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REPORT No. 217

GEOLOGICAL SURVEY OF JAPAN

PETROLOGY OF THE KITA-MATSUURA BASALTS IN THE NORTHWEST KYUSHU, SOUTHWEST JAPAN

By

Hajime KURASAWA

GEOLOGICAL SURVEY OF JAPAN
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Konosuke SATO, Director

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Abstract

The Kita-matsuura district is situated in the southwestern end of the Circum-Japan Sea alkali rock province. Older rocks of this district are represented by the schists of the Nishi-sonogi peninsula in the southwest and the granitic rocks in the northeast. The Tertiary basement rocks resting on these older rocks are the Oligocene Kishima group and the Miocene Sasebo group, the age of the constituent formations becoming younger westward. This Tertiary system is divided into the area of micro-folds in the east and the area of basin structure in the west, the latter being characterized by the Sazagawa thrust movement.

These basement rocks are covered by basalts that were erupted along the tectonic line accompanied by the faults trending NW–SE. The basalts have gone through several periods of activity and dormancy, and their total amount has reached 49 km^3 which is nearly one half of all basalts hitherto erupted in western Japan.

By the volcano-stratigraphic and paleomagnetic methods, the present writer has classified these basalts into five groups, I through V. The natural remanent magnetism of each group is denoted, in ascending order, as R (reversed), N (normal), N, R and N, showing that magnetization is reversed in two of the groups. The basaltic activities covered a long period, probably between the middle of the Pliocene of Tertiary to the Pleistocene of Quaternary.

In the Kita-matsuura district, the activity began with the eruption of very small volumes of tholeiitic basalts (Group I). It was succeeded by the stage of full-scale activity by which the volcanic rocks belonging to the alkali rock series, a principal member of basalts, were erupted (Groups II–IV), intervened with two or three dormant stages. Toward the end of this active period, eruption of intermediate to acidic volcanic rocks occurred in the eastern area. In the last stage, the volcanic activity characterized by conspicuous contamination took place (Group V), which put an end to the volcanism of the Kita-matsuura district.

This serial volcanic activities can be regarded as one cycle of volcanism in a certain area. The volcanism of the Kita-matsuura district was started with the activity of oversaturated magma, which gradually changed to the activity of more strongly undersaturated magma; then came the activity of weakly undersaturated magma, finally ending in the activity which was marked with contamination.

After detailed studies of these basalts, with reference to their dimensions, petrological and petrochemical properties, and the characteristics of the parental magma inferred for each group, the writer has reached a conclusion that the variance of the basalts of this district is ascribed to different compositions of their parental magmas, that is, the parental magma of each group was generated independently. Difference of parental magma is reflected especially in the silica-saturation rate, and this rate is represented by excess or deficiency of normative quartz.

From the above viewpoints, it is concluded that the chronological changes in the Circum-Japan Sea alkali suite which was active in West Japan is controlled

fundamentally by the changes in the composition of the parental magmas of the erupted materials, as typically manifested by the rocks of the Kita-matsuura district.

I. Introduction

The Cenozoic volcanic rocks which are widely distributed in West Japan belong mostly to the Circum-Japan Sea alkali rock province (TOMITA, 1935). The Kita-matsuura basalts to be discussed in the present paper are distributed in the northwestern part of Kyushu, extending over the prefectures of Nagasaki and Saga.

Since about 1956 the writer has been carrying out petrological and geochemical studies of the volcanic rocks, particularly basalts, of the San-in region and northwestern Kyushu, West Japan, with an attempt to find a clue for clarifying the genesis of volcanic rocks.

Of all the basalts distributed in West Japan, the Kita-matsuura basalts of northwestern Kyushu present activities of the largest scope. The major portion of these basalts belongs to the alkali rock series, accompanied by subordinate amounts of rocks belonging to the tholeiitic rock series and calc-alkali rock series. Hence, the Kita-matsuura district where various kinds of rocks are distributed would be the most desirable area for discussing the genesis of basalts.

The volcanic rocks of the Kita-matsuura district were surveyed and presented in the 1: 50,000 geologic map sheets, namely, "Imari," "Hirado" and "Sasebo (unpublished)" compiled by SAWAMURA and others, and "Karatsu" and "Yobuko" compiled by MATSUI and others. Using these maps as a guide, the present writer surveyed the district, attaching importance to volcano-stratigraphy, and also collected specimens for the purpose of geochemical researches. About 600 thin sections were prepared and about 100 specimens were chemically analyzed for correlation and examination of these rocks.

Nevertheless, the obtained results were not satisfactory either for correlation of various kinds of basalts or for elucidation of the relationship between the basalts and the intercalated conglomerates. Therefore, the writer attempted an application of remanent magnetism for correlation of the rocks, i.e. paleomagnetic method, to the stratigraphic correlation. On the basis of the results of these researches, the Kita-matsuura basalts were classified into five groups from the volcano-stratigraphic viewpoint.

Studies of the volcanic rocks of this district and its neighbourhood have become active in recent years. Major researches on the volcano-stratigraphy of these rocks are exemplified by the reports of YAMASAKI & MATSUMOTO (1959, 1960) and SAWAMURA et al. (1952). On the other hand, petrological and genetical discussions were made by AOKI (1959), MATSUMOTO (1961), and others. OCHI (1956–Present) has been carrying out a petrologic study of basalts sporadically distributed in northern Kyushu. ISHIBASHI (1962, 1964) is continuing his study of pyroxene in these basalts. FUKUYAMA (1961) has reported on the basalts of the Kita-matsuura district.

AOKI (1959), through his study of the volcanic rocks in the Higashi-matsuura district and Iki Island, has discussed crystallization differentiation of volcanic rocks of the alkali rock series. Also, he has pointed out that the calc-alkali rock series comprises rocks derived from two different types of magma, namely, alkali olivine basalt magma and tholeiite magma.

