara Plateau. They are widely exposed especially from Midagahara plain to Kaminoko-daira plain. Similar deposits are also found within the caldera. Neither explosin craters nor steep cliffs, at which the mud flows are supposed to have been generated, are found now at higher levels of the upper surface of Midagahara Plateau. Presumably, they were generated by explosion occurred at the post-caldera cone at the end of this period. Probably the cone was first destroyed by the explosions and its large parts have been removed later by the head erosion of the Yukawa River.

Two explosion craters, Mikurigaike and Jigoku-dani, situated in the northern part of Murodô-daira, were formed in the fourth period of the history of Tateyama Volcano. Tamadono lava of the third period, of which Murodô-daira is composed, and underlying rocks were blown up, and deposits of explosion breccia were formed around the craters. Solfataric activity is still continued in Jigoku-dani crater.

The floor of the southwestern part of the caldera is largely covered by deposits of mud flow. The enlargement of caldera by slumping of caldera walls is an action still going on. In 1858 (the 5 th year of An-sei Era), a part of the caldera walls near Tonbiyama was suddenly collapsed by the shock of earthquake, and a mud flow was generated. The deposit of the mud flow is distributed in the southwestern part of the caldera and along the Yukawa and Jôganji Rivers (MACHIDA, 1962).

Several hot springs, such as Tateyama-onsen and Shin'yu, are found within the caldera.

Not much is known on the geology of the area on the south side of the caldera, as the area is remote and hardly accessible. Layers of lava and ejecta of the first period and those of pyroclastic flow of the second period are distributed in this area. Their total thickness is not so large as in Midagahara Plateau. They cover thinly an elevated basement, which had formed a ridge projecting westward from the main ridge of the Tateyama Mountains before the volcano rose to a certain height.

History of Activity

As shown in the foregoing pages, the history of Tateyama Volcano can be divided into four periods as follows:

First period. Formation of a stratified cone by repeated eruptions of lava and ejecta from a summit crater. (Fig. 3, A)

Second period. Repeated eruptions of pyroclastic flow followed by formation of a collapse caldera on the southwestern flank of the cone. (Fig. 3, B)

Third period. Formation of a new cone on the northeastern side of the caldera by repeated eruptions of lava and Pyroclastic rocks. Eruption took place also within the caldera. (Fig. 3, C)

Fourth period. Gas explosions and solfataric activity.

The center of activity moved northeastward in the later periods.
Probably, each of the later three periods was preceded by an interval of quiescence with unknown duration. Erosion has done much to modify the shape of the caldera, which was originally formed by engulfment. The major part of the post-caldera cone and underlying caldera walls have been removed, and the caldera has been enlarged toward northeast.

No evidences clearly indicating the age of any of these periods have been found yet. Fukai (1960) has pointed out, that a glacial cirque existing to the north of Shishidake cuts a pyroclastic layer, which is, according to the present writers' observation, a product of the second period. Accordingly, the writers consider, that the age of the formation of the collapse caldera was late Pleistocene.

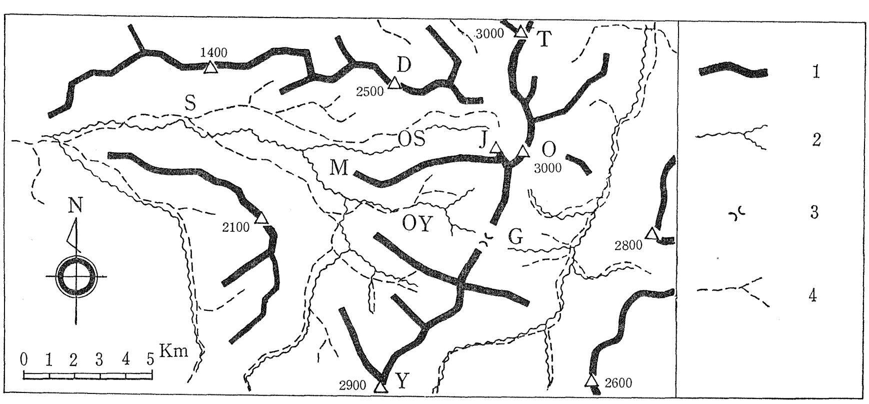


Fig. 2 Map illustrating the topography of the area now occupied by Tateyama Volcano, before the birth of the volcano.

1 Mountain ridge, 2 River, 3 Coll, 4 Course of the present river.
D : Dainichi-dake, G : Goshikigahara, J : Jôdosan, M : Midagahara,
O : Ônanji, OS : Old Shômyô R., OY : Old Yukawa R., S : Senjugahara,
T : Tsurugi-dake, Y : Yakushi-dake.

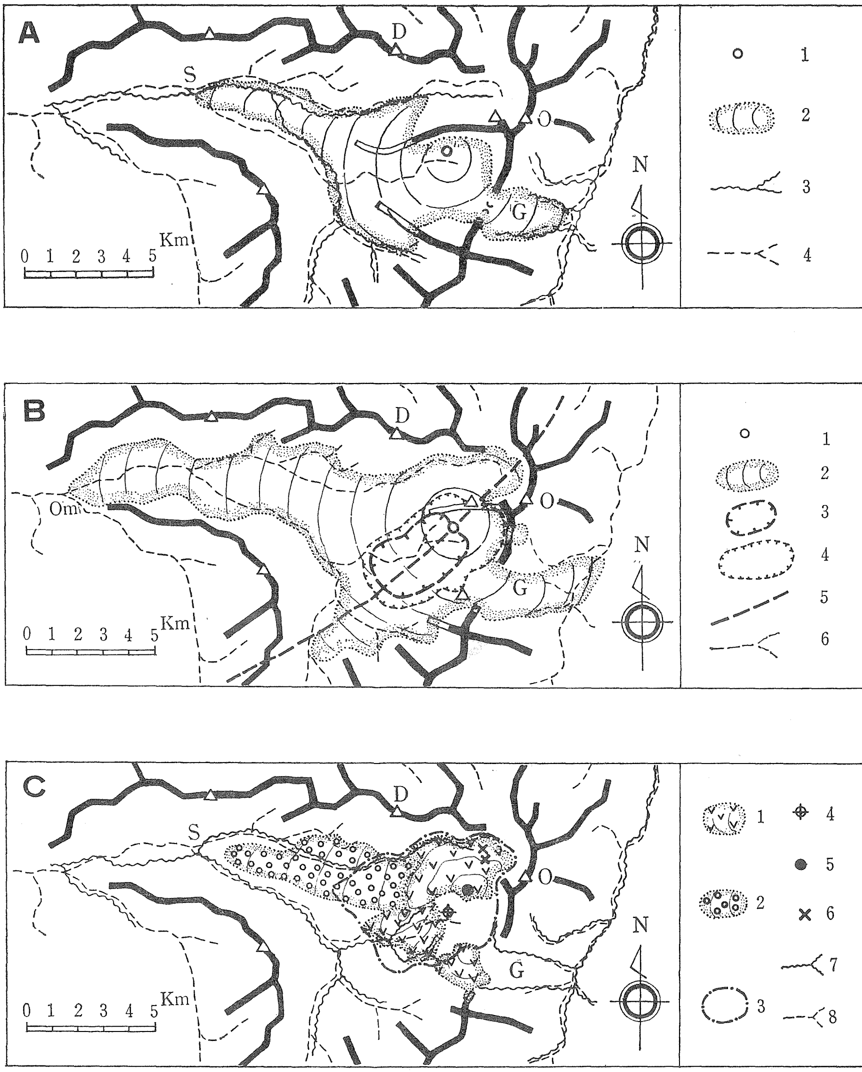


Fig. 3 Maps illustrating the distribution of volcanic products of the first, second, and third periods.

