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GEOLOGICAL SURVEY OF JAPAN

GEOLOGY AND PETROLOGY OF THE NŌHI RHYOLITES, WITH SPECIAL REFERENCE TO THOSE ALONG THE HIDA RIVER

By

Kiyoo KAWADA

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Isamu KOBAYASHI, Director

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Geology and Petrology of the Nōhi Rhyolites, with Special Reference to Those along the Hida River*

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Kiyoo KAWADA**

Abstract

The Nōhi rhyolites form an enormous volcanic pile, whose total area of distribution attaining to about 4,000 km^2, and the volume exceeding 8,000 km^3. The Nōhi rhyolites extend in a NW-SE direction from the northern margin of the Ryōke belt to the Hida belt, passing through the Mino belt, of the Chūbu region, and evidently truncate the basement structure.

The Nōhi rhyolites consist mainly of rhyolite or rhyodacite welded tuff and contain a small amount of clastic and air-fall deposits.

According to the radiometry of the intrusive rocks prior to and posterior to the effusion of the rhyolites, the age of the rhyolite is younger than 97 m.y. and older than 60 m.y.

The Nōhi rhyolites were effused out from the fissures which took place in the fault-shearing zones of the basement, and the pyroclastic flow deposits were laid down in a graben-like depression. Very large thickness of the rhyolites, more than 2,000 m, is due to alternatively repeating of effusion and volcanotectonic depression. Vent-breccia was found in two places, both very close to the western margin of the rhyolites.

The rhyolites along the Hida River are stratigraphically divided into two, the Shirakawa rhyolites above and the Hidagawa rhyolites below. The Hidagawa rhyolites consist mainly of rhyodacite welded tuff. The boundary against the Paleozoic rocks on the west side is in fault in nearly all places. However, at Kuzumaki, the rhyolites abut on the cliff of the Paleozoic rocks which evidently represents an old fault scarp of the western boundary of the graben of the pre-Nōhi age.

The Shirakawa rhyolites consist of alternations of welded tuff, conglomerate and tuff breccia. The Shirakawa rhyolites unconformably cover the Hidagawa rhyolites, and also cover the basemental Paleozoic rocks in the area to the west of the faults between the Paleozoic rocks and the Hidagawa rhyolites.

In the Hidagawa rhyolites which form the main part of the Nōhi rhyolites, the thickness of each cooling unit exceeds 100 m. In the Shirakawa rhyolites which are product of a local and late volcanic activity, the cooling unit is several ten meters thick.

The welded tuff of the Hidagawa rhyolites is exclusively rhyodacite with SiO_2 content of 67~68%, and that of the Shirakawa rhyolites is rhyolite with

* The Doctor Thesis presented to Kyoto University

** Geology Department

SiO_2 content of 72~73%. The welded tuff of the Shirakawa rhyolites is rich in quartz and alkali feldspar, while that of the Hidagawa rhyolites is rich in plagioclase and mafic minerals. From chemical compositions, both rhyolites belong to the calc-alkaline rock series, and are very similar with other late Mesozoic rhyolites on the Inner Side of Southwest Japan in the variation diagrams of major elements.

Remarkable difference in secondary minerals is recognized between the Hidagawa and the Shirakawa rhyolites. The altered rocks are divided into montmorillonite, transitional and chlorite zones. The boundary between the chlorite zone and the transitional zone coincides roughly with the boundary between the Hidagawa rhyolites and the Shirakawa rhyolites.

The Nōhi rhyolites occupy a similar or the same position in the history of the late Cretaceous igneous activity with those of other rhyolites of Southwest Japan, and are very similar, in an aspect of mode of emplacement, to the Okunikkō rhyolites to the east and the Kōto rhyolites to the west of the Nōhi rhyolites.

Introduction

The Nōhi rhyolites widely distributed in the inner part of the Chūbu region form a volcanic pile consisting chiefly of pyroclastic flow deposits. Before the name Nōhi rhyolites was given by the writer and his co-workers (KAWADA et al., 1961), the acid volcanic rocks of this area were collectively called "quartz porphyry". Also, other pyroclastic flow deposits that are widely distributed on the Inner Side of Southwest Japan were previously called "quartz porphyry", like the Nōhi rhyolites.

Not only in the Chūbu district but throughout the Inner Side of Southwest Japan, "quartz porphyry" is closely associated with granites. The rock is characterized by the hard and dense crystalline groundmass, so that the rock has been sometimes regarded as a shallow facies or marginal facies of granite. Accordingly, the rock was believed to have been differentiated from the granite magma and have formed the intrusive complex mass. However, the mass of "quartz porphyry" shows, in spite of its large scale, a relatively simple lithology, which is hardly explained by the traditional petrogenesis. Petrologists seldom dealt with the rock as an interesting subject. In other words, the "quartz porphyry" remained as one of the blind spots in the geology of Japan, despite the fact that the rock occurs extensively on the Inner Side of Southwest Japan.

The writer's study of the Nōhi rhyolites was motivated by the geological quadrangle survey of the Ashio massif and the neighborhood that was carried out from 1948 to 1952 (KAWADA, 1955; KAWADA and OZAWA, 1955). In the area extending from the north of Ashio-machi to the Lake Chūzenji, Nikkō City, "quartz porphyry", similar to that occurred on the Inner Side of Southwest Japan west of the Fossa Magna, is also widely distributed. At the time of the survey the writer regarded this rock as a hypabyssal rock intruding the Paleozoic formation, and although the direct relation between the "quartz porphyry" and the surrounding granite was not confirmed, he considered that the both rocks constitute an intrusive complex mass formed by a serial igneous activity. However, his attention was drawn to the fact that the "quartz porphyry" abounds in xenoliths of Paleozoic rocks, as compared with the granites. He also realized that the abundance of these xenoliths, not only near the contact with the Paleozoic formation but also inside the "quartz porphyry", could not be reasonably explained by intrusive origin.

As a most suitable field for clarifying the true character of "quartz porphyry", the inner part of the Chūbu region would be considered first. It was known since many years ago that the distribution of the "quartz porphyry" in this area which is called Mino-Hida massif is much wider than that in the Ashio massif. As a part of the quadrangle survey project by the Geological Survey of Japan, the writer took up the rock in question as a theme of his study.

One of the past leading studies of geology of this area is the geological report on the Hida massif and the neighborhood by Ichitaro BAN (1888). There are also the geological maps with explanatory texts, on scales of 1/200,000 and 1/75,000, which were published in succession over a period of about 30 years since the late 1800's up to 1929. It is worthy to mention that BAN, in his discussion about formation of the "quartz porphyry" extensively distributed from the Shirakawa Valley to the Kiso Valley, pointed out that intrusion and effusion of this rock have occurred in the disturbed part of the basement composed of Paleozoic and Mesozoic rocks. BAN recognized also that the inner portion of the rock body occasionally shows a volcanic rock facies such as tuff. This is an important fact having been confirmed through the geological survey over a wide area, and his work should be highly evaluated.

In 1930's H. SHIBATA studied the granitic rocks in the Naegi district, Mino province, and described "quartz porphyry" in relation to those rocks (SHIBATA, 1939). He discriminated three types of the "quartz porphyry" differing in time of intrusion, and revealed the fact that the "quartz porphyry" had intruded as a forerunning event of the Naegi granites and was intruded by the latter. As the time lapsed into the 1950's, the present writer and his co-workers carried out the geological quadrangle survey of the Mino-Hida massif. Thus, the area became one of the model fields for comprehensive study of the late Mesozoic geology of Japan. The result of the survey was summarized by the writer and co-workers, and the name Nōhi rhyolites was given to the "quartz porphyry" in question (KAWADA et al., 1961). They pointed out that the major portion of the "quartz porphyry" is composed of rhyolites erupted onto the ground surface, and a welded structure is recognized in the greater part. After that, the study of the Nōhi rhyolites made rapid progress, and in this connection the analogous acid volcanic rocks widely distributed on the Inner Side of Southwest Japan began to attract attention of petrologists. In 1962, a symposium on the Mesozoic igneous activity on the Inner Side of Southwest Japan was held on the occasion of the Annual Assembly of the Geological Society of Japan in Hiroshima. Since then, collective researches with the above-mentioned theme were continued, and the results were summarized in a monograph entitled "Late Mesozoic igneous activity and tectonic history in the Inner Zone of Southwest Japan" (1967) by the research group inclusive of the present writer.

At that time it was revealed that the late Cretaceous volcanic rocks resembling the Nōhi rhyolites are widely distributed in many parts of the Inner Side of Southwest Japan, namely, the western Chūgoku region including a part of northern Kyūshū, the eastern Chūgoku region, the Kinki region, and the Chūbu region, from west to east. Occurrence of similar volcanic rocks was confirmed also in the Shimonita tectonic zone (ARAI et al., 1966) along the northern margin of the Kantō Mountains and in the Ashio massif, which may be regarded as an extension of the Inner Side of Southwest Japan in the light of the basement rocks beneath the late Cretaceous volcanic rocks. Especially in the Ashio massif, the rhyolites which were previously called quartz porphyry were named Okunikkō rhyolites by the writer (KAWADA, 1966c), and were correlated with the Nōhi rhyolites of the Mino belt.

Recently, the writer discovered the late-Cretaceous volcanic rocks in the lowland around the Lake Biwa and in the surrounding mountains, where the distribution of such rocks was not known before (KAWADA et al., 1969). For these rocks the writer proposes a name Kotō rhyolites. In lithology these rocks are similar to the Nōhi rhyolites, and apparently belong to the volcanic activity roughly contemporaneous with the latter. Thus, the distribution of the late Mesozoic volcanic rocks on the Inner Side of Southwest Japan extends from the western Chūgoku region to the Ashio massif.

In the eastern and the western parts of the Chūgoku region, the general distribution of the rhyolites is reported to be harmonic with the basement structure, trending in a nearly E-W direction. However, the Nōhi rhyolites distributed through three major geologic provinces, Ryōke belt, Mino belt and Hida belt, are evidently intersecting the basement structure at oblique angles.

The western boundary of the Nōhi rhyolites is almost straight. Especially where the rhyolites contact with the Paleozoic formation, it is clearly observed that the west margin of the rock body is obliquely intersecting the structure of the Paleozoic formation. Along the upper reaches of the Hida River, two kinds of rhyolites, old and young, of different mode of emplacement and lithology are recognized. Vent-breccia of the rhyolites is also exposed there. Therefore, this area is quite important for elucidating the stratigraphy and mode of emplacement of the Nōhi rhyolites, and this is the very reason the writer chose this area as the main field of his study. Indivisual results of the studies in this area have been already reported in the following papers; KAWADA (1961a, 1961b, 1965, 1966b, 1967), KAWADA and ISOMI (1967, 1968), ISOMI and KAWADA (1965) and, SUMI and KAWADA (1968).

In this paper the writer introduces the outline of the whole Nōhi rhyolites in Chapter I, and some remarkable facts of the Nōhi rhyolites in the southern Hida massif in Chapter II. He discusses the geology of the rhyolites along the Hida River in Chapter III, and their petrology in Chapter IV. In Chapter V he attempts to correlate the Nōhi rhyolites with other late Cretaceous volcanic rocks on the Inner Side of Southwest Japan.

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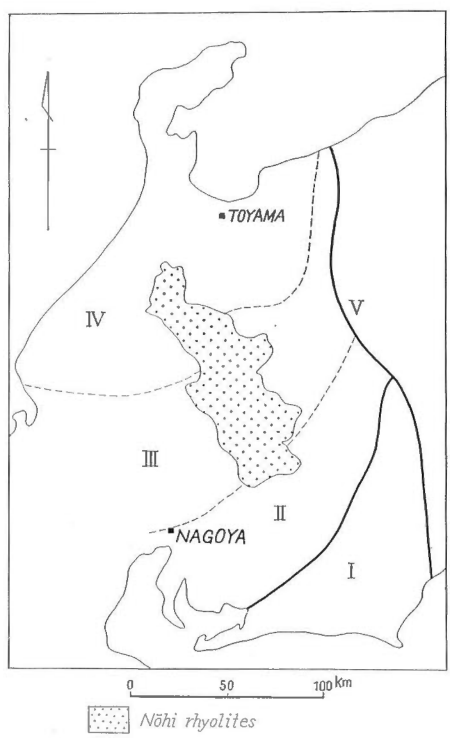
I. General Remarks on the Nōhi Rhyolites

I. 1 Geological setting

In the inner part of the Chūbu region, the Nōhi rhyolites stretch from the northern part of the Ryōke belt to the Hida belt across the Mino belt, as shown in Fig. 1.

Along the southern boundary the Nōhi rhyolites are extensively intruded and thermally metamorphosed by the Inagawa granite of the Ryōke belt and by



I. Outer Side of Southwest Japan II. Ryōke metamorphic belt
III. Zone of unmetamorphosed Paleozoic rocks (Mino belt)
IV. Hida metamorphic belt V. Fossa Magna terrain
Fig. 1 Area of distribution of the Nōhi rhyolites.

the Naegi-Agematsu granite (YAMADA, 1966b).

In the Mino belt the rhyolites broadly contact with the Paleozoic formation on the east and the west. The northern boundary of the terrain of the rhyolites is in fault contact with the mass of the Hida belt. The areal extension of the Nōhi rhyolites is the largest in the Mino belt as compared with other two belts.

The greater part of the boundary between the Nōhi rhyolites and the Paleozoic formation on the east and the west is demarcated by faults. Available data are still deficient for the eastern margin, but the western margin evidently shows the character of a structural line. This structural line is called the Nōhi west-boundary sheared zone (ISOMI et al., 1967). The Paleozoic formation in contact with the western margin of the rhyolites, and that isolated inside the rhyolites near the western margin are markedly sheared.

The west-boundary sheared zone runs NW-SE, roughly parallel to the elongation of the rhyolites.

The width of the west-boundary sheared zone, inclusive of the part of the Paleozoic formation covered by the rhyolites, attains to about 1 km at maximum. Such a intense fault-shearing is nver observed inside the rhyolites. Therefore, the Nōhi west-boundary sheared zone must have been formed prior to the effusion of the rhyolites.

The general strike of the Paleozoic formation in the Mino belt is NE-SW on the west side of the mass. However, as seen in the isolated mass inside the terrain of rhyolites, the strike changes into the direction of N-S and then turns again into the direction of NE-SW on the east side of the mass. The fault-shearing zone along the western boundary of the Nōhi rhyolites corresponds to the area where the strike of the Paleozoic formation abruptly changes.

I. 2 Geological age

There is no fossil evidence to tell the geological age of the Nōhi rhyolites. However, they can be dated to Late Cretaceous from the following indirect evidences. The Omodani rhyolites not far from the Nōhi rhyolites rest conformably on or gradually pass into the Late Cretaceous Asuwa formation (KAWAI et al., 1957), and show rhyolitic composition. The Nōhi rhyolites can be correlated with the Late Cretaceous Omodani rhyolites.

The Nōhi rhyolites are intruded by the so-called "Late Cretaceous" granites. The radiometric age of the biotite from the granites is 60 to 70 m.y. (KAWAI et al., 1966–1967; SHIBATA et al., 1962). On the other hand, the Nōhi rhyolites cover the quartz diorite near Shirakawa-machi along the Hida and contain the pebble of the quartz diorite. The radiometric age of the biotite from the quartz diorite is 97 m.y. (Unpublished data, measured by Yoshio UEDA). Hence, the age of the Nōhi rhyolites is between 97 m.y. and 60 m.y., which agrees well with the geologically presumed the "Late Cretaceous" age.

I. 3 Areal extension and volume

I. 3. 1 Areal extension

The Nōhi rhyolites constitute the great mass elongated in the NW-SE direction, which extends from the northern part of the Ryōke belt, passes through the Mino belt, and reaches the Hida belt. The length of elongation is about 130 km, with the maximum width 40 km. The exposed area of the Nōhi rhyolites, excluding the analogous Omodani rhyolites, is about 3,500 km^2. However, inclusive of the area where the rhyolites were eroded out and the Paleozoic rocks are exposed at present and the area where the rhyolites are intruded by granites or covered by younger rocks, the restored total areal extension would become as large as 4,000 km^2 or more, which is about 8 times the size of Lake Biwa.

I. 3. 2 Thickness

The thickness of the rhyolites was previously estimated at 600 m on an average, but the result of later survey has suggested that the thickness should be much greater.

The dip angle of the rhyolites is less than 30°, mostly 10 to 20°. Due to the block movement the direction of dip is not uniform regionally. Places where a continuous columnar succession can be obtained are very few. The average thickness 600 m was calculated from the relative height and the dip angle of the rhyolites.

It has been lately reported that in the upper reaches of the Tsukechi River the rhyolites always dip toward the northeast and the total thickness exceeds 2,500 m (YAMADA, 1967b). Moreover, the base of the rhyolites is intruded by the Naegi-Agematsu granite. Consequently, it is most likely that the thickness of such the order is not exceptional but is applicable to most of the areas where the rhyolites are distributed, and the average thickness may attain to 2,000 m.

I. 3. 3 Volume

Supposing the thickness is 2,000 m, the total volume of the mass would be 8,000 km^3. In view of the scale of volume of pyroclastic flow deposits, this value can be ranked as Order 7 after R. L. SMITH (SMITH, 1960a).

II. Outline of the Nōhi Rhyolites in the Hida Massif

The results of the writer's geological survey on the rhyolites in the area to the north of quadrangle G and H of the geological map (Fig. 2) have not yet published. The wholesale description of the rhyolites in the district is out of the scope of this paper, only some important facts are mentioned in this chapter.

II. 1 Relations between the Nōhi rhyolites and the basement

II. 1. 1 Hida belt

The rhyolites contact with the Funatsu granodiorites in the south of Furukawa-machi. In this area, which corresponds to the eastern margin of the rhyolites distribution, the boundary between the rhyolites in the west and the Funatsu granodiorite in the east is represented by a fault running NW-SE, parallel to the elongation of the rhyolites.

In the northwest of Furukawa-machi, the northern margin of the rhyolites is in contact with the Mesozoic Tetori group by the fault of E-W trends. However, small exposures of the Funatsu granodiorite and Mesozoic formation are exceptionally observed at a few places inside the terrain of the rhyolites. These small outcrops of the basement are covered by the rhyolites.

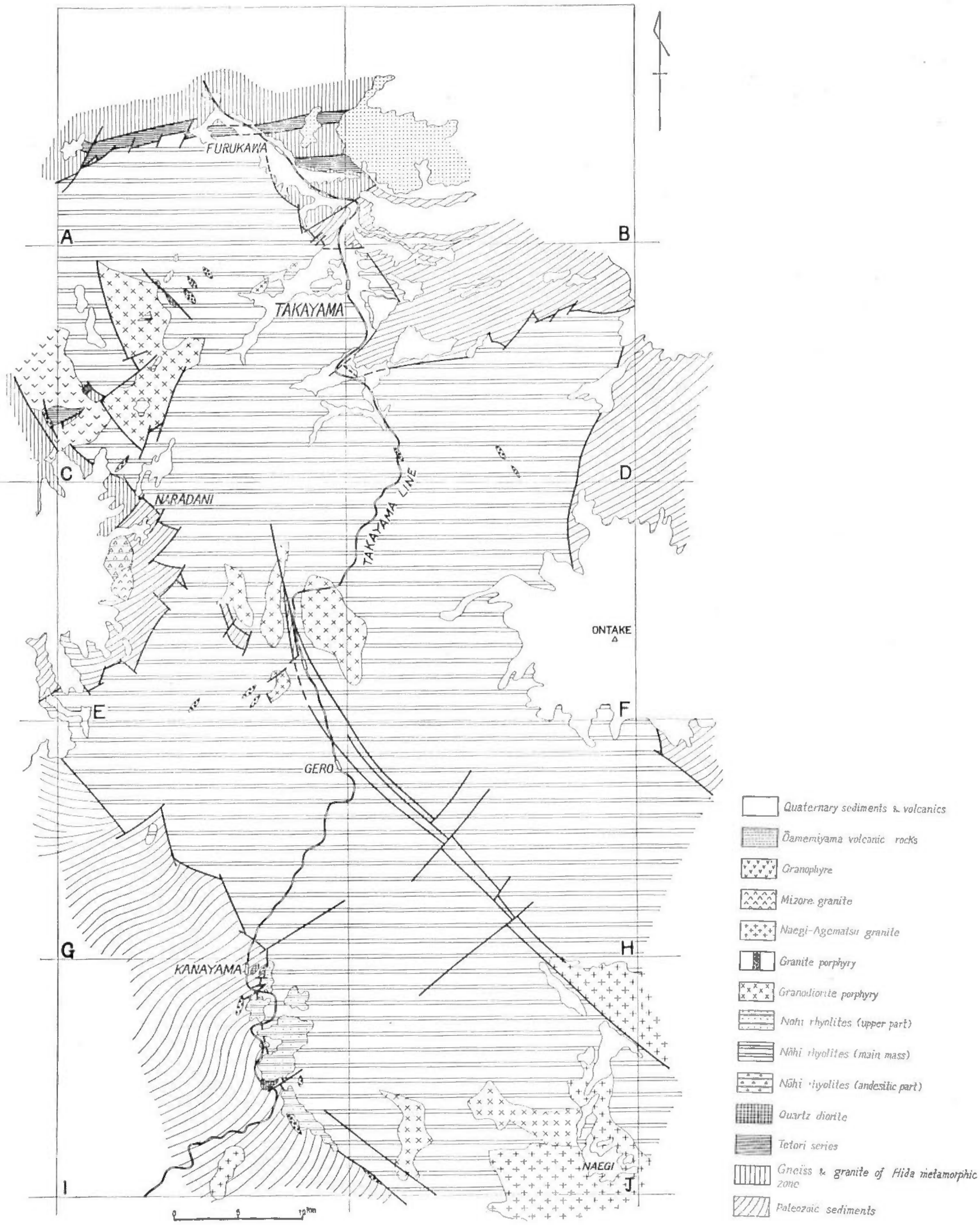


Fig. 2 Summarized geological map of the central and northern parts of the distribution area of the Nōhi rhyolites.

II. 1. 2 Hida marginal structural belt

The fault contacts between the rhyolites and the Paleozoic formation of the Hida marginal structural belt are observed in Takayama City and the area around Naradani. In both areas the faults have a trend of NNW-SSE, parallel to the elongation of the rhyolites. These faults correspond respectively to the eastern and western boundaries of the rhyolites.

II. 1. 3 Mino belt

The contacts between rhyolites and the Paleozoic formation on the west are exposed in a long distance between Naradani and Kanayama. The strike of the boundary faults between the two is either NW-SE or NE-SW in the Naradani area. While in the Kanayama area, the strike of the fault is predominantly NW-SE.

II. 2 Characteristics of the rhyolites

The Nōhi rhyolites in the southern Hida massif are composed mainly of rhyolite welded tuff as in the Mino massif, and comprise a small amount of andesite lava, andesite tuff breccia and clastic rocks.