MATSUMOTO (1961c), working independently, has reported as follows:

Despite the fact that the Matsuura basalts and post-Miocene basalts of northwestern Kyushu can be classified by their mineral compositions into alkali rock series, tholeiitic rock series and calc-alkali rock series, their chemical compositions reveal an abnormal differentiation, that is, all these basalts have undergone the fractionation trends of the calc-alkali rock series, not those of the alkali rock series or tholeiitic rock series. As the cause of this abnormality, MATSUMOTO has given contamination of an alkali olivine basalt magma with a basic rock such as porite at an early stage, and further contamination of this composite magma with granitic rocks. MATSUMOTO calls the resultant basalt "abnormal basalts".

For the purpose of clarifying the origin of the Kita-matsuura basalts, the present writer has endeavoured, in the first place, to find out the order of eruption, the volume of erupted rocks, and the time relations of the respective rock groups, and, in the second place, to define the petrological and chemical properties of the basalts that are classified on the basis of the results thus obtained.

This paper discusses the origin of the Kita-matsuura basalts as deduced from the results of the above-mentioned researches; the genetical discussion is developed further for the basalts widely distributed in West Japan.

II. Acknowledgements

The writer wishes to express his sincere thanks for the guidance, discussion, field survey, and encouragements kindly offered by the following persons:

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Mr. Kazunori MATSUI of the Geology Department of the Geological Survey, joined several field trips to the northwestern Kyushu and the discussions which greatly benefited the writer. To Mr. Tomosaburo SAITO of the Geophysics Department of the Geological Survey, the writer is indebted for the use of a magnetometer and helpful advices for the magnetic measurements.

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The writer owes much to these Authorities and without whose help this study could not have been made.

III. Geology and Volcanic Activity of Kita-matsuura District

III. 1 Topography

The Kita-matsuura basalts are distributed in the northwestern part of Kyushu, West Japan, in the area between Long. 129°31'–129°50' E and Lat. 33°10'–33°25' N (Fig. 1). The area of distribution is bounded on the east by Arita-gawa flowing into Imari Bay, and on the north and west by the shoreline.

On the lava plateau composed of the Kita-matsuura basalts, dissection is fairly advanced. The surface of the plateau gradually lowers from east to west. The highest part is represented by Kunimi-yama (776.7 m) which, along with Eboshi-dake (597.1 m), Hatten-dake (707.4 m) and Kakui-dake (670.2 m), forms the plateau's eastern margin serving as the watershed of the district. The east slope of this watershed is steep. In the central part of the plateau are found such ridges as Kohochi-dake (411.8 m) and Senryu-shira-dake (373.3 m).

Shisa-gawa, Saza-gawa and Ainoura-gawa are the principal streams flowing westward, dissecting the plateau and eroding the Tertiary basement (Fig. 2).

The basement of the basalt lavas is composed largely of the Tertiary Sasebo group, and the basal plane of the basalts is generally flat, paralleling the surface

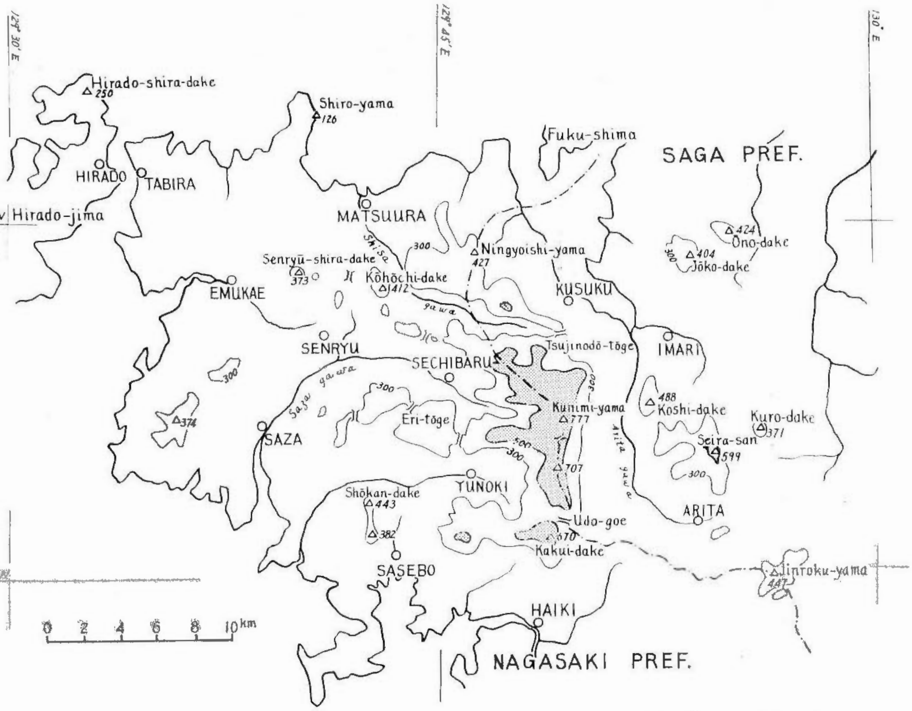


Fig. 2 Topographic map of the Kita-matsuura district, Northwest Kyushu.

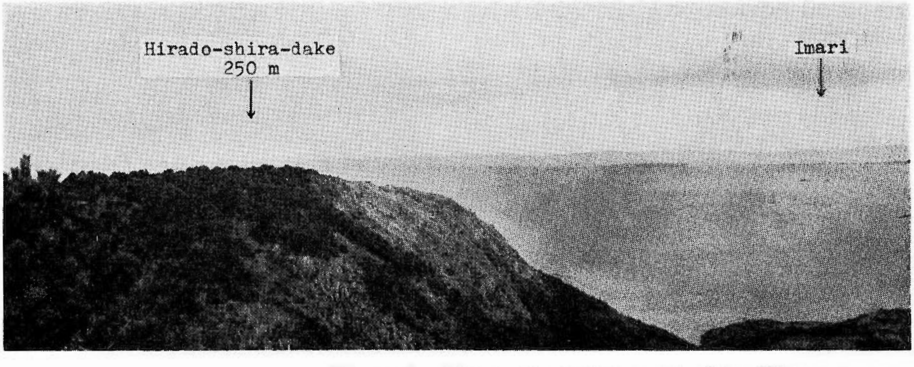


Photo. 3 The northwestern coast of the Kita-matsuura

of the plateau.

