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Geologic Study on the Myoko Volcanoes, Central Japan
— Part 1. Stratigraphy —

By

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Abstract

The Myoko volcanoes* constructed from the Yakeyama, Myoko, Kurohime, Iizuna, Madarao, and Sadoyama volcanoes, are situated in the boundary area between Nagano and Niigata prefectures, central Japan. Most of the volcanoes are distributed along the anticlinal or synclinal axis of the basal Neogene strata. Except for the older volcanoes, Sadoyama and Madarao, the volcanic cones form a north-south trend, arranged at nearly equal intervals of about 8 km, and become younger in age toward the north. The migration of eruptive activity toward the north seems to be closely related with that of the movement of the underlying rock mass.

"MYOKO" are the typical stratovolcano, except for the dome-shaped Yakeyama volcano. In particular, three volcanoes, the Myoko, Kurohime, and Iizuna, are "double" stratovolcano provided with a small summit caldera. They are similar to each other in shape, but are different from each other in growth history, petrography, and other characteristics. The Myoko volcano consists of an older and a younger volcanoes, and furthermore, the younger one stratigraphically consists of four groups, which correspond petrographically to a basalt-andesite series, respectively. The Iizuna volcano consists of two groups of two basalt-andesite series, and the Kurohime volcano of a single group belonging to a basalt-andesite series.

The mode of eruption in each group tends to change as follows; eruption of scoria fall by basaltic magma→alternative eruption of lava and bomb by basic to intermediate andesite magma→eruption of a somewhat volumious pyroclastic flow associated with viscous lava flow by comparatively acidic hornblende andesite magma. Moreover, the volcanic mud flow deposit also tends to concentrate at the middle to upper part in each group.

I. Introduction and Acknowledgements

"MYOKO" are situated near the prefectural border between Nagano and Niigata, central Japan (Fig. 2). They are also situated at the northern part of the Fossa Magna, and the northern margin of the Fuji volcanic belt. They are isolated far from the volcanic front, and consist of six volcanoes. They seem to be some important features from the volcano-geologic view point.

The volcanoes distributed separately in Northeast Japan along the Sea of Japan

* The term of the Myoko volcanoes will be symbolized by "MYOKO" in this paper.

Fig. 1. Myoko volcano in early spring as seen from the eastern foot.

are characterized by hornblende andesite. The Myoko volcanoes are composed of many kinds of volcanic rocks, including hornblende andesite which is closely related to basalt and pyroxene andesite in occurrence. They are located to the east of the volcanoes of the so-called Japan Alps featured by biotite-hornblende andesite, and to the west of the volcanoes such as the Takayashiro, Kenashi, Naeba, and other volcanoes which hardly yield hornblende andesite. They are not so voluminous as the Fuji or Hakone volcanoes, although they are different from each other in size.

Many works are published concerning a single volcano or Japanese volcanoes as a whole. But much attention has not been paid to the mutual relation of volcanic rocks in many volcanoes crowded in a certain area, and also to the relation between such areas. Such kind of work is strongly required to relate the study of individual volcano to the whole. "MYOKO" are crowded in a limited area, and may be treated as one unit.

Four volcanoes of "MYOKO" that is Iizuna, Kurohime, Myoko, and Yakeyama, are arranged at nearly regular intervals from south to north, and the active center seems to migrate gradually to the north. The basement rocks of "MYOKO" are tilted to the east, eruptive materials of the volcanoes have flowed down

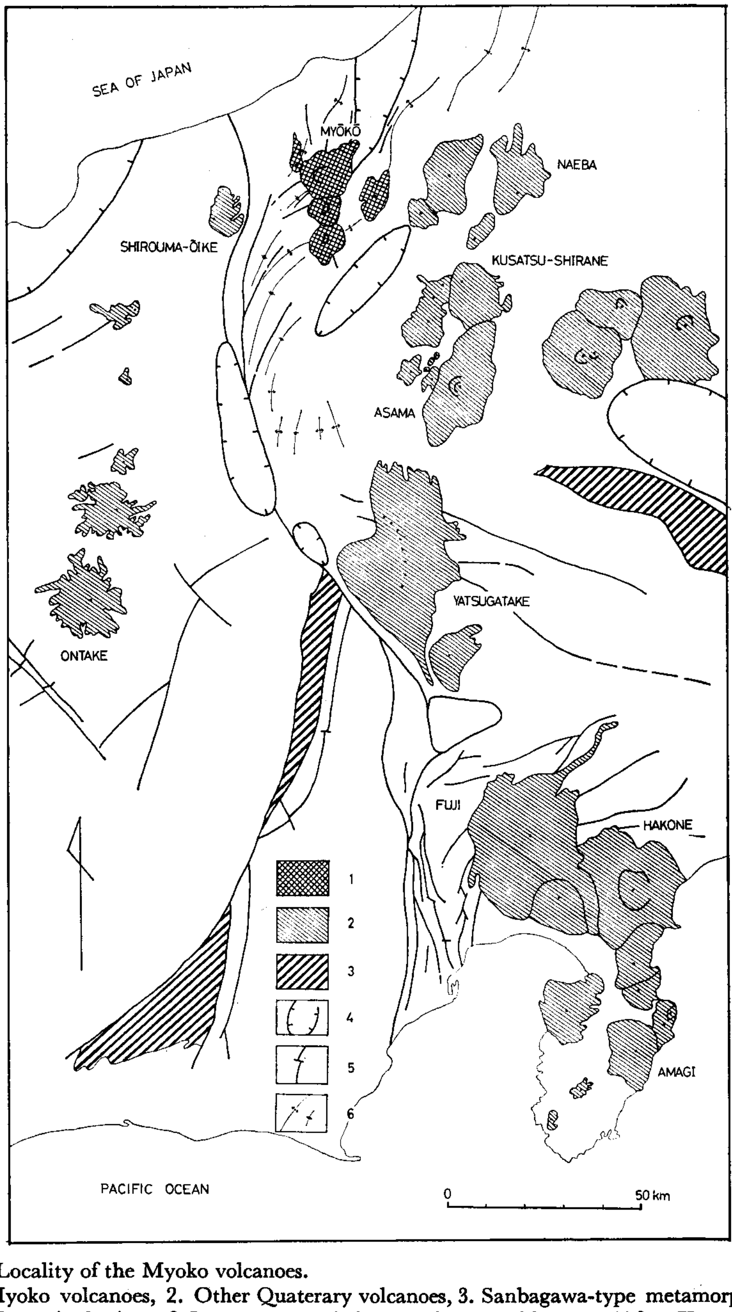

Fig. 2. Locality of the Myoko volcanoes.
1. Myoko volcanoes, 2. Other Quaterary volcanoes, 3. Sanbagawa-type metamorphic rocks, 4. Tectonic basins of Quaternary period, 5. Faults, 6. Fold axses. (After KAWACHI, 1972, partly modified)

to the east, and accordingly, the basement rocks crop out in the western part of the present area. In short, it is possible to confirm some relation between the arrangement of volcano and basement structure.

A Neogene volcanic association ranging from basalt to rhyolite in the northern part of the Fossa Magna, is observed, and its geotectonic situation is well established (KOBAYASHI, 1957). To relate "MYOKO" to the Neogene volcanic association is very significant in considering the genesis of volcanic rocks.

In order to satisfactorily combine both petrographical and stratigraphical aspects, the writer has tried, first of all, to establish the historical development of each volcano in "MYOKO" stratigraphically, and then to study the rocks of each volcano by means of microscopical observation and bulk chemical analysis petrographically.

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II. The Geologic situation of the Myoko Volcanoes.

The area of "MYOKO" corresponds geologically to the northern part of the

Fossa Magna (NAUMANN, 1885), the zone acrossing the Honshu arc from north to south and dividing the arc into Northeast and Southwest Japan. It has been formed throughout the so-called Green Tuff movements, that has started with faulting movement accompanied by intense volcanic activities in early Neogene age (MINATO *et al.*, 1965). The Fuji volcanic belt including "MYOKO" extends along the tectonic zone.

Table 1. Outline of the geohistory in the northern part of the Fossa Magna (compiled by using KOBAYASHI, 1957, 1968; Niigata prefecture, 1964). F: Formation.

Age		Nagano Prefecture			Niigata Prefecture
		Name of Strata	Event		Name of Strata
Quaternary	Holocene	Younger deposits	Formation of Myoko volcanoes and basins (Takada Plain, Nagano Basin)	Yakeyama volcano; Myoko volcano; Kurohime volcano	Younger deposits
Quaternary	Pleistocene	Younger deposits		Myoko volcano; Kurohime volcano; Iizuna volcano; Madarao volcano; Sadoyama volcano	Younger deposits
Quaternary	Pleistocene	Toyono F.	Formation of Omine surface; Crustal movement of Sarumaru phase	Iizuna volcano; Madarao volcano; Sadoyama volcano	Uonuma F.
Tertiary	Pliocene	Sarumaru F.	Activity of salic and mafic magmas		Tanihama F.
Tertiary	Pliocene	Shigarami F.	Activity of mafic to intermediate magma (Arakurayama pyroclastic rocks)		Nadachi F. Kawazume F.
Tertiary	Miocene	Ogawa F.	Activity of salic magma (Susobana tuff)		Nodani F.
Tertiary	Miocene	Aoki F.	Crustal movement of "Bessho phase" (Formation of Central upheaval zone. Intrusion of quartz diorite and porphyrite)		Nishiyama F.
Tertiary	Miocene	Bessho F.			Hiuchiyama F. Upper Hiuchiyama F. Middle
Tertiary	Miocene	Uchimura F.	Formation of "Green Tuff"		Hiuchiyama F. Lower

The structural development of the northern part of the Fossa Magna was summarized by KOBAYASHI (1957) as follows (Table 1). The area has been going through a series of characteristic igneous activity since the Miocene. In the early Miocene, submarine eruptions took place over the southern area. By the eruptions there was accumulated a thick series of lavas and pyroclastics of basalt, andesite, and rhyolite, which corresponds to the so-called Green Tuff. The strata including the volcanic rocks are called the Uchimura formation, attaining to 3,000–4,000 m in total thickness. Subsequently, during the Bessho stage in the middle Miocene, the Bessho formation characterized by black shale was deposited, and at the latest stage, an extent area of Ueda-Matsumoto (central upheval zone, IIJIMA, 1962) changed from subsidence to upheaval, accompanied with the intrusions of quartz diorite and porphyrite. As the result, the large depositional basin was divided into two, a western and an eastern basins, where the Aoki formation composed of sandstone, mudstone, and conglomerate was deposited. During the Ogawa stage in the late Miocene, a large amount of pyroclastics (pyroclastic flow and fall deposits) called the Susobana tuff were formed as the result of eruption of biotite rhyolitic magma in the border area between the western basin and central upheaval zone. Moreover, the Arakurayama pyroclastic rocks (TAKESHITA *et al.*, 1960) and Togakushi volcanic rocks (TAKESHITA, 1965) were piled up by activity of basic to intermediate magmas in the central part of the depositional basin at the Shigarami stage during Pliocene. The Shigarami formation consists of thick volcanic rocks (about 1,000 m) and sedimentary rocks, such as conglomerate, sandstone, and mudstone. The depositional basin migrated to the west stage by stage throughout these events.

The next volcanic activity was caused at the Sarumaru stage during Plio-Pleistocene. It is characterized by eruptions of lavas and pyroclostics of biotite rhyolite, and some of the pyroclastic deposits are welded pyroclastic flow deposits (TAKEUCHI *et al.*, 1965). Non-volcanic constituent of the Sarumaru formation is sandstone and conglomerate. After these volcanisms, probably in the middle Pleistocene, the activity of "MYOKO" started, accompanied with the subsidence of the Nagano basin and the Takada plain (Fig. 3).