II. 2. 1 Clastic rocks associated with rhyolites

Such clastic rocks as conglomerate, tuff, sandstone and shale are found to occur either as the basal constituents of the rhyolites or as intercalations.

The most remarkable development of the clastic rocks is seen in the south of Sakashita as shown in Fig. 3, where the predominant rock is tuffaceous conglomerate, with the thickness exceeding 200 m.

The conglomerate is composed of subround cobbles and a small number of

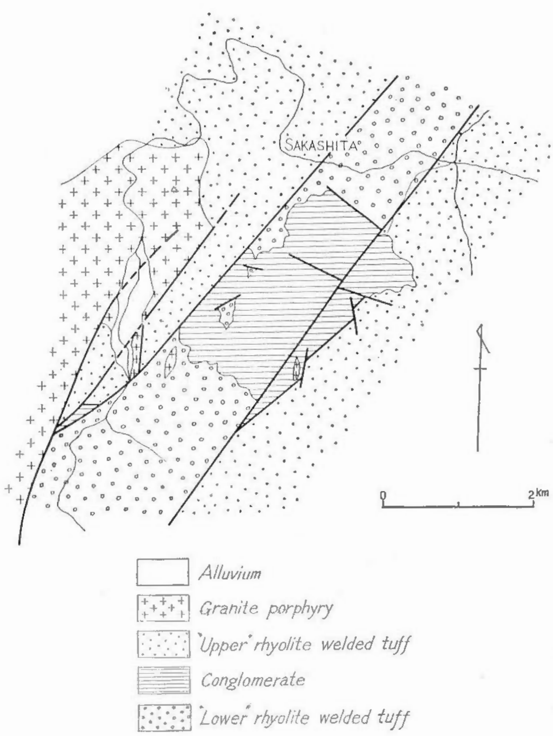


Fig. 3 Geological map around Sakashita, Kiyomi-mura in the Hida massif.

boulders of rhyolites welded tuff, Paleozoic sandstone, slate and chert of the northern part of Mino belt, and also black schist of the Hida marginal belt.

The matrix is tuffaceous, with little clastic material. Sorting is poor. The conglomerate dips towards the northwest gently, usually around 10°.

A bed of clastic rocks, consisting of tuff, sandstone and shale, is developed in the vicinity of Mikkamachi, as shown in Fig. 4. The bed, intercalated in the rhyolite welded tuff, is 20 to 30 m thick and almost horizontal.

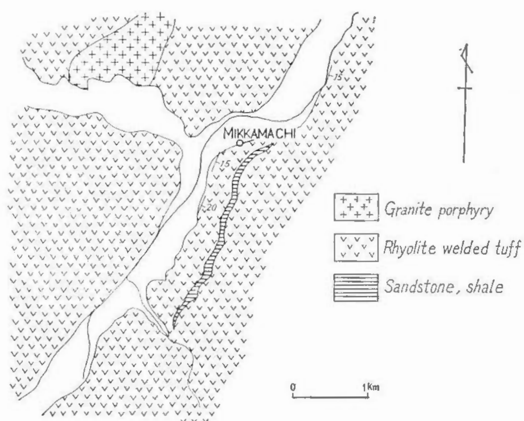


Fig. 4 Geological map around Mikkamachi, Kiyomi-mura in the Hida massif.

II. 2. 2 Andesite lava and andesite tuff breccia

In the area south of Naradani the andesite lava and andesite tuff breccia are found as isolated small mass inside the Paleozoic terrain.

They are accompanied by a small amount of rhyolitic tuff and tuff breccia. The relation with the main mass of the Nōhi rhyolites is not known. The rhyolitic tuff and breccia in the andesitic mass are not lithologically different from those of the Nōhi rhyolites. Therefore, the andesitic mass in question is tentatively included in the Nōhi rhyolites.

The andesite lava is dark gray and it is partly aphyric with glassy groundmass and partly porphyritic abounding in phenocrysts. The principal constituent minerals are labradorite, monoclinic pyroxene and orthorhombic pyroxene.

The tuff breccia contains block and lapilli of andesite lava, basalt lava and rhyolite welded tuff.

These andesitic rocks are intruded and thermally metamorphosed by the Mizore granite which is southerly extension of the Shirakawa granite. In the thermally metamorphosed andesite, veinlets of quartz are locally developed and the matrix shows a mosaic texture on account of recrystallization. Aggregates of scaly biotite are also recognized in the metamorphosed part.

II. 2. 3 Rhyolite welded tuff

The rhyolite welded tuff, constituting the major portion of the Nōhi rhyolites, is widely distributed throughout the area. It ranges from rhyolite to rhyodacite in composition. In general, it abounds in phenocrysts which amount to a maximum of 40% of the whole rock.

The principal phenocrysts are quartz, oligoclase~andesine, alkali feldspar, biotite, hornblende, monoclinic pyroxene and orthorhombic pyroxene. In many cases, however, biotite, hornblende and pyroxenes are altered to chlorite and clay minerals. Glass in the matrix has turned to quartz due to devitrification.

Some of the tuff retain a distinct welded texture, whereas in others the texture is indistinct. It is not known whether this difference is ascribed to the degree of welding or to a secondary effect such as alteration. Pumice lenses are recognized everywhere.

There are some portions containing especially large pumice lenses, several to more than ten centimeters in length. Welded tuff containing such large pumice lenses can be traced horizontally.

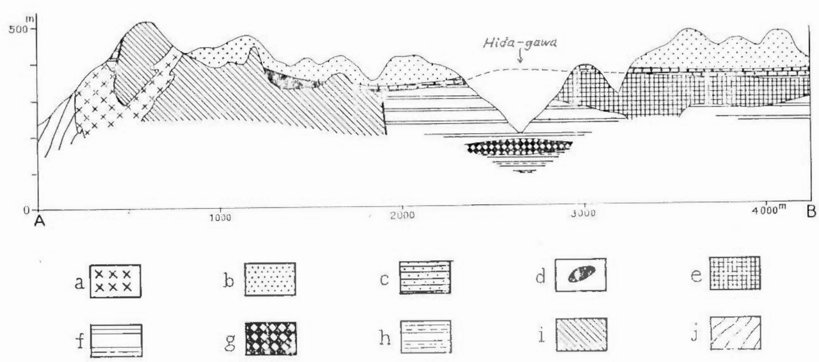
Around Mikkamachi, the rhyolite below the layer of clastic sediments abundantly contains large pumice lenses. The pumice is flattened and 5-6 cm in length, and shows dark green colour. The foliation plane presented by pumice lenses has the strikes of N10°~20°E and dips 20° towards the east (Fig. 4). Most of the clay minerals in the pumice lenses is sericites. The thickness of this characteristic rhyolite welded tuff is about 100 m and can be traced in the distance of several kilometers.

III. Geology of the Nōhi Rhyolites along the Hida River*

III. 1 Lithology and succession

III. 1. 1 Basement rocks

The basement of the Nōhi rhyolites along the Hida River is composed of the Paleozoic formation of the Mino belt. It generally consists of chert, sandstone and slate.



a: Granite porphyry b: Shirakawa rhyolites c: Utō bedded tuff
d: Shirakawaguchi formation e: Shimoyui rhyodacite lava
f: Kanayama rhyodacite welded tuff g: Breccia h: Undivided welded tuff i: Shinzu formation j: Paleozoics of chert facies

Fig. 5B Geological cross section of the Nōhi rhyolites along the Hida River.

* Geological map of the western margin of the Nōhi rhyolites along the Hida River (Fig. 5A) is annexed to this report in a pocket.

Paleozoics of chert facies

The general strike of the Paleozoic strata of the Mino belt is NNE-SSW. The Paleozoic formation along the Hida River has the general strikes of NE-SW. Being located in the Nōhi west-boundary sheared zone, the Paleozoic rocks suffered intense shearing. The sheared zone of this area is about 1 km wide. Sheared chert presents irregularly broken bedding plane and numerous fissures. Where the shearing is more intense, the rock is brecciated. Brecciated chert is milky white. The slate is mostly fissile and is broken into small pieces.

Shinzu formation (Paleozoics of non-chert facies)

Shinzu in the northern part of Shirakawa-machi (Fig. 6) is the type locality

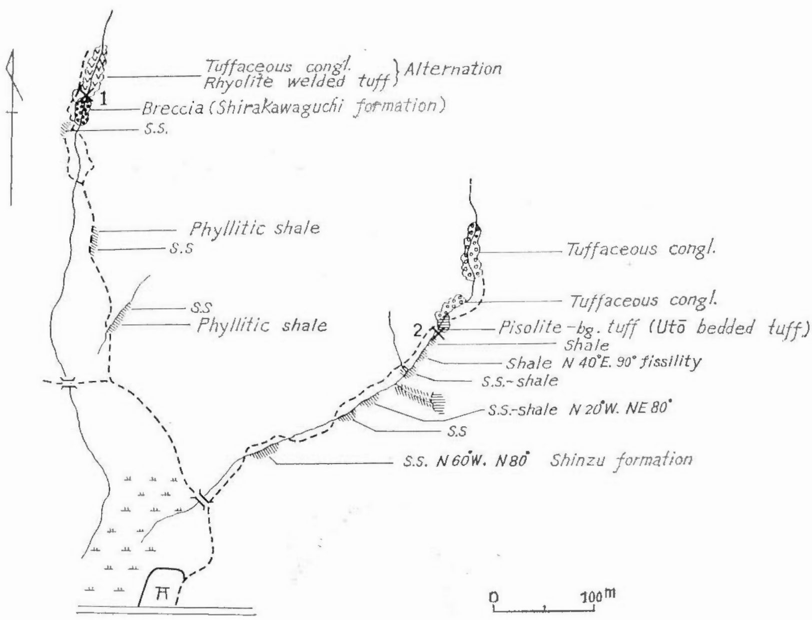


Fig. 6 Route map of the area north of Shinzu, Shirakawa-machi.

of this formation. The formation is in fault contact with the Hidagawa rhyolites which is the lower member of the Nōhi rhyolites. It is distributed along the western margin of the rhyolites, and its strike is NW-SE.

The slate is light brown or light greenish brown, and is highly fissile. The bedding plane has the strike of N20°W and dips 80° towards the northeast, or has the strike of N60°W with the same dip. These strikes are different from the general strike of the Mino belt or from that of the chert facies Paleozoics of this area. The slate occasionally shows original fine lamination.

The sandstone is mostly arkosic. A thin layer composed of small fragments of andesite and basalt, which is essentially the same with the "schalstein", is rarely included.

The boundary between the Shinzu formation and the Paleozoics of chert facies is demarcated by faults, so that their stratigraphical relation is not known.

III. 1. 2 Igneous rocks older than the Nōhi rhyolites

Igneous rocks that had intruded into the Paleozoic formation prior to the effusion of the Nōhi rhyolites are represented by quartz diorite. The quartz diorite is an intrusive rock occurring as stocks of a small scale. The quartz diorite is exposed in two places, east of Kanayama Station and near Kawamata of Shirakawa-machi, both located in the Paleozoic formation along the western margin of the rhyolites. The rock is fine to medium-grained hornblende-biotite quartz diorite, without schistocity.

In the neighborhood of Kanayama, the quartz diorite is intruded into the Paleozoic rocks and the contact metamorphic aureole is considerably extensive only in the Paleozoic rocks. No effects of metamorphism are found in the rhyolites situated very near to the quartz diorite. Therefore, the quartz diorite is concluded to be older than the Nōhi rhyolites.

In the neighborhood of Kawamata, Shirakawa-machi, the quartz diorite is intruded into the Paleozoic rock. The Paleozoic rocks are thermally metamorphosed by the quartz diorite. The quartz diorite is covered by the Shirakawa rhyolites which are the upper member of the Nōhi rhyolites. The former also occurs as pebbles in the conglomerate which is a member of the latter.

As already mentioned in Chapter I, the K-Ar age of biotite in this rock shows 97 m.y.

III. 1. 3 Basal clastic sediments of the Nōhi rhyolites

Ashidani formation

The Ashidani formation is distributed in the south of Tajima, Kanayama-machi. It is in fault contact with the Paleozoic formation and is unconformably overlain by the Shirakawa rhyolites. The formation consists of tuffaceous sandstone, siltstone, black shale and tuffaceous shale. The thickness, so far as observed in the field, is about 30 m. The bedding is distinct, partially showing fine lamination. Fissility is developed well along the bedding plane. Black shale contains fragments of carbonized plants and trail fossils. The tuffaceous shale in the uppermost part of the formation is not lithologically different from the tuffaceous shale occasionally contained in the Nōhi rhyolites.

Because the Ashidani formation is rich in rhyolitic material, the formation is supposed to be a member of the Nōhi rhyolites, probably the basal part of the Hidagawa rhyolites.

III. 1. 4 Stratigraphic division of the main part of the Nōhi rhyolites

The Nōhi rhyolites along the Hida River exclusive of the Ashidani formation can be divided stratigraphically into two parts. The stratigraphic succession and lithologic character of the rhyolites are given in Table 1.

The lower part of the Nōhi rhyolites is called the Hidagawa rhyolites, and the upper part the Shirakawa rhyolites. The two parts differ from each other not only in the structural relation with the Paleozoic basement but also in the depositional environment and lithology. In general the Utō bedded tuff, consisting of aquatic sediments, marks the boundary between the two parts. Where the Utō bedded tuff is absent, the basal conglomerate of the Shirakawa rhyolites unconformably covers the Hidagawa rhyolites in many cases. However, no definite evidence is available to show a gap in the period of emplacement of the two parts.

Table 1 Schematic succession of the Nōhi rhyolites along the Hida River

<table>
<tr><th></th><th colspan="2">Name of formation</th><th>Lithologic character</th><th>Thickness (in m)</th></tr>
<tr><td rowspan="7">Nōhi rhyolites</td><td colspan="2" rowspan="3">Shirakawa rhyolites</td><td>Rhyolite welded tuff</td><td>Upper limit unknown</td></tr>
<tr><td>Tuff-breccia ("Explosion breccia deposit")</td><td rowspan="2">250+</td></tr>
<tr><td>Tuffaceous conglomerate</td></tr>
<tr><td colspan="2">Utō bedded tuff</td><td>Tuff and tuffaceous sandstone</td><td>40~5</td></tr>
<tr><td rowspan="2">Hidagawa rhyolites</td><td>Shimoyui rhyodacite</td><td>Lava</td><td>80</td></tr>
<tr><td>Kanayama rhyodacite
Unclassified rhyodacite</td><td>Porphyritic welded tuff</td><td>300+
Lower limit unknown</td></tr>
<tr><td colspan="2">Ashidani formation</td><td>Tuffaceous sandstone and shale</td><td>30+</td></tr>
<tr><td>Basements</td><td colspan="2">Shinzu formation
Paleozoics of chert facies</td><td>Sandstone and clayslate</td><td></td></tr>
</table>

III. 1. 5 Hidagawa rhyolites

Table 1 shows the succession and lithologic character of the Hidagawa rhyolites. The welded tuff, constituting the main mass of the Hidagawa rhyolites exposed along the Hida River, is divided into two parts, with a bed of breccia in between. The part above the breccia bed is called the Kanayama rhyodacite. However, the welded tuffs above and below the breccia can not be lithologically distinguished from each other. Therefore, where the breccia bed is not recognized, it is impossible to divide the welded tuc. The thickness of the Kanayama rhyodacite is about 300 m. However, thickness of the rhyolites below the breccia is unknown.

Kanayama rhyodacite welded tuff

On account of the advanced crystallization as a whole, a distinct welded texture is retained only in small portions. But the rock partially abounds in pumice lenses, and the structure can be inferred from the foliation plane indicated by the arrangement of these pumice lenses. The strike of the foliation plane is variable along the Hida River, but the dip is generally gentle, being 10 to 25° (Pl. XI-1).

The rock is light gray or bluish gray and abounds in phenocrysts throughout. The amount of accidental fragments such as Paleozoic rocks varies from place to place. The volumetric ratio of phenocrysts in the rock is about 45%.

Breccia

The breccia is exposed in the cutting of National Highway No. 41, south of Shimoyui Station of the National Railways Takayama Line. In this outcrop the breccia is 10 to 15 m thick. Bedding is indistinct, but the breccia as a whole is nearly horizontal. It is composed of angular fragments of chert, sandstone and slate of the Paleozoic strata. Fragments are occasionally as large as several tens of centimeters in diameter. The matrix is composed chiefly of fine pieces of Paleozoic rocks, accompanied by small fragments of welded tuff and ash, and these are irregularly intermixed. The breccia is supposed to be the basal facies of the Kanayama rhyodacite welded tuff. Due to the construction work of the national highway the greater portion of the outcrop became invisible. Similar breccia, 30 m thick, is known at Kuzumaki.

Shimoyui rhyodacite lava

The Shimoyui rhyodacite lava is distributed along the east bank of the Hida River south of Shimoyui Station. The rock has a distinct flow structure with the strike of N-S or N20°E, with a dip 20~30°. It dips towards the west in the western end of the mass but the east in the central part. The rock is probably a dome-like intrusive body having a vent somewhere near its center. It penetrates the Kanayama rhyodacite welded tuff and covers the latter, and is overlain by the Utō bedded tuff.

The rock is a light greenish gray lava showing a porphyritic texture. No accidental fragments are contained.

III. 1. 6 Utō bedded tuff

The Utō bedded tuff is a sedimentary formation intercalated between the Hidagawa rhyolites and the Shirakawa rhyolites. Its thickness is not uniform, ranging from 5 m to 40 m. It consists of fine-grained compact tuff, tuffaceous sandstone and tuffaceous conglomerate in alternation, and is well bedded in general. In the north of Shinzu the Utō bedded tuff unconformably rests on the Shinzu formation without intervening of the Hidagawa rhyolites and is covered by the Shirakawa rhyolites. It is generally horizontal, and in the north of Shinzu it dips 5° towards the northeast (Pl. IX-1, 2).

In the north of Shinzu (Fig. 6), the fine-grained tuff in the upper part contains pisolites. The pisolites (Pl. VIII-1) are spherulitic or oval, 3 to 6 mm in diameter. The core part of the pisolite contains broken pieces of quartz and feldspar, whereas the crustal part is composed of dense salic minerals.

The fine-grained tuff exposed in the southeast of Shirakawa-machi also contains pisolite. The tuff of this locality shows cross lamination and is evidently subaqueous deposits.

III. 1. 7 Shirakawaguchi formation

The Shirakawaguchi formation, occurring in the north of Shirakawa-machi (Fig. 6), is an unusual type of breccia unconformably overlying the Paleozoic formation. The thickness is variable, and attains to about 50 m at maximum.

The formation is developed at the base, or just above the base, of the Shirakawa rhyolites.

At its type locality north of Shinzu, the formation is intercalated with a thin bed of welded tuff, and its facies is different between above and below this welded tuff (Fig. 7).

The Shirakawaguchi formation below the welded tuff bed (Pl. X-2) is about 30 m thick. It is a pile of the sheared material of the Paleozoic sandstone, slate and chert. Angular fragments of various sizes, including boulders, are irregularly intermixed. In some places, boulders of sheared chert as large as 2 m in diameter are found. Some of the sandstone fragments are 0.5 to 1 m in diameter. The Shirakawaguchi formation above the welded tuff is mostly composed of angular fragments of sheared chert. The size of the chert fragments is variable, and some are as large as several meters in diameter while others are only several centimeters across. The matrix is composed chiefly of fine pieces of chert, with

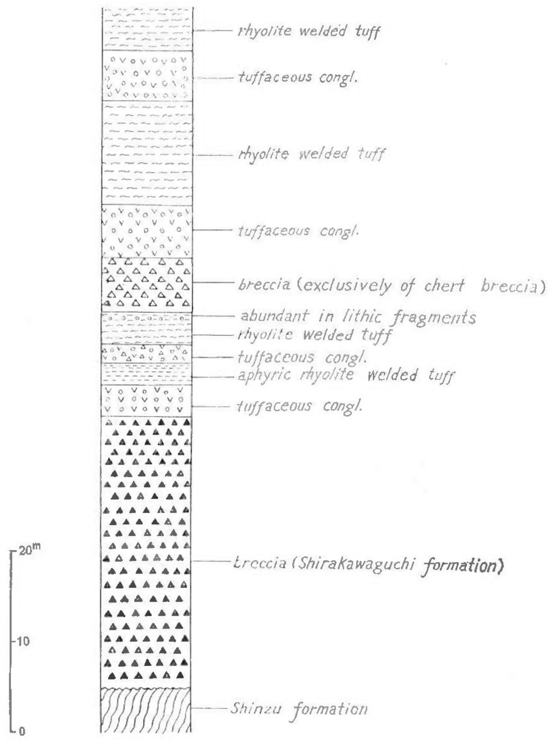


Fig. 7 Idealized column of the Shirakawaguchi formation and the Shirakawa rhyolites (north of Shinzu, Shirakawa-machi).

a small amount of ash. The thickness varies from 7 m to 20 m.

The Shirakawaguchi formation is considered to be a kind of old talus breccia deposited along the lower part of the fault scarp which belongs to the Nōhi west-boundary sheared zone. It is very loose and tends to be easily eroded out. Such a loose deposits might be preserved by immediate accumulation of cover bed. The tuff of the Shirakawa rhyolites played a role of the protecting cover bed.

In conclusion, the faulting movement which caused accumulation of the pile of breccia of the Shirakawaguchi formation, was one of the subsequent movements of the Nōhi west-boundary shared zone and succeeded by the effusion of the Shirakawa rhyolites.

III. 1. 8 Shirakawa rhyolites

The Shirakawa rhyolites cover the Utō bedded tuff. In the west of Shinzu the rhyolites are overlapping the Paleozoic strata and unconformably cover the latter. Along the west bank of the Hida River north of Shirakawa-machi, the rhyolites are unconformable with the underlying Hidagawa rhyolites.

The Shirakawa rhyolites consist of tuffaceous conglomerate, tuff breccia and welded tuff (Fig. 7).

What is called tuff breccia comprises explosion breccia deposit, which is a kind of air fall deposit, and pyroclastic flow deposit. At Shinzu, in the northern part of Shirakawa-machi, the Shirakawaguchi formation is developed at the base of the Shirakawa rhyolites. In the north of Shinzu, at least, three beds of welded tuff are recognized. The thickness of each bed in the Shirakawa rhyolites is 10～30 m, much thinner than the welded tuff in the Hidagawa rhyolites. Welded tetxture is usually distinct.

1) Tuffaceous conglomerate

The tuffaceous conglomerate is developed, in many places, at the base of the Shirakawa rhyolites, but is found occasionally intercalated between pyroclastic flow deposits. It is composed mostly of fragments of welded tuff and Paleozoic rocks. Many of the fragments of welded tuff, ranging in diameter from several to 200 cm, are worn to subround forms. The characteristics of these fragments are similar to those of the welded tuff in the Hidagawa rhyolites. Fragments of the Paleozoic chert, sandstone and slate are mostly subangular in form, ranging from several centimeters to 1 m in diameter. Sorting is not recognized in general. The matrix is composed of fine pieces of Paleozoic rocks accompanied by fragments of rhyolites and ash (Pl. X-2).