Map A : First Period

1 Summit crater, 2 Lavas and ejecta, 3 River system just before the second period, 4 Present river system

Map B : Second Period

1 Summit crater, 2 Pyroclastic flow deposit, 3 Rim of the original collapse caldera, 4 Rim of the present caldera, 5 Fault, 6 Present river system

Map C : Third Period

1 Lavas and ejecta, 2 Pumice flow, 3 Margin of the area covered by mud flow deposits, 4 Summit crater of the pre–caldera cone, 5 Summit crater of the post–caldera cone, 6 Explosion craters formed in the fourth period, 7 River system just before the third period, 8 Present river system

D : Dainichi Mt., G : Goshikigahara, O : Ônanji Mt., Om : Omi., S : Senjugahara.

First Period

Judging from the distribution of outcrops of basement rocks covered by the volcanic products, the area on the west side of the Tateyama Mountains, that is now occupied by the volcano, had been drained by two valleys, the Old Shômyô in the north and the Old Yukawa in the south, before the topography of the area was greatly changed by a growing volcanic cone. The two valleys had been separated from each other by a short ridge projecting westward from Jôdosan of the main ridge. (Fig. 2)

A vent was opened in the Old Yukawa Valley at the time of the birth of the volcano. A volcanic cone grew gradually by repeated eruptions of lava and ejecta. Until the cone rose to a considerable height, ejected materials had deposited largely in the Old Yukawa Valley and lavas had flowed down westward in the same valley. In the later stages of this period, the volcano grew so high, that certain lavas flowed down on the eastern slope of the main ridge passing through a coll, now filled up by the deposit of Goshikigahara Plateau. Also the Old Shômyô Valley was partly filled by the products of the later stages of this period, and the valley was completely buried by the pyroclastic flow deposit in the second period. The ridge between the two valleys is now almost entirely hidden below Midagahara Plateau.

Exactly how high the cone rose in this period is, of course, uncertain, but if the upper surfaces of the deposit formed in this period are projected upward with an appropriately increasing angle and if the summit crater was small, it can be estimated that the volcano reached a height of more than 2600 m[1)]. The summit seems to have been located at the center of the northeastern half of the present caldera. The total volume of the materials erupted in this period may be approximately 9 km^3.

In the northeastern part of the present caldera, where the central portion of the cone was dissected deeply down to the bottom, a thick pile of layers of tuff breccia is exposed on the caldera walls. Gneissose rocks crop out in small areas being covered

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1) Exactly speaking, the slopes of the pre-caldera cone in Midagahara and Goshikigahara Plateaus, which are seen in a cross section, cross each other at a point close to the north rim of the latter plateau, if they are projected upward. Judging from the distribution of lavas and ejecta, however, it is not possible to conclude, that the summit of the cone was located so closely to the top of the main ridge of the Tateyama Mountains. The asymmetry shown by the structures of the both plateau seems to suggest that there is a fault lying from SW to NE passing through the center of caldera. Goshikigahara Plateau on the southeast side of the fault seems to have been upheaved relatively against the Midagahara Plateau on the opposite side of the fault. The centers of activity of the third and fourth periods were just located on the northern extension of this fault. SHIBATA and TOYOSAWA (1957) have recognized a fault in the basement rocks exposed in a valley of a tributary of the Makawa River on the southwest side of the caldera. The fault runs from SW to NE and the northwest side of the fault was subsided relatively against the oppoite side, according to them. Therefore, it is possible, if not probable, that this fault represents the southwestern extension of the possible fault mentioned above. If this fault actually exists, the dislocation seems to have taken place before the beginning of the third period. The throw of the fault is supposed to have been at most 300m at the center of the cone. The existance of the fault, however, has not yet been confirmed by observing the fault plane on the caldera walls.

by the deposit of ejecta. The deposit is composed of pyroclastic materials which were ejected from the vent and thickly accumlated around it, and contains abundant fragments of andesite and not a few fragments of basement rocks. The deposit is generally strongly altered and shows greenish or brownish tint.

Andesite blocks contain phenocrysts of plagioclase, hornblende, pyroxene, and opaque ore. Hornblende and pyroxene crystals are comletely altered into chlorite and opaque materials. Decomposed crystals of biotite and irregularly shaped crystals of quartz are also found sporadically. Cavities are filled by carbonate crystals. As the deposit occupied the core portion of the volcano for a long time, it was altered considerably by gas or solution, which came from the conduit permeating through the deposit.

Away from the center of volcano, rocks are usually free from alteration. On the northwest wall of the caldera, an alternation of lava and ejecta layers is exposed along a path descending from Matsuo Pass on Midagahara Plateau to Tateyama-onsen on the caldera floor. Two lava layers crop out, and each of them is about 50 m thick. The lower layer shows platy jointing and is composed of augite-hypersthene andesite. The upper one is composed of opacitized hornblende-bearing augite-hypersthene andesite, the chemical composition of which is shown in Table 1. Augite-hypersthene andesite free from hornblende and biotite is also found at Mizutani in the Yukawa Valley a little downstream from the western caldera rim. Augite-hypersthene andesite containing a small amount of biotite phenocrysts is exposed at Kariyasu Pass to the east of Goshikigahara Plateau.

A lava bed named Zaimoku-iwa (wood-like rock), which shows remarkable columnar jointing, is exposed on the westernmost cliff of Midagahara Plateau, half-way up from Senjugahara to Bijo-daira along the funicular railway. This lava is brown hornblende-augite-hypersthene andesite containing sporadic phenocrysts of biotite. Groundmass is rich in glass and pilotaxitic. Comparatively large crystals of plagioclase rich in minute glass inclusions and irregularly shaped crystals of quartz are found sporadically. They may be xenocrysts derived from basement rocks. The chemical composition of this lava is shown in Table 1. (Plate IV, Fig. A)

Zaimoku-iwa lava lies on a breccia bed, which, in turn, covers a gravel bed deposited on biotite gneiss. The upper portion of the cliff is occupied by a welded pyroclastic flow deposit of the second period, which covers the Zaimoku-iwa lava. It is certain, that the lava flowed down from east to west in the valley of the Jôganji, and deposited on the valley floor. However, in the vicinity of Kuwatani to the east of Senjugahara, the lava is not exposed on the cliff of the plateau, and the deposit of pyroclastic flow directly covers the basement rocks. This fact seems to suggest, that the lava bed of that part had been removed by erosion of the river during an interval of quiescence before the opening of the second period. During this interval, the volcano may have been cut by radial valleys formed on the slopes.

Biotite-hornblende-augite-hypersthene andesite is also found in the Makawa Valley on the southwest side of the caldera.

Second Period

After a period of quiet with unknown duration, Tateyama Volcano manifested a short-lived but violent eruption, discharging a large amount of pyroclastic materials. Pyroclastic flows were erupted successively and rushed headlong in all directions on the slopes of the mountain along the radial valleys. Some flows raced down the Jôganji Valley and seem to have reached the east margin of Toyama Plain more than 20km west of the crater. Some flows went over the barriers of surroundig ridges, overflowing through saddles, and poured into valleys on the opposite side of the ridges. Thus, those rushed eastward descended on the eastern side of the main ridge of the Tateyama Mountains, and those directed north poured into the valley on the north side of Dainichi Mountain, passing through a saddle between Dainichi and Tsurugagozen peaks.