The Neogene system in the area is characterized by the unique fold-fault structure which was almost built up untill the Plio-Pleistocene (KOBAYASHI, 1957, 1968). As shown in Fig. 3, the fold-fault structure strikes to the northeast in the area of "MYOKO". But it changes the direction gradually to north-south in the southern outside of this area, and converges to the Matsumoto basin. The structure seems to change the direction to north-south again in the northern outside of "MYOKO". The principal faults, most of which are generally crossing over the anticline or syncline with low angle, are depressed at the west side, and the overthrows become

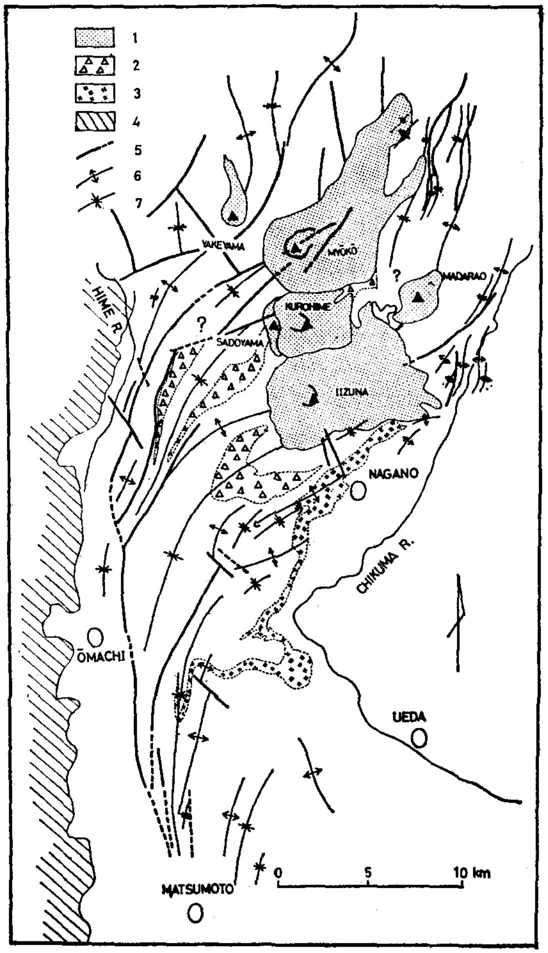

Fig. 3. Geologic structure of the basal Neogene strata in the northern part of the Fossa Magna (HAYATSU, 1972a).
1. Myoko volcanoes, 2. Vocanic rocks in the Shigarami formation (Arakurayama pyroclastic rocks and Togakushi volcanic rocks), 3. Susobana tuff, 4. Pre-Neogene strata, 5. Faults, 6. Anticlinal axes, 7. Synclinal axes. (Compiled by using the maps in YAGI et al, 1958; Geographical Society of Nagano Prefecture, 1962; Niigata Prefecture, 1962, 1964, 1966; TAKANO, 1969; HAYATSU, 1968.)

larger to the south (KOBAYASHI, 1957). At the east side of the Nakayama-Otari fault which is the most principal fault in the northern part of the Fossa Magna, the older strata appear gradually to the north, and at the west side of the fault the younger strata appear conversely to the north (HIMEKAWA RESEARCH GROUP, 1958).

A few short reports on the pre-Neogene strata of the present area have been published. According to SAITO (1968), the rhyolite masses distributed near Otari-mura along the Hime river, some of which are welded pyroclastic flow deposits, and showed K-Ar age of 58×10^6 Y.B.P. They cover the Palaeozoic and Mesozoic strata, and are covered with the Neogene strata discordantly at some localities. According to OKAMOTO (personal communication, 1972), the Omine ash flow deposits, which were erupted during the Sarumaru stage and widely distributed in the east side of Omachi, include much lithic fragments of granitic rocks. Such granitic rocks must be present under the Neogene strata in the west side of Otari-Nakayama fault, if the Omine ash flow deposits were erupted in that area. ISOMI and KAWADA (1968) estimated that the Joetsu zone (HAYAMA, 1966) and the oldest rocks in the Sado island correspond to the northern extension of the Hida marginal zone.

From the facts mentioned above, it may be presumed that the base of the Neogene strata in the area "MYOKO are constructed from the Palaeozoic and Mesozoic strata associated with igneous and metamorphic rocks.

"MYOKO" are built in a geologic district located between the central upheaval zone and mountain mass of the so-called Japan Alps. The upheval zone is composed of thick Green Tuff intruded by quartz diorite and porphyrite, the mountain mass is composed of the Palaeozoic and Mesozoic rocks, and on the other hand the present district mainly consists of Neogene thick sedimentary rocks. The district is bounded by two tectonic lines, namely the Matsumoto-Nagano tectonic line (HIRABAYASHI, 1968) and the Itogawa-Shizuoka tectonic line (YABE, 1918).

Although the stratigraphic correlation between Niigata and Nagano Prefectures is not satisfied up to present, SAITO (1968) reported that the Otari fault seems to extend far under the Myoko volcano to the northeast extension. HIRABAYASHI (1968) proposes that the Mt. Yakeyama–Mt. Hiuchiyama district is an upheaval zone, as compared with the central upheaval zone, and calls it the Otari upheaval zone. In the district of the Yakeyama volcano and northwest half of the Myoko volcano, there are distributed the strata corresponding to the Bessho and Ogawa formations. On the other hand, in the adjacent district including the Kurohime, Iizuna, Sadoyama, and Madarao volcanoes, the younger strata, such as the Shigarami, Sarumaru, and Toyono formations are widely distributed. The Neogene strata at the Myoko volcano and its neighbourhood are about 5,000 m thick, according to AKAHANE (personal communication, 1970). Four volcanoes, the Madarao, Iizuna, Myoko, and Yakeyama volcanoes, excepting the Sadoyama and Kurohime volcano, are formed on anticlinal or synclinal axis of the basement rocks (Fig. 3).

III. Stratigraphy of the Myoko Volcanoes

As already mentioned, "MYOKO" consist of the six volcanoes, namely the

Yakeyama, Myoko, Kurohime, Iizuna, Madarao, and Sadoyama volcano. Three of them, the Myoko, Kurohime, and Iizuna, are arranged from north to south at about 8 km intervals. The Yakeyama, a single active volcano of this area, is situated at about 8 km northwest of the main volcano of Myoko. The Madarao and

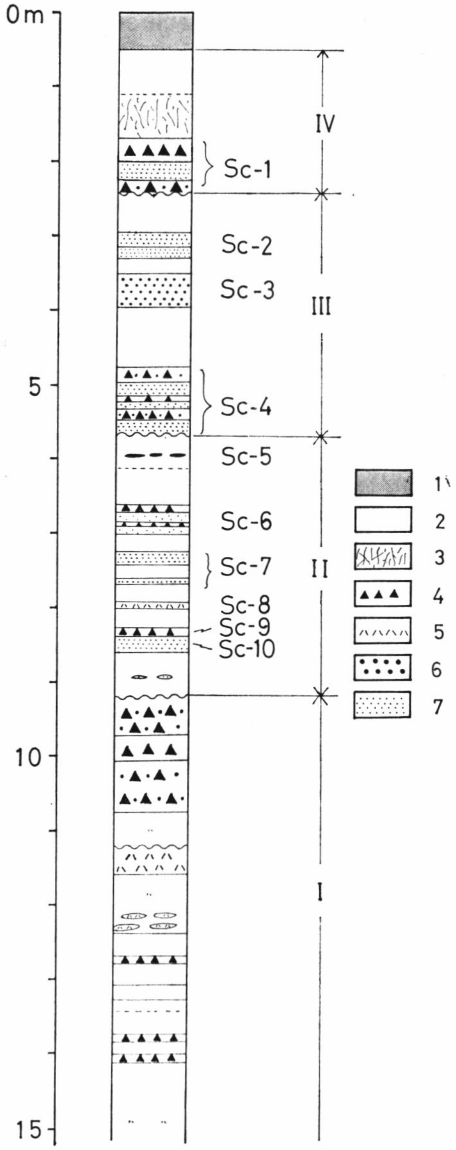

Fig. 4. Summarized standard colummar section of the loam in the area of the Myoko volcanoes. 1. Humus, 2. Loam (s. st.), 3. Cracky zone, 4. Scoria, 5. Pumice, 6. Lapilli, 7. Volcanic ash.

Sadoyama are the older volcanoes which lie on the west side and east side of the Kurohime, respectively.

"MYOKO" are the typical stratovolcano, except for the dome-shaped Yakeyama volcano. In particular, three volcanoes, the Myoko, Kurohime, and Iizuna, are the double stratovolcano which is provided with a small summit caldera. They are similar in shape, but are different from each other in growth history, age, mode of eruption and petrography.

Judged from such available data as stratigraphy of eruptives, degree of dissection, absolute age determination by ^{14}C method, and record of explosion (see later systematically), the order of activity of "MYOKO" are as follows: the Sadoyama, Madarao, Iizuna, Kurohime and Myoko, and Yakeyama volcano. The activities of Yakeyama volcano, which is the youngest and is still active, are recorded in history. The Iizuna volcano started its activity at the Toyono stage in the middle Pleistocene, judging from the stratigraphical occurrence of the eruptives at the foot (TAKEUCHI *et al.*, 1965), but the starting age of activity of the other volcanoes has not been known. The Sadoyama and Madarao are highly dissected in comparison with the others, and seem to be much older than the others.

Most parts of the pyroclastic fall deposits (called Loam) widely distributed at the eastern foot of "MYOKO" (TAKADA PLAIN RESEARCH GROUP, 1966) were also supplied from these volcanoes. They comprise four formations, designated as Loam IV, III, II, and I in descending order (Fig. 4). Their stratigraphy support the order of activity in age mentioned above. The details including the petrographical data will be published separately.

In the area of "MYOKO", some lacustrine or fluvial deposits are found besides the eruptives. They were generally formed at the later time of or after the volcano-building. The lake deposits, represented by the Sasagamine (TAKADA PLAIN RESEARCH GROUP, 1966), Furuma, Mure, Nojiri (TOYONO RESEARC HGROUP *et al.*, 1964), and Myoko caldera (HAYATSU, 1972 b) lake deposits, are scattered around volcanoes or within calderas. The river-terrace deposits are mainly distributed along the Seki and Torii rivers.

A. **Sadoyama volcano** (1,827.6 m high)

The Sadoyama volcano located in just west of the Kurohime volcano is a small stratovolcano. It is composed of lava and pyroclastics, some of which are pyroclastic flow deposits. The strata constructing the Sadoyama volcano are called the Sadoyama group as a whole. All rocks are hornblende andesites, and their mineral assemblage is rather uniform. Most of the eruptives are covered with those of the Kurohime volcano. The volcanic body is more dissected than the

Madarao volcano, and the primary form as a volcano is remarkably destroyed. The basement is the Shigarami formation, and the volcano is built on the east limb of the syncline. The highest contact point of the basement rocks with the Sadoyama volcano is about 1,400 m in altitude.

B. **Madarao volcano** (1,381.3 m high)

The Madarao volcano is a stratovolcano situated to the west of the Kurohime volcano. The volcanic body is much more dissected than the Iizuna volcano. Judging from this fact, it is much older than the latter. This is in accordance with the field evidence that some of the eruptives of the Madarao volcano underlie the mud flow and pyroclastic fall deposits from the Iizuna volcano. Most of the rocks are pyroxene andesite. The strata constructing the Madarao volcano are called the Madaro group as a whole. The Nashikubo alternation of sandstone and mudstone (YAGI *et al.*, 1958) and Oyakawa alternation of sandstone and conglomerate (YAGI *et al.*, 1958) which are correlated with the Sarumaru formation by TOMIZAWA (1970), seem to construct the basement of the Madarao. This volcano is formed on an anticlinal axis.

C. **Iizuna volcano** (1,917.4 m high)

The first study on the geology of the Iizuna volcano was carried out by YAMASAKI (1895). He briefly described the topography and rocks as a part of his study on "MYOKO" and concluded that the volcano is a stratovolcano. Thereafter, four chemical analyses of rocks of the Iizuna volcano were reported by YAMADA (1934) in his petrographical report on the present volcano. The outlines of the growth history and eruptives were made clear mainly by YAGI *et al.*, (1958). They classified the eruptives into somma lava, central cone lava, and parasitic cone lava, and subdivided each lava. This work was followed by TAKEUCHI (in TOMIZAWA, 1970). SAWAMURA (1960) published a stratigraphical study on the southwestern area of this volcano. According to him, the summit caldera is a sort of explosion caldera. The older volcanic rocks underlying the Iizuna volcano were studied in detail, and called the Palaeo-Iizuna volcanic rocks by TAKEUCHI *et al.*, (1965). SUZUKI (1965, 1966), on the basis of his geomorphological and stratigraphical studies, concluded the subsidence of the Iizuna volcanic cone, due to the load of the volcanic cone. Other geological studies on this volcano were also carried by TAKEUCHI (1954) and YAGI *et al.*, (1955).

1. Geomorphology

The Iizuna volcano is a stratovolcano whose summit is called Mt. Iizunayama

(1,917.4 m high). The summit caldera is a horse's hoof in shape, with longer diameter of about 2,500 m, and shorter diameter of about 2,000 m. Near the northwestern rim of the caldera, a group of lava domes, namely Kenashiyama, Nakanomine, Takadekki, and Tengudake, is arranged in the SW-NE direction, and another lava dome (1,340 m high ridge) is situated at the NE extension. A Peak Kasayama located on the midslope of the somma, also seems to be a lava dome. It may be recognized topographically that the surface of the northern to northwestern midslope of the somma is cut and displaced by several faults running to the SW-NE direction.

The area between the volcanic cone and Togakushi mountain mass is occupied by marsh about 900 m high, where many small ponds are scattered. Some previous workers have paid special interest to the fact that about 600 m high surface of the southwestern to southeastern foot inclines slightly to the center of the volcanic cone. The skirt of this volcano spreads gently to the east. The cone is much more dissected than those of the Myoko and Kurohime volcanoes, and the rim of caldera has indistinct outline.

2. Geology of the basement rocks

The many geologic studies on the basement rocks around the Iizuna volcano were carried out by TOMIZAWA (1953), SAITO (1955), YAGI *et al.* (1958), TAKEUCHI *et al.* (1965), TAKESHITA (1965), TOMIZAWA (1970) and others. The following descriptions are mainly based on the previous works.