2) Tuff breccia

What is called tuff breccia here comprises two or three types of different origins. One of them is an air fall deposit, consisting of pieces of basement rocks broken by explosion. Tuff breccia of this type generally contains a great quantity of accidental fragments. The other type is a pyroclastic flow deposit. After leaving the vent the pyroclastic flow in hot condition was transported over a short distance, and accumulated in the area not very far from the vent. Irregular-shaped essential materials are abundant in the tuff breccia of this type.

Classification of the tuff breccia is difficult because of poor outcrops. Also, whether the deposition took place on the ground surface or in the water cannot be determined, since available information is scanty. However, the greater part of the tuff breccia seems to have accumulated on the ground surface.

There is another type of tuff breccia, an explosion breccia deposit. In many cases this type can be easily distinguished by the constituents and by the presence or absence of grading. On account of the unique features of essential materials and the absence of sorting, the writer has discriminated this explosion breccia deposit from a normal current deposit.

The following description is based on the representative outcrops of the tuff breccia in the Shirakawa rhyolites.

Explosion breccia deposit

It consists largely of fragments of Paleozoic rocks. It also comprises, as an accessory fragment, the rhyolite welded tuff fragments. Accidental breccia is composed of Paleozoic chert, sandstone and slate. The kind and volumetric ratio of fragments are locally variable. In an area where the Paleozoic chert makes the basement, the explosion breccia abounds in chert fragments. The size of fragments is usually several to more than ten centimeters in diameter, occasionally as large as several tens centimeters. The matrix consists of small pieces of fragments and ash. The thickness ranges from 3 m to 10 m. A weak grading is noticed.

Tuff breccia rich in essential material

The tuff breccia abounding in essential material alternates often with welded tuff. It consists of fragments of Paleozoic chert, sandstone and slate. It also contains rhyolite welded tuff or non-welded rhyolite tuff as accessory fragment. The essential material is irregular in shape and presents a "pseudo-conglomerate" feature.

Fragments of Paleozoic rocks are subangular to subround, but those of thyolites occurring as accessory fragment are generally better in roundness. The essential material is mostly rhyolite welded tuff, with subordinate amounts of pumice and non-welded rhyolite tuff. In many cases the essential material shows a lenticular elongation or occurs as irregularly torn pieces. The peripheral part of the essential material is irregularly interfingering with the matrix, so that the boundary is not clear. This fact indicates that the essential material was deposited and deformed before it was completely solidified.

The matrix is dark gray in color, and is composed of glass shards, crystal fragments, lithic fragments and ash. The tuff breccia is 5 ~ 20 m thick, and sorting is not recognized.

3) Welded tuff

The welded tuff is rhyolitic and alternates with the above-mentioned tuff breccia. The maximum thickness of a flow unit is 50 m.

The rock is dark gray or light blue when fresh. The welded texture is usually distinct. The foliation plane, according to the arrangement of the pumice lenses contained therein, is almost horizontal except for the part near the vent.

III. 1. 9 Igneous rocks younger than the Nōhi rhyolites

In the western margin of the Nōhi rhyolites along the Hida River, development of dikes is remarkable, penetrating both Hidagawa and Shirakawa rhyolites. The dikes also intrude the Paleozoic formation along the western margin. Most of the dikes are granite porphyry, though quartz porphyry and felsite are also found. These dikes are distributed throughout the distribution area of the Nōhi rhyolites, but they are especially developed in the western margin of the Nōhi rhyolites along the Hida River.

Small dikes are several meters in width and large ones are as wide as several hundred meters. In most cases the trend of intrusion is nearly N-S.

The large dikes of granite porphyry in the northwest of Shinzu brought about a thermal metamorphism in the surrounding Paleozoic formation and rhyolites.

The granite porphyry has a conspicuous porphyritic texture. Especially the rock penetrating the vent-breccia below the Shichisō bridge contains large phenocrysts of alkali feldspar, attaining to 5 cm in diameter. Along its contact with the wall rocks the dike shows a fine-grained facies, about 20 cm wide, where phenocrysts of alkali feldspar are smaller, 1 ~ 2 cm in diameter (Pl. XII-I).

III. 2 Vent-breccia

Vent-breccia has been discovered in two places, Tajima of Kanayama-machi and Kuzumaki of Shirakawa-machi, along the Hida River, but is known in no other parts of the whole distribution area of the Nōhi rhyolites. These localities of the vent-breccia are in the present river-bed of the Hida River, where dissection is most advanced. Distribution of the vent-breccia is roughly along the boundary between the Hidagawa rhyolites and the Paleozoic formation.

The vent-breccia of Tajima is exposed along the Hida River for a distance of 800 m, with a maximum width 500 m. The vent-breccia of Kuzumaki is exposed also along the river for about 600 m, but the outcrops are poorer than those at

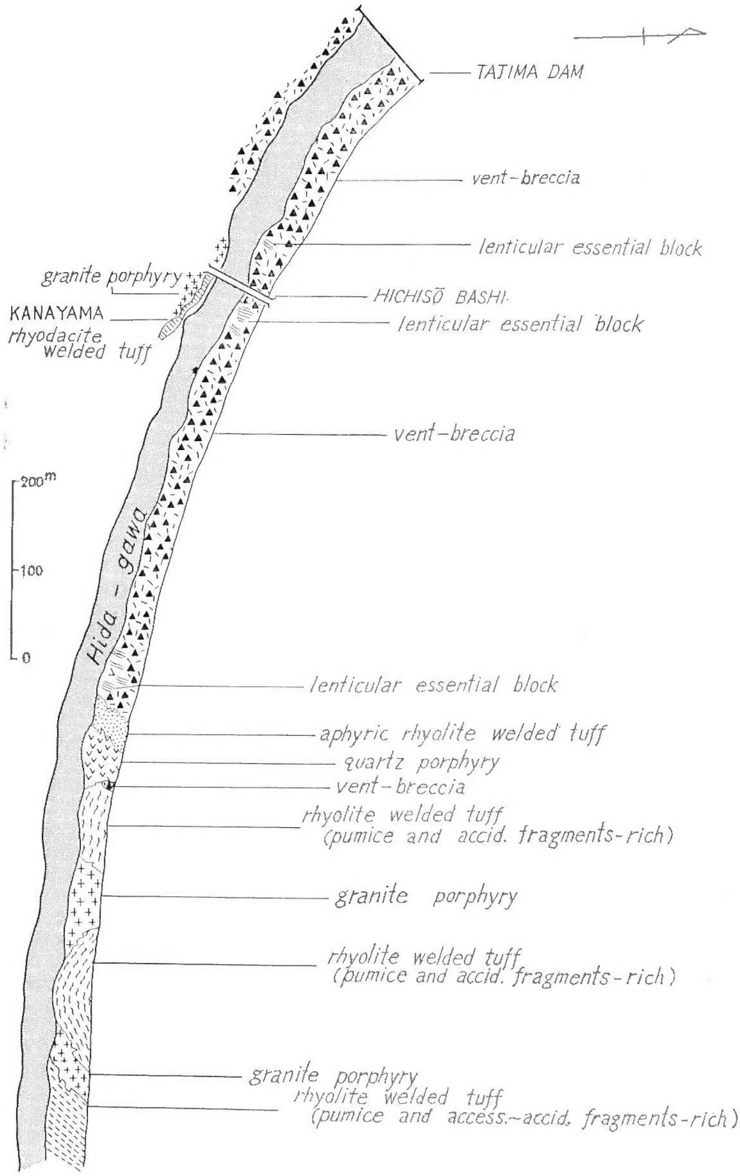


Fig. 8 Geological route map of the area where vent-breccia is exposed, south of Tajima, Kanayama-machi.

Tajima. The following description is based on the vent-breccia of Tajima.

The vent-breccia is bounded by the faults both from the Paleozoic formation and the Hidagawa rhyolites, and is covered by a part of the Shirakawa rhyolites. Dikes of granite porphyry and quartz porphyry are developed around the vent-breccia and intruded into the latter.

III. 2. 1 Description of the vent-breccia

The vent-breccia is composed mainly of essential materials, accessory and accidental blocks and the matrix. The essential material has a "pseudo-pebble" feature or a slender lenticular shape.

Essential material

Essential material is found throughout the area where the vent-breccia is distributed. It is dark gray to light gray in color, and abounds in crystals, crystal fragments and glass shards.

Blocks of essential material showing a "pseudo-pebble" feature are several centimeters to 1 m in diameter. Their margins are irregularly interfingering with the matrix, so that the boundary is not distinct.

Essential material of lenticular or narrowly elongated type has strange shapes (Pl. XIII-2). Some have flame-like tapering ends, while others look like a bunch of clouds intermingled with the matrix. Sometimes these are torn to pieces and scattered throughout the matrix.

Elongated ones are several centimeters to 1 m long, and are aligned vertically. The strike of the alignment is N20° $\sim$ 30°E, so far as the measurement was possible.

Accessory block

Most of the accessory blocks are rhyolitic to rhyodacitic welded tuff, rarely with non-welded tuff. They have subangular or subround shape of various sizes, ranging in diameter from 10 cm to 2 m (Pl. XIII-1). The boundary between the accessory blocks and the matrix is distinct. In some blocks of welded tuff, a foliation plane due to pumice lenses is observed but its strike is not uniform. Many of large blocks have their longer diameter in the vertical direction.

Accidental block

The accidental blocks are Paleozoic chert, sandstone and slate, several centimeters to 1 m in diameter. A large quantity of much smaller pieces is also contained. Sorting is not recognized.

"Pseudo-pebble"

The "pseudo-pebble" is sandstone and mudstone differing in facies from the Paleozoic formation. Judging from the lithologic character this "pseudo-pebble" was derived probably from the clastic sediments associated with the Nōhi rhyolites. The blocks are several tens centimeters to several meters in diameter.

In some cases blocks showing stratification are contained. The boundary between the blocks and the matrix is irregular and indistinct.

Matrix of the vent-breccia

The matrix is dark gray and consists of glass shards, crystals and crystal fragments of quartz, alkali feldspar and plagioclase, accompanied by broken pieces of welded tuff and accidental material and fine dust. It shows a vitroclastic texture.

Microscopic character of the essential material

The essential material abounds in phenocrysts and their fragments. The volumetric ratio of phenocrysts exceeds 60%.

Phenocrysts are quartz, oligoclase $\sim$ andesine, alkali feldspar and biotite. Chlorite, sericite, and carbonate minerals are found as the secondary minerals.

In the matrix minute salic minerals are developed. The matrix partially shows a structure of long-stretched glass shards.

III. 2. 2 Consideration of the vent-breccia

Summarizing the above description, the features of the unusual "breccia" differing from normal conglomerate or tuff breccia will be given below.

1) The greater part of the matrix is composed of glass shards and crystal fragments as essential material. Coarse or fine clastic material derived from Paleozoic formation is scanty.

2) Inside the "breccia" are found numerous essential blocks presenting a "pseudo-pebble" feature or a slender lenticular shape. The lenticular blocks are aligned in the vertical direction.

3) Boulders of welded tuff occurring as accessory blocks are arranged with their longer diameter in the vertical direction. The rhyolites in the vicinity do not show an upright structure.

4) Sorting as commonly observed in normal conglomerate is entirely absent in the "breccia".

Possible causes of such a unique type of breccia are as follows:

a) As the "breccia" is distributed along the boundary with the Paleozoic formation in the western margin of the Nōhi rhyolites, the "breccia" may be regarded as a basal conglomerate. However, the features in 1), 2) and 4) deny this possibility.

b) Its position near the west-boundary sheared zone suggests a possibility of fault breccia. But, no evidence of shearing by faulting is found in the "breccia".

c) Intrusive breccia is out of the bounds of possibility for the reason given in 1).

Thus, the only possibility remains in referring this "breccia" to vent-breccia. By accepting this "breccia" as a vent-breccia, its characteristic mode of occurrence can be reasonably explained. Therefore, the writer has determined that this "breccia" is a vent-breccia.

The writer thinks that the cause of the vent-breccia was as follows:

After the vent was opened, vesiculation of the magma advanced rapidly, and large quantities of blocks and fragments of the vesicular magma were erupted out. After that, the gas pressure lowered rapidly and the eruptive activity waned remarkably. The ejecta of this stage were unable to fly over a large distance, so they fell and accumulated around the vent. This deposit may occasionally have fell into the vent secondarily and filled it, but such a portion seems to be small, so far as the vent at Tajima is concerned. Most of the vent-breccia must have come into existence when the ejecta were solidified within the vent, without having been thrown out high into the air as the gas pressure had lowered. The slender elongate form of the essential material seems to indicate that a part of the vesicular magma was in a "plastic" state, and it ascended through the vent to get into the vent-breccia which was not completely solidified yet.

III. 3 Mode of emplacement

The succession and division of the Nōhi rhyolites along the Hida River were mentioned in Chapter III. 1. 4.

As stated already, the Hidagawa rhyolites and the Shirakawa rhyolites of this area are noticeably different not only in the lithologic character but also in the structural relation with the Paleozoic formation and in the depositional environment. In this section, the two groups of rhyolites are compared and their made of emplacement is discussed.

Judging from the lithology and the thickness of cooling unit, exceeding 100 m, the Hidagawa rhyolites can be correlated to some parts of the thick pyroclastic flow deposits along the upper reaches of the Tsukechi River northeast of this area. The Shirakawa rhyolites are local pyroclastic flow deposits, because the distribution is limited along the Hida River in the western margin of the Nōhi rhyolites.

III. 3. 1 Hidagawa rhyolites

The Hidagawa rhyolites distributed along the Hida River are in most places in fault contact with the Paleozoic formation of the western margin. The very contact other than the fault relation is observed only in the west bank of the Hida River, beneath the Kuzumaki bridge west of Kuzumaki, where the Hidagawa rhyolites abut on the cliff of the basement Paleozoics.

There is no field evidence to indicate that the Hidagawa rhyolites were distributed farther west, stretching from the present location toward the Paleozoic massif. It is most likely that the above-mentioned cliff of the basement was preexistent before the Hidagawa rhyolites were being accumulated. This cliff seems to be a product of an early stage of the graben which was formed in association with the west-boundary fault-sheared zone. The cliff along the western margin had the character of a fault scarp and made the boundary between the Paleozoic formation and the Hidagawa rhyolites. The Hidagawa rhyolites were checked by this wall and could not advance beyond it. In a depression that was formed near this fault scarp on the slope of the Paleozoic massif, shallow water deposits such as the Ashidani formation, consisting of tuff of sedimentary origin, were laid down.

The main mass of the Hidagawa rhyolites consists of pyroclastic flow deposits, the greater part of which is welded tuff.

The pyroclastic flow deposits, whose cooling unit exceeds 100 m in thickness, buried the graben successively. Through repeated accumulation and subsidence of the pyroclastic flow deposits, the graben gradually became deep. The subsidence is due to a volcano-tectonic depression.

At about the time when the graben was almost filled up, the Utō bedded tuff of sedimentary origin was accumulated along the western margin. The Utō bedded tuff covered not only the Hidagawa rhyolites but also part of the Paleozoic formation west of the fault scarp.

Nearly contemporaneous with, or immediately after, the deposition of the bedded tuff, faulting occurred in the Paleozoic formation on the west side of the fault scarp. The Shirakawaguchi formation is a product of this movement.

III. 3. 2 Shirakawa rhyolites

The Shirakawa rhyolites are a product of the eruption of a lesser scale compared with the Hidagawa rhyolites. After the graben was filled up by the Hidagawa rhyolites, volcanic activity took place again accompanying faulting along the western margin of the graben. The product of the eruption of this period is the alternation of air fall deposits with clastic material and pyroclastic flow deposits.

The Shirakawa rhyolites overlapped the Paleozoic massif on the west side of the fault scarp and unconformably covered the Paleozoic formation.

III. 3. 3 Vent of the rhyolites

The source area of the Nōhi rhyolites is undoubtedly within the area now covered by the rhyolites. As to the Shirakawa rhyolites, the vent-breccia has been found along the Hida River. Obviously the center of eruption for the Shirakawa rhyolites was located in the western margin.

Within the distribution area of the Hidagawa rhyolites, no vent or vent-breccia has been found. The vent for the Hidagawa rhyolites must have been located in the east, somewhere inside the graben, and the pyroclastic flows might have moved westward until the advance was stopped by the fault scarp in the western margin.

III. 4 Geologic history

In the preceding section, the writer considered the mechanism of formation of the rhyolites and the process of tectonic development.

In this section the geologic history of the rhyolites is outlined.

1a) In the basement Paleozoics along the western margin of the rhyolites, a remarkable fault-sheared zone was developed. The formation of this zone preceded the effusion of the rhyolites.

1b) The quartz diorite intruded into the fault-sheared zone.

2) In the Paleozoic massif a small depression was formed due to the faulting in the western margin, and in this depression the clastic sediments (Ashidani formation) were laid down. During this period the initial effusion of the Hidagawa rhyolites began.

3) Through the repeated effusion of pyroclastic flow of a large scale and volcanotectonic depression which probably accompanied the effusion, thick deposits were accumulated. The main mass of the Hidagawa rhyolites was formed during this period.

4) As the volcanism waned, a shallow water deposit and a tuff of sedimentary origin (Utō bedded tuff) were deposited.

5) The structurally unstable western margin was subjected again to faulting and volcanic explosion. During the period the Shirakawaguchi formation was formed, followed by the deposition of the Shirakawa rhyolites.

6) After the rhyolites were formed, dikes of granite porphyry and quartz porphyry intruded the Paleozoic formation and the rhyolites.

IV. Petrology

IV. 1 Description of rocks

IV. 1. 1 Quartz diorite, granite porphyry and quartz porphyry

Quartz diorite

The quartz diorite is gray to pale gray in color, medium-grained and equigranular (Pl. I-2). Variation of megascopic features is scarcely observed in this intrusive mass. Typical quartz diorite commonly contains plagioclase as many as 50% in volume, accompanied by quartz, alkali feldspar, biotite, hornblende and opaque iron minerals.

Plagioclase occurs as euhedral tablets showing normal sequence of zoning. Albite twin lamellae are often accompanied by twins after pericline or carlsbad

Table 2 Modal analysis of the quartz diorite

Mineral	Volume percent
Quartz	22.2
Plagioclase	55.5
Alkali feldspar	5.3
Biotite	8.7
Hornblende	8.3
Total	100.0

law. Judging from that the refractive index of plagioclase is; $\alpha \leqq 1.543$ and $\gamma \geqq 1.562$, the composition of the plagioclase ranges An 28 to An 50.

Biotite occurs as euhedral tablets or subhedral plate, and inclusions in it are commonly apatite, zircon, and iron opaque minerals. The pleochroism is distinct: Z=Y, light brown to reddish brown; X, yellow pale brown. γ of biotite is 1.655 $\pm$ 0.001.

Hornblende is commonly pale green in color, and occurs in euhedral and prismatic form, measuring 1~2 mm in length. Some of hornblende is altered to chlorite.

Quartz and alkali feldspar are anhedral and interstitial.

Granite porphyry

Granite porphyry occurs in a dike swarm, just along the western margin of the Nōhi rhyolites. The rock is pale greenish gray to pale green in color. It contains large phenocrysts of a alkali feldspar, plagioclase, quartz, biotite and hornblende (Pl. XII-2). Groundmass is holocrystalline and micrgranitic. Essential constituents of the groundmass are quartz, alkali feldspar and plagioclase. Alkali feldspar reaches as large as 4 mm long, and is sometimes altered to kaolinite and fibrous sericite.

Quartz porphyry

Quartz porphyry occurs as a dike, and intruded in the Paleozoic rocks or the Nōhi rhyolites in areas along the Hida River. The rock is dark to pale gray in color, and porphyritic in texture (Pl. II-1). Main constituent minerals of the phenocryst are quartz, alkali feldspar, plagioclase and biotite. Groundmass is composed of microcrystalline to cryptocrystalline aggregates of quartz.

IV. 1. 2 Rhyolite~rhyodacite welded tuff

The main phenocryst minerals of the Nōhi rhyolites are quartz, alkali feldspar, plagioclase, biotite, hornblende, monoclinic pyroxene, orthorhombic pyroxene and opaque minerals.

Orthorhombic pyroxene is observed in a small amount in some rhyolite welded tuffs whereas it is abundant in some rhyodacite lava and welded tuff (Pl. III-1, IV-1). Olivine is present in a few rhyolite welded tuffs.

Apatite, zircon, sphene, and allanite are accessory minerals mainly in welded tuff.

As alteration products, chlorite, calcite, sericite, epidote are seen in rhyolite and rhyodacite welded tuff.

Most phenocrysts are scattered isolatedly but sparse glomeroporphyritic clots of pyroxene and plagioclase are found in some welded tuffs.

Matrix

The matrix of welded tuff is gray or pale bluish gray in color. The length of essential pumice lenses are generally less than 5 cm (Pl. V-1). Accessory and accidental lithic fragments and crystal fragments, mainly quartz and plagioclase, are generally abundant.

The matrix is composed mainly of glass shards and devitrified material from them (Pl. V-2, VI-1, 2). Devitrified products are mainly quartz, and a small amount of alkali feldspar. Commonly chlorite, sericite and carbonate minerals are alteration products, and epidote is also present in a few welded tuffs.

Microscopically, the welded tuffs are characterized by flattened and deformed wedge-shaped glass shards or streaks of devitrified glass which are bent around lithic fragments and crystals.

Some quartz and plagioclase phenocrysts in the collapsed pumice lenses are generally deformed by compression during the emplacement.

Frequently the collapsed pumice lenses in the welded tuffs altered to pale green or colorless fibrous sericite.

The main matrix minerals and the texture of the welded tuff are considered to have been formed by welding and crystallization after turbulent pyroclastic flow deposits accumulated.

The matrix of these acid pyroclastics has not been studied on the Cretaceous rocks in detail. According to the author's investigation under the microscope, quartz and alkali feldspar are dominant in most specimens. These minerals are usually less than 0.03 mm in diameter, but collapsed pumice lens in the interiors of dense welding part commonly crystallizes to intergrowth of alkali feldspar and quartz measuring as long as 0.3 mm (granophyric crystallization described by R. L. S/ITH, 1960b, p. 152–153).

Spherulitic radial intergrowth of quartz and alkali feldspar is found in some welded tuffs.

Phenocryst

Quartz is abundant but rare as euhedral and bipyramidal form. Most of quartz phenocrysts are fragments of subhedral and anhedral shape. Large bipyramidal quartz phenocryst reaches about 4 ~ 5 mm long, but commonly 2 ~ 3 mm. Some quartz phenocrysts are somewhat resorbed, and invaded by the matrix substances showing corroded form. Quartz phenocryst often contains many fluid inclusions with bubbles which concentrated along curved cracks.