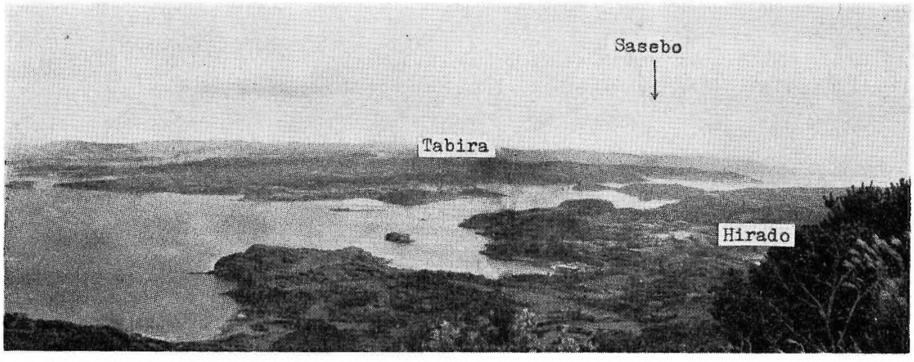
To the east of the Kita-matsuura basalt lava plateau are found rhyolites, andesites and basalts, intruding or covering the Tertiary system. Being resistant to erosion, these rocks form peaks rising above the surrounding hilly land. Major peaks are Ono-dake (424 m), Joko-dake (404 m), Koshi-dake (487.7 m), Seira-san (599.2 m), Kurokami-yama (518.2 m), Mayu-yama (518.2 m) and Jinroku-zan (447 m).

The basalt lavas constituting these peaks are contemporaneous with the Kita-matsuura basalts distributed to the west. The peaks are the remnants of plateau lavas that were eroded away for the most part but were retained in small areas.

The Tertiary system of the hilly land is folded and is marked with dome and basin structures. One-dake and Joko-dake, whose summits are made up of volcanic rocks, are located in the center of the basin structure.

A fault system of a NW–SE trend is developed in the vicinity of Imari City, showing a directional character similar to the shape of Imari Bay. This trend extends as far as the eastern half of the distribution area of the Kita-matsuura basalts.

Photo. 4 Showing the topography around Senryu coal mine. Basalt plateau as seen from the north hill of Senryu.



basalt plateau as seen from Hirado-shiradake.

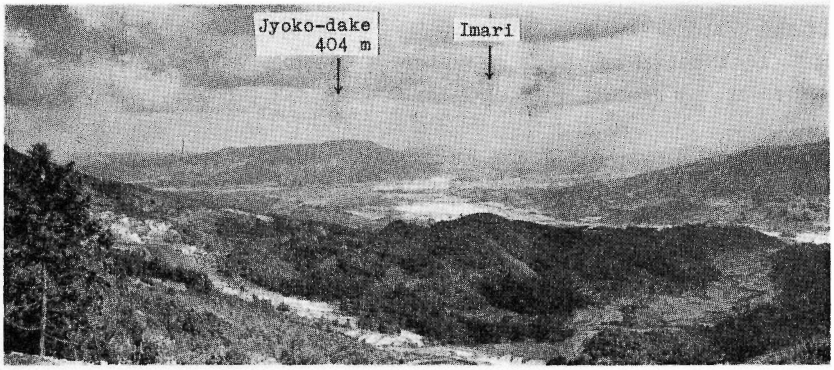
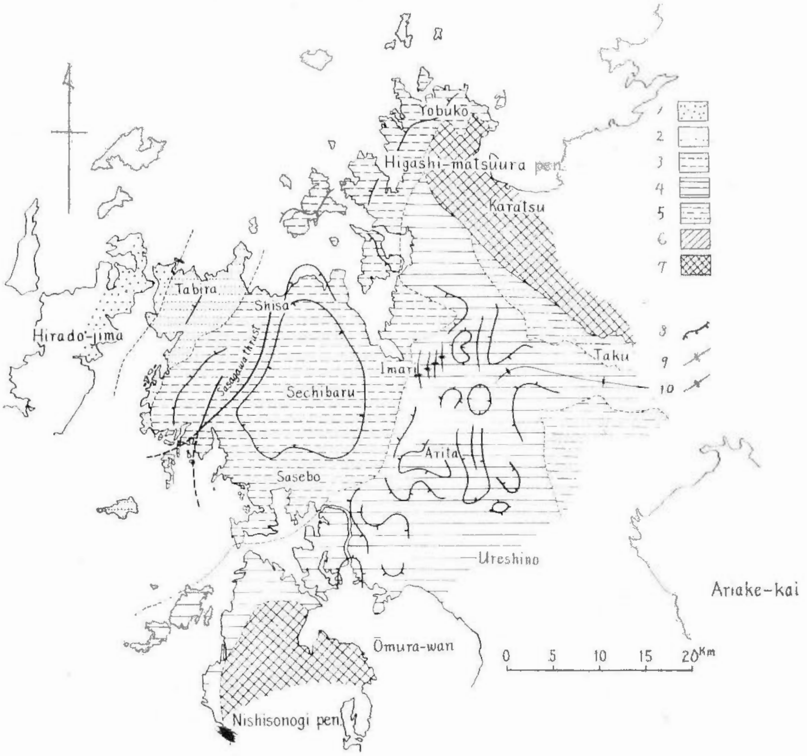


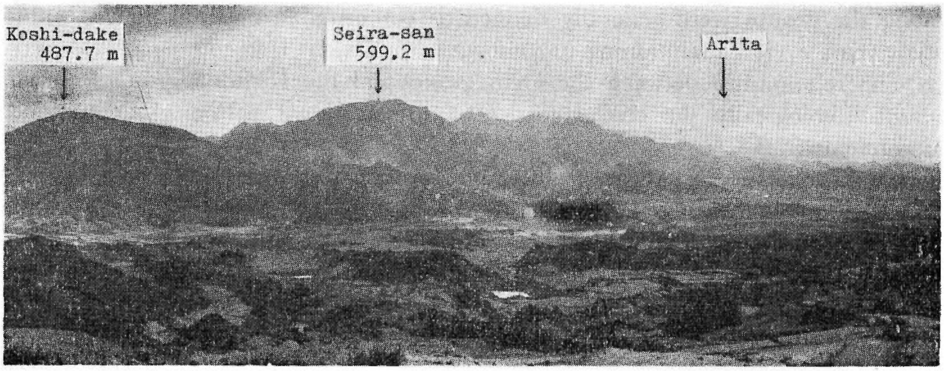
Photo. 5 The photograph shows the topography of the northeastern part of the Kita-matsuura basalt plateau.