The strata which consist of sandstone and conglomerate beloging to the Ogawa formation, are distributed at the western side of the Iizuna volcano. The strata form an anticlinal structure called the Nishikyo-Kamikuskawa anticline (KOBAYASHI, 1957). YAGI *et al.* (1958) assumed that the anticline must extend far under the Iizuna volcanic cone and be connected with the Tomikura anticline running along the spine of the Sekita mountains. At the western side of the anticline, the Shigarami formation constructed mainly of the Togakushi volcanic rocks (TAKESHITA, 1965) is distributed with the general strike of N 40°–45°E and dip of 20°–30° NE.

The basement rocks of the eastern side of the anticline, namely of southern area of the volcano, are characterized by the Sarumaru formation consisting of sandstone and conglomerate intercalated with some acidic tuff beds, and also by the underling Arakurayama pyroclastic rocks of about 1,000 m in thickness (TAKESHITA *et al.*, 1965). The strata form as a whole a synclinal structure of NE-SW direction. The volcanic rocks included in the upper part of the Sarumaru formation in the area are distinguished from the eruptive materials of the Iizuna volcano and called the Palaeo-Iizuna volcanic rocks by TAKEUCHI *et al.*, (1965). The basement rocks in the eastern area of this cone have been left unknown because of the cover of thick volcanic materials.

Many fragments of unmentamorphosed siltstone are included as lithic fragments in a pumice fall layer erupted from the Iizuna volcano. The fragments have most probably been introduced into the magma from the wall of the upper part of the vent just at the explosion. Therefore, the siltstone must be distributed as the basement rocks of the Iizuna volcano.

3. Geology of the Iizuna volcano

As shown in Table 2, the growth history of the Iizuna volcano is divided into the Ist and IInd stages, and the latter is further subdivided into three stages, the stratovolcano, caldera, and lava dome stages. The characteristic features of the eruptives in each stage are described as follows. All eruptives from the Iizuna volcano are covered by those from the Kurohime volcano as far as observed in the field. The geologic map of the Iizuna volcano is shown in Fig. 5.

a). The eruptives of the Ist stage (Tonosawa group).

The following three strata belong to the eruptives of the Ist stage. Namely, the Tonosawa lavas construct a ridge at the right side of the Tonosawa valley at the northeastern foot of the cone, the Menozawa lavas are distributed along the Menozawa valley in the caldera and at the lower part of the Peak Menoyama, and the Katsurasawa lava is exposed near the Third Power Plant along the Toriigawa river. The strata consist of the alternation of lavas and pyroclastics although their detailed features are unknown because of their limited exposure. Judged from the degree of dissection of the Katsurasawa and Tonosawa lavas, and also from the structure of the Menozawa lavas with gentler inclination than the overlying IInd stage eruptives, it is assumed that the deposits belonging to the Ist stage are discordantly covered with those of the IInd stage.

The rocks are pyroxene andesites and pyroxene-hornblende andesites. As far as being observed, the eruptives incline to the same direction as the younger eruptives at each point. Therefore, it is reasonably concluded that a stratovolcano has been built up throughout the activity of the Ist stage, and its eruption center has been located close to that of the IInd stage.

b). The eruptives of the IInd stage (Iizuna group).

i) The stratovolcano stage.

The eruptives belonging to the earlier substage of the stratovolcano stage are represented by the following ones the Kurotaki pyroclastic rocks corresponding to lower part of the Kurotaki lava named by Takeuchi in Tomizawa (1970), being exposed along a valley on the southeastern slope of the cone; the Nishizawa lavas distributed along valleys on the southwestern slope; the Menoyama lava constructing

Table 2. Stratigraphic succession of the Iizuna volcano. Symbols are same as those in Table 4.

				Name of strata: Eruptives	Name of strata: Others	Rocks
Pleistocene	II stage	Lava dome stage		Kenashiyama L. Takadekki L. Tengudake L. 1340m-rige L. Nakanomine L. Kasayama L.	Lake deposits Mud flow deposits	ho andesite ↑
Pleistocene	II stage	Caldera stage			Mud flow deposits	↑
Pleistocene	II stage	Stratovolcano stage	Later	Morozawa P.f. Iizunayama L.		ho-px andesite ↑ px andesite ↑
Pleistocene	II stage	Stratovolcano stage	Earlier	Menoyama L. Kurotaki P.r Nishizawa L. 1017m-rige S. Toriigawa L.		px-ol basalt
Pleistocene	I stage			Katsurasawa L. Tonosawa L. Menozawa L.		ho andesite px andesite
Pleistocene / Plio-cene	Basement			Sarumaru F. Shigarami F. (Arakurayama P.r.)		

the Peak Menoyama; the Scoria fall deposit distributed at 1,017.5 m high ridge in the south of Reisenji; and the Toriigawa lava corresponding to the Toriigawa basalt

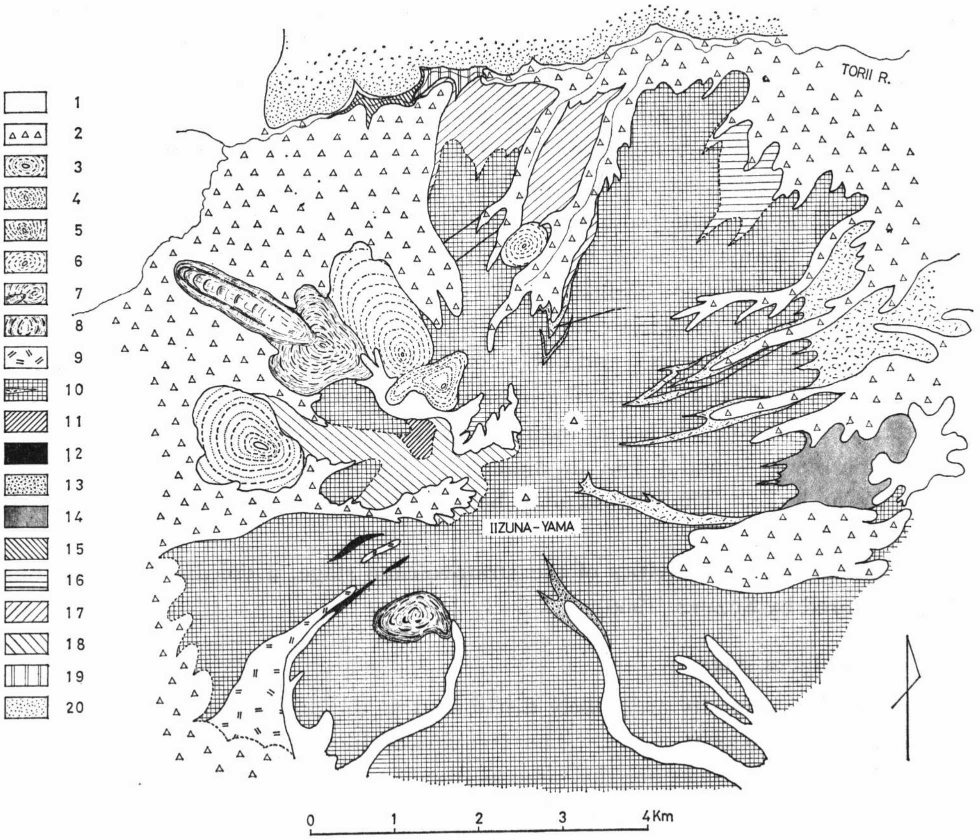

Fig. 5. Geologic map of the Iizuna volcano.
1. Alluvial deposit, 2. Mud flow deposit, 3. Kenashiyama lava, 4. Tengudake lava, 5. Takadekki lava, 6. 1340m-ridge lava, 7. Nakanomine lava, 8. Kasayama lava, 9. Morozawa pyroclastic flow deposit, 10. Iizunayama lava, 11. Menoyama lava, 12. Nishizawa lava, 13. Kurotaki pyroclastics, 14. 1017 m-ridge scoria deposit, 15. Toriigawa lava, 16. Tonosawa lava, 17. Katsurasawa lava, 18. Menozawa lava, 19. Basement rocks, 20. Kurohime volcanic rocks.

named by YAGI *et al.* (1958). All the eruptives of this earlier substage are as a whole called the Iizuna basalts in the present paper. They are composed mainly of thick scoria deposits, accompanied by lava flows. For example, the Kurotaki pyroclastic rocks are constructed from thick scoria deposits (10 m+) which are consisting of numberles fall units, and some thin lava flows (several centimeter to about 1 m) intercalated at the upper most horizon. Most rocks of the earlier substage are dark gray augite-olivine basalt.

The later substage eruptives in this stage are represented by the Iizuna lavas having the most extensive distribution in this volcano. The Iizuna lavas consist of lavas and pyroclastics, some of which are pyroclastic flow deposits, and cover directly the Iizuna basalts at several points. Both of lavas and pyroclastics are olivine bearing pyroxene andesites, and are rather uniform in lithofacies, in spite of large volume and many fall and flow units. The eruptives distributed limitedly on southeastern and southwestern slopes of the somma may be distinguished from the Iizuna lavas in having somewhat different lithofacies. But they are tentatively treated as the Iizuna lavas on the present geologic map, because their distribution and stratigraphy have not been studied in detail.

The Morozawa pyroclastic flow deposits, being partly distributed on the southwestern slope of the volcano, and covering the Iizuna lavas, is the latest eruptives of this stage. The deposit consists of grayish white, subangular blocks including breadcrust bombs and volcanic ash as matrix, and is very poorly sorted. The maximum size of the blocks is about 1 m in diameter. The essential blocks are hornblende-pyroxene andesite. The deposit may belong to the intermediate type defined by ARAMAKI (1957).

Throughout the activities of the stratovolcano stage, a volcano has been built up, as figured by SUZUKI (1966).

ii). The caldera stage.

Mud flow deposits are widely distributed at the northwestern foot of the volcano, and very poorly sorted. The constituent blocks are generally angular to subangular. The blocks are the same as fragments of lavas and pyroclastics which construct the present somma, and the fragments of the eruptives of the lava dome stage have not been found in the deposit. As thought by SAWAMURA (1960), the facts mentioned above suggest that the mud flow deposit was formed by landslide of the northwestern part of the stratovolcanic cone by explosion near the summit. Other detailed features of the deposit are unknown because of poor exposure.

iii). The eruptives of the lava dome stage.

The latest activity of the IInd stage, started at the western half of the volcano, has built a group of lava domes named the Kenashiyama, Nakanomine, Takadekki, Tengudake, 1,340 m high ridge, and Kasayama. All lava domes, except for the Kasayama, are arranged on a straight NE-SW line.

The Nakanomine lava constructs the dome of Nakanomine and a tongue-shaped ridge extending to the west from the western mid-slope of the dome. The ridge retains almost perfectly the primary landform of a lava which flowed down from the dome, and a ditch of the concavo collapse is observed on the surface of the flow.

The rocks of this lava dome stage are hornblende andesite, except for the Nakanomine and Kasayama lavas consisting of pyroxene andesite.

D. **Kurohime volcano** (2,053.4 m high)

The first report on this volcano appeared in 1895 (YAMASAKI). After that, YAMADA (1934) published a stratigraphical and petrographical reports on the volcano. Lately somewhat detailed geological study was carried out by YAGI *et al.* (1958). The general features of the Kurohime have become clearer by their studies, but the exact stratigraphy and correlation have to be waited in the further studies.

1. Geomorphology

The Kurohime volcano is a typical double stratovolcano. Its highest point named Kurohimeyama (2,053.4 m) is situated at the southeastern rim of a caldera, and rises 1,250 m above the comparatively flat eastern surface. The upper part of the somma slope has a steep inclination of 30∼40 degrees. The caldera is shaped as a horse's hoof with the longer diameter of about 2,000 m in the north-south direction, and the shorter diameter of about 1,500 m in the east-west direction. Within the caldera there is a central cone called Shokurohime which rises at 220 m above the caldera bottom. The part between the somma and central cone is occupied by the carpet of striped bambooe-bush and by some ponds.

The topographically important features of the Kurohime volcano are the following three: a). The primary surface of the volcanic body is generally well preserved, and no deep radial drainage has been formed as yet.
b). The primary forms built by some lava flows are very well preserved, and have very smooth surface. c). Some gently projecting heights, which were regarded as parasitic cones by the previous workers, are observed on the eastern to northern mid-slope of the somma, and such heights, named Hesoyama, Yamakuwayama, unnamed high ridge of 1,531 m, and Ushibuseyama are not harmonized with the general slope of the somma.

2. Geology of the basement rocks

The Arakurayama pyroclastic rocks (TAKESHITA *et al.*, 1960), Togakushi volcanic rocks (TAKESHITA, 1965), and Machi alternation of sandstone and mudstone belong to the Shigarami formation (TOMIZAWA, 1970). They are distributed at the Togakushi mountain mass in the southwest of the Kurohime volcano. The former two rocks are characterized by thick pyroclastics (about 1,000 m in thickness) intercalating thin lava flows (MINAMI, 1968; personal comunication). The volcanic rocks were produced throughout the submarine volcanism during late Miocene during late Miocene and early Pliocene (TAKESHITA *et al.*, 1960). The Shigarami formation has a general strike of N45°E and a dip of 20° NE. Two peaks, Masugatayama and Chohanyama in the northeast of the volcano, are constructed from pyroclastics and lavas which may be correlated with the Togakushi volcanic rocks or the Arakurayama pyroclastic rocks. The rocks are sap-greenish gray, altered pyroxene andesite. The Sadoyama volcanic rocks building the Sadoyama volcano are also exposed near Takasawa at the northeastern foot of the Kurohime.