Many plagioclase phenocrysts occur in euhedral or subhedral prismatic form. Most of plagioclases show zonal structure. Especially in some rhyodacite welded tuffs, strongly zoned plagioclase phenocrysts are common. Plagioclases, as estimated by refractive indices and maximum extinction angles using the high-temperature curves after DEER et al., (1963), are mostly calcic oligoclase and andesine. Some optical characters of plagioclases are shown in Table 3.

Alkali feldspar occurs as stout tabular to euhedral phenocrysts which are generally 1 ~ 2 mm long and occasionally reach as large as 4 ~ 5 mm. It rarely exhibits twinning. Perthitic and cryptoperthitic structure are recognized in some large phenocrysts. Characteristic microcline lattice structure is absent or not clear. Occasionally large single crystals show heterogeneous wavy extinction. The optic angles average about $40° \sim 50° (-)$. An alkali feldspar has the optic angle $40° (-)$ and refractive index 1.525 ± 0.001 (β).

Biotite occurs in subhedral to anhedral plate. It is mostly altered to chlorite or bleached colorless sericite. In many chloritized biotite crystals, sphene,

Table 3 Optical properties of phenocrysts in the rhyolite welded tuff

Number \ Mineral	Plagioclase		Alkali feldspar		Monoclinic pyroxene		Rhombic pyroxene		Olivine		
Refractive index & 2V	α	γ	2V(−)	β	2V(+)	β	α	γ	2V(−)	α	γ
a KY 123	1.545	1.563	40°	1.525	50°	1.711	1.721	1.739	45～50°	1.800	1.843
b K 220	1.540	1.558									
c TK 28	1.550	1.571									
d T 65	1.543	1.565	51°								
e K 601	1.545	1.561									

a & b: Shirakawa rhyolite welded tuff c: Unclassified dacite crystal tuff
d: Unclassified dacite welded tuff e: Granite porphyry

ilmenite, and magnetite have also formed as alteration products. Unaltered biotite is commonly colored with dark brown to moderate brown (Z, Y) and moderate yellow to pale yellow (X). Some biotite phenocryst in olivine-bearing rhyolite welded tuffs is green.

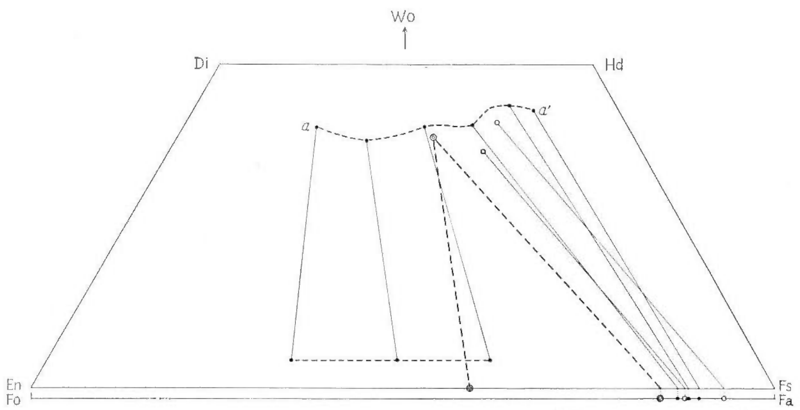
Amphibole can be divided in two groups; common hornblende and cummingtonite. Common hornblende is euhedral or subhedral and greenish brown in color. The size of hornblende is 1～2 mm long. Sometimes pale green common hornblende or colorless cummingtonite appear as mantles on pyroxene crystals, along cleavage and cracks, and also as nearly complete pseudomorphs. The phenomenon suggests that both hornblende and cummingtonite were formed from pyroxenes. Inclusions are common and mostly are opaque minerals, apatite, plagioclase and sphene.

Monoclinic pyroxene occurs in euhedral to subhedral prismatic form. It is usually 1 ~ 2 mm long but sometimes as large as 3 ~ 4 mm. It is very pale green and slightly pleochroic. The optic angle (2V+) of one specimen is 51° ±3° and refractive index is; β = 1.711±0.001, then it is referred to a composition of $En_{27}Fs_{34}Wo_{39}$ (HESS, 1949).

Orthorhombic pyroxene crystals generally are long or short stout prisms (Pl. VI-1, 2). They are pale rose green and moderately pleochroic. The refractive index of one specimen is; $\alpha \leqq 1.721 \pm 0.001$ and $\gamma \geqq 1.739 \pm 0.001$, referring to a composition of $En_{41}Fs_{59}$.

Olivine phenocrysts are found in some rhyolite welded tuffs; though very little is preserved and now the olivine is represented mostly by pseudomorphs of chlorite, carbonate minerals, and iron minerals (Pl. VII-1, 2). The olivine is characteristically euhedral and its outline is well preserved. The optic angle (2V−) of one specimen is 45 ~ 50° and the refractive indices are; $\alpha \leqq 1.800 \pm 0.001$ and $\gamma \geqq 1.843 \pm 0.001$, corresponding to a composition of $Fo_{14}Fa_{86}$, namely ferrohortonolite (BOWEN and SCHAIRER, 1953).

In Fig. 9, assumed chemical compositions of pyroxenes and olivines in the Nōhi rhyolites are plotted. The tie-lines between the monoclinic pyroxene and co-existing orthorhombic pyroxene and between the monoclinic pyroxene and co-existing olivine are nearly parallel to those of other districts, respectively. It is supposed, accordingly, that the monoclinic and orthorhombic pyroxenes and the olivine in the Nōhi rhyolites crystallized side by side, namely they are the products of parallel crystallization.



• British and Icelandic Tertiary acid glasses (After CARMICHAEL, 1961)
o Quartz andesite and dacite of Higashiyama volcano, Hachijōjima (After ISSHIKI, 1963)
◎ Nōhi rhyolite welded tuff
a---a' Crystallization trend of monoclinic pyroxene

Fig. 9 Variation of chemical composition of pyroxenes and olivines.

IV. 2 Petrochemistry

IV. 2. 1 Major components

The major chemical components of the Nōhi rhyolites and granite porphyry are given in Tables 4 and 5. It si evident in Table 4 that the SiO_2 content of the Hidagawa rhyolites is around 67~68%, whereas that of the Shirakawa rhyolites is 72~73%, showing a 4~5% difference from the former. This difference is reflected on the content of Al_2O_3. In the Hidagawa rhyolites the Al_2O_3 content is 14~15%, while in the Shirakawa rhyolites it is 12~13%, clearly showing a decrease.

In the content of Na_2O+K_2O the Hidagawa rhyolites differ little from the Shirakawa rhyolites, but the CaO content is obviously higher in the former. Content of the total iron is also higher in the Hidagawa rhyolites, sometimes two times as much that in the Shirakawa rhyolites. However, there are some exceptional cases. For example, specimen K207 has the highest content of CaO among all the specimens of the Shirakawa rhyolites, and the value is not much different from the CaO content of the Hidagawa rhyolites. A similar tendency is noticed in the content of total iron, too. This specimen shows the most unusual facies among all the specimens of the Shirakawa rhyolites, and the modal analysis of minerals in this specimen is given in Table 6. The rock contains ferrohortonolite in association with orthorhombic pyroxene and monoclinic pyroxene. Accordingly, the peculiarity of the CaO and $FeO+Fe_2O_3$ contents in specimen K207 is presumed to have a close relation with the above-mentioned mineral association.

The difference in the major components between the Hidagawa rhyolites and the Shirakawa rhyolites is distinct also in their norm, revealing that the Hidagawa rhyolites belong to dacite~rhyodacite and the Shirakawa rhyolites to rhyolite.

Table 4 Chemical analysis ot the Hidagawa rhyolites and the Shirakawa rhyolites (with one specimen of granite porphyry, K222)

Division	Hidagawa rhyolites				Shirakawa rhyolites				
Oxide \ No.	K4	K136D	K216	K160	K24	K207	K220	K123-1	K222
SiO_2	67.80	66.84	68.40	68.54	72.94	72.40	72.92	72.17	71.68
TiO_2	0.33	0.37	0.33	0.37	0.19	0.32	0.19	0.27	0.32
Al_2O_3	14.72	15.19	14.52	14.95	13.44	13.18	12.98	13.59	12.66
Fe_2O_3	0.86	1.06	0.94	1.14	0.80	0.74	0.74	0.58	0.48
FeO	2.36	2.30	2.36	2.34	1.30	2.50	1.53	0.80	2.29
MnO	0.06	0.06	0.06	0.06	0.03	0.06	0.04	0.06	0.05
MgO	0.71	0.54	0.55	0.65	0.20	0.54	0.26	0.22	0.56
CaO	2.31	3.40	2.39	3.52	1.84	2.69	1.74	2.29	2.17
Na_2O	2.70	3.23	2.82	3.28	2.81	2.95	2.34	3.20	2.87
K_2O	4.46	3.02	3.59	2.79	4.68	3.40	4.20	3.88	3.61
P_2O_5	0.08	0.09	0.09	0.10	0.03	0.08	0.05	0.08	0.07
H_2O (+)	1.69	1.71	1.88	1.06	0.78	0.62	1.31	1.02	1.43
H_2O (−)	0.22	0.22	0.27	0.18	0.12	0.12	0.32	0.18	0.28
CO_2	1.58	1.76	1.70	0.95	0.70	0.16	1.29	1.52	1.19
Total	99.88	99.79	99.90	99.93	99.86	99.76	99.91	99.86	99.66
Q	27.87	27.58	31.08	29.44	33.90	34.68	38.34	33.81	34.86
or	26.16	17.81	21.15	16.14	27.83	20.03	25.04	22.82	21.15
ab	23.07	27.26	24.12	27.79	23.59	24.64	19.92	26.74	24.12
an	10.48	15.85	11.02	16.59	8.90	12.48	7.72	10.50	9.69
c	1.56	0.85	1.84	0.51	0.51	0.13	1.63	0.31	0.53
Salic total	89.14	89.35	89.21	90.47	94.73	91.96	92.65	94.18	90.35
en	1.80	1.31	1.31	1.61	0.50	1.31	0.70	0.50	1.41
fs	3.30	3.03	3.17	3.03	1.45	3.43	1.85	0.70	3.30
mt	1.16	1.39	1.39	1.62	1.16	1.16	1.16	0.93	0.70
il	0.61	0.61	0.61	0.61	0.30	0.61	0.30	0.46	0.61
ap	0.34	0.34	0.34	0.34	0.07	0.34	0.34	0.34	0.34
Femic total	7.21	6.68	6.82	7.21	3.48	6.85	4.35	2.93	6.36

(Analyst: T. Ōmori)

In Table 5 are given the major components of the rhyolites collected within the area of the Tsukechi geologic sheet-map a little east of the Hida River drainage basin. The table reveals that in chemical composition specimens T65 and T203 are similar to the Hidagawa rhyolites, and specimens T303 and T95 are similar to the Shirakawa rhyolites. The rhyolites of this area, however, are not stratigraphically classified.

In Fig. 10 the major components of the Nōhi rhyolites are plotted. For comparison, the major components of rhyolites in the Aioi and Arima groups of the Kinki district and in the Abu group of Yamaguchi Prefecture, reports on which have been already published, are also plotted. As far as the variation

Table 5 Chemical analysis of the Nōhi rhyolites (unclassified welded tuff)

Oxide \ No.	T65	T203	T303	T95	T165
SiO_2	64.33	69.08	74.22	74.35	71.10
TiO_2	0.65	0.34	0.15	0.14	0.25
Al_2O_3	15.48	14.91	13.08	12.87	14.23
Fe_2O_3	1.34	1.22	0.47	0.78	1.16
FeO	4.57	2.26	1.55	1.15	1.56
MnO	0.03	0.04	0.03	0.03	0.11
MgO	1.57	0.71	0.33	0.22	0.46
CaO	3.61	3.16	1.27	1.23	2.46
Na_2O	3.00	3.48	3.33	3.04	3.45
K_2O	3.92	3.30	4.33	4.37	3.66
P_2O_5	0.18	0.10	0.06	0.05	0.08
H_2O (+)	0.86	1.03	0.67	0.87	0.96
H_2O (−)	0.24	0.26	0.22	0.20	0.16
Total	99.78	99.89	99.71	99.30	99.64
Q	19.75	27.60	34.26	36.66	30.50
or	23.37	19.48	25.60	25.60	21.70
ab	25.17	29.36	28.31	26.22	29.36
an	15.96	14.66	5.50	5.20	11.33
c	0.47	0.23	0.84	1.13	0.33
Salic total	84.72	91.33	94.51	94.81	93.22
en	3.92	1.80	0.80	0.50	1.10
fs	6.33	2.77	2.24	1.19	1.72
mt	1.85	1.62	0.70	1.15	1.62
il	1.21	0.61	0.30	0.30	0.46
ap	0.67	0.34	0.34	0.34	0.34
Femic total	13.98	7.14	4.38	3.48	5.24

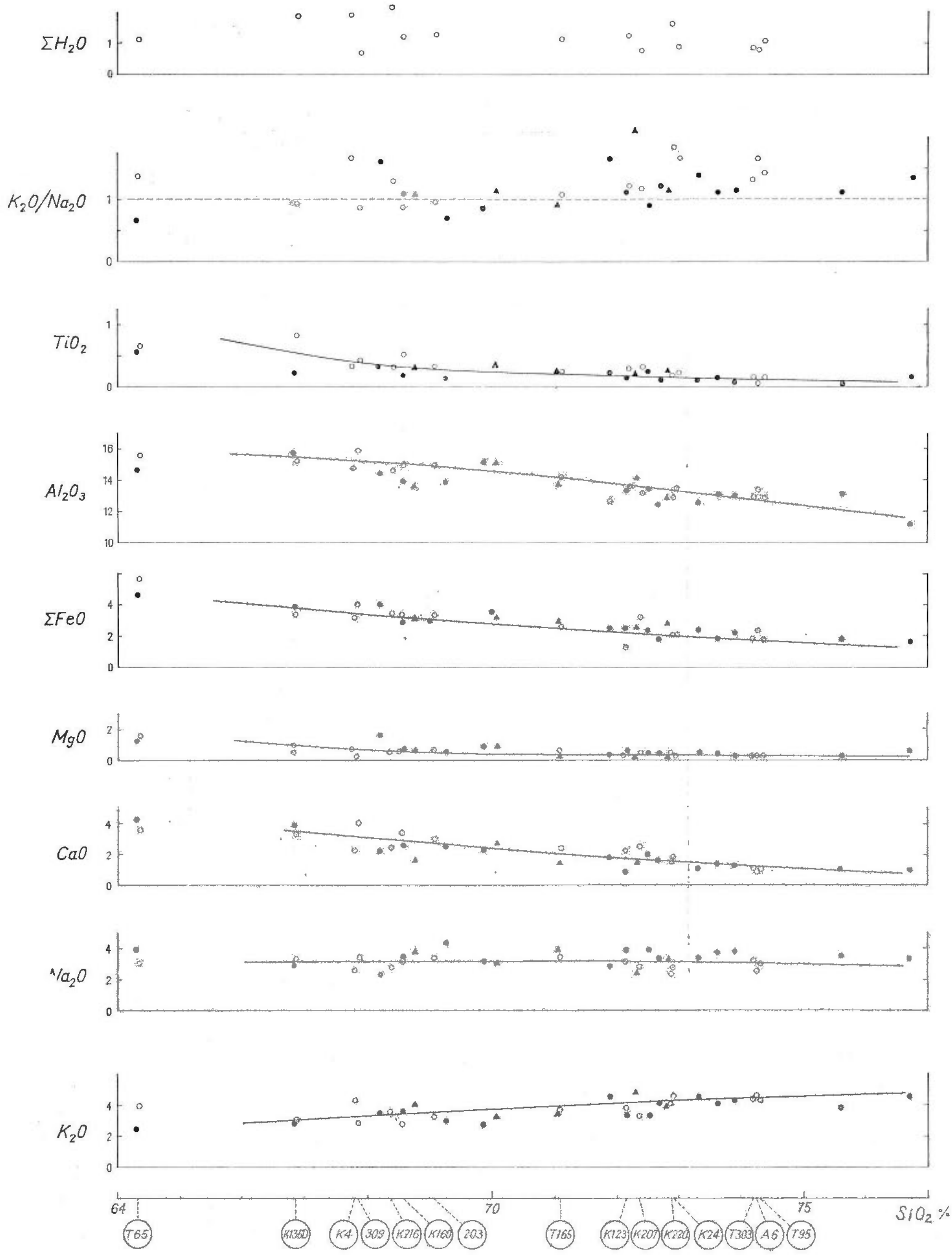
(Analyst: T. Ōmori)

diagram reveals, the Nōhi rhyolites have a strong resemblance to other rhyolites. The former, however, shows some anomaly in the alkali content. About K_2O in particular, specimens T65 and K4 show an unusually high content, more or less deviating from the variation curve. These two specimens have the lowest content of SiO_2 among the welded tuffs of the Nōhi rhyolites, but they contain considerable amounts of alkali feldspar and biotite as revealed by the modal analysis. Specimen K4 also contains sericite as a secondary mineral. These facts account for the unusual value of K_2O.

Except for the slight scattering of the alkali value, no remarkable variations are noticed in other major components.

IV. 2. 2 Relations between chemical and mineralogical compositions

Comparison between the Hidagawa rhyolites and the Shirakawa rhyolites



○ Nōhi rhyolites ● Rhyolites in the Aioi and Arima groups
△ Rhyolites in the Abu group
Sample Nos. refer to those of Tables 4, 5.

Fig. 10 SiO_2-oxides variation diagram of the Nōhi rhyolites and rhyolites of other districts.

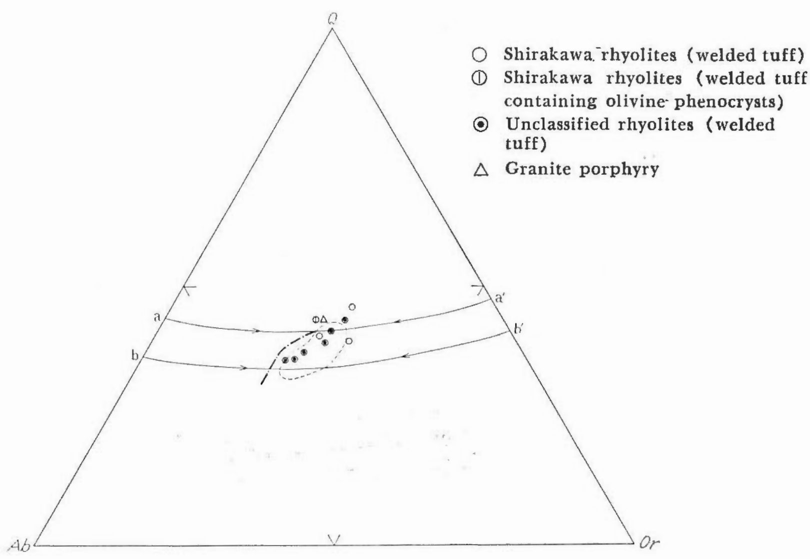
viewed from the diagrams of normative quartz, orthoclase, albite and anorthite

The Q–Or–Ab and An–Ab–Or diagrams are given in Figs. 11 and 12.

The Hidagawa rhyolites were excluded from the Q–Or–Ab diagram, since the total of Q+Or+Ab was below 80% in most of the rocks. This is because the Hidagawa rhyolites have the composition of dacite~rhyodacite. When the Shirakawa rhyolites and unclassified rhyolites were plotted on the Q–Or–Ab diagram and compared with the result of experiments by TUTTLE and BOWEN (1958), many of the rhyolites were found to fall near the minimum points under the H_2O pressure ranging from 500 kg/cm^2 to 2,000 kg/cm^2, and the values are concentrated in the neighborhood of 1/3 Ab, 1/3 Or and 1/3 Q, which agrees well with the general tendency of acid effusive rocks of the world. It is not certain, however, whether this diagram is applicable to heterogeneous and phenocryst-rich rocks such as the rhyolite welded tuff. Further examination will be needed.

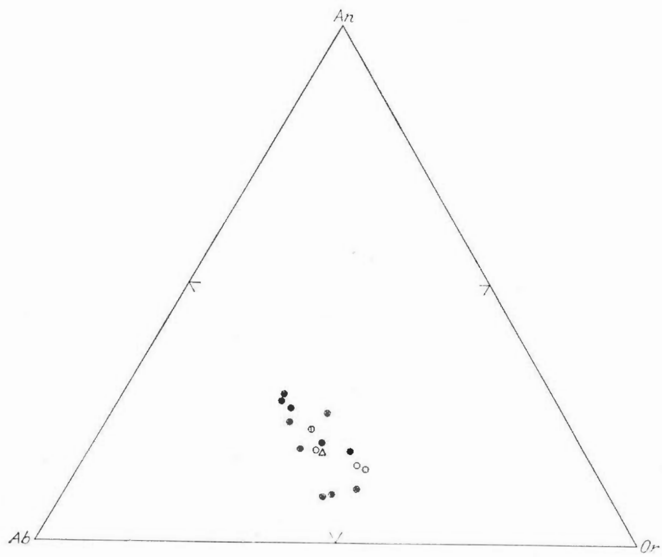
In the $(FeO+Fe_2O_3)-(Na_2O+K_2O)-MgO$ diagram (Fig. 13), it is difficult to represent accurately the liquid composition of phenocryst-rich rocks such as the Nōhi rhyolites. The Nōhi rhyolites show no remarkable variety in chemical composition, so that all the rocks are within the range of rhyolite~dacite.

In the above diagram, the samples are concentrated near the $(FeO+Fe_2O_3)-(Na_2O+K_2O)$ line and their MgO content is not much different. The Nōhi rhyolites belong to the calc-alkaline rock series.



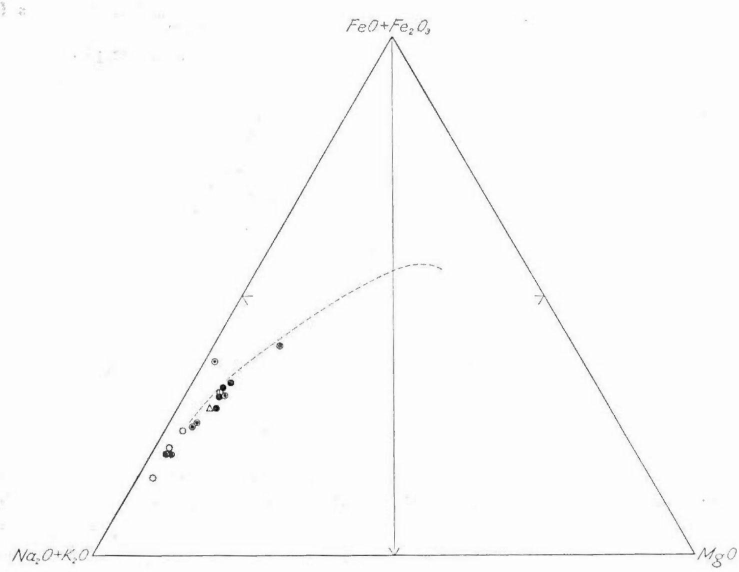
Lines a–a′ and b–b′ are the quartz-feldspar boundaries at 500 kg/cm^2 and 2,000 kg/cm^2 of H_2O pressure. Chain line is a line linking isobaric minima at the respective pressures. Broken line demarcates the area of maximum concentration of acid effusive rocks of the world. (After TUTTLE and BOWEN, 1958).