Due to the frequent occurrence of landslips, the district is rapidly changing its topography. Especially, the area of distribution of the basalts is marked with topographic features resulting from landslips. At the same time, the landslips have worked to expose geological cross-sections which are greatly helpful in correlation of the respective basalts.



1. Hirado formation 2. Nojima group 3. Sasebo group
4. Kishima group 5. Ochi group 6. Pre-Ochi group
7. Pre-Tertiary (granites and schists) 8. Strike and dip
9. Synclinal axis 10. Anticlinal axis

Fig. 3 Geologic map of the basement of the Kita-matsuura district. (after IMAI et al., 1958)



Kita-matsuura district as seen from the top of the northeastern ridge of the

III. 2 Geology

The Kita-matsuura basalts are widely distributed in the center of the Karatsu and Sasebo coal fields, northwestern Kyushu.

To the northeast of the Kita-matsuura district are found the Paleozoic Sangun metamorphic rocks and the pre-Cenozoic granodiorites. In the Nishi-sonogi Peninsula to the southwest, the Sambagawa crystalline schists are distributed (Fig. 3).

The Tertiary system resting on these older rocks is divided, in ascending order, into Ochi group, Kishima group, Sasebo group, Nojima group and Tabira formation (Hirado formation), the age becoming younger westward (Table 1).

The Kishima group, corresponding to the Ashiya group in the northern part of Kyushu, is composed entirely of marine deposits whose sedimentary facies gradually changes to a deep water facies toward upper horizons.

The Sasebo group consists of brackish-water to shallow-sea deposits in alternation. The group is intercalated with many coal seams.

Each of these groups contains large amounts of feldspar and mica that are supposed to have come from the older rocks. In the part, the stratigraphic relations

Table 1 Stratigraphic succession of the Kita-matsuura district, Northwest Kyushu.

Recent	Alluvium	(Remarks)	
Pleistocene	Kita-matsuura basalts	←Basalt	
	Upper conglomerate (Seira-san (Imari) andesites) (Arita rhyolites)	←Andesite ←Rhyolite (tuff)	
	Kita-matsuura basalts	←Basalt	
Pliocene	Lower conglomerate		(Peneplanation)
	Kita-matsuura basalts	←Basalt { Main faulting Folding	↑
Miocene	Sasebo group	←Dacitic tuff	
Oligocene	Kishima group	←Rhyolitic tuff	
Pre-Tertiary	Granites, Schists		

among the groups were generally defined as conformable or transitional, but in recent years a view maintaining unconformable relations is becoming prevalent.

The relationship between the Ochi group and the Kishima group seems to present lithologically the characteristics of a transitional period of depositional environments.

Views are diversified on the geologic ages, as well as on the stratigraphic division, of these groups. According to NAGAHAMA & MIZUNO(1962), the Ochi group and the Kishima formation in the lowermost part of the Kishima group are assigned to Early Oligocene, the Kishima group excluding the Kishima formation to Late Oligocene, and the Sasebo group to Early-Middle Miocene. The total thickness of the Tertiary system exceeds 3,000 m.

Covering the Tertiary system various kinds of volcanic rocks are found, among which the Kita-matsuura basalts being most predominant. The activities of these basalts extended over the epochs of Pliocene and Pleistocene. Prior to these basalts, the Mayu-yama andesites had been erupted. The Arita rhyolites and the Seira-san andesites which are abundantly distributed south of Imari City are considered to have been erupted during a certain stage of the long period of the Kita-matsuura basalts activities.

After the activities of the above-mentioned volcanic rocks terminated, the Recent talus deposits, landslip deposits and alluvial deposits have accumulated. The basalts are intercalated with the lower and upper conglomerates, as will be mentioned later.

III. 3 Relationship between basaltic activity and geologic structure

The basement rocks of the Kita-matsuura district comprise the Sangun metamorphics with granodiorites, and the Sambagawa metamorphics which are distributed in the Nishi-sonogi Peninsula. The former shows a trend of NEN–WSW and the latter a N–S trend. The Kita-matsuura district is situated in the northern part of this N–S trend.

The structures of the older rocks had exerted a fundamental influence upon the later geologic structures of the Tertiary system.

Exposures of the Tertiary sedimentary formations in the Kita-matsuura district show that the age becomes younger toward the west, without any conspicuous unconformities among them. It is observed also that the time interval between the basalts and the underlying Tertiary system becomes smaller westward. These facts suggest that the center of the Tertiary sedimentary basin migrated gradually to the west.

The peneplanation of the Tertiary system beneath the basalts may have been nearly completed by the time the deposition of the Tertiary system was over. The upper limit of the Tertiary system is recognized at an altitude as high as 500 m in the vicinity of Kunimi-yama, and the surface slopes down to the west with a gradient about 1.5°.

The Sazagawa thrust is largely dividing the Kita-matsuura district into two areas. This thrust is the greatest tectonic line of the district, and started its remarkable movement since the period of deposition of the Fukui formation of the upper Sasebo group. The thrust movement was contemporaneously accompanied by a fold movement. The largest stratigraphic up-throw of the Sazagawa thrust attains to 800 m. This thrust is still active.