A thick deposit of pyroclastic flow layers was formed by the eruption. The deposit is well exposed on the surrounding cliffs of Midagahara Plateau. (Plate IV, Fig. B) Its thickness varies in different places. Generally speaking, it increases with the distance from the crater and becomes maximum at the north margin of the plateau, where the deposit filled up the valley of the Old Shômyô. Thus, on the caldera walls at the south margin of the plateau, the deposit is at most about 80 m thick, while in the neighbourhood of Shômyô water fall, cliffs of more than 500 m high are entirely composed of the deposit.

The pyroclastic flows erupted in earlier stages of the eruption are pumice flows, while those in later stages are scoria flows. Pumice flow layers are well exposed in the western part of Midagahara Plateau, occupying the lower portion of the pyroclastic flow deposit. Scoria flow layers occupy the upper portion and especially well observed in the eastern part of the plateau. As the deposit is generally welded in considerable degree, a boundary between two successive flow units is not clear. Therefore, it is usually difficult to count the flow units exposed on a cliff. For example, at least five layers seem to be exposed on the neighbouring cliffs of Shômyô water fall (Plate I). Each layer shows different degree of development of columnar jointing and has a hard zone in the middle portion. However, the result of the measurment of vertical change in density of rocks exposed on the lowest 50 m of the cliff shows that one of such layers, exposed at the bottom of the cliff, is composed of more than two flow units. Accordingly, it seems to be suggested, that the whole cliff is composed of much more sheets of pyroclastic flow.

The writers had a chance to examine samples of the core boring carried out in Murodô-daira by T. K. A. Co Ltd.. Here, the deposit of pyroclastic flow is covered by layers of lava of the third period, and five layers of welded scoria were recognized within the uppermost 85 m of the deposit. Each layer has weakly welded zones at the top and bottom, and seems to represents a single flow unit. The degree of welding increases from upper to lower layers.

The nonwelded portion of pumice flow deposit found near the bottom of the deposit is composed of lumps of pumice being white and buff in colour, lithic fragments of old lavas and basement rocks, and matrix consisting of glass shards and crystal fragments. Pumice lamps are augite-green hornblende-hypersthene dacite with vitric groundmass rich in elongated cavities. Some lumps contain also biotite phenocrysts sporadically. The matrix is remarkably richer in crystals than the pumice lumps, owing to the accumlation of crystal fragments being denser than glass shards through sorting by gravity during the travel of the materials. The crystal fragments are plagioclase, hypersthene, augite, hornblende, biotite, quartz, and opaque minerals. The matrix seems to have been contaminated considerably by foreign materials. Irregularly shaped crystals of quartz, and crystals of biotite and hornblende surrounded by plagioclase crystals appear to have been derived from gneissose rocks of the basement.

Scoria lumps erupted in later stages are augite-hypersthene andesite with vitric groundmass containing abundant dark dusty materials and minute slender crystals of plagioclase and pyroxene. The lumps are dark grey or nearly black in colour and rich in small round cavities. Scoria lumps embedded in a sample of welded scoria collected from a lower level of the boring hole mentioned above, seem to contain a few crystals of opacitized hornblende. However, it is not certain, whether the crystals are true phenocrysts in the scoria lump or not, because the rock is so strongly welded and crystallized, that it is hard to distinguish each scoria lump from matrix and fragments of old lavas in thin sections.

The matrix of the scoria flow deposit contains glass shards and crystal fragments of plagioclase, hypersthene, augite, hornblende, biotite, quartz and opaque ore. As quartz, biotite, and hornblende are absent or rare in scoria lumps, they were certainly derived from basement rocks. The accumlation of crystal fragments in the matrix mentioned above took place also in the deposit of scoria flows.

Welding took place more or less in the greater part of the pyroclastic flow deposit. In strongly welded portions, pumice or scoria lumps were flattened and crystallization of glass proceeded in considerable degree. A strongly welded layer of scoria flow exposed near Denka-sugi in the western part of Midagahara Plateau looks so much like a lava, that it was errorneously described as a lava of the first period (YAMASAKI *et al.*, 1962). The fact, that non-welded portions are not found near the boundary between two successive layers, shows that the layers were emplaced successively without time intervals sufficiently long for complete cooling of each flow layer.

Chemical compositions of a sample of welded pumice lump and a scoria lump are shown in Table 1. The scoria erupted in the later stage is more basic than the pumice of the earlier stage. The density of the pumice tuff is 1.7 in the non-welded parts, and it increases up to 2.57 in strongly welded portions. (Plate V, Figs. A and B)

In the former report (Yamasaki et al., 1962), the total volume of the pyroclastic materials erupted in this period was estimated to be 10 km³, but it has become clear, that the calculation was made on the basis of overestimated values for the thickness of the deposit. Although the deposit is more than 500 m thick in certain places, it is only the case when the deposit filled up deep valleys at the foot of the mountain. Generally, the deposit seems most likely to be less than 150 m thick. A series of geologic cross sections were made by the writers for recalculating the total volume of the deposit. The result thus obtained is 8.5 km³.

By the sudden discharge of a large quantity of materials from the depth, an engulfment of overlying rocks was caused, and a collapse caldera was formed on the southwestern flank of the volcano. Judging from the distribution of lava flows erupted in the next period, the northeastern part of the summit area of the cone, i.e. the northeastern half of the area occupied by the present caldera, was remained not collapsed. Lavas of the next period were mainly erupted from a central vent, which was opened in that remaining part of the volcano, and flowed down chiefly toward north and northwest.

Consequently, the original collapse caldera occupied the southwestern half of the area of the present caldera. Although an exact estimation of the volume of materials disappeared by the engulfment is difficult, since the original shape of the caldera has been greatly modified by later erosion and eruption, the volume does not seem likely to largely exceed 7 km³, according to the rough calculation made by the writers.

Provided that the mean density of the pyroclastic flow deposit is 2.2 and that of magma and solid rocks, from which the pyroclastic materials were derived, is 2.6, the volume of materials discharged by the eruption is estimated to be 7.2 km³. This value roughly corresponds to the estimated value for the volume of materials disappeared by the engulfment mentioned above.

Third Period

In the eastern part of Midagahara Plateau, the deposit of welded pyroclastic rocks of the second period is covered by layers of lava and pyroclastic materials of the third period. Probable succession of lavas from lower to upper is as follows: (Fig. 4)

Murodô-yama lava: Quartz-bearing hypersthene-biotite-hornblende andesite. The lava is rich in reddish brown hornblende phenocrysts. Reddish brown biotite is also common, but hypersthene is rare. Vitric groundmass is commonly devitrified. Murodô-yama Mountain is mainly composed of this lava.

Kunimi-dake lava: Biotite-bearing augite-hornblende-hypersthene andesite. Biotite and hornblende are reddish brown and partly decomposed into black opacite. Kunimi-dake and Tengubira are composed of this lava.

Tamadono lava: Hornblende-augite-hypersthene andesite. It flowed down on a slope between Jôdosan and Murodô-yama peaks and formed a flat plain of Murodô-daira at the north foot of Murodô-yama. It descended also on the western slope of Kunimi-dake Mountain and formed Kagamiishi-daira plain. A sample of the lava collected at the northern margin of Murodô-daira was chemically analyzed. The result is shown in Table 1.