Fig. 11 Normative Q–Or–Ab diagram of rhyolite welded tuff and granite porphyry.



○ Shirakawa rhyolites (welded tuff)
⦶ Shirakawa rhyolites (welded tuff containing olivine phenocrysts)
• Hidagawa rhyolites (welded tuff, with one specimen of lave)
⊙ Undivided rhyolites (welded tuff)
△ Granite porphyry

Fig. 12 Normative An—Ab—Or diagram.



Symbol: Same as Fig. 12.
Broken line represents the boundary between the pigeonitic rock series (upper) and the hypersthenic rock series (lower) after H. KUNO (1954).

Fig. 13 $(FeO+Fe_2O_3)-(Na_2O+K_2O)-MgO$ diagram.

Table 6 Modal analyses of the Nōhi rhyolites and granite porphyry (volume percent)

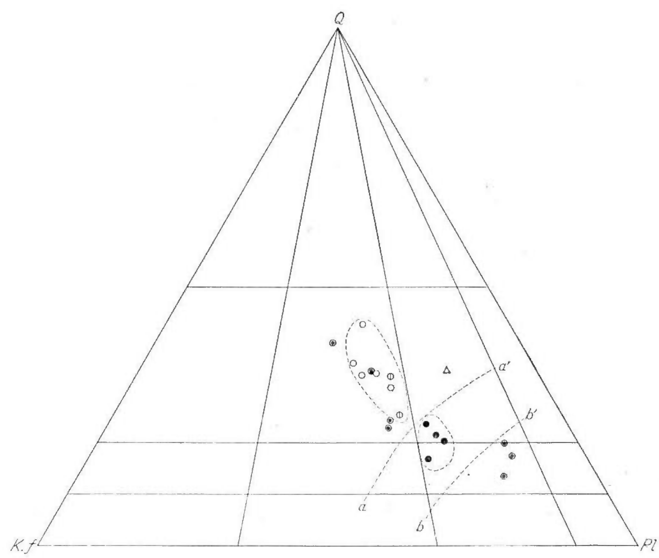
No. / Mineral	K4	K136 D	K216	K160	K24	K207	K220	K123 -1	K222*	T65	T303	T95	T165
Quartz	8.8	9.1	6.9	5.6	9.9	10.3	12.6	13.5	16.0	5.3	16.4	12.1	11.7
Plagioclase	20.4	24.1	20.4	21.4	10.8	18.8	13.0	20.3	24.4	26.8	11.8	13.7	25.1
Alkali feldspar	8.5	10.1	8.0	10.4	8.9	10.8	11.4	12.4	6.8	5.6	13.4	10.3	16.2
Mafic mineral	3.3	4.1	3.1	4.6	2.3	5.3**	2.4	1.6	1.2	7.2	1.8	0.9	8.4
Total phenocryst	41.0	47.4	38.4	42.0	31.9	45.2	39.4	47.8	48.4	44.9	43.4	37.0	61.4
Matrix	59.0	52.6	61.6	58.0	68.1	54.8	60.6	52.2	51.6	55.1	56.6	63.0	38.6

* Granite porphyry.

** Kinds and abundance of mafic minerals are; ferrohypersthene (2.3%), ferroaugite (1.5%), ferro-hortonolite (0.6%), biotite (0.4%), iron oxide (0.3%) and hornblende (0.2%).

Correlation between chemical and modal compositions

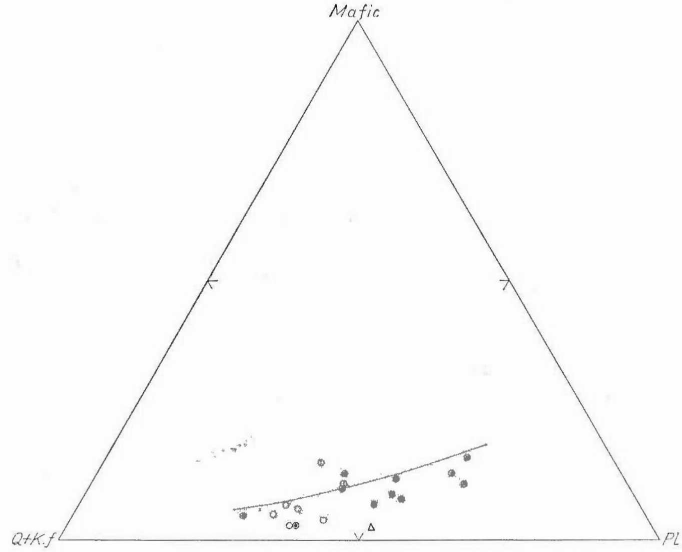
The result of volumetry of phenocrysts in the Nōhi rhyolites is shown in Table 6 and plotted in the Q--K.f--Pl diagram (Fig. 14). The samples comprise unclassified rhyolites and granite porphyry, besides the Hidagawa and Shirakawa rhyolites. The diagram reveals that the Hidagawa rhyolites are concentrated in



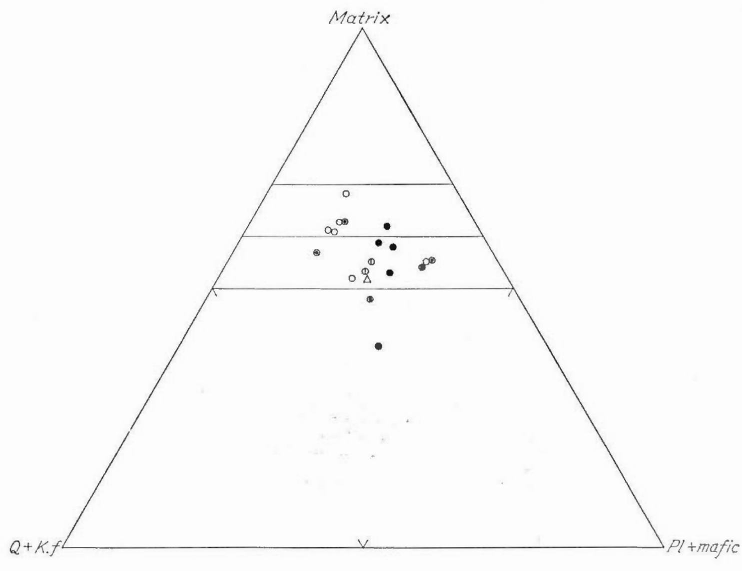
Broken lines, a–a′ and b–b′, indicate the limits of distribution of specimens having SiO_2 up to 70% and those having 65% and less.

Symbol: Same as Fig. 12 Q: quartz K.f: alkali feldspar Pl: plagioclase plase

Fig. 14 Modal analysis of salic phenocrysts in the Nōhi rhyolites and granite porphyry.



Solid line indicates a trend of the Hidagawa rhyolites.
Symbol: Same as Fig. 12.
Fig. 15 Modal analysis of total phenocrysts in the Nōhi rhyolites and granite porphyry.



Symbol: Same as Fig. 12.
Fig. 16 Modal analysis of phenocrysts and matrix of the Nōhi rhyolites and granite porphyry.

the area of granodiorite~quartz diorite, whereas the Shirakawa rhyolites are in the adamellite area. This shows a good correlation between the chemical composition and the mineral composition based on the mode of phenocrysts. The unclassified rhyolites in Table 5 also show that the rocks having less than 65%

SiO_2 fall within the range of granodiorite~quartz diorite.

A tendency that the Hidagawa rhyolites are richer in plagioclase and mafic minerals than the Shirakawa rhyolites is clearly revealed in the (Q+K.f)−Pl−Mafic diagram (Fig. 15). Hence, this diagram also tells that the chemical composition is correlated well with the modal mineral composition.

In the (Q+K.f)−(Pl+mafic)−Matrix diagram (Fig. 16), matrix and phenocryst were also dealt with, so that all the components of the rocks were plotted. So far as the measured samples are concerned, the Hidagawa rhyolites and the Shirakawa rhyolites show no noticeable difference from each other in the volumetric ratio of phenocryst and matrix. It is evident, however, that plagioclase and mafic minerals are more abundant in the Hidagawa rhyolites, irrespective of the volume of matrix.

IV. 3 Rock alteration

IV. 3. 1 Zoning of altered rocks and its relation to geologic structure

For the purpose of studying the alteration of the Nōhi rhyolites, the writer

Table 7 Samples examined by X-rays

Sample No.	Rock Name	
K222	Granite porphyry	
K123-1	Rhyolite welded tuff	(Block in vent breccia)
K207	Rhyolite welded tuff	Shirakawa rhyolites
K188	〃	
KY178	〃	
K170	〃	
K176	〃	
K220	〃	
K216A	〃	
K216D	〃	
K175C	〃	
KY87A	〃	
K177	〃	
K86	〃	
KY23A	〃	
KY23B	〃	
K160	Dacite lava	Hidagawa rhyolites
K83	Rhyolite welded tuff	
K4	〃	
K136A	Rhyolite lava	
K136C	Rhyolite welded tuff	
K136D	〃	
K24	〃	
K180	〃	
K98	〃	
K99	〃	

examined altered minerals in the Nōhi rhyolites occurring in the area between Tajima and Shinzu via Shimoyui. The sampling localities are shown in Fig. 17. Samples examined were 25 from welded tuff and lava, and one sample from granite porphyry, totaling 26 (Table 7). In order to avoid possible influence of admixed clastic material derived from Paleozoic rocks that may have been already altered or metamorphosed, the writer limited the object of his examination to volcanic rocks consisting of essential material. Nevertheless, welded tuff sometimes contained numerous accidental fragments of Paleozoic rocks, so that it was necessary to eliminate those fragments. Fig. 18 shows the approximate percentages of clay minerals in the fraction smaller than 2 micron separated from those twenty-six samples.

Altered zone was divided into the montmorillonite zone, the transitional zone

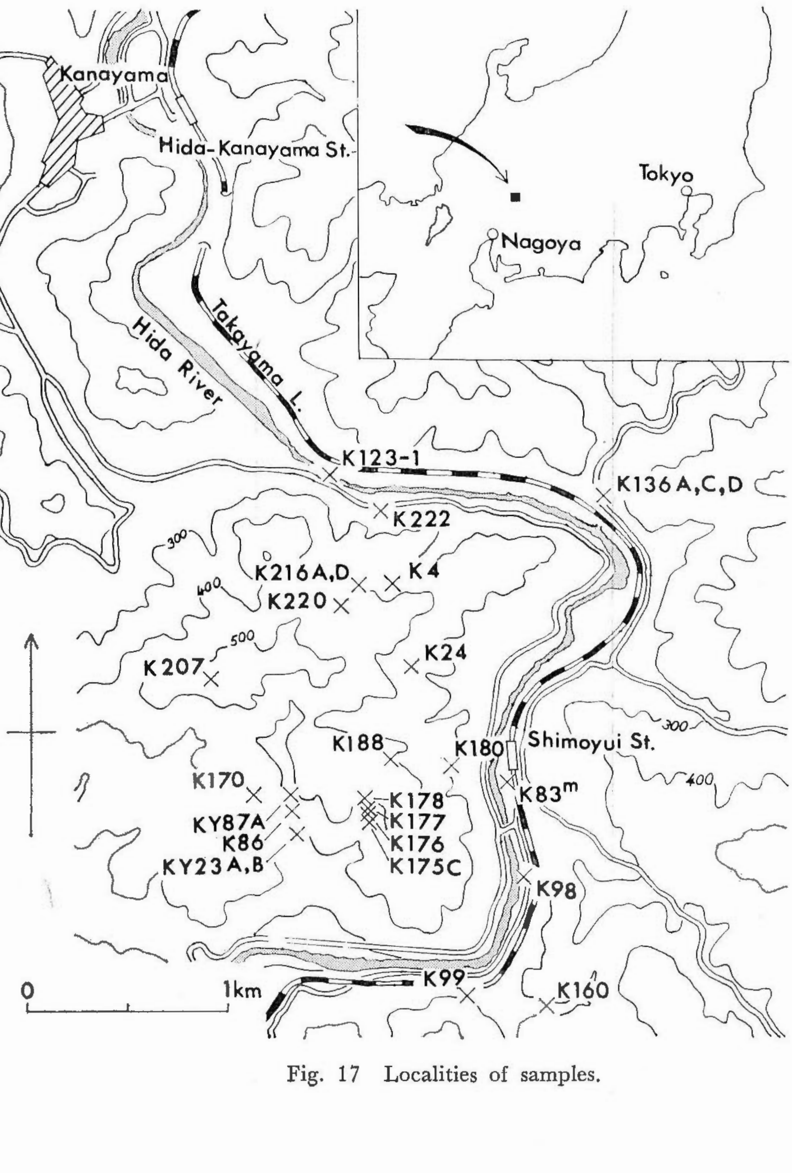


Fig. 17 Localities of samples.

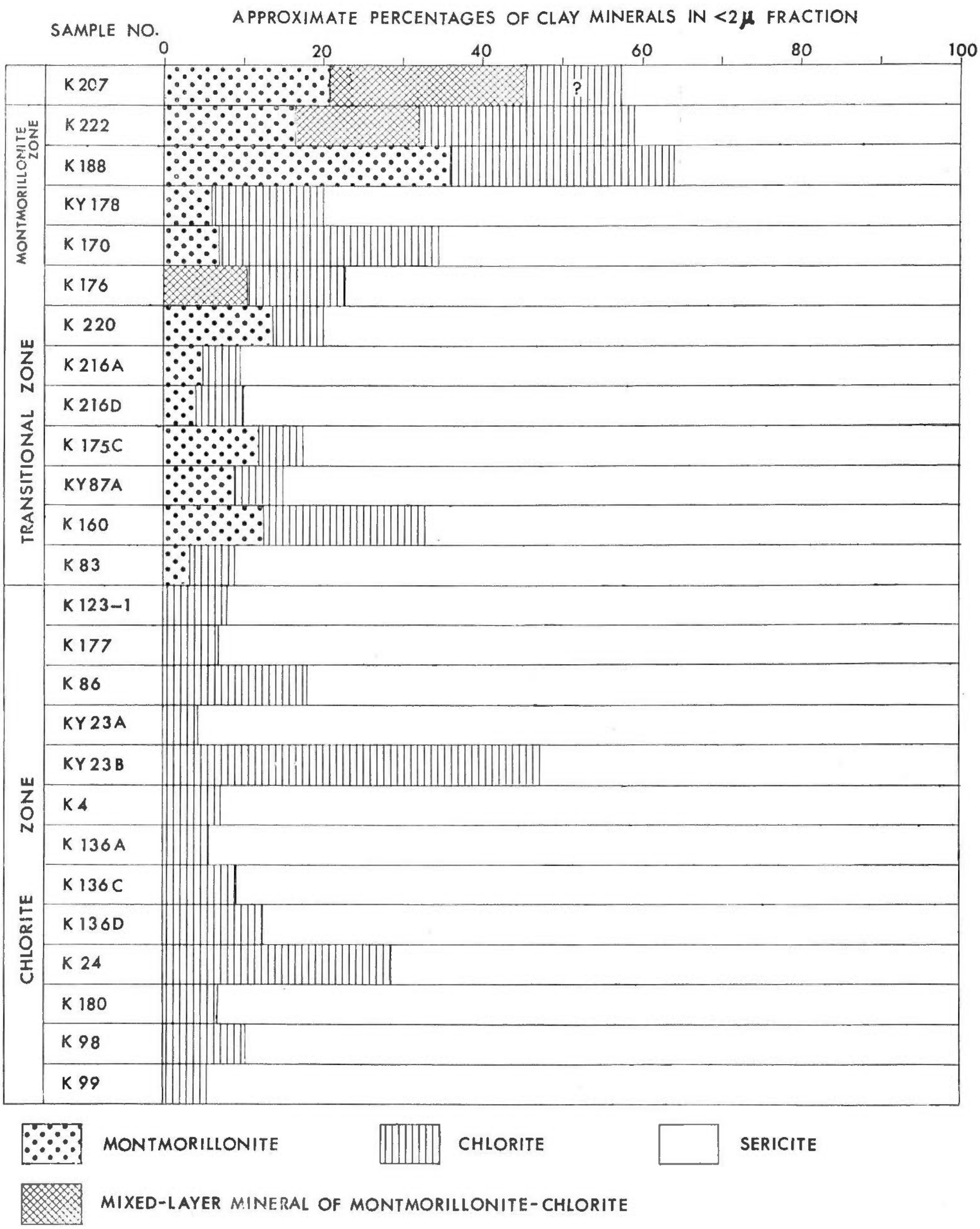


Fig. 18 Approximate percentages of clay minerals in the fraction smaller than 2 microns.

and the chlorite zone from the low temperature side to the high temperature side, according to the condition under which montmorillonite is altered into chlorite by dehydration. The montmorillonite zone does not contain chlorite and the chlorite zone is devoid of montmorillonite, whereas in the transitional zone both montmorillonite and chlorite are found. The association of altered minerals is summarized in Fig. 19.

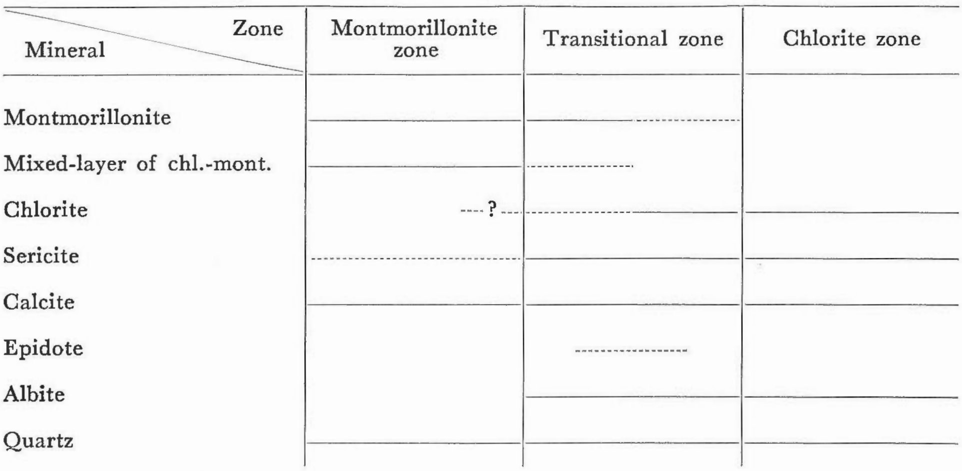
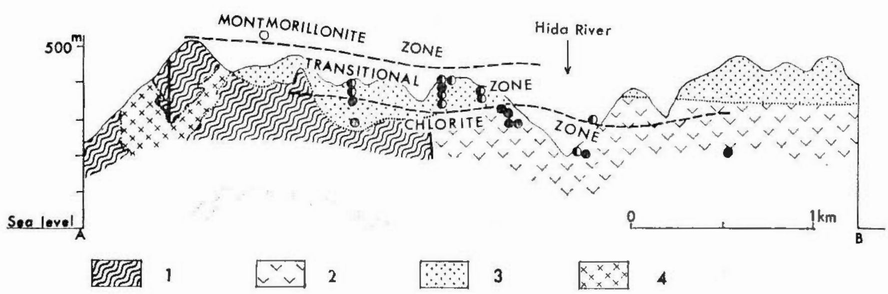


Fig. 19 Summary of mineral association in altered zones.

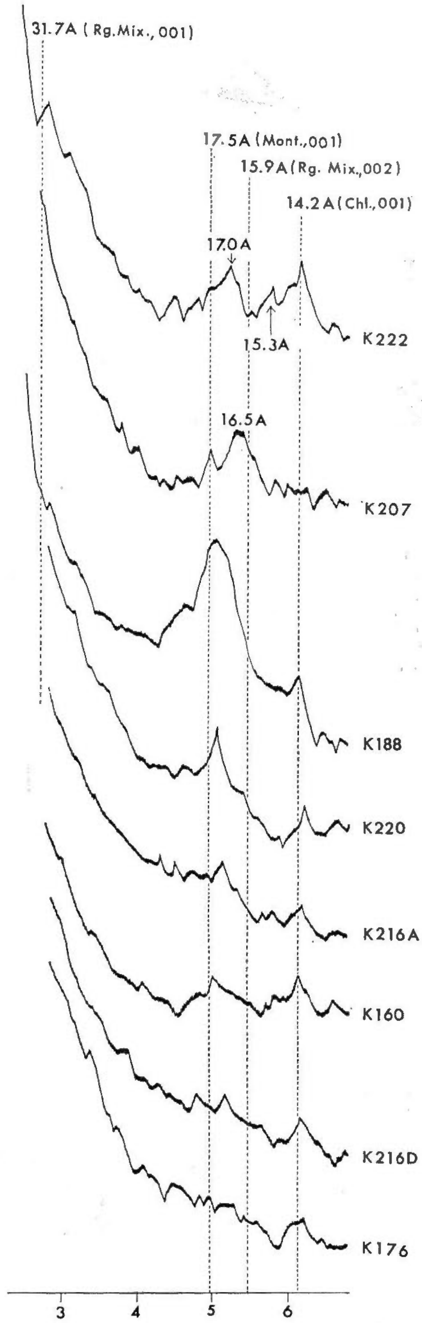


1: Paleozoic formation 2: Hidagawa rhyolites 3: Shirakawa rhyolites
4: Granite porphyry
Open, semi-solid and solid circles represent the modified location of samples belonging to montmorillonite, transitional and chlorite zones, respectively.

Fig. 20 Section of altered zones.

Rocks representing each of the altered zones are located on the geologic section in Fig. 20. The localities of the respective samples were projected on the N 59° W section passing through a point 700 m south of Shimoyui Station, and this is why some of them are plotted above the ground surface. The direction of projection is N 7° W which is the general trend of the geologic structure, so it is inclined 52° against the line of section.

Only one sample was taken from the montmorillonite zone at a locality 540 m above sea level, the highest of all the sample localities. The sampled rock is a welded tuff belonging to the Shirakawa rhyolites. Samples from the transitional zone are the Shirakawa rhyolites, with two exceptions of the Hidagawa rhyolites; they were collected at 330～420 m above sea level. The chlorite zone was sampled at localities between 200 m and 330 m above sea level. Most of the samples belong to the Hidagawa rhyolites, the rest being of the Shirakawa rhyolites.



Rg. Mix.: 1:1 regular mixed-layer mineral of chlorite-montmorillonite, Mont.: Montmorillonite, Chl.: Chlorite.