Then, a conspicuous fault (block) movement occurred in this district. The faults that have resulted from this movement have a NW–SE or E–W trend. They are generally parallel to the boundary between the basement rocks and the Tertiary system in the Higashi-matsuura district northeast of the Kita-matsuura district, and their intervals are apt to become wider with increasing distance from the basement rocks. Consequently, these faults can be regarded as step faults caused by uplift or subsidence of the basement. The Kusuku, Nagahama, Kunimi-yama and Shokan faults, from north to south, are enumerated as the representative E–W faults in the Kita-matsuura district. Throw of the Kunimi-yama fault is about 1,000 m near Kunimi-yama in the east, and about 540 m in the drainage basin of Shisa-gawa, becoming larger near the river's mouth in the west. The Kunimi-yama fault had conducted more than two remarkable movements.

In the Kita-matsuura district and the neighbouring areas volcanic activities took place from the end of Tertiary to Quaternary; the Ochi to Kishima groups contain rhyolitic tuff, whereas the Sasebo group is characterized by dacitic tuff-breccia, and the Mayu-yama dacite and andesite must have been active toward the end of Tertiary.

As the time lapsed into the epoch of Pliocene, the activities of the Kita-matsuura basalts began, and lasted for a long period from Early Pliocene to Pleistocene. In the course of these activities, the Arita rhyolites and the Seira-san andesites were erupted, as observed in the south of Imari City. The age of this volcanism may be ranked between Group III and Group IV of the Kita-matsuura basalts (Table 1). In contrast with these intermediate to acidic rocks distributed in the area east of Arita-gawa, the basic rocks, i.e. basalts, are distributed in the Kita-matsuura district to the west, presenting the difference in the tectonic movements of the two areas; the former area has undergone the complex fold movement of the Tertiary system, while in the latter the Sechibaru basin structure and the NW–SE fault movement are known.

The Kita-matsuura basalts are extensively distributed in the east and west, with the Sazagawa thrust interposed between. The eastern area is marked with E–W faults, as mentioned above, and eruption of the basalts was controlled by weak lines along these faults. Most of the basalt dikes have intruded along larger faults, and some of them are traceable as far as 10 km or more. These larger faults, in many cases, worked after the deposition of the conglomerates.

From the field observations of the distribution, especially the volumes, of pyroclastic rocks accompanying the basalts, it is inferred that the greatest vent of the Kita-matsuura basalts must have situated at the eastern margin of the present lava plateau, i.e., in the vicinity of Kunimi-yama. In the area centering on Kunimi-yama and Hatten-dake, more than 150 m thick pyroclastic materials are distributed, containing in the lower part a large volume of blocky volcanic bombs (Photo. 6). Ridges of Kohochi-dake and Senryu-shira-dake to the west are possible vents, too, although the absence of noticeable accumulation of pyroclastics prevents a haste conclusion.

Concerning the location of vents of the Kita-matsuura basalts, SAWAMURA holds the following view: The basalts were erupted from the vicinity of Seira-san which lies between Imari City and Arita City. The mountains scattered in the eastern area, namely, Hachiman-dake (763.6 m), Tokuren-dake (444.5 m), Onibana-yama (467.7 m) and Jinroku-yama (447 m), the ridges of Ono-dake (424 m) and Joko-dake (404 m), and the basalt lava plateau of the Higashi-matsuura district, all these constitute one vast plateau of basalt lavas. The basalt plateau is

Photo. 6 The outcrop of the pyroclastics showing blocky part of the volcanic ash belonging to the Group IV, Tsujinodo-toge nearby.

lower in the center around Seira-san than the surrounding area. This feature is interpreted by SAWAMURA as a depression which occurred in the center of a shield-shaped volcanic body (IMAI et al., 1958).

SAWAMURA's view is not acceptable because no structural evidence is available to justify the eastern margin of the Kita-matsuura basalt lava plateau, or the cliff extending north-south in the southwest of Imari City, as being a caldera wall. Same problem applies to other areas. Hence, the present writer thinks that the cliff of the eastern margin of the Kita-matsuura basalt lava plateau is ascribed to a mesa topography, as is the case with other lava plateaus scattering in the adjacent areas.

All the facts so far mentioned suggest that the Kita-matsuura basalts were produced by fissure eruptions controlled by tectonic lines of a NW–SE trend as manifested by the movements of Kunimi-yama, Nagahama, Kusuku and Shokan faults which succeeded the Sazagawa thrust movement. The locations of the vents are not clear, except the afore-said largest one, but the NW–SE structural trend of the Kita-matsuura district indicates a close relation to the basaltic activities.

III. 4 Age of activities of Kita-matsuura basalts

The age of eruption of basalts in northwestern Kyushu has been discussed by many researchers, especially from the stratigraphic viewpoints. NODA & MUTA (1957, 1959) and NAGAHAMA & MATSUI (1958) reported on the area of the Nishi-sonogi Peninsula, IMAI, SAWAMURA & YOSHIDA (1958) on the Kita-matsuura district, YAMASAKI & MATSUMOTO (1959, 1960) on the Karatsu coal-field area, and

IWAHASHI (1961) on the whole area of northwestern Kyushu. These people, through their researches on the basalts and associated conglomerates distributed in the respective areas, have inferred the age of eruption of the basalts.

As suggested by the above researches, it is most important to trace these conglomerates as a key bed for determining the age of the basalts in northwestern Kyushu.

According to NODA & MUTA (1959), beneath the younger basalts which are developed in the northern part of the Nishi-sonogi Peninsula the Omodaka conglomerate is extensively distributed, consisting of rounded pebbles of hypersthene basalt, sandstone, shale and quartz. This conglomerate lies unconformably on the older basalts, Paleogene beds and crystalline schists. The Omodaka conglomerate can be correlated with the conglomerate at the base of the basalts in the Kita-matsuura district. At Kawadana-machi and Sonogi-machi of Sonogi-gun, Nagasaki Prefecture, the thick tuff-breccia above the lower basalts unconformably resting on the Paleogene Ashiya group is intercalated with conglomerate, limonite, diatom earth and lignite. On the basis of the fossil plants occurring in the lignite, NODA & MUTA assigned this tuff-breccia to Neogene in age and correlated the conglomerate with the Omodaka conglomerate.