Mimatsu-daira lava: Biotite-bearing hornblende-augite-hypersthene andesite. It is light coloured porous andesite with partly devitrified glassy groundmass. Gromeloporphyritic aggregates of plagioclase, augite and hypersthene are not rare. Tridymite crystals are formed in gas cavities. Mimatsu-daira is composed of this lava.

Tenguyama lava: Quartz-bearing biotite-hypersthene-hornblende dacite. Large phenocrysts of plagioclase and reddish brown hornblende are abundantly contained in

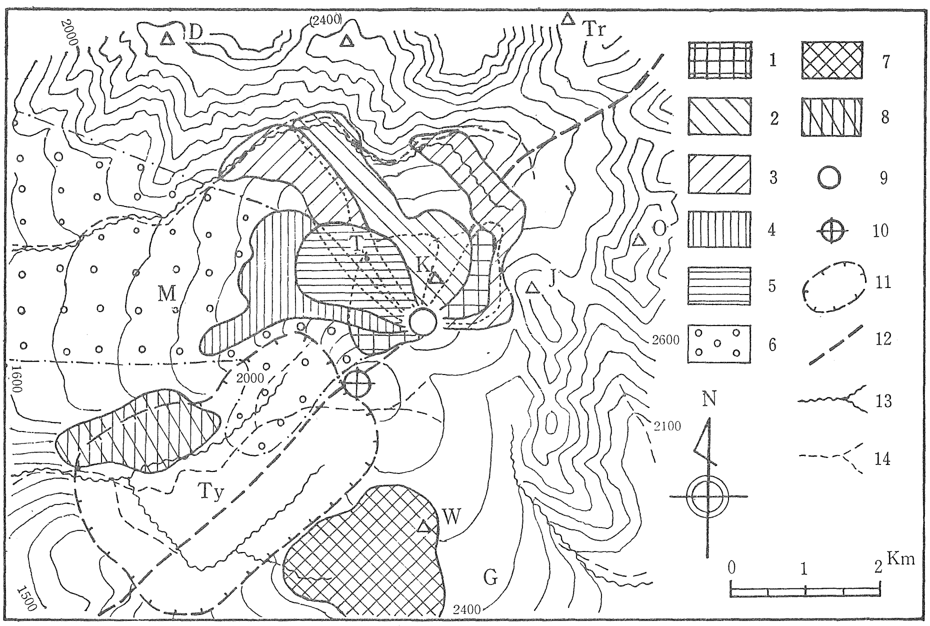

Fig. 4 Map illustrating the distributin of lavas of the third period in the eastern part of Midagahara Plateau, Goshikigahara, and caldera.

1 Murodô–yama lava
2 Kunimi–dake lava
3 Tamadono and Kagamiishi–daira lava
4 Mimatsu–daira lava
5 Tenguyama lava
6 Pumice flow
7 Lavas and ejecta of Tonbiyama and Washidake
8 Lavas erupted within the caldera
9 Main crater of the post–caldera cone
10 Summit crater of the pre–caldera cone
11 Rim of the original collapse caldera
12 Probable fault*
13 River system just before the third period
14 Present river system

D: Dainichi–dake, G: Gorhikigahara, J: Jôdosan, K: Kunimi–dake, M: Midagahara, T: Tenguyama, Tr: Turugagozen, Ty: Tateyama–onsen, W: Washidake,
(* See foot note, page 81)

vitric groundmass. Quartz crystals are rare. The chemical composition of this lava is shown in Table 1. Tenguyama is composed of this lava. The lava is more than 100 m thick and probably formed a lava dome at the time of eruption. The southern part of the dome has been demolished by erosion acting on the northern caldera wall.

The eruption of Tenguyama lava seems to have been preceded by a pumice eruption. Thus in the vicinity of Mimatsu Hutte on Mimatsu-daira, a deposit of pumice flow is exposed resting on a stratified deposit of pumice tuff. The pumice flow deposit is covered by Tenguyama lava. Fragments of welded pyroclastic rocks of the second period are embedded in the pumice flow deposit. Probably, the surface of the western Midagahara Plateau was once veneered by a thin deposit of the pumice flow, but the deposit has been partly removed by erosion and partly covered by deposits of mud flow.

An exact estimation of the volume of pumice erupted is, consequently, impossible. The present writers consider that the volume may not exceed 0.3 km^3. A deposit of pumice flow is also found on the floor of the central part of the caldera. A part of the pumice flow, therefore, seems to have poured into the caldera.

Lavas of hornblende-augite-hypersthene andesite with or without biotite deposited thick on an eroded surface of a lava of the first period at the foot of the northwestern caldera wall. The petrographic features of the lavas are quite similar to those of some of the lavas mentioned above. Judging from the mode of occurrence of them, it is conceivable, that they were erupted from a vent opened on the marginal fault of the caldera.

A stratified deposit of pyroclastic materials about 40 m thick is exposed at the east margin of Murodô-daira. It is composed of layers of tuff breccia, lapilli tuff, scoria tuff, and pumice tuff. The lower one-fifth of the deposit is composed of layers of sand and silt intercalated by scoria layers. Many accessory and accidental lithic fragments are embedded in the ejected materials. The deposit covers an eroded surface of the welded scoria flow deposit of the second period. This fact shows, that the activity of the third period was preceded by an interval of erosion of unknown duration.

By repeated eruptions of ejecta and lava flows mentioned above, a new cone was built on the northeast side of the caldera. Exactly how high the post-caldera cone rose is, however, unknown, because its central part has been removed completely and is now occupied by the northeastern part of caldera. A short ridge projecting into the caldera from Kunimi-dake is likely to be a remnant of the central conduit filled by hard lavas. If it is true, the summit of the post- caldera cone is considered to have been located a little south of Kunimi-dake, and its height seems to have been only a little larger than that of Kunimi-dake.

Washidake and Tonbiyama standing on Goshikigahara Plateau are composed of lavas of biotite-hornblende-augite-hypersthene andesite. As they are now isolated far from the supposed center of volcano, it is not certain, whether they were erupted from

Table 1 Chemical compositions of lavas and essential fragments of pyroclastic flows of Tateyama Volcano (Analyzed by N. NAKANISHI)

	I a L	I b L	II a Pfl	II b Pfl	III a L	III b L
SiO_2	62.87	63.44	61.21	57.35	62.32	62.51
Al_2O_3	16.57	16.21	16.67	17.18	15.67	16.11
TiO_2	1.08	0.96	1.13	1.06	1.02	1.09
Fe_2O_3	2.57	2.36	2.32	3.01	2.97	2.07
FeO	3.27	2.77	4.07	4.89	2.83	3.47
MnO	0.15	0.13	0.15	0.15	0.13	0.15
MgO	2.19	1.67	2.94	3.21	2.54	2.29
CaO	5.10	5.41	5.62	6.24	5.20	5.54
Na_2O	3.30	3.22	3.18	2.91	3.34	3.58
K_2O	2.22	2.65	2.19	1.85	2.44	2.26
$H_2O(+)$	0.51	0.57	0.56	0.60	1.04	0.53
$H_2O(-)$	0.10	0.58	0.19	0.57	0.19	0.40
P_2O_5	0.35	0.38	0.42	0.30	0.28	0.31
Total	100.28	100.35	100.65	99.32	99.97	100.31

Norms and Solidification Indices (S.I.)*

	I a	I b	II a	II b	III a	III b
Q	20.91	21.83	17.37	13.65	21.37	18.08
or	13.02	15.63	12.96	10.91	14.41	13.36
ab	27.89	27.18	26.94	25.06	28.26	30.30
an	22.98	22.14	24.73	28.11	20.55	21.20
C	0.33	...	...	...	...	...
Py wo	...	0.92	0.15	0.37	1.41	1.81
Py en	5.45	4.16	7.32	7.99	6.32	6.41
Py fs	2.37	1.79	3.08	5.01	1.29	3.14
mt	3.72	3.42	3.36	4.38	4.31	3.01
il	2.04	1.81	2.14	2.02	1.94	2.06
ap	0.84	0.91	1.01	0.71	0.67	0.71
S.I.	16.2	13.4	20.0	20.6	18.4	16.8

L···Lava, Pfl···Pyroclastic flow.