Fig. 21 X-ray diffraction patterns of the complexes with ethylene glycol.

The boundary between the montmorillonite zone and the transitional zone cannot be determined as there is only one sample of the former, but it is certain at least that the montmorillonite zone occupies the uppermost position. The boundary between the transitional zone and the chlorite zone rises and falls between 270 m and 360 m above sea level. This boundary coincides roughly, but not entirely, with the boundary between the Hidagawa rhyolites and the Shirakawa rhyolites. In the west the boundary is found in the Shirakawa rhyolites but in the east it is located within the Hidagawa rhyolites, and so it may be slightly inclined eastward. On the whole, however, the boundary is considered to be nearly horizontal. Since the neighboring Nōhi rhyolites also have a horizontal structure, this boundary suggests that the altered zones are generally parallel with the stratigraphic succession. This is a noteworthy point.

IV. 3. 2 Altered minerals

Altered minerals are montmorillonite, chlorite-montmorillonite mixed layer mineral, chlorite, sericite, calcite, albite and quartz, accompanied by a small amount of epidote.

Montmorillonite, formed by replacing mafic minerals, is a pale green mineral showing a weak double refraction. In the X-ray diffraction pattern, the mineral shows a 15 Å reflection and basal reflection of higher order. When treated with ethylene glycol the 15 Å reflection shifts to 17 Å.

The chlorite-montmorillonite mixed layer mineral is variable in frequency of occurrence of chlorite and montmorillonite layers. For example, by the ethylene glycol treatment the 14.5 Å reflection in natural condition causes reflection at 31 Å and 15.3 Å in some cases, and in other cases the 14.8 Å reflection in natural condition causes a reflection at 16.5 Å. Also, there are cases where no definite reflection of mixed-layer is noticed, but in ethylene glycol complexes the mineral shows interference between 17 Å and 14 Å, or irregular reflections between 16 Å and 20 Å. Fig. 21 shows various patterns of X-ray diffraction of the mixed-layer mineral.

Chlorite, replacing mafic minerals, is pale green and shows an abnormal interference color. In the X-ray diffraction pattern, it shows a 14 Å reflection and higher order basal reflections. These reflections do not shift in the ethylene glycol treatment.

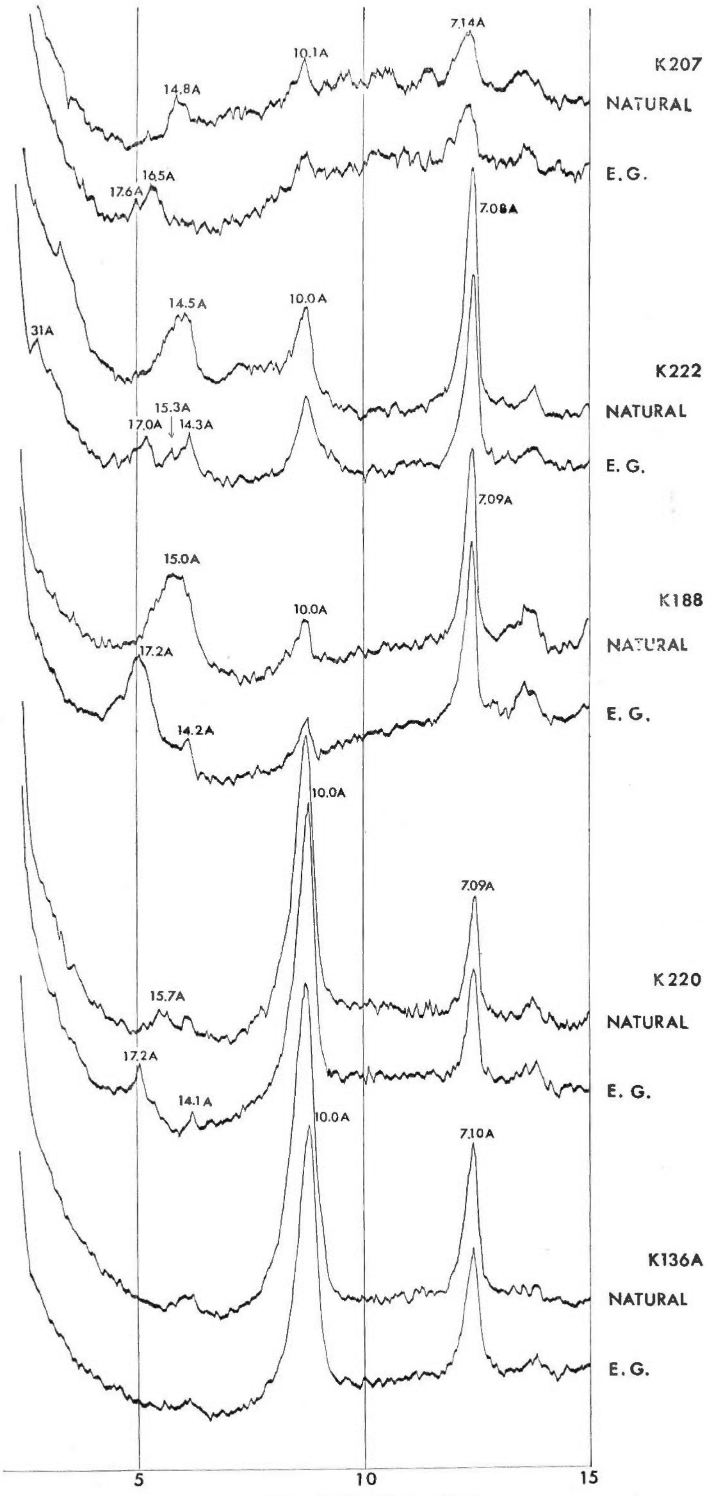
Sericite occurs within plagioclase. In the X-ray diffraction pattern the mineral shows a 10 Å reflection and higher order basal reflections, which do not shift in the ethylene glycol treatment.

IV. 3. 3 Microscopic and X-ray characteristics of altered rocks

Montmorillonite-bearing altered rhyolite welded tuff (specimen K270, montmorillonite zone)

To the naked eye the rock is dark gray and hard. Under the microscope the rock is found to contain quartz, plagioclase, alkali feldspar, biotite, hornblende, orthorhombic pyroxene, monoclinic pyroxene and olivine, as phenocrysts.

Plagioclase is transparent, showing a conspicuous zonal structure, and is not affected by albitization. On rare occasions a green clay mineral or calcite fills the cracks. Monoclinic pyroxene is generally fresh, but a green clay mineral is partially developed along the outer margin and cleavage. Orthorhombic pyroxene is much more altered than monoclinic pyroxene, and a pale green fibrous clay



E.G.: Complexes with ethylene glycol.

Fig. 22 X-ray diffraction patterns of the fraction smaller than 2 microns separated from altered rocks.

mineral is developed along the crystal's outer margin and cleavage. Pseudomorphs after mafic minerals, probably olivine, are found, now replaced by opaque iron ore, green clay mineral and calcite.

The green clay mineral occurs mostly as pseudomorphs after mafic minerals, and coexists with irregular-shaped iron ore. The mineral shows pleochroism, ranging from light brown to pale bluish green, and shows a somewhat strong double refraction. This is probably a mixed layer mineral. According to the X-ray diffraction (Fig. 22) of the fraction smaller than 2 μ separated from specimen K207, clay minerals are montmorillonite, mixed layer mineral and sericite. Another clay mineral, possibly chlorite, is also contained.

Epidote-chlorite-bearing altered rhyolite welded tuff (specimen K188, transitional zone)

The rock is gray and very hard. Under the microscope it contains abundant phenocrysts of quartz, plagioclase and alkali feldspar. Plagioclase is entirely albitized, resulting in large amounts of sericite and calcite, and rarely epidote. Pseudomorphs after mafic minerals, 0.2∼0.5 mm in size, are found; they are all made up of a combination of two or three of such minerals as epidote, chlorite and calcite.

Chlorite is pale green and shows a very weak double refraction.

The X-ray diffraction pattern of the fraction smaller than 2 micron separated from specimen K188 is given in Fig. 21. It reveals that clay minerals are montmorillonite, chlorite and sericite, but under the microscope montmorillonite cannot be recognized.

Chlorite-sericite-bearing altered rhyodacite welded tuff (specimen K136A, chlorite zone)

To the naked eye the rock is very hard, pale green, abounding in chlorite, and has dark green patches. Under the microscope it is found to contain quartz and plagioclase in abundance. Plagioclase is albitized, resulting in large amounts of albite, calcite and sericite, rarely accompanied by chlorite. Pseudomorphs after mafic minerals, 0.2∼0.5 mm in size, are found, having been altered completely into aggregates of chlorite and calcite. The matrix has altered into the aggregates of quartz, feldspar, sericite, chlorite and calcite. Size of the secondary quartz attains to 0.2 mm.

V. Comparison between the Nōhi Rhyolites and Other Late Cretaceous Volcanic Rocks on the Inner Side of Southwest Japan

The late Cretaceous volcanic rocks are distributed not only in various parts of the Inner Side of Southwest Japan in a narrow sense, but also in the mountains of northern Kantō region east of the Fossa Magna. Noticeable ones other than the Nōhi rhyolites are, from west to east, the Abu group in the western Chūgoku region (MURAKAMI and NISHINO, 1967), the Takada rhyolites in the central Chūgoku region (YOSHIDA, 1961), the Aioi group in the eastern Chūgoku region (KISHIDA and WADATSUMI, 1967), the Arima group in the western Kinki region (KASAMA, 1968), the Kotō rhyolites in the eastern Kinki region, and the Okunikkō rhyolites in the northern Kantō Mountains (Table 8). In lithology and petrology these rocks bear a strong likeness to the Nōhi rhyolites.

Table 8 Succession of Late Cretaceous to Paleogene igneous activities in various areas of the Inner Side of Southwest Japan

Area \ Stage	I	IIa	IIb	III	IV
Western part of Chūgoku district (MURAKAMI et al., 1967)	Quartz diorite ~ granodiorite	Abu group (rhyolites)	Plutonic ~ hypabyssal rocks	Hiroshima granites ((70—92 m. y.))	
Central part of Chūgoku district (YOSHIDA, 1961)		Takada rhyolites	Plutonic rocks (Quartz diorite~ granodiorite)	Hiroshima granites ((70—92 m. y.))	
Eastern part of Chūgoku district (KISHIDA et al., 1967)	Biotite granite Quartz diorite	Aioi group (rhyolites)	Granodiorite porphyrite	Harima granites ((79 m. y.))	Tenkadaiyama group (rhyolites)
Western part of Kinki district (KASAMA, 1968)		Arima group (rhyolites)		Rokkō granites ((72—75 m. y.))	Kongōdōji group (rhyolites)
Eastern part of Kinki district (KAWADA et al., 1969)		Kotō rhyolites	Granodiorite porphyry	Gozaishoyama granites ((65 m. y.)) Hira granite ((64 m. y.))	
Chūbu district (ISOMI and KAWADA, 1968)	Quartz diorite (97 m. y.)	Nōhi rhyolites	Granodiorite porphyry Granite porphyry	Naegi-Agematsu granite ((60—72 m. y.)) Shirakawa granite *((62 m. y.))	Futomiyama group (rhyolites) (59 m. y.) Ōamemiyama volcanic rocks
Northern Kwantō district (ISOMI and KAWADA, 1968)	Quartz diorite ~ granodiorite (116 m. y.)	Okunikkō rhyolites	Granodiorite porphyry Granite porphyry	Kobugahara granodiorite ((63 m.y.)) Chūzenji granite ((64 m.y.))	Katashinagawa rhyolites

(( )) : Radiometric age of biotite by K-Ar method.
* : Unpublished, measured by Ken SHIBATA.

They are similar also in the process of the causative igneous activity. A considerable resemblance is noticed in their mode of emplacement, too.

In the western Chūbu region, the late Cretaceous volcanic rocks distributed centering on the upper reaches of the Kuzuryū River, on the west of the Nōhi rhyolites, are called the Omodani rhyolites (KAWAI et al., 1957), whose distribution is roughly coincides with that of the Hida marginal structural belt. Except for some information about the distribution and the stratigraphic position, little is known about the mode of occurrence, lithology, petrology and mode of emplacement of the Omodani rhyolites, so that they cannot be compared with the Nōhi rhyolites at the present stage of our knowledge.

V. 1 Comparison by lithology and petrology

The main body of the above-mentioned volcanic rock is composed of thick deposits of rhyolitic or rhyodacitic pyroclastic flow. As mentioned in Chapter IV, the variation diagram of major components of the Nōhi rhyolites is markedly similar to that of other volcanic rocks.

V. 2 Comparison by magmatic history

The magmatic history of the late Cretaceous volcanic rocks in each area and their correlation are shown in Table 8.

Stage I in the table corresponds to the period of intrusion of quartz diorite or granodiorite of a small scale, which preceded the period of effusion of the principal rhyolites.

Stage IIa is the period of effusion of the principal rhyolites.

Stage IIb is the period of activity of various kinds of hypabyssal rocks that intruded after the effusion of the principal rhyolites. The major lithology is granodiorite porphyry or granite porphyry. Although hypabyssal rocks of this stage have not been confirmed yet in the central and eastern parts of the Chūgoku region, they are most likely developed in these parts also.

Stage III is the intrusive period of the late Cretaceous granites represented by the batholithic Hiroshima granites of the Chūgoku region.

Stage IV is the period of Paleogene volcanism. Volcanic rocks of this stage are narrower in distribution and smaller in scale than those of stage IIa.

As is known from Table 8, the succession of stages of the late Cretaceous igneous activity is common throughout the Inner Side of Southwest Japan in a broad sense inclusive of the northern Kantō Mountains. In particular, the coincidence between the Chūbu region and the northern Kantō Mountains in the history of the late Cretaceous igneous activity is striking. A conclusion that, in the light of the basement structure, the Jōetsu belt and the Ashio belt of the northern Kantō Mountains correspond respectively to the Hida marginal structural belt and the Mino belt of the Chūbu region (ISOMI and KAWADA, 1968) agrees well with the above-mentioned remarkable coincidence in the history of the late Cretaceous volcanic activity.

V. 3 Comparison by mode of emplacement

The late Cretaceous volcanic rocks of the Chūgoku region are intruded in various places by the late Cretaceous granites that are known by the name of "Chūgoku batholith", so that their distribution is often cut apart, making it difficult to clarify the mode of emplacement of these volcanic rocks. In a wide view, however, the volcanic rocks are distributed with a roughly E-W or ENE-WSW trend (NISHINO and MURAKAMI, 1965; KISHIDA and WADATSUMI, 1967). This trend roughly coincides with the general trend of the basement structure.

In the eastern part of the Inner Zone of Southwest Japan, the elongation of the late Cretaceous volcanic rocks is in a NNW-SSE or N-S direction, at a right angle to the above-mentioned trend.

The Nōhi rhyolites extend NNW-SSE, cutting the general trend of the basement. This form of distribution resulted from the effusion of rhyolites along the Nōhi west-boundary sheared zone and other faults developed in the basement, and from the thick accumulation of pyroclastic flow deposits inside the tectonic depression stretching in the NNW-SSE direction.

The distribution form of the Okunikkō rhyolites in the northern Kantō Mountains in controlled also by the N-S trending faults. That the effusion of the Okunikkō rhyolites took place along the fault of a N-S trend developed in the basement rocks is concluded from various evidences (KAWADA, 1966c).

The Kotō rhyolites east of Lake Biwa stretch also NNW-SSE, like the Nōhi rhyolites. The Kotō rhyolites and the Paleozoic formation on the east are bounded by NNW-SSE faults. From the fact that intrusion of granite porphyry belonging to the later period of volcanic activity is frequent along this boundary, it is possible that the Kotō rhyolites effused out along the NNW-SSE faults that were developed in the basement. The main area of deposition of the pyroclastic flows was probably a depression stretching in a NNW-SSE direction, generally agreeing with the trend of the present distribution.

Thus, the Nōhi, Okunikkō and Kotō rhyolites in the eastern half of the Inner Side of Southwest Japan have a common character in the respect that they owe the formation of a fissure for their eruption and a depression for their thick accumulation to the activity of a major fault zone, trending NNW-SSE or N-S, which was developed in the basement rocks.

VI. Summary and Conclusion

1) The Nōhi rhyolites form an elongate mass with long axis of NW-SE, and spread over the northern part of the Ryōke belt, the Mino belt, the Hida marginal structural belt, and the Hida belt in Central Japan. The mass obviously truncates the zonal arrangement of the basement complexes. The site of the Nōhi rhyolites is the area where the strike of Paleozoic rocks shows an abnormal trend, namely N-S.

2) The Paleozoic rocks along the western boundary of the rhyolites are intensely sheared. No effects of shearing are recognized in the rhyolites adjacent to the sheared Paleozoic rocks. Therefore, the Nōhi west-boundary sheared zone was formed prior to the eruption of the rhyolites. Effects of a similar shearing movements are also observed in the Paleozoic rocks which are isolately exposed in several places inside the terrain of rhyolites.

3) Small bodies of quartz diorite intruded the Paleozoic formation. The quartz diorite is covered by an upper member of the Nōhi rhyolites, and the latter contains pebbles of the former. Moreover, no thermal effect by the intru-

sion is recognized in the rhyolites which are very close to the quartz diorite. Therefore, intrusion of the quartz diorite was prior to eruption of the rhyolites. The radiometric age of the quartz diorite is 97 m.y.

4) The Nōhi rhyolites were erupted through the large fissures which were related to the fault-shearing of the basement. The trend of these fissures was perhaps roughly NW-SE. By the eruption were laid down the pyroclastic flow deposits in a graben-like tectonic depression with NW-SE trend. Through alternate repeating of eruption and volcano-tectonic depression, the thickness of the rhyolites grew to exceed 2 km and the volume attained to about 8,000 km^3.

5) The rhyolites along the Hida River are stratigraphically divided into two, the Shirakawa rhyolites above and the Hidagawa rhyolites below, with an unconformable relation. The Hidagawa rhyolites and the Shirakawa rhyolites are remarkably different from each other not only in lithology but also in their structural relation with the Paleozoic formation.

6) The Hidagawa rhyolites, constituting the main part of the Nōhi rhyolites along the Hida River, were accumulated in the large depression which was formed in the east of the Nōhi west-boundary sheared zone. The rhyolites could not advance farther west by the fault scarp that had been formed in the Nōhi west-boundary sheared zone. The thickness of cooling unit exceeds 100 m by far.

7) The Shirakawa rhyolites were a product of a local volcanic activity that took place in the western margin after the Hidagawa rhyolites were formed. The thickness of cooling unit is several tens meters. The Shirakawa rhyolites not only covered the Hidagawa rhyolites but also extended westward in a short distance to overlap the Paleozoic formation and unconformably covered the latter.

8) Comparison of chemical compositions reveals that the welded tuff and lava in the Hidagawa rhyolites are rhyodacite with SiO_2 content of 67-68%, whereas the welded tuff in the Shirakawa rhyolite is rhyolite with SiO_2 content of 72-73%. The difference in the chemical composition is verified by the modal analysis of phenocrysts. That is, the Hidagawa rhyolites are rich in plagioclase and mafic minerals and correspond to an effusive equivalent of granodiorite, while the Shirakawa rhyolites tend to abound in quartz and alkali feldspar and correspond to an effusive equivalent of adamellite.

9) The Hidagawa and the Shirakawa rhyolites both belong to the calc-alkaline rock series.

10) Vent-breccia of the Shirakawa rhyolites is found in two places, both located on the western boundary of the rhyolites. Judging from the areal distribution and the thickness of cooling unit, the Hidagawa rhyolites were a product of the fissure eruptions of larger scale compared with the Shirakawa rhyolites. The vent-breccia of the Hidagawa rhyolites, however, has not been observed at present owing to covering of the rhyolites of ensuing eruptions.

11) The state of alteration is fairly different between the lower and upper members of the rhyolites. According to the X-ray diffraction patterns of fraction smaller than 2 microns of secondary minerals, alteration zoning by the assemblage of secondary minerals is possible. That is, the altered rhyolites of the Hidagawa and Shirakawa rhyolites are classified into montmorillonite, transitional and chlorite zones in the order from the weaker (lower temperature) to the stronger (higher temperature). The transitional zone is characterized by the presence of the mixed-layer mineral of chlorite-montmorillonite. The boundary between the chlorite and the transitional zones coincides roughly with the

boundary between the Hidagawa and the Shirakawa rhyolites.

12) Subsequently to the eruption of the rhyolites, granodiorite porphyry, granite porphyry and quartz porphyry took place in the terrain of the rhyolites and in the westerly bordering zone of the Paleozoic rocks. The intrusion of the three above-mentioned rocks was successive. The intrusive rock which immediately followed the eruption of the rhyolites was granodiorite porphyry, and formed a stock or boss. The granite porphyry that occurred secondly was intruded mostly in a form of dike. The most acid rock, quartz porphyry, was lastly intruded in a form of dike. The intrusive rocks mentioned above represent the last stage of volcanism of the Nōhi rhyolites.

13) The intrusion of the so-called Cretaceous granites, such as the Naegi-Agematsu and the Shirakawa granites, was the final stage of the Late Cretaceous igneous activity in Central Japan.

14) The volcanism of the Nōhi rhyolites was succeeded from the intrusion of the quartz diorite having a radiometric age of about 97 m.y., and followed by the intrusion of granites having a radiometric age of about 60 m.y. That is, the Nōhi rhyolites were formed in a certain period of Late Cretaceous (60~97 m.y.).

15) The Nōhi rhyolites agree well with other rhyolites of the Inner Side of Southwest Japan in various aspects as follows: a) that they form an enormous pile of volcanic rocks characterized by a predominance of pyroclastic flow deposits; b) that the main lithology is rhyolite~rhyodacite; c) that they belong to the calc-alcaline rock series; d) age of eruption; e) kind of and relation to the accompanying igneous rocks. Above all, a striking similarity in the mode of emplacement, the geologic structure and in the history of igneous activity is recognized among the three rhyolite complexes in Southwest Japan in a broad sense, namely the Nōhi rhyolites, the Okunikkō rhyolites in the northern Kantō region and the Kotō rhyolites to the east of the Lake Biwa.