NAGAHAMA & MATSUI hold a view that the Saikai tuff-breccia and the upper conglomerate correspond to the above-mentioned conglomerate.* In other words, by this conglomerate they divide the basalts into two, upper member and lower member. Occurrence of the Saikai tuff-breccia is characteristic to the Nishi-sonogi Peninsula; the tuff-breccia is composed almost exclusively of andesitic and basaltic pebbles. Examination in detail reveals that the hypersthene-olivine basalt of the lower member is sandwiched between conglomerates; the lower conglomerate is composed of round pebbles of sandstone, shale, basalt, andesite, rhyolite and mica schist, whereas the upper conglomerate consists of quartzite pebbles with a small amount of sand. MATSUI maintains that the lower conglomerate requires further study as it may correspond to a part of the Omodaka conglomerate.**

YAMASAKI & MATSUMOTO (1959, 1960), based on the result of their survey in Kishima-gun, Saga Prefecture, have discriminated between the Eribun conglomerate and the Sarushi conglomerate. The Eribun conglomerate, distributed at Eribun, Taku City, is about 5 m thick and unconformably rests on the Tertiary system. It consists of sand, gravel and silt, intercalated with lignite. Fossil plants contained in the lignite are not helpful for age determination, but from the fact that the Eribun conglomerate occurs below the older basalts, its age is supposedly different from that of the Sarushi conglomerate. The Sarushi conglomerate covers the sanukitic basalt and is covered by the Matsuura basalts. YAMASAKI & MATSUMOTO have assigned the age of the Eribun conglomerate to Stage G of Late Miocene and that of the Sarushi conglomerate to Stage H of Pliocene.

The conglomerate below the basalts of northwestern Kyushu, centering on the Sasebo coal field of Nagasaki Prefecture, has been named the Hachinokubo conglomerate by IWAHASHI (1961). This conglomerate is widely distributed, though discontinuously, throughout northwestern Kyushu. It lies unconformably on the Tertiary system, older basalts and crystalline schists, and is covered by the Matsuura basalts or intruded by dikes of the latter. Pebbles constituting the conglomerate are quartzite, chert, hard sandstone, conglomerate and quartz schist, accompanied by

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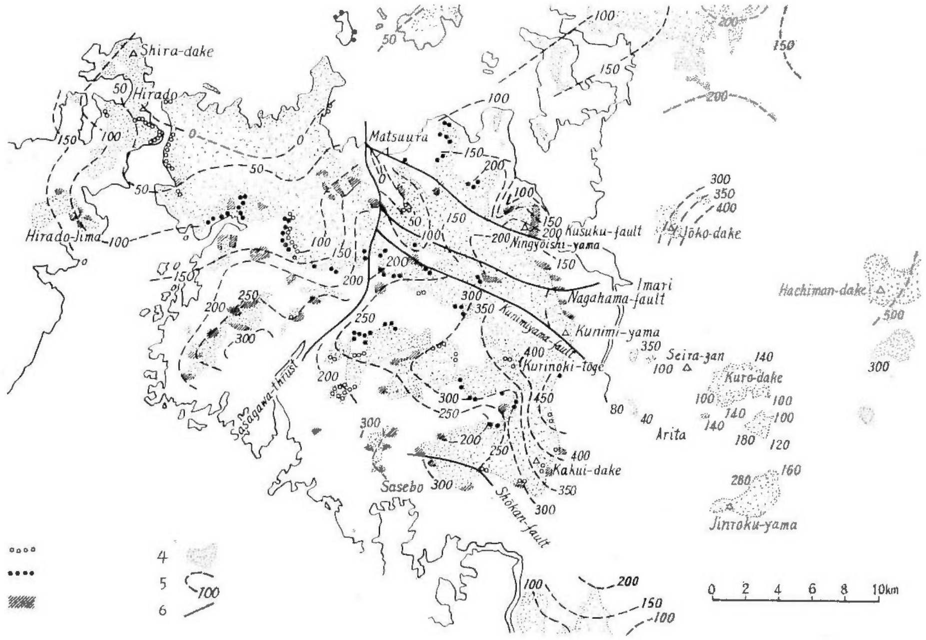
* Private communication.

** Private communication.

some round pebbles of igneous rocks.

On the 1 : 50,000 geologic map sheet of "Imari," **Imai**, **Sawamura** and **Yoshida** (1958) divided the conglomerates intercalated within the Kita-matsuura basalts into younger conglomerate and older conglomerate (Fig. 4). They further subdivided the older conglomerate into upper and lower. Because of the extensive distribution throughout the Kita-matsuura district these conglomerate serve as key beds for stratigraphic division of the Kita-matsuura basalts.



1. Upper conglomerate 2. Lower conglomerate
3. The position of the outcrop with directly contact between the Tertiary strata and the basalt lava flows
4. Distribution of the Kita-matsuura basalts
5. Contour line showing the surface of the basement
6. Main faults

Fig. 4 Height of the surface of the basement, and distribution of the conglomerates related with the activity of the Kita-matsuura basalts (after Imai et al., 1958)

In the field the present writer made an attentive pursuit of the relationship between the conglomerates and the basalts for the purpose of stratigraphic division of the basalts. The area surveyed by the writer generally overlaps that of **Sawamura**.

The conglomerates serving as key beds will be discussed below. These deposits have been described under various names, such as sand and gravel bed or conglomerate, by many researchers. However, the present writer calls them by the name of conglomerate, for the reasons that the deposits are not always composed of sand and gravel only, that their age may go back to a period older than Pleistocene, and that some of them show fairly advanced consolidation.