Judged from the above-mentioned facts and other geological data in the surrounding area (YAGI *et al.*, 1958; TOMIZAWA, 1970; HAYATSU, 1963), the Kurohime volcano seems to be undoubtedly built on the Shigarami formation and the overlying Sadoyama volcanic rocks. The former as the basement rocks may be composed of thick pyroclastic rocks, having the general structure of N45°E strike and about 20° NE dip. The basement rocks may be, as a whole, not remarkably cut and displaced by any significant faults in contrast with those under the Iizuna and Myoko volcanoes.

3. Geology of the Kurohime volcano

As shown in Table 3, the growth history of the Kurohime volcano is divided into the following four stages, the older stratovolcano (1st), younger stratovolcano (2nd), caldera (3rd), and central cone (4th) stage. The younger stratovolcano stage is further divided into the earlier and later substages. The strata constructing the Kurohime volcano are called the Kurohime group as a whole. The detailed characteristic features and stratigraphy of each eruptives were already reported by HAYATSU (1972a), so that the outline of each stage is buiefly described in the present paper. As far as observed in the field, eruptive materials from the Kurohime are covered with those from the Myoko along the Seki river. The geologic map of the Kurohime volcano is shown in Fig. 6.

a). The eruptives of the older stratovolcano stage

The eruptives of the older stratovolcano stage are alternately piled up by lavas and pyroclastics. They are basalt and basic andesite, dark or pale purplish gray, and very compact. They cover directly the Sadoyama volcanic rocks, and are covered with the eruptives of the younger stratovolcano stage.

The eruptives of the older stratovolcano stage are observed at the gently projecting heights named Yamakuwayama and Hesoyama. The similar heights, such as 1,531 m high ridge and Ushibuseyama, are also located on the mid-slope. The former two and the latter two seem to be common in structure, although the latter two can not be confirmed because of the overlying younger eruptives.

The projecting heights are distributed semicircularly on the eastern to northeastern mid-slope. All eruptives of the older stratovolcano stage incline to the same direction as the overlying younger eruptives at each outcrop, and the former show a little steeper dip than the latter. Judging from the facts, it may be concluded that the older stratovolcano was of the almost same scale as the younger one, and the eruption center of the older stratovolcano was located at the almost same point as that of the younger one or slightly northeastward.

Table 3. Stratigraphic succession of the Kurohime volcano. Symbols are same as those in Table 4.

			Name of strata		Rocks
			Eruptives	Others	
Pleistocene	Central cone stage		Shokurohime L. Sutakayama L.	Komazume M.f.	ho-px andesite
Pleistocene	Caldera stage			Nabewarigawa M.f.	↑
Pleistocene	Younger stratovolcano stage	Later	Nagamizu L. Kalasawa L. 1531m-rige L. Mikaerizaka L. Nagahara L. Nanamagarizaka L. Sekigawa L. Ichirozawa L.		ho-px andesite px andesite
Pleistocene	Younger stratovolcano stage	Earlier	Furuike L. Ushibuseyama L. Yunoirigawa L. Komagataki L. Takasawa P.f. Naenataki L.		↑ px andesite
Pleistocene	Olderstrato volcano stage		Hesoyama L. Yamakuwayama L.		↑ ol-px basalt
Pleistocene	Basement		Sadoyama G.		
Pliocene	Basement		Shigarami F.		

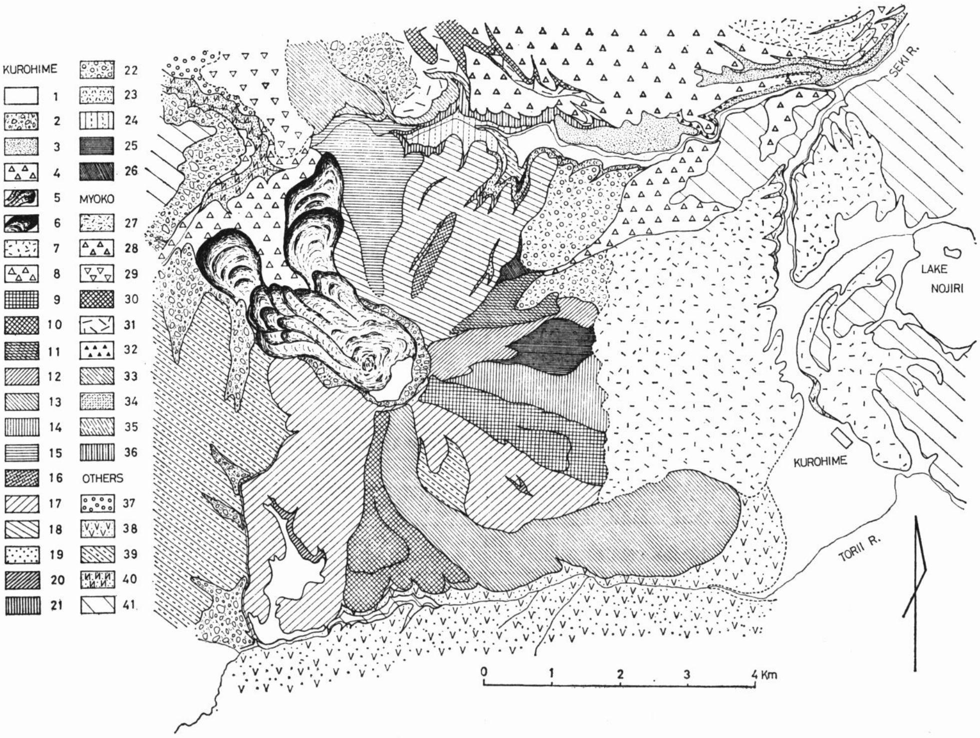

Fig. 6. Geologic map of the Kurohime volcano (HAYATSU, 1972a).
1. Alluvium, 2. Talus or alluvial fan deposits, 3. Lower terrace gravel, 4. Komazume mud flow deposit, 5. Shokurohime lava, 6. Sutakayama lava, 7. Loam IV (Nakago loam), 8. Nabewarigawa mud flow deposit, 9. Nagamizu lava, 10. Karasawa lava, 11. 1531m-ridge lava, 12. Mikaerizaka lava, 13. Nagahara lava, 14. Nanamagarizaka lava, 15. Sekigawa lava, 16. Ichirozawa lava, 17. Furuike lava, 18. Ushibuseyama lava, 19. Scoria fall deposit associated with the Ushibuseyama lava, 20. Yunoirigawa lava, 21. Komagataki lava, 22. Takasawa pyroclastic fall deposit, 23. Takasawa pyroclastic flow deposit, 24. Naenataki lava, 25. Hesoyama lava, 26. Yamakuwayama lava, 27. Akakura pyroclastic flow deposit, 28. Suginosawa mud flow deposit, 29. Taguchi mud flow deposit, 30. Nishikawasani lava, 31. Shibutamigawa pyroclastic flow deposit, 32. Tagiri mud flow deposit, 33. Ikenomine lava, 34. Shiratagirigawa pyroclastic flow deposit, 35. Sanbongi lava, 36. Gohachigi lava, 37. Sasagamine lake deposit, 38. Iizuna volcanic rocks, 39. Sadoyama group, 40. Hyosawagawa pyroclastic rocks, 41. Basement rocks.

b). The eruptives of the younger stratovolcano stage

The younger stratovolcano has been built on the dissected older one. It is divided by long pause of activity into the earlier and later substages. The eruptives of both substages distinctly differ from each other in quality and quantity as will be stated in the following.

(i) The earlier substage.

The eruptives of the earlier substage consist of many thick lava flows and small amount of intercalated pyroclastics. The scoria fall and pyroclastic flow deposits are also associated. The volume and distribution of unit eruptives shown in the geologic map (Fig. 6) are overwhelmingly predominant in the earlier substage than in the later substage. The total volume is also greater in the earlier substage than in the later substage. The distrubution of the eruptives and basement rocks shows that many lavas flowed down to the northern and eastern foot of the cone. The rocks of the earlier substage are augite-hypersthene andesite except for the Takasawa pyroclastic flow and fall deposits.

Almost part of the younger stratovolcanic cone was formed throughout the activity of the earlier substage. Thereafter, the volcanic activity stopped for a while, and some radial valleys were carved on the surface of the cone, especially on the eastern slope.

(ii) The later substage.

The activity of the later substage is characterized mainly by the effusion of lava flows, and subordinately by the ejection of pyroclastics. The lavas with relatively high fluidity flowed down along radial valleys carved the eruptives of the earlier substage. The primary landforms of lava flows are well preserved, and their flow fronts generally show the small plateau-like form.

The pyroclastic deposits are very small in amount in contrast to those of the earlier substage. But it is noteworthy that the essential lapilli fall deposit consisting of quartz-phenocryst bearing hornblende andesite is widely distributed at the eastern foot of the volcano. This lapilli bed included in Loam III (see Fig. 4) covers the Nagahara and Nagamizu lavas. The eruptives of this substage are more variable in lithofacies. Most of the rocks are augite-hypersthene andesite and hornblende-pyroxene andesite. The Sekigawa lava of this substage underlies the Sanbongi lava of the Myoko volcano.

A stratovolcanic cone called the younger stratovolcano was built on the older one throughout a series of activities of the earlier and later substages. It should have been 2,400 m to 2,500 m high at that time.

c). The caldera stage

A caldera with 2.0×1.5 km in diameters has been formed at the summit of the younger stratovolcano. A thick mud flow deposit, the Nabewarigawa, is distributed at the northwestern foot. This deposit consists of the fragments of the eruptives constructing the somma, and is covered by the eruptives of the central cone stage. The rock facies resembles closely to that of the mud flow deposit formed by the explosion of the Bandai volcano in 1888 (SEKIYA *et al.*, 1890). Judged from this facts, it is safely concluded that the mud flow deposit was formed by a large scale landslide of the summit part of the younger stratovolcano as in the case of the explosion observed at the Bandai volcano. This conclusion is also supported by the fact that the volume of the mud flow deposit (0.12 km^3) is nearly harmonized with the estimated volume of the summit part lost by the landslide.

d) The eruptives of the central cone stage

The next activity began in the caldera. The Sutakayama lava which erupted first overflowed the northwestern rim of the caldera, and flowed down to the northwest. At flow fronts 2.3 to 2.5 km apart from the crater, each flow formed the small plateaus about 750 m in width. The Shokurohime lava, the latest eruptives in the Kurohime volcano, is the second eruptives of this stage. The dome-shaped Shokurohimeyama peak was built by this lava within the caldera. The primary small landforms of this lava flow are very well preserved. Therefore, it is topographically recognized that some flows of the Shokurohimeyama lava, having about 200 to 300 m in width, and about 1.5 to 2.0 km in length, flowed down to the northwest.

It is one of the characteristic features in the Kurohime volcano that the effusion of the lava flows with relatively higher fluidity were repeated throughout the building of the central cone. The rocks of this stage are hornblende-olivine bearing pyroxene andesite.

No fault cutting the eruptives of the Kurohime volcano has been found in field. This corresponds well to the fact that the structure of the basement rocks beneath the volcano is presumed to be simple. Neither hot spring nor fumarole is seen on the Kurohime volcano and in its surrounding area.

E. **Myoko volcano** (2,445.9 m high)

The geologic works on the Myoko volcano have been published most among all volcanoes belonging to "MYOKO". The first account of the geology of the Myoko was published by YAMASAKI (1895). The earliest chemical work on the rocks of the volcano was done by SUZUKI (1961). YAMASAKI *et al.* (1961) studied the pyroclastic flow deposit of the central cone stage. TAKANO (1969) discussed the tilting of the volcano from the point of the geomorphology. Since 1968, the Myoko volcano has been investigated by the MYOKO VOLCANO RESEARCH GROUP (1969). Other works were done by Yagi (1940), SUGIYAMA (1955), MURAI (1960), KUNO (1962), EARTH SCIENCE CLUB of ARAI HIGH SCHOOL (1965), and TAKADA PLAIN RESEARCH GROUP (1966).

1. Geomorphology

The Myoko is a sort of double stratovolcano consisting of a large central cone and somma. The somma is constructed from the Peak Akakurayama (2,141.1 m), Mitaharayama (2,340 m), Okurayama (2,172.1 m), Kannayama (1,909 m) and Maeyama (1,935 m), and is characterized mainly by a extensively wide gentle-sloped skirt, especially at the east side, in contrast to that of the Kurohime. The eastern part of the somma is largely dissected and cut by several deep valleys, but the western part is well preserved. Across the middle of the eastern slope runs the Maruyama fault named by SUGIYAMA (1955).