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濃飛流紋岩類——とくに飛驒川流域における流紋岩類の地質学的岩石学的研究——

河　田　清　雄

要　旨

濃飛流紋岩類は西南日本内帯における白亜紀後期（ほぼギリヤーク世）の火山活動に属し，火砕流堆積物を主体として中部地方の内域に広く分布する。分布総面積は約4,000km^2，平均層厚2,000m以上で容積は8,000km^{3}に達する巨大な火山性累層を形成している。

濃飛流紋岩類はNW—SE方向に伸長し，その分布は中部日本の領家帯北縁，美濃帯，飛驒外縁帯および飛驒帯にまたがっている。その分布は明瞭に基盤岩類の帯状配列を切っている。

濃飛流紋岩体の西縁の古生層には著しい断層被砕帯が形成され，〝西縁破砕帯〟とよばれている。西縁破砕帯は古生層の一般走向の折れ曲りの部分に生じた断層破砕帯で，その形成時期は少なくとも流紋岩類の噴出以前であったことは明らかである。

濃飛流紋岩類は基盤の断層破砕に関係して生じた大きな割れ目を通して噴出したと推定されるが，その割れ目の方向はおよそNW—SEであった。流紋岩類はNW—SE方向の構造性陥没によるグラーベン状地帯に火砕流堆積物を主体として厚く堆積した。

飛驒川沿いの流紋岩類は層序的に2つに区分される。上部は白川流紋岩類，下部は飛驒川流紋岩類で，両者は不整合関係である。飛驒川流紋岩類と白川流紋岩類とは岩相上のみならず古生層に対する構造的な関係においても明瞭な相違がみられる。

飛驒川流紋岩類は，飛驒川に沿った地域における濃飛流紋岩類の主体を構成し，濃飛西縁被砕帯の東側に生じた大きな陥没帯に累積した。流紋岩類は濃飛西縁破砕帯によって生じた断層崖により，それよりも西方に越えて出てはいかなかった。そのcooling unitの厚さは100m以上と推定される。

白川流紋岩類は飛驒川流紋岩類が形成された後で，西縁において発生した局地的な火山活動の産物である。cooling unit の厚さは約20mである。白川流紋岩類は飛驒川流紋岩類をおおうと共に西方に向かってはみ出して古生層にオーバーラップし，これを不整合におおう。飛驒川流紋岩類と白川流紋岩類の化学組成を比較してみると飛驒川流紋岩類中の熔結凝灰岩と熔岩は流紋石英安山岩質で，SiO_2の含有量は67～68％である。一方，白川流紋岩類中の熔結凝灰岩では流紋岩でSiO_2は72～73％である。この化学組成の違いは，斑晶鉱物の容量比にも明らかに示されている。飛驒川流紋岩類は斜長石と有色鉱物にとむ傾向を示し，白川流紋岩類はアルカリ長石と石英にとむ傾向を示す。したがって，飛驒川流紋岩類は花崗閃緑岩の噴出岩相である流紋石英安山岩に，白川流紋岩類は，アダメロ岩の噴出岩相である流紋岩に，それぞれ対応している。

飛驒川流紋岩類と白川流紋岩類はそれぞれカルクアルカリ岩系に属する。

白川流紋岩類の火道角礫岩は，濃飛流紋岩類の西縁の古生層との境に近い2カ所から発見された。飛驒川流紋岩類は cooling unit の厚さや，分布範囲から推定して，白川流紋岩類に較べて，大きな規模の割れ目噴出によって生じたものである。飛驒川流紋岩類の火道はくり返して噴出した火砕流によっておおわれているため，その存在は確認できない。

流紋岩類の変質は，層序的な上位と下位で明瞭な差を示している。2ミクロン以下の変質鉱物の粒子によるX線の回折図によれば，変質鉱物の組合せによる変質帯の区分が可能である。すなわち，飛驒川流紋岩類と白川流紋岩類は，3つの変質帯に分けられる。弱いほう（低温）から強いほう（高温）に向かってモンモリロナイト帯，モンモリロナイトとクロライトの混合層鉱物からなる漸移帯，クロライト帯として，区分される。漸移帯はクロライトとモンモリロナイトとの混合層鉱物で特徴づけられる。クロライト帯と漸移帯との境は，飛驒川流紋岩類と白川流紋岩類との境にほぼ一致している。

流紋岩類の噴出に引きつづく火成活動としては，花崗閃緑斑岩，花崗斑岩，石英斑岩の活動があり流紋岩類の分布地域および西縁の古生層中に貫入した。上記の 3 つの岩石はそれぞれ連続的な関係を示している。流紋岩類に引きつづくすぐ直後の活動は，花崗閃緑斑岩であり，ストックまたはボス状に貫入した。これらに引きつづいて花崗斑岩と石英斑岩が岩脈状に貫入した。

上記の貫入岩はいずれも濃飛流紋岩類の火山活動の最末期を代表している。

いわゆる〝白堊紀花崗岩〞とよばれている苗木―上松花崗岩，白川花崗岩等の貫入は中部地方では白堊紀火成活動の最終段階に相当する。

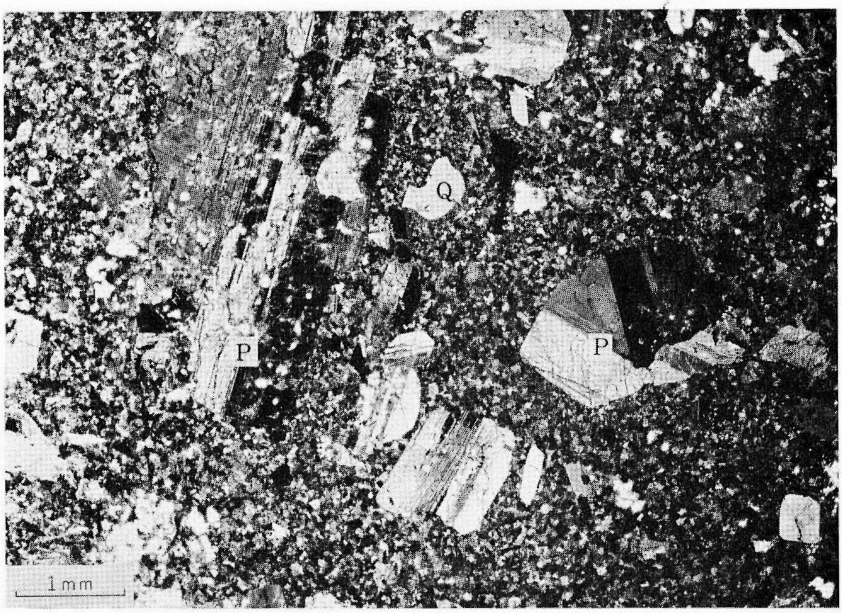
濃飛流紋岩類の火山活動の時期は，97×10^6年を示す石英閃緑岩に対する不整合関係と60×10^6年を示す花崗岩類による貫入関係とから推定される。すなわち，濃飛流紋岩類は白堊紀末のある時期（$60\sim97\times10^6$年）に形成された。

濃飛流紋岩類は西南日本内帯の他地域の白堊紀末流紋岩類に，次のような点で類似している。

a）火砕流堆積物を主体とした巨大な火山岩累層で特徴づけられること，b）主要な岩相は流紋～流紋石英安山岩であること，c）カルクアルカリ岩系であること，d）噴出の時代，e）伴う貫入岩類の種類と関係がよく似ていること，その中でも特に広義の西南日本において，濃飛流紋岩類と足尾山地の奥日光流紋岩類（河田，1966），琵琶湖東部の湖東流紋岩類（河田他，1969）は，その形成の様式や，火成活動と地質構造において著しい共通性がある。

PLATES
AND
EXPLANATIONS

(With 13 Plates)



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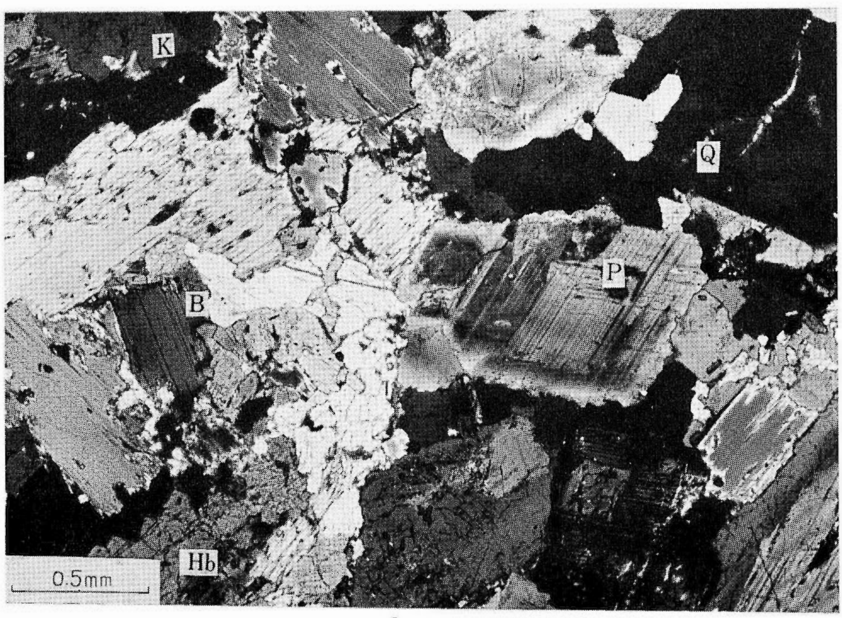
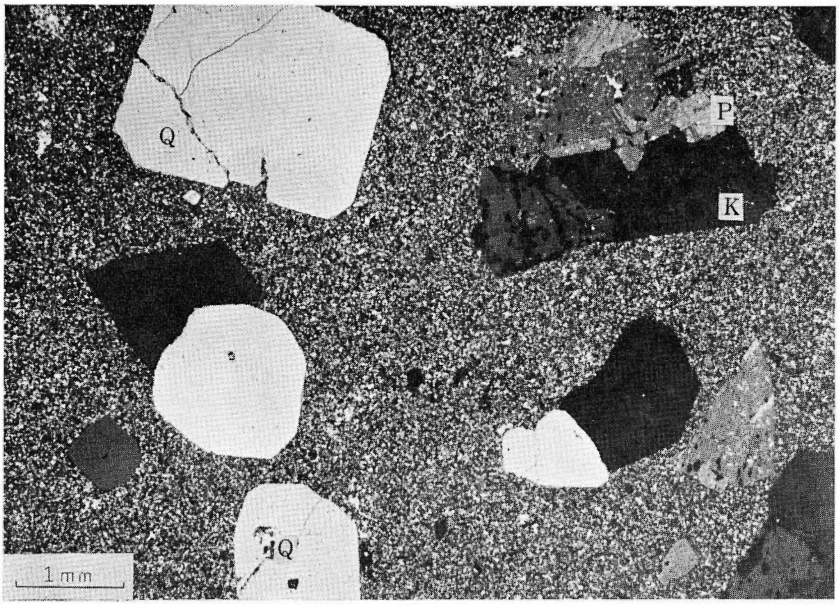


2

1. Ryodacite lava (Shimoyui rhyodacite)
   Groundmass minerals are microcrystalline to cryptocrystalline quartz and feldspar. Crossed nicols. Specimen no. K 160 (Southeast of Shimoyui, Shirakawa-machi)
2. Quartz diorite.
   Crossed nicols. Specimen no. K 350 (Kawamata, Shirakawa-machi)
   K: Alkali feldspar P: Plagioclase Q: Quartz B: Biotite
   Hb: Hornblende



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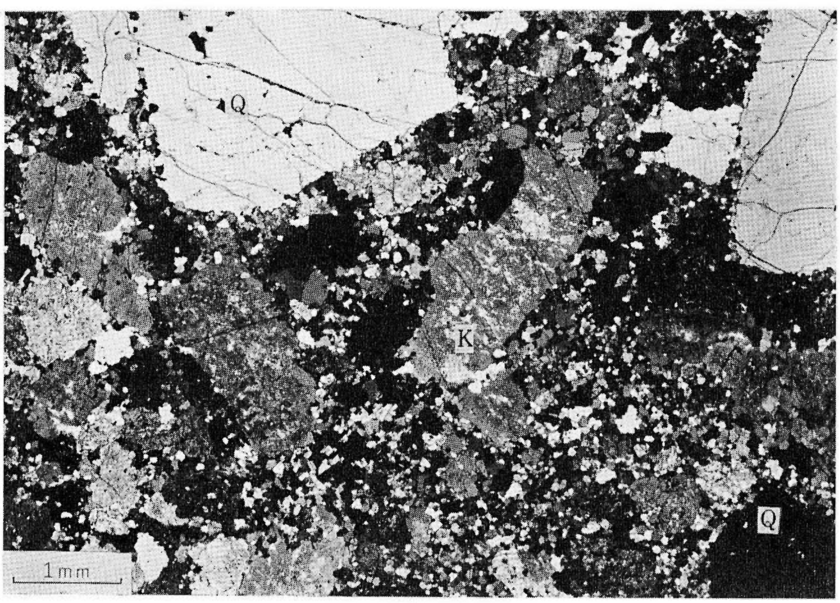
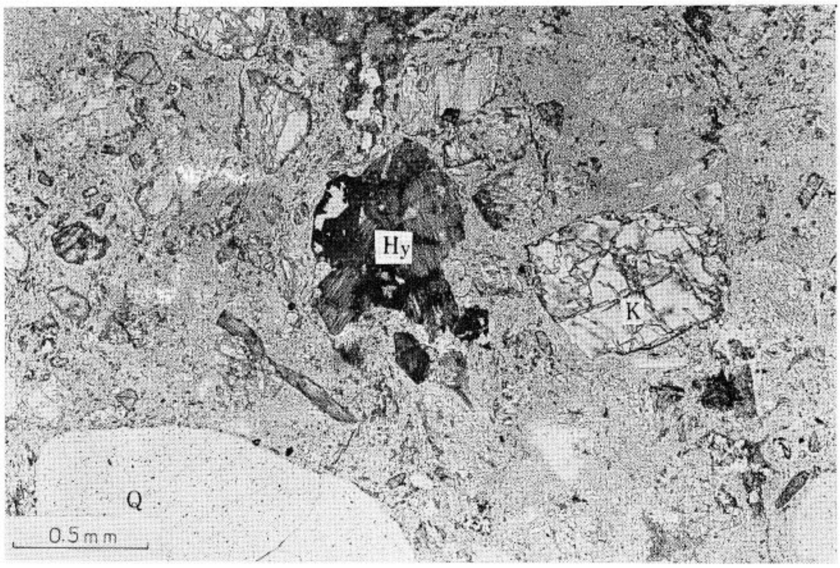


2

1. Quartz porphyry
   Typical texture of the quartz porphyry is quite different from that of welded tuff. Quartz and alkali feldspar phenocrysts show distinct idiomorphic form. Groundmass consists of microcrystalline quartz and alkali feldspar. Crossed nicols. Specimen no. K 87 (South of Kanayama-machi, on the east bank of the Hida River)
2. Thermally metamorphosed rhyolite welded tuff
   Groundmass is recrystallized to holocrystalline and mosaic texture. Clots of fine-grained scaly biotite are recognized. Large phenocrysts of quartz and feldspar are relics. Crossed nicols. Specimen no. T 34 (South of Tsukechi-machi, on the west bank of the Tsukechi River)

K: Alkali feldspar P: Plagioclase Q: Quartz



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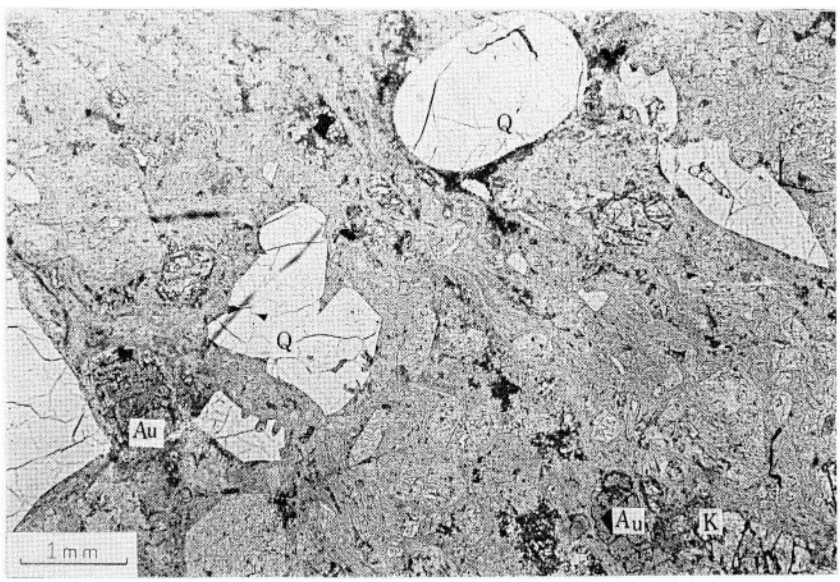
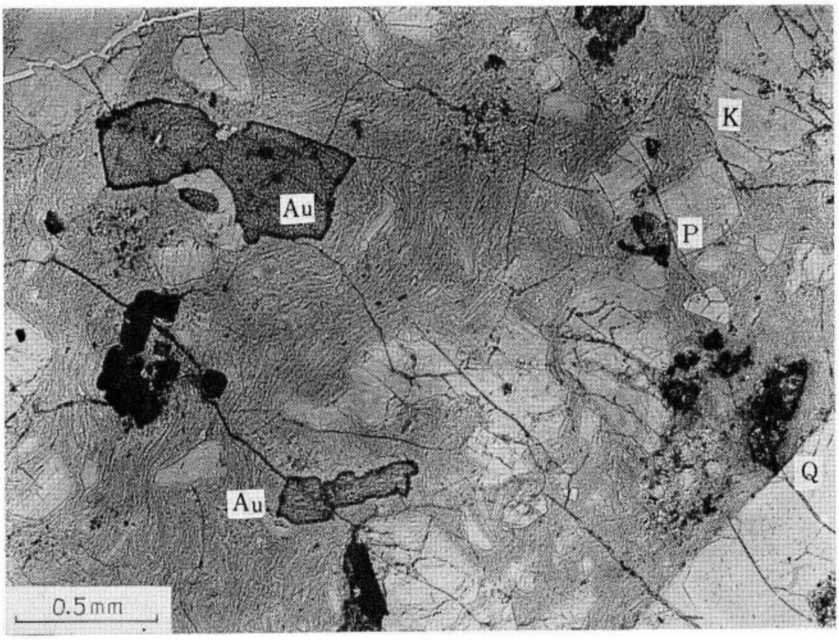


2

1. Altered rhyodacite welded tuff (Hidagawa rhyolites)
   Hypersthene phenocryst is mostly altered to pale greenish clay minerals. Matrix is mostly devitrified. Lower nicol only. Specimen no. K 136 D (East of Tajima, on the west bank of the Sami River)
2. Altered rhyodacite welded tuff (Hidagawa rhyolites)
   Considerably devitrified, but the texture of compressed glass shards is preserved. Corroded quartz is conspicuous. Lower nicol only. Specimen no. K 216 (Northwest of Shinzu, Shirakawa-machi)

K: Alkali feldspar Q: Quartz Au: Augite Hy: Hypersthene



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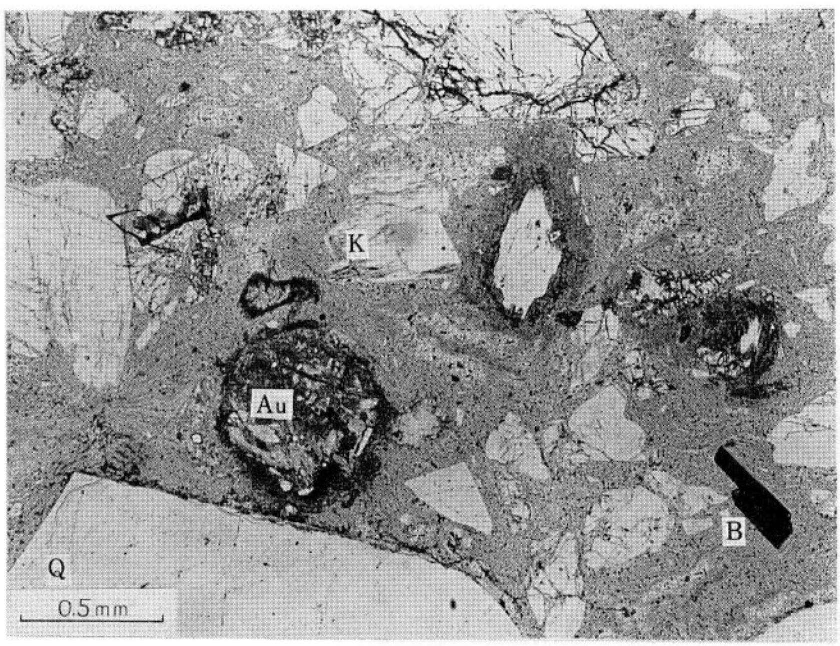
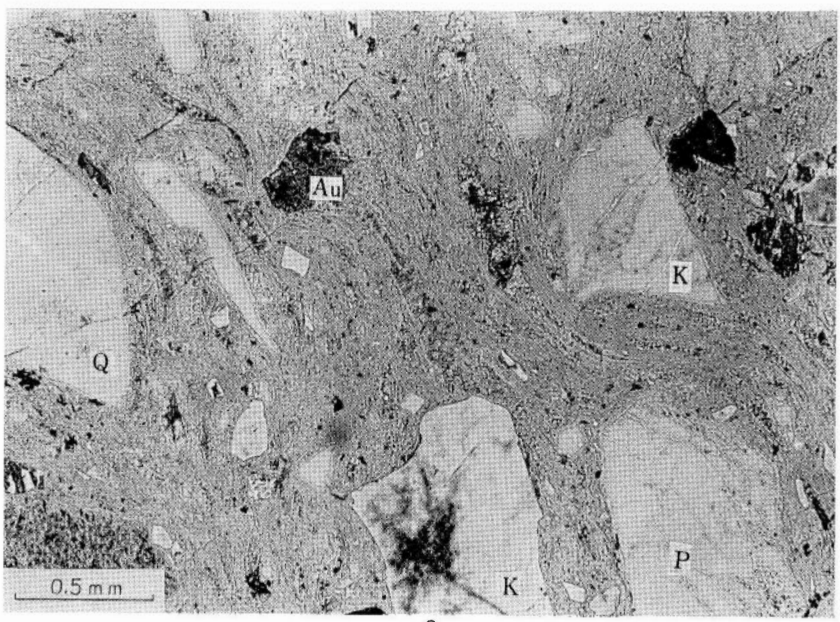


2

1. Rhyodacite welded tuff (Unclassified rhyolites)
   Plagioclase and augite are dominant phenocryst minerals. Strongly stretched glass shards show dense welding. Lower nicol only. Specimen no. H 166 (West of Hagiwara-machi, on the west bank of the Maze River)
2. Altered rhyodacite welded tuff (Unclassified rhyolites)
   Welded matrix is well preserved, however partly devitrified. Most of crystals show fragmental form. Lower nicol only. Specimen no. 67–MM 1 (West of Mikkamachi, Kiyomi-mura)