*$S.I. = 100 \times MgO/(MgO+FeO+Fe_2O_3+Na_2O+K_2O)$ (KUNO, 1959)

I a Botite-bearing brown hornblende - augite - hypersthene andesite. Loc. Zaimoku-zaka between Senjugahara and Bijo-daira (NN-61060501). Lava erupted in the first period.

I b Hornblende - bearing augite - hypersthene andesite. Loc. On the northwestern caldera wall below Matsuo Pass. (NN-61082609). Lava erupted in the first period.

II a Biotite-bearing augite-hornblende-hypersthene dacite. Collapsed pumice lump in the welded pumice flow deposit. Loc. West of Shômyô-daki (NN-61082706). Pumice flow erupted in the early stage of the second period.

II b Augite-hypersthene andesite. A collapsed scoria lump in welded scoria flow deposit. Loc. West of Jigoku-dani (NN-61082503). Scoria flow erupted in the later stage of the second period.

III a Quartz-bearing biotite-hypersthene-hornblende dacite. Loc. On the northeast flank of Tenguyama (NN-61082506). Lava erupted in the third period.

III b Hornblende-angite-hypersthene andesite. Loc. North margin of Murodô-daira (NN-61082404). Lava erupted in the third period.

the central vent or from a lateral vent.

It is difficult to estimate the total volume of the materials erupted in this period, because not a little amount of the materials seem to have been removed by erosion. According to a rough calculation made by the writers, the total volume may not largely exceed 1 km^3.

Two succesive layers of mud flow deposit cover the surface of Midagahara Plateau in places. They are especially widely distributed from Midagahara plain to Kaminoko-daira plain. A thin ash bed lies between the two layers, each of which is generally 2 or 3 m thick. They contain large blocks of lavas of the third period, which are embedded in muddy matrix. Probably, at the end of this period, the volcano manifested a violent explosion, and a part of the post-caldera cone was destroyed, generating these mud flows. Mud flows also rushed down into the caldera and deposited on the floor.

Fourth Period

The center of the volcanic activity in the fourth period is located in the northern part of Murodô-daira. The volcano has manifested only weak explosions forming two explosion craters. Mikurigaike is a lake in an explosion crater. The maximum diameter of the crater is about 230 m and the bottom of the crater is about 50 m below the surface of Murodô-daira plain. The lake is about 15 m deep. A deposit of explosion breccia is distributed around the crater. The deposit is composed of rock fragments of various sizes derived from Tamadono lava and underlying rocks.

Jigoku-dani, an active solfatara field, is also an explosion crater about 60 m deep and 350 m wide. Many active gas holes and hot springs are scattered in and around the valley, and rocks exposed in the area are strongly altered. On the bottom of the valley lies a deposit of solfataric clay. A deposit of explosion breccia is found in the surrounding area of the valley. Fragments of welded pyroclastic rocks of the second period are found sporadically among those of Tamadono lava and other rocks. No ejected fragmeuts, which seem to be essential, have been found from these explosion breccia. The volcano presumably has not erupted red-hot materials in this period.

Chemistry of Products

All lavas and essential fragments in pyroclastic rocks examined by the writers microscopically seem to belong to the calc-alkali rock series defined by Kuno (1959). The groundmass is often glassy or so finely crystallized that the exact identification of constituent minerals is impossible. Even in such cases, however, that the rocks are members of that rock series is suggested strongly either by the presence of phenocrysts of hornblende or biotite, which are absent in rocks of the tholeiitic rock series, or by the presence of phenocrysts of plagiocase with a zone of dusty inclusions, and of sporadic

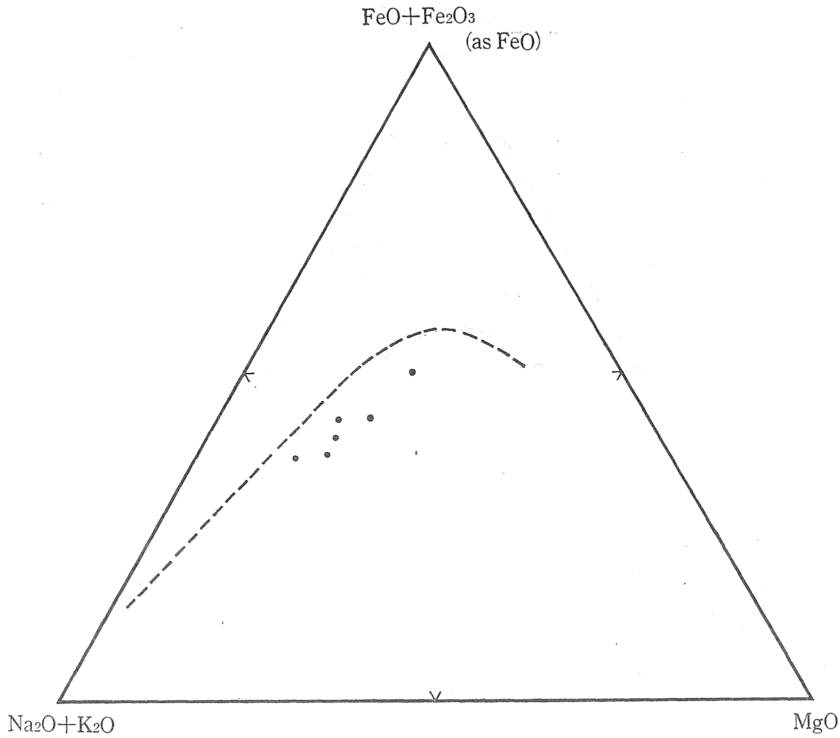

Fig. 5 Triangular diagram MgO—$FeO+Fe_2O_3$—Na_2O+K_2O showing chemical compositions of lavas and essential fragments in pyroclastic flows of Tateyama Volcano. The broken line shows the boundary between the area for the calc-alkali rock series and that for the tholeiitic and alkali rock series. All points are located in the area for the calc-alkali rock series on the lower side of the line.

cognate inclusions, both of which are common in rocks of the calc-alkali rock series.