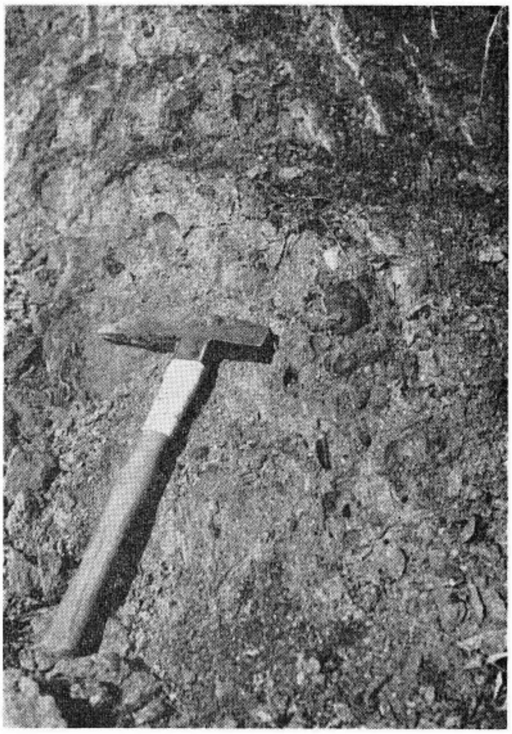


Photo. 7 The outcrop of the lower conglomerate showing round pebbles of older rocks such as shale, at the east of Ebirao in Emukae.

III. 4. 1 Lower conglomerate

The lower conglomerate as named here is correlatable with the lower member of the older conglomerate of Imai, Sawamura and Yoshida (1958). This conglomerate is extensively distributed under nearly all the lavas of the Kita-matsuura basalts. It is particularly well-developed in an area about 4 km wide trending northwest from Kunimi-yama, but its occurrence is not continuous so it is not observed in every outcrop. The conglomerate consists mainly of fine-grained gravel, sand, silt and clay, the gravel abounding in round pebbles of older rocks such as quartzite and shale; pebbles are less than 10 cm in diameter. The thickness of the conglomerate varies greatly, ranging from 40 m to 1 m. Altitude of its distribution is also variable, as exemplified by 460 m above sea level near Kunimi-yama in the east and 100 m near Emukae in the west.

III. 4. 2 Upper conglomerate

The upper conglomerate described here corresponds roughly to the upper member of the older conglomerate of Sawamura. It occurs sandwiched between basalts and abounds in gravel. This conglomerate is developed also on the south side of the distribution area of the lower conglomerate. Its thickness is less than 10 m. The distribution altitude ranges from 470m, as observed at Hatten-dake and the southwestern slope of Kurinoki-toge in the east, to near the coast at Hirado-guchi and Tabira-machi in the west. Constituents of the conglomerate are round pebbles of basalts and subordinate andesites, accompanied by sand, silt and clay.

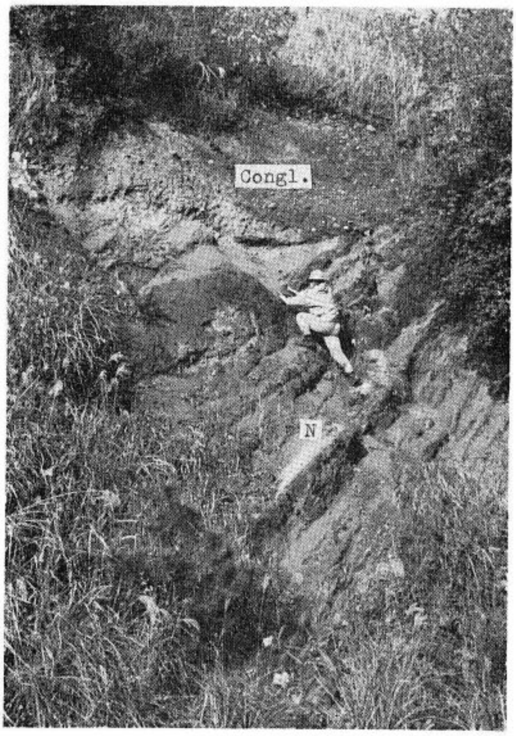


Photo. 8 Showing the boundary between the Nojima group of Tertiary age (N) and the lower conglomerate (Congl.) is extensively distributed under nearly all the lavas of the Kita-matsuura basalts, along the road to the northwest of Emukae of the northwest of Sasebo City.

Fine-grained portions are occupied mostly by dacitic tuff. Pebbles are larger than those of the lower conglomerate, sometimes as large as 50 cm in diameter. Pebbles of older rocks are usually absent.

III. 4. 3 Relationship between conglomerates and basalts

In the Kita-matsuura district the upper and lower conglomerates mentioned above are intercalated within the Kita-matsuura basalts. So far as this district is concerned, distribution of the conglomerates is discontinuous but they are correlatable over a wider area.

The lower conglomerate occurs at the base of the basalts and unconformably rests on the Tertiary Sasebo group, with a few exceptions. In the drainage basin of Shisa-gawa which rises near Tsujinodo-toge and flows through Matsuura City, and in the mountain slope at about 2 km northeast of Emukae-machi, the basalt lava of the lowermost horizon in this district is exposed beneath the lower conglomerate. A similar relation is observed in a small outcrop near Senboku about 1.5 km southwest of Kurinoki-toge. Occurrence of basalt lavas underlying the lower conglomerate is thus very rare.

In the northern part of the Nishi-sonogi Peninsula south of the Kita-matsuura district, both lower and upper conglomerates are found, the former being underlain by olivine basalt with a very small amount of olivine-quartz basalt. Between the lower and upper conglomerates, doleritic hypersthene-olivine basalts are sandwiched. The upper conglomerate is overlain by the Saikai tuff-breccia, and the basalts above this tuff-breccia are called the upper basalts.

In the Kishima district of Saga Prefecture, the Eribun conglomerate is distributed beneath the older basalts and is assigned to Stage G of Miocene. No beds corresponding to this conglomerate are found in the adjacent areas. The Sarushi conglomerate, unconformably covering the older basalts and other older rocks, is distributed below the Matsuura basalts. Corresponding to this conglomerate are the Hachinokubo and Omodaka conglomerates. The age of the Sarushi conglomerate is assigned to Stage H of Pliocene.