   K: Alkali feldspar P: Plagioclase Q: Quartz Au: Augite B: Biotite

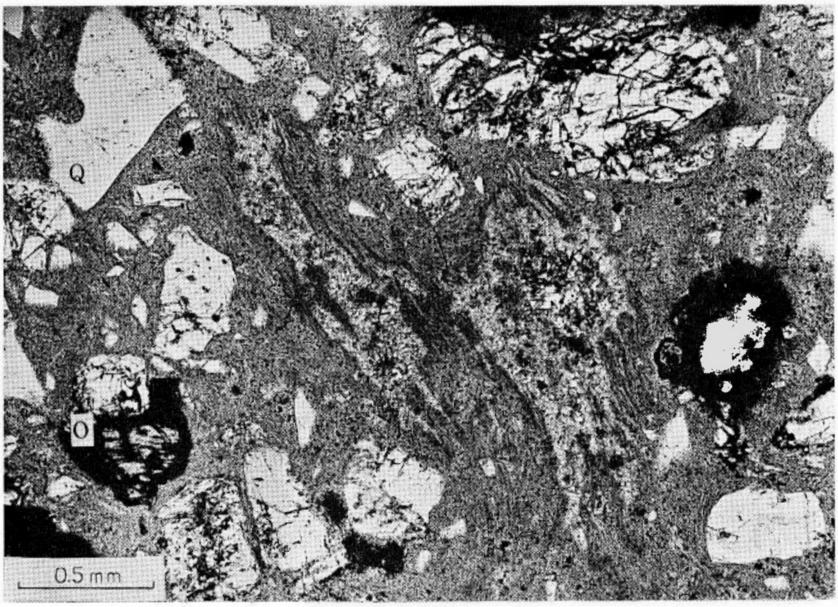
1



2

1. Fine-grained glassy rhyolite welded tuff (Shirakawa rhyolites)
   Crystal fragments are scattered uniformly. Glass shards are stretched and strongly welded. Pumice is flattened by compaction. Lower nicol only. Specimen no. 67–KY 87 (North of Shinzu, Shirakawa-machi)
2. Rhyolite welded tuff (Shirakawa rhyolites)
   One of well-developed welded structure, i.e. eutaxitic texture is obvious in this tuff. Lower nicol only. Specimen no. K 24 (North of Shinzu, Shirakawa-machi)

K: Alkali feldspar P: Plagioclase Q: Quartz Au: Augite



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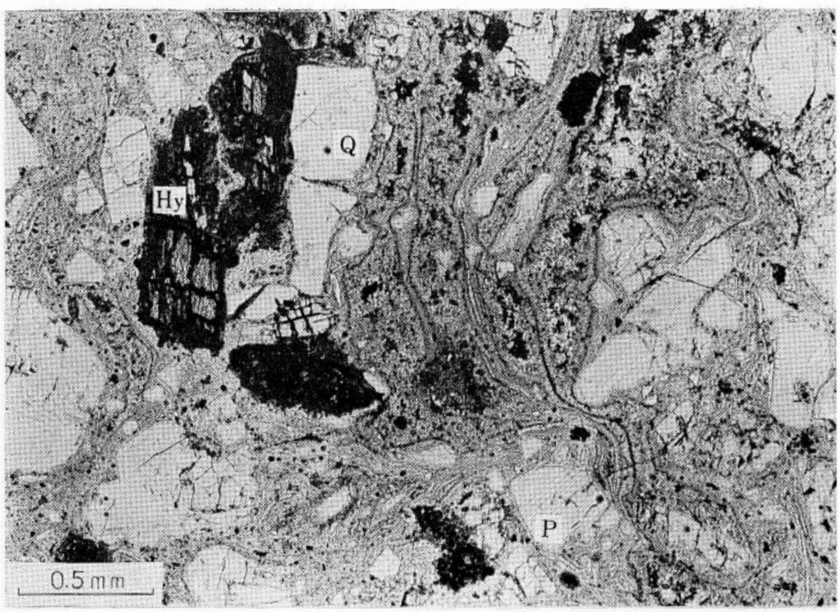
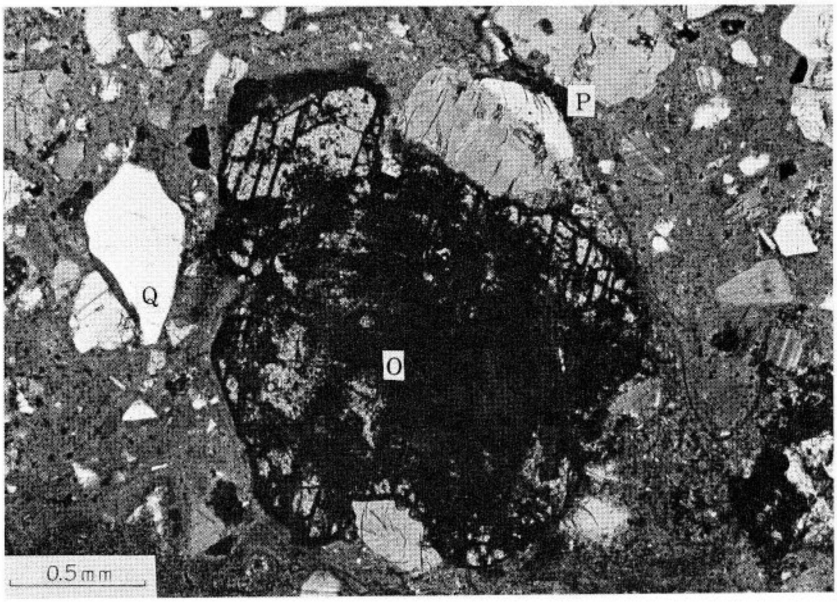


2

1, 2. Porphyritic rhyolite welded tuff (Shirakawa rhyolites)
Strongly welded glass shards invade into cracks of phenocryst. Most of glass shards are devitrified to very fine-grained quartz. Hypersthene is altered to green clay minerals along cracks and rims. Lower nicol only. Specimen no. K 207 (North of Shinzu, Shirakawa-machi)
Q: Quartz O: Olivine P: Plagioclase H: Hypersthene



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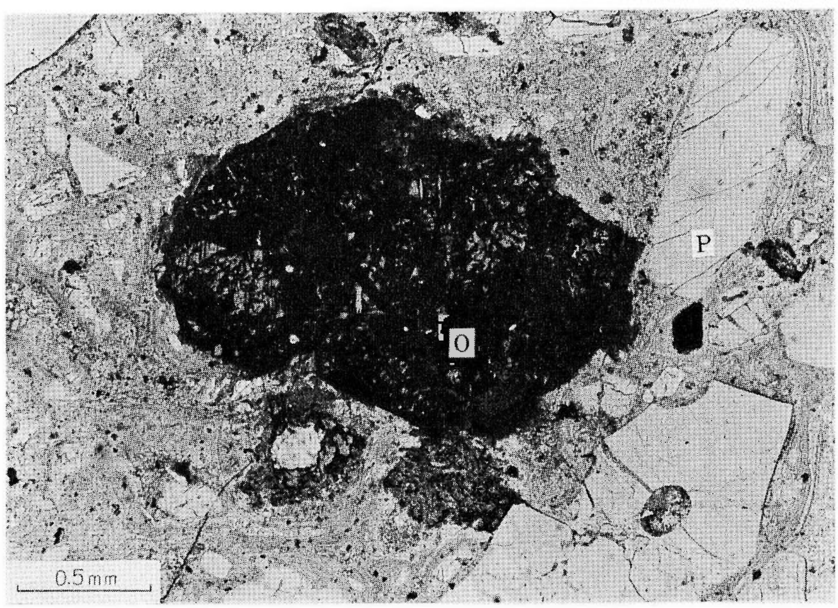
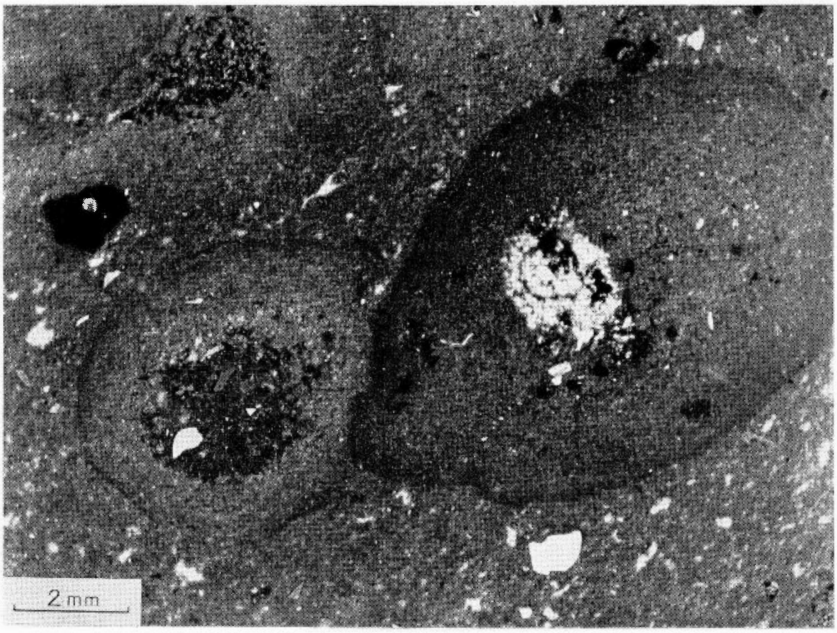


2

1,2. Only one thin section in which olivine (ferrohortonolite) is identified Olivine is largely replaced by opaque iron minerals. Lower nicol only. Photographed from the same specimen with Pl. VI–1, 2. Lower nicol only.

P: Plagioclase Q: Quartz O: Olivine



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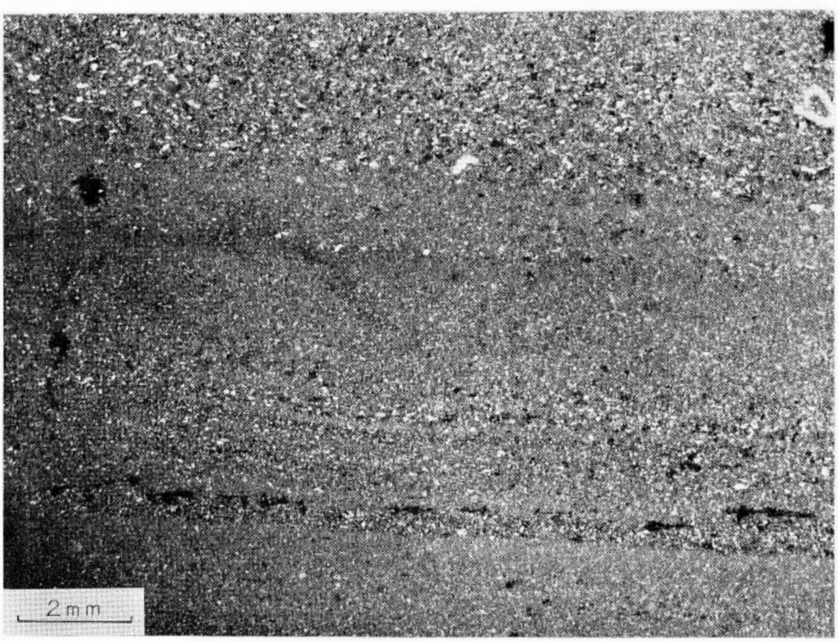
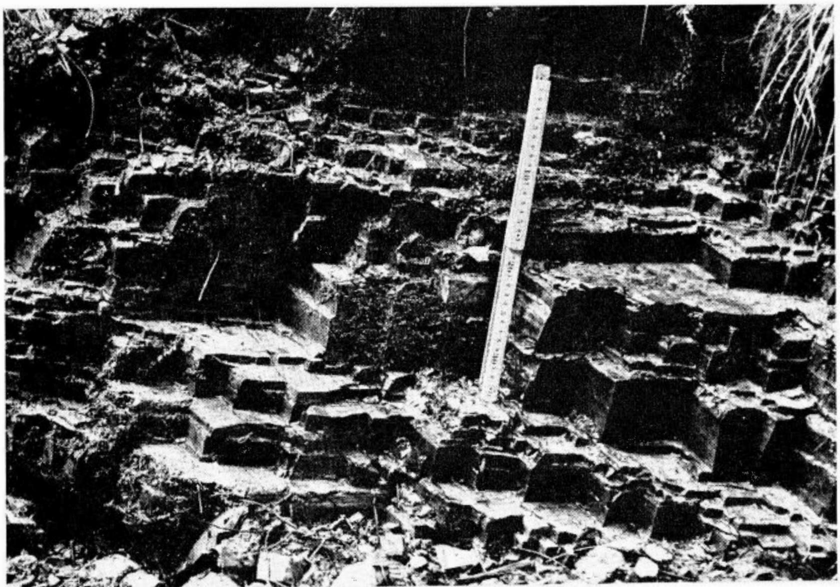


2

1. Accretionary lapilli in Utō bedded tuff (pisolite tuff)
   Crystal fragments of quartz and feldspar are seen in the central parts of accretionary lapilli. Grain size becomes progressively finer from central to peripheral parts of lapilli. Specimen no. 67–KY 82 (North of Shinzu, Shirakawa-machi) Corresponding to locality no. 2 in Fig. 6.
2. Utō bedded tuff
   Very thin units of graded bedding are seen. Specimen no. K 131 (East of Tajima, Kanayama-machi)

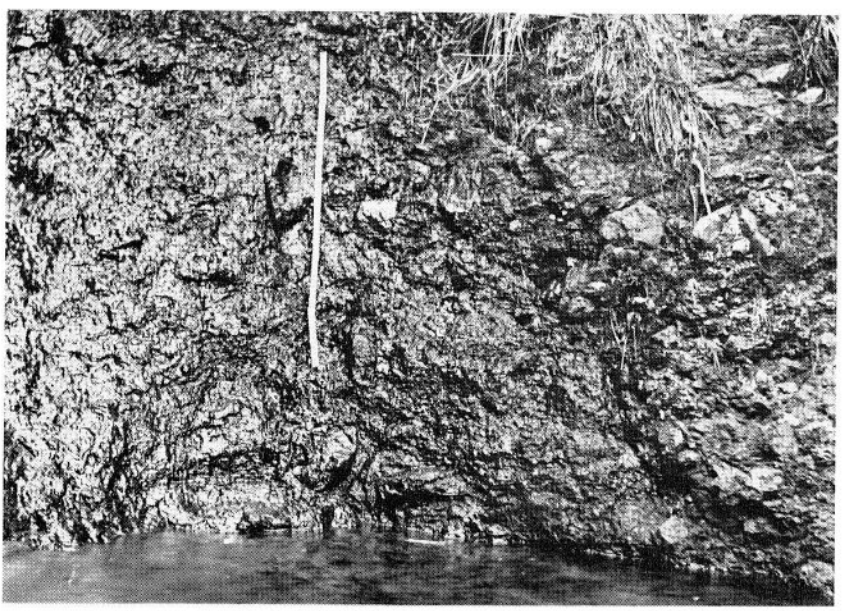


1

2

1. Utō bedded tuff
   Fissility is seen in parallel with well-developed bedding. White scale is 35 cm long. (North of Shinzu, Shirakawa-machi)
2. Unconformity plane between Utō bedded tuff and underlying Shinzu formation.
   Shinzu formation in the lower right was intensely sheared when Nōhi west-boundary sheared zone was formed. White scale is 35 cm long. (North of Shinzu, Shirakawa-machi) Corresponding to locality no. 2 in Fig. 6.

1



2

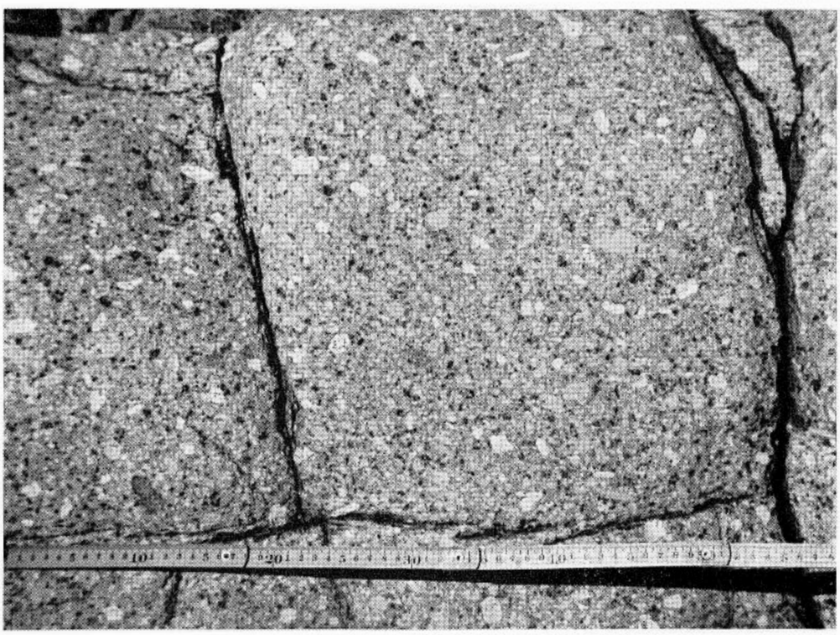
1. Tuffaceous conglomerate (Shirakawa rhyolites)
Boulders in the upper and lower parts of this photograph are rhyolite welded tuff, whereas subangular cobbles around the boulders are Paleozoic sandstone. Scale is 35 cm long. (North of Shinzu, Shirakawa-machi)
2. Typical exposure of the Shirakawaguchi formation
The "chaotic" part in the middle and left part of the photograph consists of sheared material of the Paleozoic sandstone, slate and chert. The boulders of the right part are mostly Paleozoic sandstone. Scale is 1 m long. (North of Shinzu, Shirakawa-machi) Corresponding to locality no. 1 in Fig. 6.

1

2

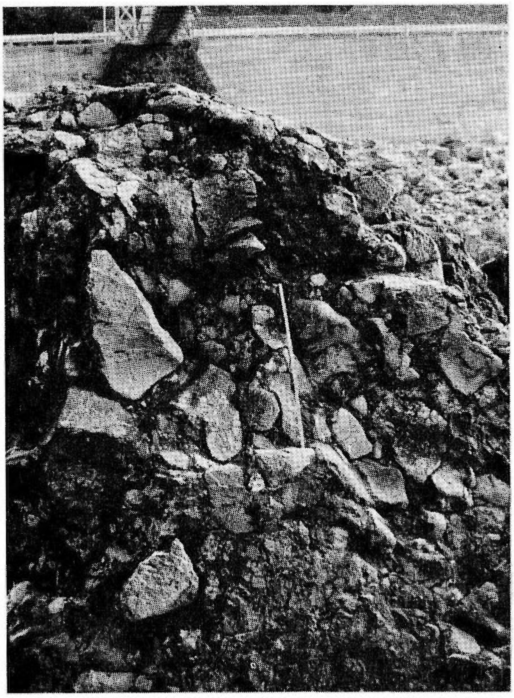
1. Pumiceous rhyodacite welded tuff (Hidagawa rhyolites)
   Strongly collapsed pumice fragments are seen on the weathered surface. Scale in cm. (Near Shimoyui Station of the Japan National Railways on the east bank of the Hida River)
2. Collapsed and flattened pumice fragments in the rhyodacite welded tuff (Hidagawa rhyolites)
   Phenocryst are considerably sheared and deformed. (Near Shimoyui Station of the Japan National Railways on the east bank of the Hida River)

1



2

1. Granite porphyry dike intruded into the rhyolite welded tuff
Rhyolite welded tuff in the left part contains a large amount of lithic fragments. Near the contact the granite porphyry grades into fine-grained marginal facies. (Near Tajima power station in the Hida River)
2. Close-up view of the granite porphyry
Large euhedral phenocrysts are mostly alkali feldspar. Scale in cm. (Near Tajima power station in the Hida River)



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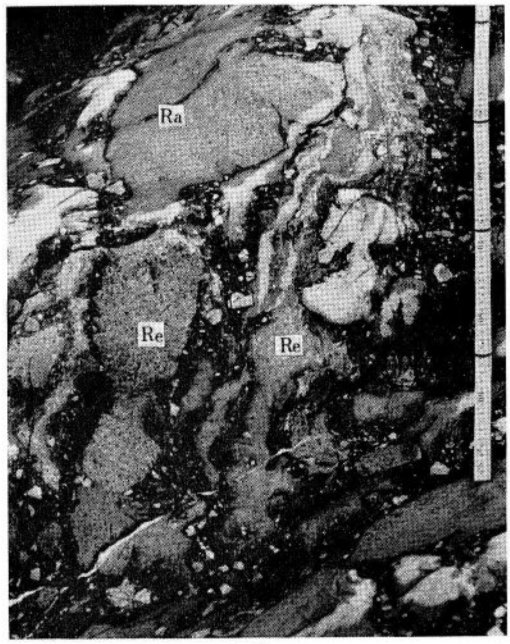

2

1. Vent-breccia
Subangular boulders in the middle part are rhyolite welded tuff (accessory fragments). The boulders are mostly aligned in the vertical direction. Scale is 1 m long. (Under Shichisō bridge across the Hida River, Kanayama-machi)
2. Essential materials in the vent-breccia
The white parts of wavy slender lenticular form (Re) is essential material. The gray part of "pseudo-pebble" form is also considered to be essential material. The darker matrix consists of glass shards, crystal fragments, accessory fragments and accidental fragments. Scale is 70 cm long. (Under Shichisō bridge across the Hida River, Kanayama-machi)
Ra: Accessory block

地質調査所報告は１報文について報告１冊を原則とし，その分類の便宜のために，次のようにアルファベットによる略号をつける。

A. 地質およびその基礎科学に関するもの
- a. 地　質
- b. 岩石・鉱物
- c. 古生物
- d. 火山・温泉
- e. 地球物理
- f. 地球化学

B. 応用地質に関するもの
- a. 鉱　床
- b. 石　炭
- c. 石油・天然ガス
- d. 地下水
- e. 農林地質・土木地質
- f. 物理探鉱・化学探鉱および試錐

C. そ の 他

D. 事業報告

As a general rule, each issue of the Report, Geological Survey of Japan will have one number, and for convenience's sake, the following classification according to the field of interest will be indicated on each Report.

A. Geological & allied sciences
- a. Geology
- b. Petrology and Mineralogy
- c. Paleontology
- d. Volcanology and Hot spring
- e. Geophysics
- f. Geochemistry

B. Applied geology
- a. Ore deposits
- b. Coal
- c. Petroleum and Natural gas
- d. Underground water
- e. Agricultural geology and Engineering geology
- f. Physical prospecting, Chemical prospecting and Boring

C. Miscellaneous

D. Annual Report of Progress

地 質 調 査 所 報 告

第 238 号

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第 240 号

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KAWADA, K.

Geology and Petrology of the Nōhi Rhyolites, with Special Reference to Those along the Hida River

Kiyoo KAWADA

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22 illus., 13 pl., 8 tab.

The Cretaceous Nōhi rhyolites, widely distributed in Central Japan and hitherto called quartz porphyries, have been revealed to be a gigantic volcanic pile consisting chiefly of pyroclastic flow deposits. In this paper, the writer outlines the geology of the rhyolites especially those of the southern Hida massif, and discusses the stratigraphic division, lithology, petrography, petrochemistry and rock alteration of the welded tuffs and associated rocks along the Hida River in detail.

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