At the center of the cone there is a caldera, about 2,800 m longer diameter in the north-south direction and about 1,900 m shorter diameter in the east-west direction. The eastern rim of the caldera is traversed by two canyons, Kitajigokudani and Minamijigokudani. Within the caldera there is a steep-sided central cone (2,445.9 m) with a craggy surface, called Myokosan or Shinyama. The central cone has the bottom diameter of about 1,400 m × 1,800 m and the height of about 400 m above the caldera bottom.

At the eastern side of the Myoko, the Nakago basin (HAYATSU, 1972a), the graben-like depression with about 7~10 km width, extends to NEN-SWS direction. The basin is coupled with the Takada Plain. The mountains of Nishikubiki-gun at the western side and the Sekita Mountains at the eastern side run in parallel with the basin. The Myoko is built up in the border area between the Nakago basin and western mountains.

2. Geology of the basement rocks

The geology of the basement rocks was summarized by TAKANO (1969) and MYOKO RESEARCH GROUP (1969). The Hiuchiyama formation constructing Mt. Hiuchiyama is distributed in the western area of the Myoko volcano (NANBAYAMA GROUP, 1955–1956; TAKADA GROUP, 1956; UTASHIRO, 1956). It consists of the alternation of black sandstone or shale and sandstone, and is intruded by sills and dykes which are mainly composed of hornblende porphyrite and rarely diabase. NISHIDA *et al.*, (1966) reported that the lower part of the Hiuchiyama formation characterized by including the Green Tuff-like tuff breccia may be correlated to the Uchimura formation in Nagano prefecture, and that other main parts of the Hiuchiyama formation are correlated with the Bessho formation.

Along the Seki river from Saruhashi to Taguchi at the western foot of the Myoko, two different strata are distributed. One is composed mainly of sandstone and pumice tuff, and rarely interbeded mudstone and conglomerate. The other is chiefly characterized by thick tuff breccia, and intercalated with mudstone, sandtone, tuff and conglomerate. MORISHIMA (1941) correlated these two with the Oguni formation in the oil field of Niigata prefecture. SAITO (1961, 1962, 1963) assumed that the former of two strata, named the Okawa formation by him, and the latter, named the Yoshiki formation, may belong to the upper Pliocene and lower Pleistocene Series, respectively.

The survey of the basement rocks is limited to the area mentioned above because of the overlying thick eruptives from the Myoko volcano. Within the volcanic body, the basement rocks are exposed at two points, that is, near the Sotaki waterfall (1,200 m in altitude) and Tsubamegawara (1,000 m in altitude) along the Otagirigawa river. The former consists of bluish gray siltstone and sandstone, and the latter is composed of the alternation of black shale and sandstone, and interbeded with biotite rhyolite pumice tuff. The latter is further intruded by dyke of augite andesite, and shows N23°E strike and 88°SE dip. It is correlated to the Shiiya formation by SUGIYAMA (1955). The common occurrences of *Sagarites* seem to support SUGIYAMA's correlation. The alternation of bluish gray siltstone and sandstone, exposed at the Yokoneyama on northeastern foot of the Myoko, is correlated with the Nishiyama formation by the MYOKO VOLCANO RESEARCH GROUP (1969). It shows N 35°–45°E strike and 15–20°NW dip. The data of three deep wells near Nihongi show the presense of shale, sandstone, and altered andesite, probably belonging to the Neogene, at the depth of 91 m, 118 m, and 158 m, respectively (MYOKO VOLCANO RESEARCH GROUP, 1969).

From the structural view-point of the basement rocks, the Myoko volcano is situated in the area between the Yakeyama anticline and Tomikura anticline (SAITO, 1961, 1962, 1963). In the southwestern area of the Myoko, a synclinal axis stretches from the northeast to the southwest (HAYATSU, 1968; TAKANO, 1969), and seems to extend far beneath the Myoko volcano to the northeast. As presumed in Fig. 3, the basement rocks under the Myoko volcano are cut and displaced by several faults. All small masses of the basement rocks which found on the volcanic body are arranged along the SW-NE faults. They are different from each other in dip, and each mass itself is cut and displaced by several small faults. Judged from the occurrence mentioned above, the basement rocks have been dragged by faulting and are separately distributed. SAITO (1968) reported that the Otari fault, one of the most representative faults in the northern part of the Fossa Magna, may extend far beneath the Myoko volcano.

3. Geology of the Myoko volcano

The names of the eruptives and their stratigraphy in the present paper are used after HAYATSU (1972b), but a new division of the group is proposed as follows. The "formation" in HAYATSU (1974) is revised to the "group in this paper. The Myoko volcano in the sense of HAYATSU (1972b) is divided into the older Myoko volcano and the yonger Myoko volcano or the Myoko volcano in the strict sence, and the latter is further divided into four stages, as shown in Table 4. The geologic map of the Myoko volcano is shown in Fig. 7.

Table 4. Stratigraphic succession of the Myoko volcano.
L. Lava, Ls. Lavas, P.f. Pyroclastic flow deposit, P.r. Pyroclastic rock, S. Scoria, deposit, S.f. Scoria fall deposit, M.f. Mud flow deposit, E. Explosion breccia, Lk. Lake deposit, G. Group, ho. Hornblende, px. Pyroxene, ol. Olivine. The stratigraphy in the Kannayama group has been established only within each brace.

				Name of strata			Rocks
				Eruptives		Others	
Holocene	Myoko volcano	IV stage	Central cone stage	Otagirigawa P.f. Tsubame L. Myokosan L. Akakura P.f. Myokosan P.r.	Myokosan G.	Chosukeike Lk. Tanegaike E. Suginosawa M.f.	ho andesite (dacite) px andesite ↑
Pleistocene	Myoko volcano	IV stage	Caldera stage		Myokosan G.	Taguchi M.f. Yashirogawa M.f. Sekigawa M.f. Caldera Lk.	|
Pleistocene	Myoko volcano	IV stage	Strato volcano stage	Nishikawadani L. Nishikawadani S.	Myokosan G.		px-ol basalt
Pleistocene	Myoko volcano	III stage		Shibutamigawa P.f. Mitaharayama Ls. Kanbazawa S.f.	Mitahara-yama G.	Nihongi M.f. (Sasagamine Lk.)	ho andesite (↑dacite) px andesite ↑ px-ol basalt ↑ ol-px basalt
Pleistocene	Myoko volcano	II stage		{ Katagaigawa P.f. Kannayama L. } Umagatazawa L.(upper) Umagatazawa L.(lower) { Shiratagirigawa P.f. Kaname L. Akakurayama Ls. } { Otaniuchi L. Makuiwa L. Kotaki L. }	Kannayama G.	Tagiri M.f. (Sasagamine Lk.)	ho andesite (dacite) ↑ px andesite ↑ px-ol basalt
Pleistocene	Myoko volcano	I stage		Osawa L. Maruyama L. Shirasawa P.f. Seki Ls. Byobuiwa Ls.	Maruyama G.		ho andesite px andesite
Pleistocene	Older Myoko volcano			Jigokudani Ls.	Jigokudani G.		px andesite px-ol basalt
Miocene	Basement					Nishihiyama F. Shiiya F. Hiuchiyama F.	

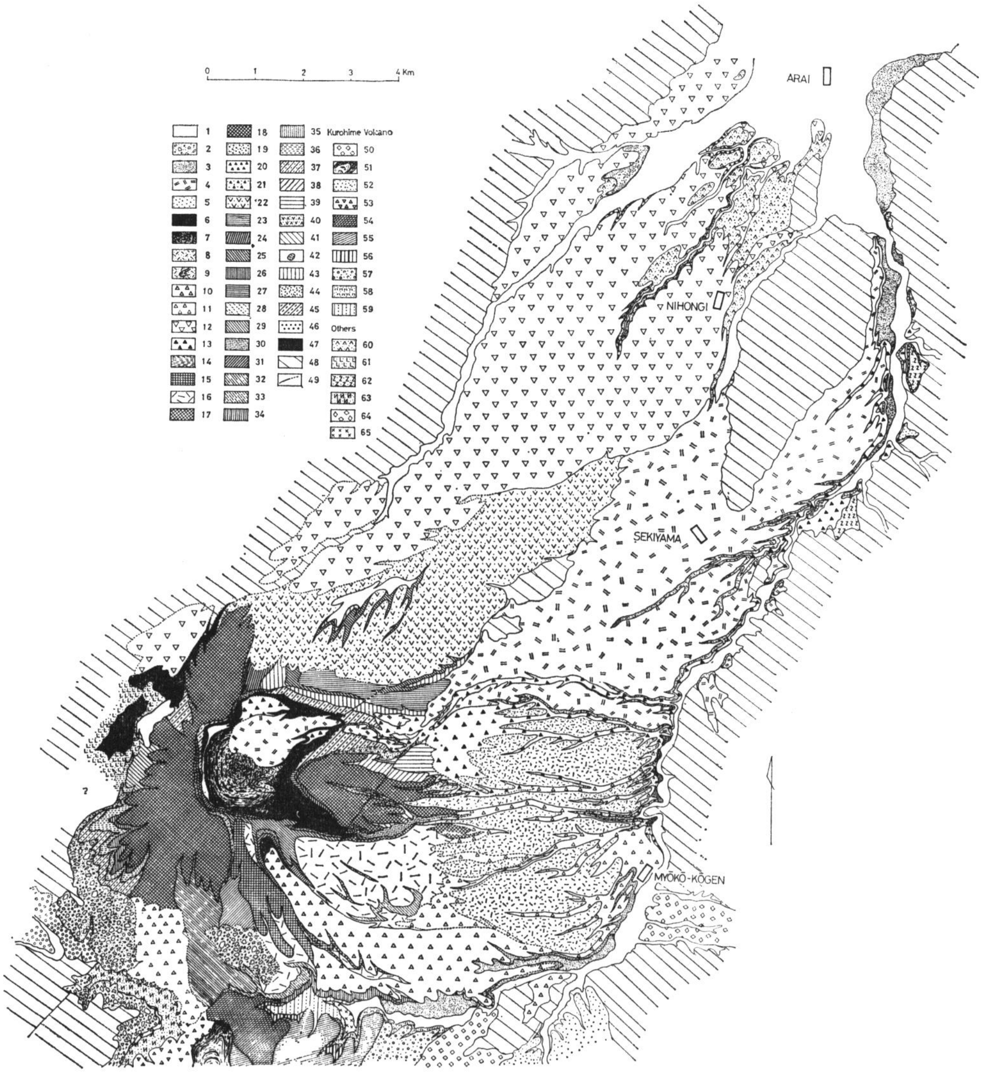

Fig. 7. Geologic map of the Myoko volcano (HAYATSU, 1972b).
1. Alluvium, 2. Talus or alluvial fan deposits, 3. Lower terrace gravel, 4. Otagirigawa pyroclastic flow deposit, 5. Middle terrace gravel, 6. Tsubame lava, 7. Myokosan lava, 8· Akakura pyroclastic flow deposit, 9. Myokosan pyroclastic rocks, 10. Suginosawa mud flow deposit, 11. Taguchi mud flow deposit, 12. Yashirogawa mud flow deposit, 13. Sekigawa mud flow deposit, 14. Caldera lake deposit, 15. Nishikawadani lava, 16. Shibutamigawa pyroclastic flow deposit, 17. Mitaharayama lavas, 18. Kasumizawa lava, 19. Kanbazawa scoria fall deposit, 20. Nihongi mud flow deposit, 21. Tagiri mud flow deposit, 22. Katagaigawa mud flow deposit, 23. Kannayama lava, 24. Mitsumine lava, 25. Umagatsazawa lavas, 26. Otaniuchi lava, 27. Makuiwa and Kotaki lavas, 28. Kurosawaike lava, 29. Kaname lava, 30. Shiratagirigawa pyroclastic flow deposit, 31. Akakurayama lavas, 32. Ikenomine 33. Sanbongi lava, 34. Gohachigi lava, 35. Garasawa lava, 36. Kurosawagawa lava, 37. Yajirogawa lava,

a) The eruptives of the older Myoko volcano
(Jigokudani group)

The Jigokudani lavas (HAYATSU, 1972b), distributed along Kitajigokudani, Minamijigokudani, and Okurasawagawa belong to the eruptive of the older Myoko volcano. They are distinguished from other eruptives by the following two: (i) There is a large unconformity between the present lavas and overying strata, (ii) All rocks of the present lavas are altered to show sap-greenish gray. The Jigokudani group consists of the alternation of lava and pyroclastics such as scoria, lapilli, and bomb. Along the valleys Minamijigokudani and Kitajigokudani, it is about 300 m in total thickness, and inclines more gently to the east than the overling strata. And it is displaced by many small faults at several places. It overlies the Neogene sedimentary rocks at Komyonotaki waterfall of Kitajigokudani valley according to the drilling data (TAKANO, 1961). The rocks are basalt and pyroxene andesite, dark gray to sap-greenish gray, and very compact. The volcano which ejected these eruptives is named the older Myoko volcano. It was undoubtedly a stratovolcano whose eruption center was located at the same point or slightly west of the younger one, judged from the distribution and structure of these eruptives. It is desirable to confirm the age of the Jigokudani group in the near future. However, this group seems to be considerably older than those of the younger stratovolcano, considered from the fact that the eruptives of the present stage are covered with those of the later stage with a most remarkable unconformity and that all rocks are altered in contrast to those of later eruptives as mentioned above.

b) The eruptives of the younger Myoko volcano

The eruptives of the younger Myoko volcano are divided into four, the eruptives of the Ist IInd IIIrd and IVth stages.