Chemical compositions of six rock samples are shown in Table 1. As shown in Fig. 5, all points for these rocks are located in the area of the calc-alkali rock series in the triangular diagram $MgO - FeO + Fe_2O_3 - Na_2O + K_2O$. These rocks are richer in $Na_2O + K_2O$ than the rocks of the tholeiitic and calc-alkali rock series of Izu district with corresponding SiO_2 contents shown by KUNO (1954), as seen in Fig 6. In Fig.6 points for Tateyama lavas are located in an area between the lines showing the trends of magmatic differentiation of Fuji Volcano and volcanoes of the Cascade Range. Therefore, it is possible, if not probable, that the lavas of Tateyama Volcano are entirely or almost entirely products of differentiation of basic magmas derived from alkali olivine basalt magma through contamination by sialic materials

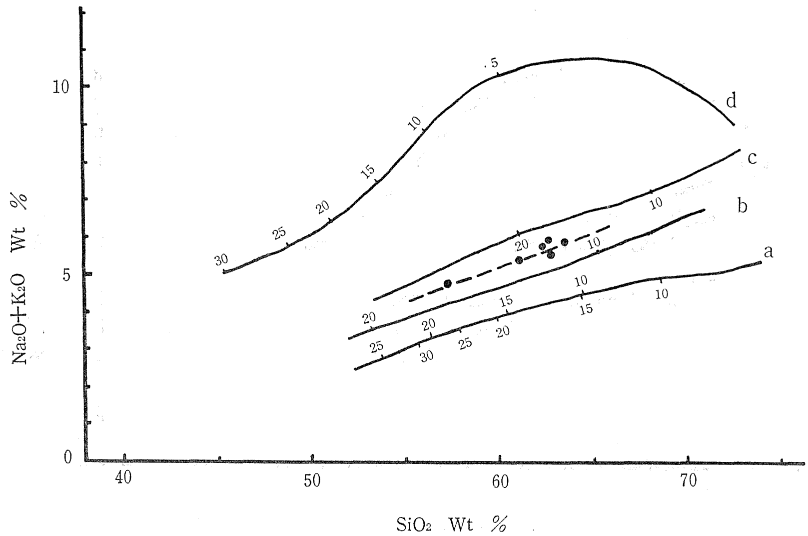

Fig. 6 Diagram illustrating the relation between SiO_2 and Na_2O+K_2O of lavas and essential fragments in pyroclastic flows of Tateyama Volcano. Mean trends of differentiation of different types of basaltic magma are also shown.

a: Tholeiitic and calc-alkali rock series in Hakone and Izu (KUNO, 1954),

b: Highalumina basalt of Fuji Volcano (KUNO, 1960),

c: Calc-alkali rock series in High Cascade Range in the western U.S.A.,

d: Alkali rock series in Circum Japan Sea petrographic province (TOMITA, 1935).

Solidification indices of calc-alkali rock series are shown by numerals below each line, and those for another rock series are shown by numerals above each line.

Acknowledgments

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Alphabetical index of place names

Bijo-daira 美女平
Buna-daira ブナ平
Dainichi (-daira) 大日(平)
Denka-sugi 殿下杉
Goshikigahara 五色ケ原
Hannoki-daki ハンノキ滝
Hida 飛騨
Jigoku-dani 地獄谷
Jôdosan 浄土山
Jôganji R.常願寺川
Kagamiishi-daira 鏡石平
Kaminoko-daira 上の子(小)平
Kariyasu Pass (Tôge) 刈安峠
Kôbô-daira 弘法平
Kunimi-dake 国見岳
Kurobe R. 黒部川
Kuwatani 桑谷
Makawa R. 真川
Masago-dake 真砂岳
Matsuo Pass (Tôge) 松尾峠
Midagahara 弥陀ケ原
Mikurigaike ミクリガ池
Mimatsu-daira 美松平
Mizutani 水谷
Murodô-daira 室堂平
Murodo-yama 室堂山
Oiwake-daira 追分平
Omi 小見
Ônanji 大汝
Onidake 鬼岳
Oyama 雄山
Ryûôdake 竜王岳
Senjugahara 千寿ケ原
Shimonoko-daira 下の子(小)平
Shin'yu 新湯
Shishidake 獅子岳
Shishigahana-daira 獅子ケ鼻平
Shômyô-daki 称名滝
Shômyô R. 称名川
Tamadono 玉殿
Tateyama 立山
Tateyama-onsen 立山温泉
Tengubira 天狗平
Tenguyama 天狗山
Tonbiyama 鳶山
Toyama Pref. 富山県
Tsurugagozen 劔ケ御前
Tsurugi-dake 劔岳
Washidake 鷲岳
Yakushi-dake 薬師岳
Yukawa R. 湯川
Zaimoku-iwa 材木岩
Zaimoku-zaka 材木坂
Zakuro-daira 柘榴平
Zara Pass (Tôge) ザラ峠