(i) The eruptives of the Ist stage (Maruyama group).

The eruptives of the Ist stage, covering the Jigokudani group with a remarkable unvonformity are covered with the Kannayama group described later. They are newly difined as the Maruyama group. The Maruyama group corresponds to the early stage's eruptives of the younger stratovolcano of HAYATSU (1972 b). It is

38. Osawa lava, 39. Maruyama lava, 40. Shirasawa pyroclastic flow deposit, 41. Takinosawa lava, 42. Neck, 43. Seki lavas, 44. Norikoshi pyroclastic rocks, 45. Byobuiwa lavas, 46. Higher terrace gravel, 47. Jigokudani lavas, 48. Neogene formations, 49. Faults, 50. Komazume mud flow deposit, 51. Sutakayama lava, 52. Loam IV (Nakago loam), 63. Navewarigawa mud flow deposit, 54. Sekigawa lava, 55. Ushibuseyama lava, 56. Komagataki lava, 57. Takasawa pyroclastic fall deposit. 58. Takasawa pyroclastic flow deposit, 59. Naenataki lava,60. Shibuegawa pyroclastic flow depost, 61. Koyaike pyroclastic flow deposit, 62. Ojika pyroclastic rocks, 63. Hyosawagawa pyroclastic rocks, 64. Mud flow deposit from the Madarao volcano. 65. Sadoyama group.

mainly composed of thick lavas, and subordinately of pyroclastics. The rocks are chiefly characterized by hornblende-pyroxene andesite, and sometimes include small amount of olivine. The Byobuiwa lavas, belonging to the Maruyama group, are intruded by a neck of hornblende bearing pyroxene andesite, several ten meters in diameter near Sotaki waterfall in the west of Tsubame spa. The eruptives of this stage are cut and displaced by two great faults of NE-SW direction near Sotaki waterfall and Maruyama, respectively. According to SUGIYAMA (1955), the former is called the Maeyama fault, and the latter the Maruyama fault. Other small faults are also observed in this gruup.

(ii) The eruptives of the IInd stage (Kannayama group).

The eruptives of the IInd stage of the Myoko volcano (s. st). is newly defined as the Kannayama group. It corresponds to the middle stage's eruptives of the younger stratovolcano of HAYATSU (1972 b). It underlies the Kanbazawa scoria fall deposit of the first eruptives of the next stage, and overlies the Maruyama group with an unconformity.

Its lower half, represented by the Umagatazawa and Akakurayama lavas, is composed of the alternation of lava and scoria tuff. The scoria tuff beds are gradually increasing to the lower part in thickness. The rocks of lava and scoria of lower half are basalt and basic andesite.

The upper half, represented by the Kannayama and Kaname lavas, consists of the alternation of thick lava and agglomerate, and is widely distributed.

The thick Katagaigawa and Shiratagirigawa pyroclastic flow deposits, construct the uppermost part of the Kannayama group. They are widely distributed on the northern slope of the Kannayama and along the Shiratagirigawa river, respectively. They consist of many flow units, and constituted by grayish white, hornblende andesite. The pyroclastic flows may belong to the intermediate type defined by ARAMAKI (1957). The Tagiri mud flow deposit, distributed at the eastern foot of the Myoko volcano, seems to be deposited at the latest time of the present stage, judged from its constituent blocks and stratigraphy.

The eruptives of this stage change from basic scoria tuff at the earlier time, through the alternation of basic to intermediate lava and pyroclastics such as agglomerate at the middle to the later time, to the pyroclastic flow deposit consisting of the essential blocks of hornblende andesite and mud flow deposit at the latest time.

(iii) The eruptives of the IIIrd stage (Mitaharayama group).

The eruptives of the IIIrd stage are newly defined as the Mitaharayama group. They are represented by the Kanbazawa scoria fall deposit, Mitaharayama lavas, and Shibutamigawa pyroclastic flow deposit.

The Kanbazawa scoria fall deposit consists of numberless fall units, having the total thickness of more than 40 m. The grains of scoria show characteristic brick red color, and include many olivine crystals. Along the Kanbazawa valley on the southern mid-slope of the somma, each fall unit is about 1 m in thickness. There, the grain size generally 1～5 cm in diameter, and the clear vertical grading is found in each bed. The scoria fall deposit is one of the best key beds in the Myoko volcano because of the extensive distribution, the large volume, and the characteristic features. It also constructs the lowermost part of Loam III, covering discordantly Loam II correlated with the Kannayama group, at the eastern foot of the volcano.

The Mitaharayama lavas occur mainly as the uppermost strata of the outer slopes of the Mitaharayama, Okurayama, and Maeyama. They are not distributed near the Kannayama and on the northeastern slope. At the caldera wall, they consist of the alternation of lava and agglomerate, and directly cover the Kanbazawa scoria fall deposit. There, the total thickness is about 80 m, and each lava is generally a few meters in thickness. No evidence showing the long interval of the deposition is recongnized in the alternation. The lithification of the agglomerate is rather weak, and vacant spaces are sometimes seen between the bombs. Both of lavas and bombs are basalt and basic andesite of dark gray.

The Shibutamigawa pyroclastic flow deposit, widely distributed on the southeastern slope of the somma, is the last eruptives of this)stage. It is generally distributed along the valleys which are carved on the Mitaharayama lavas. The thickness is more than 20 m. The essential blocks, some of which are the bread-crust bombs, are hornblende andesite, and abundantly include the so-called cognate inclusions. The pyroclastic flow deposit seems to be classified into the intermediate type of ARAMAKI (1957).

The Nihongi mud flow deposit distributed at the northeastern foot of the volcano is interposed into the upper part of Loam III, so that it may be correlated with the upper part of the Mitaharayama group.

The activity of the IIIrd stage changes the eruption mode from the ejection of the scoria fall through the alternated eruptions of lava and bomb to the eruption of the pyroclastic flow. The later time is also characterized by the avalanche of the mud flow.

It is topographically and geologically recognized that the Mitaharayama lavas distributed on the eastern slope of the Maeyama are cut and displaced by the Maruyama fault. The displacement seems to be smaller than that of the Maruyama group.

(iv) The eruptives of the IVth stage (Myokosan group).

The IVth stage, the youngest one of the Myoko volcano, is divided into earlier (stratovolcano), middle (caldera), and later (central cone) substages. The earlier substage is represented by the ejections of the Nishikawadani scoria and Nishikawadani lava. The eruptives of the earlier substage were appended on the older eruptives such as the Maruyama, Kannayama, and Mitaharayama groups.

The middle substage is the caldera forming substage, when a summit caldera and the mud flow deposits (Sekigawa, Yashirogawa, and Taguchi mud flow deposits) were formed. The caldera lake deposit (MYOKO RESEARCH GROUP, 1968) was also formed during this substage. YAMASAKI *et al.* (1961) reported that the caldera is an explosion one belonging to the Bandai volcano type (1888). HAYATSU (1972 b) considered that it is possibly a caldera combined a sort of)collapse caldera and explosion caldera.

The building of the gigantic central cone and the eruptions of the pyroclastic flows were made during the later substage. The eruptives are represented by the

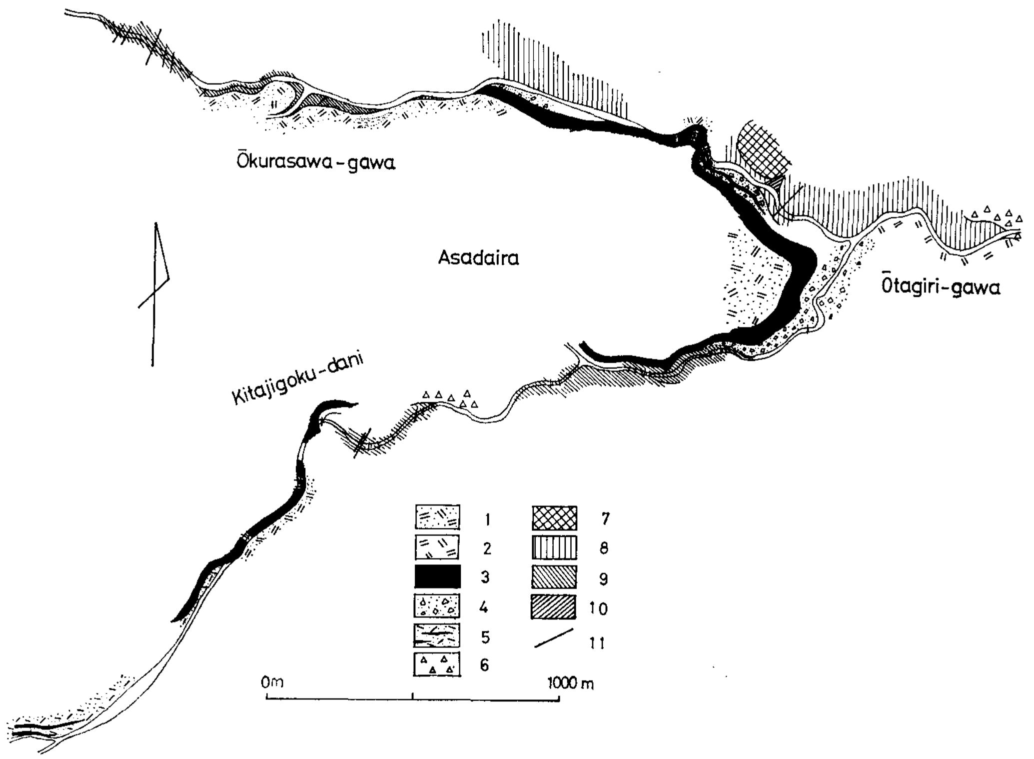

Fig. 8. Route map along the Kitagigokudani valley and Okurasawagawa river of the Myoko volcano.
1. Otagirigawa pyroclastic flow deposit, 2. Akakura pyroclastic flow deposit, 3. Tsubame lava, 4. Mud flow and alluvial deposits, 5. Myokosan pyroclastics, 6. Sekigawa mud flow deposit, 7. Neck, 8. Buobuiwa lavas, 9. Gigokudani lavas, 10. Tertiary sedimentary rocks, 11. Fault.

Myosan pyroclastics, Myokosan and Tsubame lavas, Akakura and Otagirigawa pyroclastic flow deposits, and Tanegaike explosion breccia.

The readers can see the more detailed descriptions on the eruptives of the IVth stage in HAYATSU (1975). The route map along the Kitajigokudani valley and Okurasawa gawa river of the Myoko volcano is shown in Fig 8.

F. **Yakeyama volcano** (2,400.3 m high)

The Yakeyama volcano, situated at the very northern end of "MYOKO", is a small dome-shaped volcano, and a single active one in "MYOKO". The explosions are recorded in 1361, 1852, 1949 (KUNO, 1962), and 1974. In case of the 1949 explosion, the volcanic ashes were blown off southeastwards and fallen on the snowcovered ground extending over Nagano, Gunma, and Tochigi prefectures (ICHIMURA *et al.*, 1949). The distribution of the ashes by the 1974 explosion is shown in Fig. 9.

This volcano has a mortar-shaped crater with 150×60 m in diameter at the summit. Some smaller explosion craters and fissures are found near the top. The steep-sloped summit part is constructed from lavas and pyroclastics such as agglomerate. On the other hand, the gentle-sloped northern skirt consists of pyroclastic flow deposit and lava flow. The Hayakawa pyroclastic flow deposit, distributed along the Hayakawa river, and covered by the thick lava flow, shows the ^{14}C age of 950±80 Y.B.P. (HAYATSU, 1972 c). The strata constructing the Yakeyama volcano are called the Yakeyama group as a whole. All rocks are hornblende andesite.

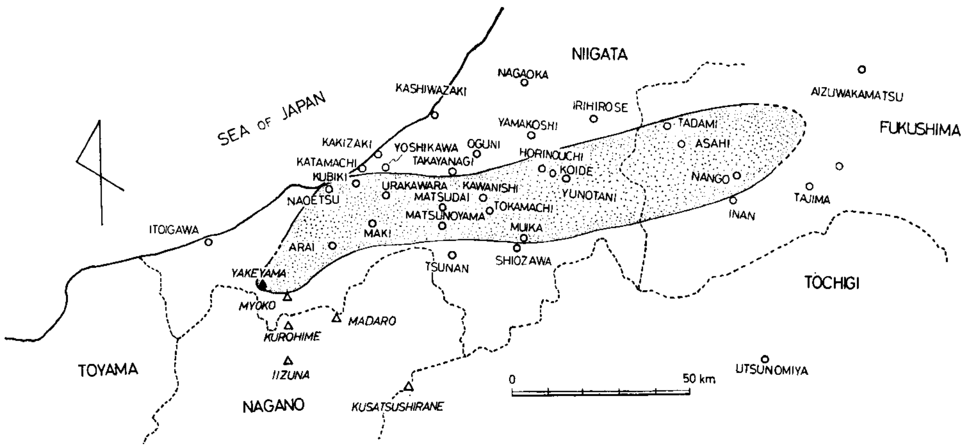

Fig. 9. Distribution of the ash fall deposit by the 1974 explosion of the Yakeyama volcano.*

* The writer is pleased to acknowledge the cooperation of the offices of the cities, towns, and villages which are shown in the present figure.

The basement rocks belong to the Miocene Hiuchiyama formation (NANBAYAMA GROUP, 1955–1956), and the volcano is built on an anticlinal axis.

IV. Arrangement of the Volcanoes and Migration of the Eruptive Center.

"MYOKO" are situated in the middle position where the Neogene sedimentary rocks constituting the basement of the volcanoes strike from south-north through northeast-southwest, lastly to south-north (Fig. 3). Four volcanoes (Madarao, Iizuna, Myoko and Yakeyama) excepting the Kurohime and Sadoyama volcanoes, are formed on the anticlinal or synclinal axis of the basement. This means that the eruptive position may be mainly controlled by the structure of the rocks just below the volcanoes. Three volcanoes of Iizuna, Kurohime, and Myoko, called the Myoko-sanzan mountains, are arranged at about 8 kilometer intervals on a south-north straight line. It suggests the existence of a south-north weak line in the basement. But the basement rocks show the northeast-southwest structural direction, and many faults cutting the basement run to the northeast-southwest or to the northwest-southeast. No large south-north fault or firssure has been confirmed as yet in the field. The Myoko-Iizuna volcanic chain is parallel to the Fossa Magna, and has no direct relation to the Quaternary stress field in the area (KOBAYASHI, 1968). Accordingly, the Myoko-Iizuna volcanic chain may be controlled by a structure in a concealed deeper place.

It is already known that the volcanoes often form a volcanic chain (SUZUKI, 1968), and in the chain an active center of eruption shows a tendency to move to a certain direction. Also in "MYOKO", except for the older volcanoes of Sadoyama and Madarao, the volcanic activity tends to become younger in the northward direction from the Iizuna through the Kurohime and Myoko to the Yakeyama volcano. In particular, when the activity of the youngest groups in these volcanoes is compared, such tendency becomes more evident. If it is accepted that the activity of the Iizuna volcano started at the Toyono stage (TAKEUCHI *et al.*, 1965), it may be roughly said that about 5×10^5 years have passed till the building of the Yakeyama volcano which is active at present and of which the principal activity was in historic time (HAYATSU, 1972 c). Accordingly, the migration velocity is assumed as about 5 cm/year for the course from the Iizuna through Kurohime and Myoko to Yakeyama volcanoes, and about 4 cm/ year for the course toward the direction of the inclination of the seismic plane under "MYOKO" (UTSU, 1974). It is noticiable that the value is the velocity of the continental shift and plate motion. When we consider the instances of other volcano groups and volcanic chains, however, it becomes clear that the moving direction of activity is unsettled, although each time scale required for the movement of the active center should be examined in future. For instance, the Yatsugatake volcanic chain shows north→south→north direction (KAWACHI, 1961), the Nikko volcanoes east→west direction (YAMASAKI, 1958), and the Eboshi volcanoes west→east direction (ARAMAKI, 1963). This means that such sort of migration is not caused by global tectonics like the continental shift and plate motion, but is rather a local geologic phenomenon.

In the east of the Myoko volcano there is the Nakago basin, which is connected with the Takada plain in the vicinity of Arai city. The Myoko volcano is built on the boundary between the Nakago basin and the western mountains. The Nakago basin has been depressed after the formation of the 600–900 m high, considerably flat surface of the Toyono formation spreading to the east of the Kurohime and Iizuna volcanoes. According to TAKANO (1969), the Myoko volcanic cone is asymmetry, namely the east slope is steeper than the west slope and the asymmetry is caused directly by the synclinal movement of the basement. The east and west slopes are stratigraphically of the almost same depositional surface, that is, both the west slope of the Mitaharayama and the east slope of the Maeyama, consist of the Mitaharayama lavas belonging to the IIIrd stage of the Myoko volcano (Fig. 7), and the primary landform of the lavas are considerably well preserved. Therefore, the asymmetry of the east and west slopes means the asymmetry of the same depositional surface. This asymmetry of the volcanic cone may be caused by a discrim inatory up-and down-movement of the basement, and also by the original difference in thickness of eruptives. Judged from the recent upheaval tendency of the west mountain mass (MIYABE *et al.*, 1966), the present east and west asymmetry seems to be caused by a different vertical movent of the basement of both sides. But there is no evidence to connect its cause with a synclinal movement as TAKANO estimated. That is, there is no symmetrical displacement of the depositional surface to a synclinal axis, running under the Myoko volcano in the direction of northeast-southwest.

It is known that in the active era of the Iizuna volcano, its environs were submerged, and the limnetic Toyono formation was deposited. On the other hand, the west area of the volcano was an upheaval zone which supplied sedimentary materials to the eastward direction (KOBAYASHI, 1957, 1958). After this, the vertical movement of the basement became active. Such a vertical movement seems to have migrated from the Iizuna-Kurohime area to the Myoko-Yakeyama area. It coincides well with the migratory tendency of the volcanic activity mentioned above. Confirmation of their causal relation is a very interesting problem.

V. Growth of the Volcano and Change of the Eruption Mode.

Throughout the growth of the volcanoes in the area, it is observed that the rock features and eruption mode changed in a definite direction. The frequency of volcanic mud flow has also a tendency to concentrate in a certain period.

A. Change of eruption mode

Throughout the activity of the Myoko volcano IIIrd stage, the change of eruption mode was as follows: eruption of large amount of scoria fall→alternative eruption of lava flow and bomb→eruption of pyroclastic flow. A similar order of the eruption, namely the eruption of a large amount of scoria fall through the alternative eruption of lava flow and bomb, lastly to the eruption of predominant pyroclastic flow accompanying viscous lava flow and pyroclastic fall, is found in the IInd and IV stages of the Myoko volcano, and the IInd stage of the Iizuna volcano. MIMURA (1971) gave an excellent example on the change of eruption mode throughout the whole life of the volcano which erupted the Mizugamori volcanic rocks. The succession is as follows; pyroclastic fall and flow→pyroclastic flow→lava flow.

The serial change shown in the Mizugamori volcanic rocks is different in course from that in "MYOKO". The change of the eruption mode observed in "MYOKO" well corresponds with change of the chemical composition of magma from basaltic through andesitic to dacitic. Namely, the eruption of scoria falls is caused by basaltic magma, the alternative eruption of lavas and pyroclastics such as bombs by andesitic magma, and the eruption of superior pyroclastic flows by dacitic magma. These modes of eruptions are similar to the Strombolian, Vulcanian, and Pelean eruptions, respectively. Such changes of the eruption mode may be mainly attributed to the increasing viscosity of magma (SUZUKI, 1969).

As well known, "one cycle eruption" (NAKAMURA *et al.*, 1963) has a regularity, that is pyroclastic fall→pyroclastic flow→lava flow (YAMASAKI, 1959; NAKAMURA *et al.*, 1963). This order is also applicable to the activities of the Otagirigawa, Akakura and other pyroclastic flow stages of the Myoko volcano, respectively, as far as pyroclastic fall and pyroclastic flow are concerned.

The following general process is observed concerning the activity of the central cone at the IVth stage of Myoko volcano excepting the latest Otagirigawa pyroclastic flow which erupted after a long dormant stage, as YAMASAKI *et al.* (1961) noticed: eruption of pyroclastic fall and flow→eruption of pyroclastics accompanying small amount of lava flow→effusion of lava flow. The process which is found throughout the central cone stage is transitional in time between that of the piling of one group mentioned above (may be called "one group cycle eruption" for the present) and that of "one cycle eruption", but shows similar change as the "one cycle eruption". Each rock, in general, is highly viscous hornblende andesite judged from their occurrence, and no remarkable difference is confirmed between the rocks composing pyroclastics and lava flow, excepting that the former is more porous than the latter. Therefore, the change of eruption mode may have been controlled by the water content in magma, as in the change of eruption mode of "one cycle eruption".

B. Volcanic mud flow

In the area of "MYOKO", the so-called volcanic mud flow deposit is often found. The volcanic mud flow deposit, in the present paper, does not always mean a wet mud flow deposit, but such a deposit where a part of the already built volcanic body was destroyed, rushed down the slope in the form of turbulent flow, and was deposited. As most of the mud flow deposit in the area is very similar in rock facies to the mud flow deposit formed by the 1888 explosion of the Bandai volcano, it is regarded to be constructed by a similar mechanism as the latter.

A comparatively large scale mud flow deposit of "MYOKO", whose stratigraphy has been made clear, seems to be concentrated at a certain period of the volcano-building. The principal mud flow deposits, such as the Tagiri mud flow deposit of the Myoko II stage, Nihongi mud flow deposit of the Myoko III stage, Sekigawa, Yashiraogawa, and Taguchi mud flow deposits of the Myoko IV stage, Nabewarigawa and Komazume mud flow deposits of the Kurohime, and mud flow deposit of caldera stage of the Iizuna, are all concentrated in the middle to upper part of each group.

Such a concentration may be caused by the following reasons: 1) A volcanic cone is high enough to be destroyed easily at the later stage, and the steep slope is favorable for mud flow. 2) A trigger for the origination of mud flow such as gas explosion, is more likely to happen at a later stage. The first condition is absolutely necessary. But even in volcanoes constructed from several groups such as the Myoko volcano, larger scale mud flow deposits have not been found at the lower part of each group, notwishstanding a cone must have been high enough to be destroyed at the early piling stage of each group excepting the oldest group. This shows clearly that the second condition is also necessary. Actually, the mud flows of the Bandai volcano (1888) and the Tokachi volcano (1926) were directly raised by gas explosion, (MARUTA, 1961, and TADA *et al.*, 1927). Judged from these facts, it is presumed that the large-scale gas explosions had a tendency to be concentrated during the middle to late stage of each group of "MYOKO".

Each group of "MYOKO" corresponds petrographically to a basalt-andesite series (though some of the groups lack the basaltic rocks), and generally yields more differentiated rocks at the upper horizon. In general, water content in magma may increase in step with crystallization of magma. If the wall rocks containing much water are taken into magma in the course of crystallization, the enrichment of water in magma may be further advanced. Then the conditions may be favorable for the explosion of the "Bandaisan type" at the later stage of a group.

It is noticeable that the upper part of each group is almost always accompanied with the mud flow and pyroclastic flow deposits, and is petrographically composed of hornblende andesite.

SUMMARY

1. The basement of "MYOKO" is composed of thick Neogene sedimentary rocks partly associated with effusive and intrusive rocks. The basement of the Iizuna and Kurohime are situated at a rather low altitude, whereas that of the Yakeyama is at the highest level which corresponds to the now ascending area. The Myoko is situated at the middle horizon between the two areas mentioned above, namely at the area where there is an abrupt change in the slope of the landform.
2. Many volcanoes, namely the Yakeyama, Myoko, Iizuna, and Madarao volcanoes, are built on the anticlinal or synclinal axes of the basement rocks.
3. The basement rocks of the Myoko and Iizuna volcanoes seem to be in a complex and unstable condition, and their eruptives have been displaced by the faults parallel to those cutting the basement. On the other hand, the Kurohime is built on the basement rocks having a comparatively simple structure.
4. The activity order in age of "MYOKO" is as follows; the Sadoyama, Madarao, Iizuna, Kurohime and Myoko, and Yakeyama volcanoes. The activity tends to become younger northward since that of the Iizuna volcano. Such tendency becomes more evident when the age of the youngest groups in the volcanoes is compared.
5. The Yakeyama volcano is a single active volcano in the present area.
6. The Myoko is divided into the older Myoko volcano and the younger Myoko volcano (or the Myoko volcano in the strict sense), and the history of the latter is further divided into four stages, I, II, III, and IV.
7. The history of the Kurohime volcano is divided into the following four stages, the older stratovolcano (1st), the younger stratovolcano (2nd), caldera (3rd), and central cone (4th).
8. The history of the Iizuna volcano is largely divided into the I and II stages, and the latter is further subdivided into three substages, the stratovolcano (1st), caldera (2nd), and lava dome (3rd).
9. The Madarao and Sadoyama volcanoes are considerably older than the others in the present area.

10. The eruptives of "MYOKO" are composed of lava, pyroclastic flows (the intermediate type and nuée ardente in the strict sense defined by ARAMAKI, 1957), pyroclastic falls, and mud flows. The mode of volcanic activity which formed several groups of "MYOKO" tends to change as follows respectively; eruption of scoria falls by the Strombolian eruption→alternative eruption of lava and pyroclastics such as bombs by the Vulcanian eruption→eruption of pyroclastic flows sometimes accompanying viscous lava flows by the Peléan eruption. The volcanic mud flows seem to be concentrated in the middle to late stage of each group.