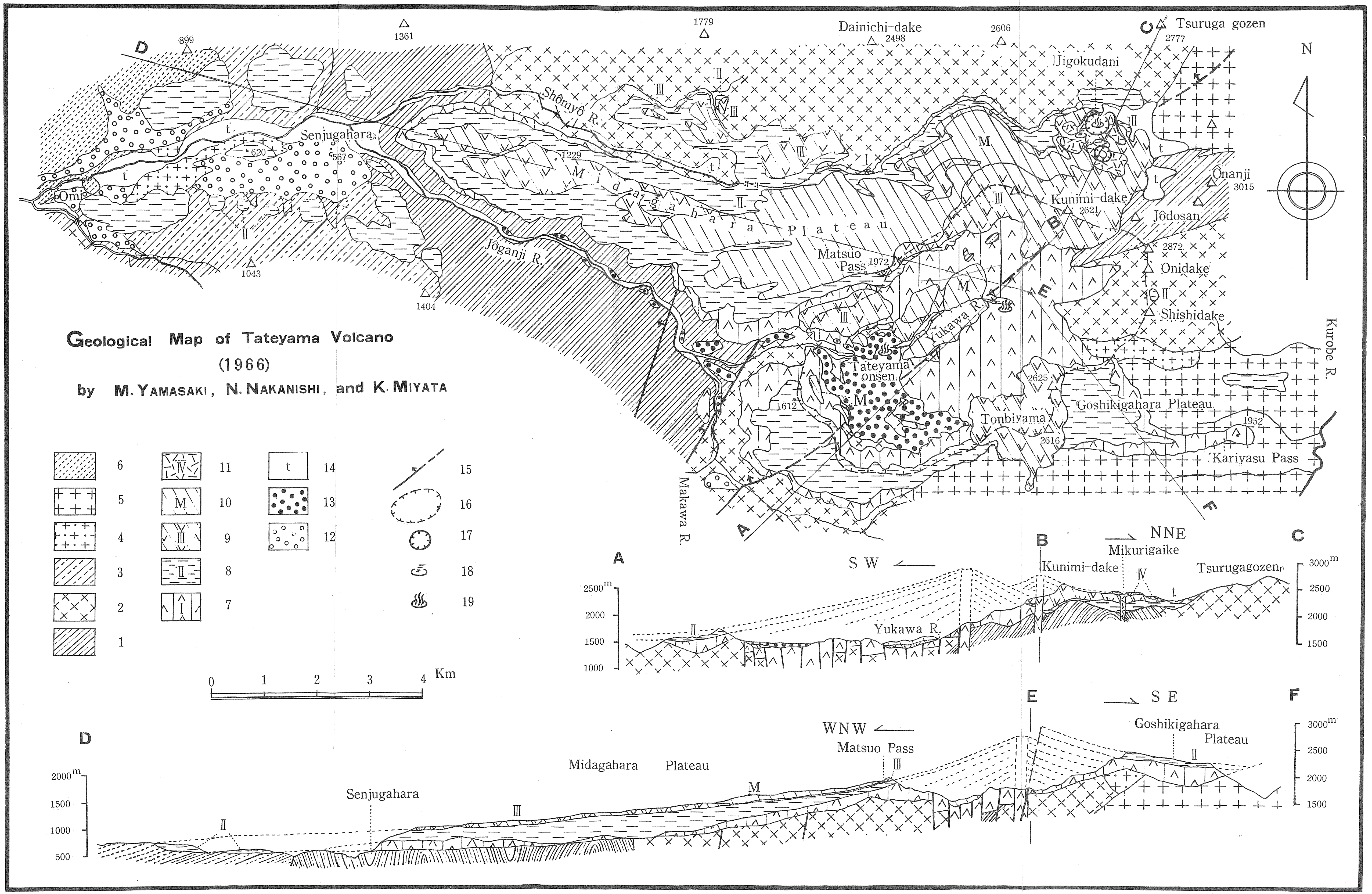


Fig. 7 Geological Map of Tateyama Volcano 1 Gneiss, 2 Granite of Tateyama type, 3 Tetori Mesozoic Formation, 4 Quartz porphyry, 5 Granite of Takase Type, 6 Tertiary, 7 Lavas and ejecta (First Period), 8 Pyroclastic flow deposit (Second Period), 9 Lavas and ejecta (Third Period), 10 Mud flow deposit (Third Period), 11 Explosion breccia (Fourth Period), 12 Terrace deposit, 13 Mud flow deposit in 1858, 14 River gravels and Talus deposit, 15 Fault, 16 Present caldera rim, 17 Explosion crater, 18 Solfatara, 19 Hot spring.

PLATE I

Explanation of PLATE I

Shômyô-daki (left) and Hannoki-daki (right) hanging on cliffs of welded pyroclatic flow layers. (Photograph taken by the Toyama Shinbun)

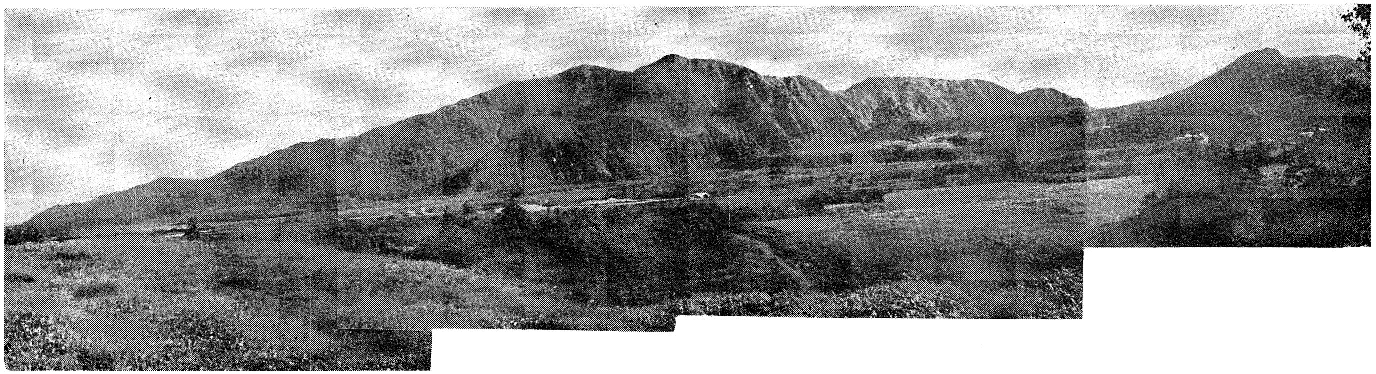
PLATE Ⅱ

Explanation of PLATE II

Fig. A Panorama of Midagahara plain and Dainichi Mountain in the background. Tenguyama is seen in the right. The caldera is on the opposite side of Tenguyama. Deep valley of the Shômyô River lies from east (right) to west (left) between Midagahara and Dainichi Mountain.

Fig. B Panorama of caldera walls surrounding the northeastern half of the caldera. The photograph was taken at a little east of Tateyama-onsen. 1 : Tenguyama, 2 : Kunimi-dake, 3 : Murodô-yama, 4 : Jôdosan, 5 : Ryûôdake, 6 : Onidake, 7 : Shishidake, 8 : Zara Pass.

A



B

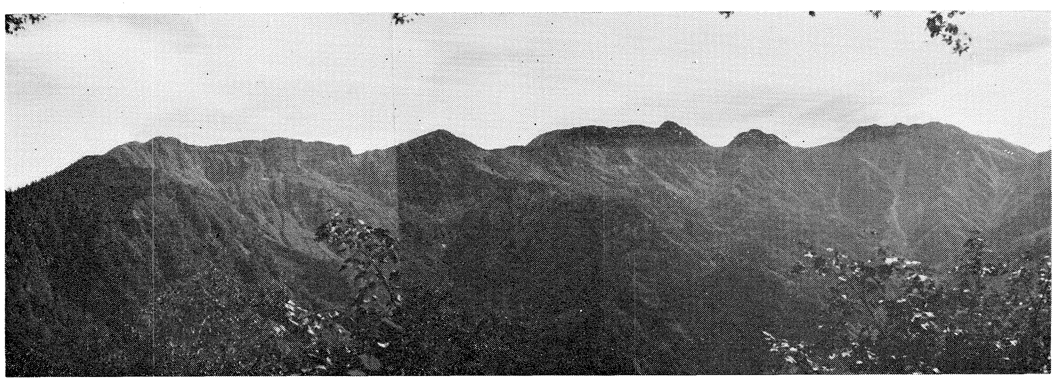


PLATE Ⅲ

Explanation of PLATE Ⅲ

Fig. A Goshikigahara Plateau viewed from Jôdosan. Layers of lava and pyroclastic flows crop out on cliffs. Small peaks of Washidake and Tonbiyama stand on the plateau, near its margin. The Kurobe Valley is on the left side of the Plateau, and Mt. Yakushi-dake is in the background.

Fig. B Solfatara in Jigoku-dani. Trurugi-dake and Tsurugagozen are in the background.

A

B

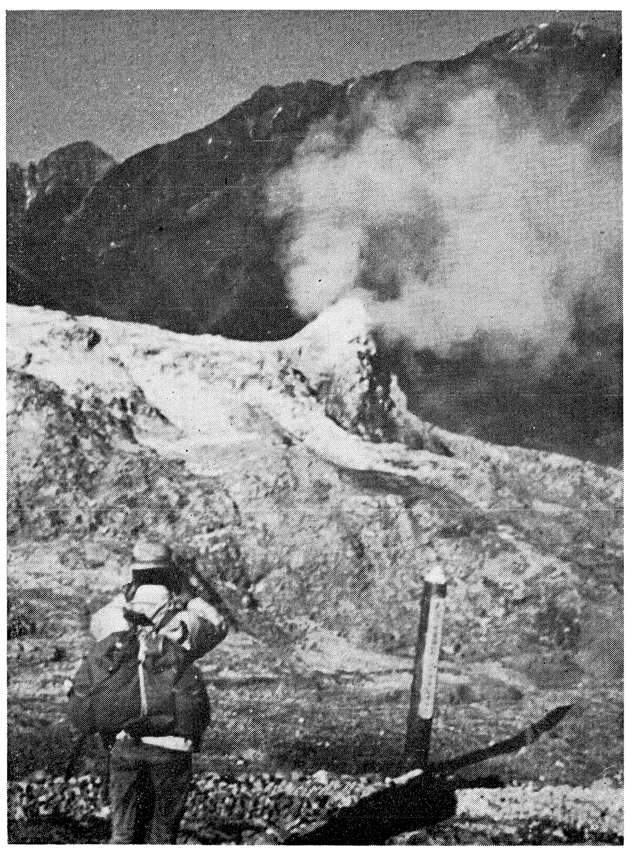


PLATE Ⅳ

Fxplanation of PLATE IV

Fig. A Columnar joints of Zaimoku-iwa lava exposed at Zaimoku-zaka between Bijo-daira and Senjugahara. Lava flow erupted in the The first period.