References

ARAI HIGH SCHOOL (1965): Study of geology and hydrography at the foot of the Myoko volcano (in Japanese). *Collecting Report of Arai High School*, (6), pp. 118–133.

ARAMAKI, S. (1957): Classification of pyroclastic flows (in Japanese). *Jour. Volc. Soc. Japan*, Ser. 2, **1** (1), pp. 47–57.

——— (1963): Geology of Asama volcano. *Jour. Fac. Sci. Univ. Tokyo, Sec.* II, 14, pp. 229–443.

HAYAMA, Y. (1966): A concealed metamorphic belt—An idea concerning the Joetsu metamorphic belt—(in Japanese). Comprehensive Research Project; The development of the metamorphic belt in Japan. Report "Metamorphic belt", (3), pp. 19–23.

HAYATSU, K. (1963): Geology of Kurohime volcano (in Japanese, MS). Graduation thesis of Shishu University.

——— (1972a): Myoko volcano group—Geohistory of the Kurohime and Myoko volcanoes—I (in Japanese). *Earth Science*, **26** (2), pp. 47–57.

——— (1972): Myoko volcano group—Geohistory of the Kurohime and Myoko volcanoes—II (in Japanese). *Earth Science*, **26** (3), pp. 91–103.

——— (1972c): ^{14}C age of the Hayakawa pyroclastic flow of the Niigata Yakeyama volcano—^{14}C age determination of Quaternary formation in Japan, 79—(in Japanese). *Earth Science*, **26** (6), pp. 262–263.

——— (1974): Discovery of "large anorthite crystals" from Myoko volcano in Central Japan and some considerations on their genesis (in Japanese). *Jour. Geol. Soc. Japan*, **80** (12), pp. 569–578.

——— (1975): The last activity and eruptives of the Myoko volcano—Geologic descriptions of the Myoko volcanoes (1) (in Japanese). *Quaternary Research*, **14** (1), pp. 1–33.

HIMEKAWA RESEARCH GROUP (1958): On the Tertiary along the Itoigawa—Shizuoka tectonic line (in Japanese). *Jour. Geol. Soc. Japan*, **64** (756),

HIRABAYASHI, T. (1969): On the Matsumoto-Nagano tectonic line and Otari upheaval zone in the northern part of the Fossa Magna (in Japanese). *Geol. Soc. Japan*, **1976** *Ann. Meet., Discussion Data "on the green tuff problems"*, pp. 117–122.

IIJIMA, N. (1962): Volcanostratigraphical and petrographical study in the northeastern part of the Fossa Magna—part 1—*Bull. Fac. Educ., Shishu Univ.*, (12), pp. 86–133.

ISOMI, H. and KAWADA, K. (1968): On the correlation of the basal rocks in the both sides of the Fossa Magna (in Japanese). *Geol. Soc. Japan*, **1975** *Autumn Meet., Discussion Data "Fossa Magna"*, pp. 4–12.

KAWACHI, S. (1961a): Yatsugatake volcanic chain—I—(in Japanese). *Earth Scinece*, (55), pp. 1–8.

——— (1961b): Yatsugatake volcanic chain—II—(In Japanese). *Earth Science*, (56), pp. 11–17.

——— (1972): On the arrangements of volcanoes in the Yatsugatake volcanic chain with special reference to the basement. *Jour. Fac. Sci., Hokkaido Univ.*, Ser. 4, (1–2), pp. 139–156.

KEINAN ARCHAEOLOGICAL RESEARCH GROUP (1966): Prehistory and encient history of the Keinan district (in Japanese). *A report on comprehensive study of the southern part of Nakakubikigun country* (Niigata Educ. Committee and Keinan Comprehensive Study Committee), pp. 127–216.

KOBAYASHI, K. (1957): The history of the structual development of the Fossa Magna region (in Japanese). *Rep. Assoc. Geol. Collaboration Japan, Matsumoto Branch,* pp. 1–44.

———(1968): On the Quaternary basal movement in the Fossa Magna (in Japanese). *Geol. Soc. Japan, Review* **2**, pp. 33–38.

KUNO, H. (1962): *Catalogqu of the active volcanoes of the Warld including solfatara field, Part II, Japan, Taiwan and Marianas,* Int. Assoc. Volc. Rome, pp. 104–110.

MARUTA, H. (1968): Some considerations on the Urabandai mud flow (in Japanese). *Geogr. Rev. Japan,* **42** (9), pp. 465–469.

MIMURA, K. (1971): The Plio-Pleistocene volcanic activity in the north of the Kofu basin, central Japan—Volcanic activity of the Mizugamori volcanic rocks—(in Japanese). *Jour. Geol. Soc. Japan,* **76** (6), pp. 375–388.

MINATO, M., GORAI, M. and HUNAHASHI, M. (1965): *The geological developments of the Japanese islands.* Tsukiji Co., Tokyo.

MIYABE, N., MIYAMURA, S. and MIZOUE, M. (1966): A map of Secular vertical movements of the earth's crust in Japan. *Ann. Acad. Sci. Fenn.,* A. **3** (90), pp. 287–289.

MYOKO VOLCANO RESEARCH GROUP (1969a): Lake deposit distributed along the Jigokudani valley of the Myoko volcano—1—(in Japanese). *Report Geosci. Educ. Soc. Niigata prefecture,* (6), pp. 44–48.

——— (1969b): A study on the building process of the Myoko volcano and the hydrogeology of its foot area, central Japan—Studies in the Quaternary formation of Niigata prefecture, Part 10—(in Japanese). *Bull Fac. Educ. Takada bracnc, Niigata Univ.,* (14), pp. 241–273.

NAKAMURA, K., ARAMAKI, S. and MURAI, I. (1963): Volcanic eruption and nature of the pyroclastic deposits. *Quat. Res.,* **3** (1), pp. 13–30.

NANBAYAMA GROUP (1955–1956): Study of the Mt. Hiuchi—Geological study in home, No. 4—(in Japanese). *Kyoikusozo (Creative Education),* **9** (1), pp. 1–34.

NAUMANN, E. (1885): *Uber den Bau und die Entstehung der Japanischen Inseln.* Berlin.

NISHIDA, S., TSUDA, K. and ICHIMURA, R. (1966): On the Neogene at the northern end of the Fossa Magna—Study on the so-called Nanbayama formation, part 1—(in Japanese). *Sci. Rep. Geol. and Miner. Dept. Niigata Univ.,* (1), pp. 1–14.

SAITO, Y. (1955): Geology of the Toyono-mura district, Kamiminochigun country, Nagano prefecture, Japan (in Japanese). *Bull. Fac. Educ. Shinshu Univ.,* (5), pp. 89–95.

——— (1961): Geology of the northern part of the Fossa Magna (Part 1). *Bull. Fac. Educ. Shishu Univ.,* (11), pp. 179–200.

——— (1962a): Geology of the northern part of the Fossa Magna (Part 2). *Bull. Fac. Educ. Shinshu Univ.,* (13), pp. 23–54.

——— (1962b): Geology of the northern part of the Fossa Magna (Part 3). *Bull. Fac. Educ. Shinshu Univ.,* (12), pp. 55–81.

——— (1963): Geology of the northern part of the Fossa Magna (Part 4): *Bull. Fac. Educ. Shinshu Univ.,* (14), pp. 123–142.

——— (1968): A few new facts concerning the Neogene system in the Nagano district (in Japanese). *Geol. Soc. Japan,* **1975** *Autumn Meet., Discussion Data "Fossa Magna",* pp. 15–20.

———, Mizukami, T. and Tsukada, M. (1960): Stratigraphical and pollen analytical studies of the Pleistocene deposits in the northern part of Nagano prefecture, central Japan. *Sci. Rept., Univ. Tohoku,* Ser. 2, Special Vol. **4**, pp. 345–355.

SAWAMURA, K. (1960): Volcano Iizuna, geology of its southwestern part (in Japanese). *Earth Science,* (48), pp. 21–25.

SUGIMURA, A. (1960): Zonal arrangement of some geophysical and petrological features in Japan and its environs. *Jour. Fac. Sci., Univ. Tokyo,* Ser. 2, **12** (2), pp. 133–153.

SUGIYAMA, R. (1955): Report on geology and petrography of the Myoko volcano (in Japanese, MS).

SUZUKI, J. (1961): Geology of the Myoko volcano, especially of the eastern part (in Japanese, MS). Graduation thesis of Tokyo University of Education.

SUZUKI, T. (1965): Geomorphology of Iizuna volcano and its adjacent areas, central Japan, Part 1. *Bull. Fac. Sci. and Eng. Chuo Univ.,* **8**, pp. 190–209.

——— (1966): Geomorphology of Iizuna volcano its adjacent areas, central Japan, Part 2. *Bull. Fac. Sci. and Eng. Chuo Univ.,* **9**, pp. 1–25.

——— (1968): Some tectonic aspects of Quaternary volcanoes in Japan (in Japanese). *Quat. Res.* **7** (4), pp. 217–224.

——— (1969): Volcanic activity and topography (in Japanese). *Physical Geograpty II,* Asakura Co., Tokyo.

TADA, F. and TSUYA, H. (1927): Explosion of the Tokachi-dake volcano (in Japanese). *Bull. Earthq. Res. Inst.,* **2**, pp. 40–84.

TAKADA GROUP (1956): On the Hiuchiyama mountain as result of Research Group (in Japanese, MS). *Assoc. Geol. Coll. Japan,* **10** *th Ann. Meet., Discussion Data,* pp. 14–16.

TAKADA PLAIN RESEARCH GROUP (1966): Quaternary at the foot of the Myoko volcano (in Japanese). *Annual Report of Cultural Asserts Investigation of Niigata Prefecture,* (6), 1–32.

TAKANO, T. (1969): A study on the formation and the tilting of the Myoko volcano, Central Japan (in Japanese). *Geogr, Rev. Japan,* **42** (9), pp. 570–591.

TAKESHITA, T. (1960): Geology of the northwestern part of Nagano city (in Japanese). *Geosci. Study,* **2** (5), pp. 256–268.

——— (1965): Togakushi volcanic rocks—Significance of its igneous activity in the northern part of Fossa Magna (in Japanese). *Jour. Geol. Soc. Japan,* **71** (838), pp. 367.

———, SAITO, Y. and MOMOSE, K. (1960): Palaeomagnetism and volcanic geology of the Shigarami formation (in Japanese). *Earth Science,* (49), pp. 26–36.

TAKEUCHI, J. (1954): Petrography and stratigraphy of the Iizuna volcano (in Japanese, MS). Graduation thesis of Shinshu University.

———, and TAKESHITA, T. (1965): The volcanism in the late Sarumaru stage, with special reference to the Palaeo-Iizuna volcano—Lower Pleistocene volcanics in northern Fossa Magna—(in Japanese). *Earth Science,* (78), pp. 1–10.

TOMIZAWA, T. (1953): Stratigraphy and geological structure of the area along the Susobana river (in Japanese). *Jour. Geol. Soc. Japan,* **59**, pp. 552–560.

——— (1970): *Geography and history of the Kamiminochigun country—Nature—(in Japanese).* Kamiminochigun country, Nagano, pp. 29–148.

TOYONO RESEARCH GROUP (1958): Loam distributed around the Nojiri lake (in Japanese). *Shinshu loam,* (3), pp. 8–9.

——— (1962): A study of the Quaternary of the area of the Nojiri lake, Nagano Prefecture (in Japanese). *Comprehensice Study on Quaternary,* (3), pp. 35–41.

———, and SAITO, Y. (1964): On the absolute age of Nojiriko formation yielding mammal fossils—^{14}C age determination of Quaternary formation in Japan, 11—(in Japanese). *Earth Science,* **18** (4), pp. 40.

UTASHIRO, T. (1956): To the comment on "Hiuchiyama study"—Geological study in home, No. 5—(in Japanese). *Kyoikusozo (Creative Education),* **9** (5), pp. 1–5.

UTSU, T. (1974): Hypocentral distribution of earthquake in and around the Japanese Islands (in Japanese). *Science,* **44** (12), pp. 739–746.

YAGI, K. and TAKEUCHI, J. (1955): Structure and rocks of the Iizuna volcano (in Japanese). *News Volcano Physics Soc.,* (2), pp. 5–6.

YAGI, T. (1940): Form of the displacement of central cone of the Myoko volcano (in Japanese). *Jour. Geogr.*, **52** (616), pp. 250–256.

———, and YAGI, K. (1958): *Geology of Kamiminochigun country* (in Japanese). Kamiminochigun country Educ. Comm., Nagano, pp. 1–480.

YAMADA, T. (1934): Iizuna and Kurohime volcanoes (in Japanese). *Bull. Earthq. Res. Inst.*, **12**, pp. 96–149.

YAMASAKI, M., NAKANISHI, N. and YAMASAKI, T. (1961): Pyroclastic flow of Myoko volcano (in Japanese). *Jour. Volc. Soc. Japan*, Ser. 2, **6** (1), pp. 1–12.

YAMASAKI, N. (1895): Report of the geological survey of the Myoko volcano group (in Japanese). *Rep. Earthq. Inv. Comm.*, **8**, pp. 23-86.