Fig. B Columnar joints of welded pyroclastic flow deposit exposed in the valley of the shômyô River upstream from Shômyô-daki.

A

B

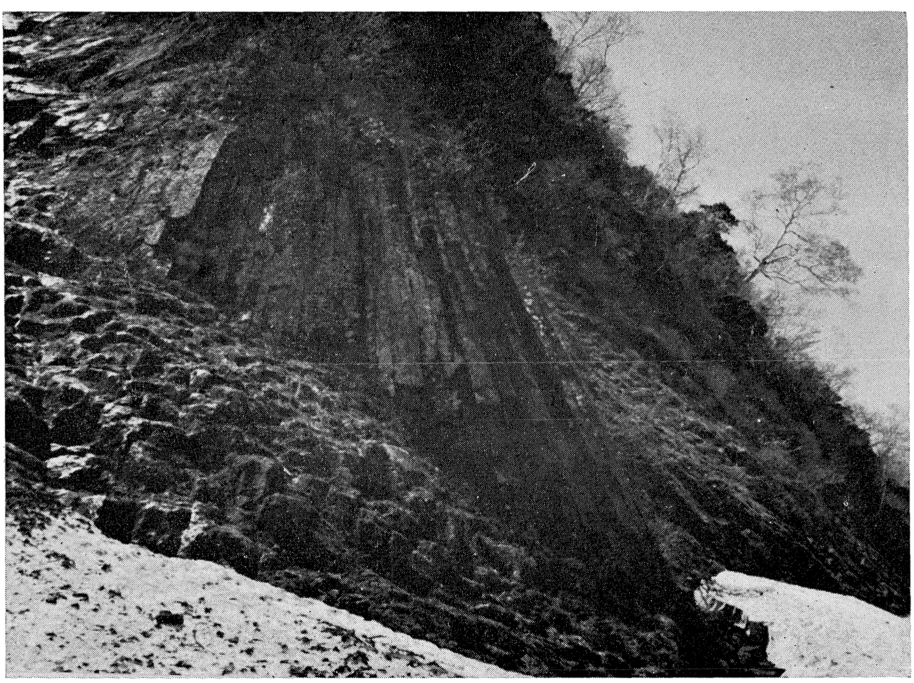


PLATE V

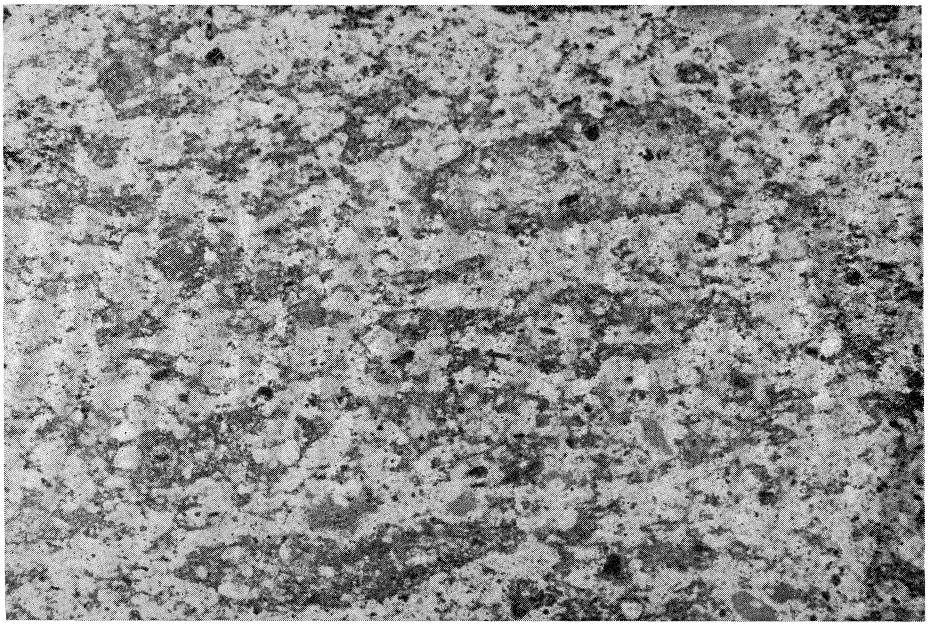
Explanation of PLATE V

Fig. A Polished surface of a hand specimen of welded pumice flow deposit. Grey flattened pumice lumps are embedded in light grey matrix. The hand specimen was collected at Shômyô-daki.

Fig. B Polished surface of a hand specimen of welded scoria flow deposit. Grey flattened scoria lumps are embedded in dark grey matrix. The hand specimen was collected at Matsuo Pass.

Pumice flows were erupted in the early stages of the second period and scoria flows in the later stages.

A



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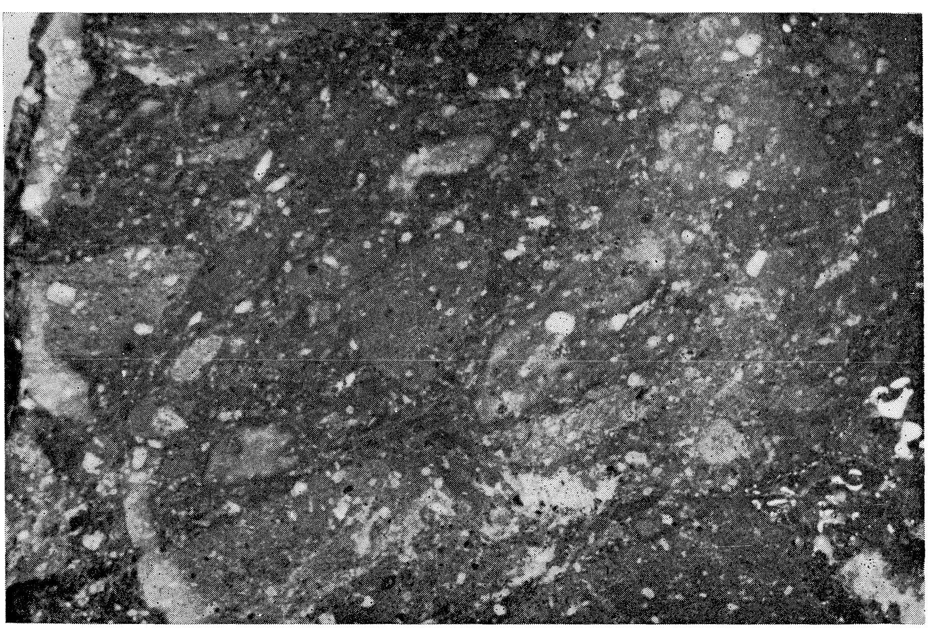
B



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