In the Kita-matsuura district, the lower conglomerate is overlain by the Matsuura basalts and the Upper conglomerate. The Upper conglomerate contains round pebbles of basalts much more than in the lower conglomerate, and is covered by the upper members of the Kita-matsuura basalts. The upper conglomerate is often interbedded with dacitic tuff. Resting unconformably on this conglomerate, pyroclastic rocks containing volcanic blocks are distributed. These pyroclastics are especially thick in the upper reaches of Shisa-gawa. No conglomerates corresponding to the upper conglomerate have been reported from other districts. Yamasaki & Matsumoto consider that the Eribun conglomerate in the lower horizon and the Sarushi conglomerate in the upper horizon are correlatable with the respective conglomerates of the Kita-matsuura district, but they have not reached a decisive conclusion as yet.

Concerning the age of these conglomerates, views are diversified as seen in the researches introduced above. Some people believe in the Plio-Pleistocene age, while others, like Noda and Muta, maintain the Neogene viewpoint, and some others, like Yamasaki and Matsumoto, assign the age to Stage G of Miocene and Stage H of Pleistocene. In the present stage of our knowledge, it is difficult to determine the age of the activities of the Kita-matsuura basalts from their relations to the conglomerates. Presence of the upper and lower conglomerates may indicate two dormant periods in the course of this chain of volcanic activities. The stratigraphic relations of the conglomerates to the basalts are presented in Table 2.

Table 2 Stratigraphic succession and remanent magnetization of the Kita-matsuura basalts.

Pleistocene	J	V*	N weak reddish tuff
?			
Pliocene	I_2	IV	R pyroclastics and reddish tuff (150m max.)
			dacitic tuff conglomerate (upper)
		III	N strong reddish tuff
	I_1	II	N
	H		conglomerate (lower)
		I	R strong
Miocene	F–G		Sasebo Group

*classified groups

N: normal magnetization

R: reversed magnetization

IV. Kita-matsuura Basalts

The Kita-matsuura basalts are very important not only because they occupy nearly one half of the total volumes of basalts widely distributed in West Japan including the San-in region and northwestern Kyushu, but also because they play a significant role in elucidating the origin of the Cenozoic volcanic rocks. To define precisely the order of eruptions of these basalts and the volumes erupted is, therefore, an indispensable and fundamental work. For this purpose, the present writer correlated the basalts by the volcano-stratigraphic method and also by their natural remanent magnetism. After classifying the basalts by these methods, the writer made the petrological study and chemical analysis of the respective basalt lavas as an initial step to clarify the origin of the basalts. Numbers in Fig. 5 refer to the specimens chemically analyzed.

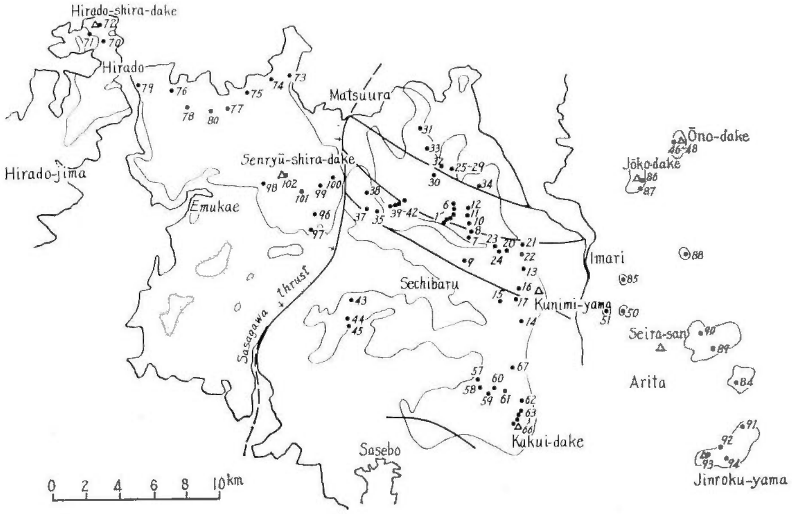


Fig. 5 Locality of the analyzed rocks in the Kita-matsuura district.

IV. 1 Classification of basalts

IV. 1. 1 Volcano-stratigraphic method

Studies of the Kita-matsuura basalts, especially the classification of the basalts by their distribution and lithology, are well presented in the 1 : 50,000 geologic map sheets of "Imari", "Hirado" and "Sasebo (unpublished)". On the basis of the results of these excellent works, the present writer carried out field survey and prepared columnar sections of the outcrops he examined. The area of survey was not limited to the Kita-matsuura district but was stretched over the areas of Arita and Takeo to the east. Similar surveys have been completed covering the whole area of northwestern Kyushu.

The Kita-matsuura basalts are thickest around Kunimi-yama, where the thickness attains to 400 m. The basalts developed in the drainage area of Shisagawa which flows down from Kunimi-yama serve as the standard of classification of the Kita–matsuura basalts. Columnar sections of the representative basalts were prepared by the writer based on the outcrops located on the north side of the village of Sanuki near the prefectural border of Saga and Nagasaki about 3 km west of Tsujinodo in the Shisa-gawa drainage area, and on the north side of the village of Kawachino west of Sanuki, and also near Fuefuki on the east slope of Kohochi-dake farther west. Fig. 6 shows those columnar sections.

In the Kita-matsuura district, the basement Tertiary Sasebo group, represented by alternating beds of sandstone and mudstone, is exposed. The basement rocks are unconformably covered by the lavas of lower basalts. Above the lower basalt lavas are found, also with an unconformable relation, the younger basalts alternating with volcanic ash and other ejecta. In the vicinity of Fuefuki, the lower conglomerate is recognized in the horizon of this unconformity between the older and younger basalts.

The lower conglomerate is overlain by volcanic ejecta consisting of lavas and pyroclastics in alternation, but their relation varies locally. The pyroclastics can be divided into three parts, lower part consisting of red volcanic ash, middle part abounding in volcanic bombs or blocks, and upper part becoming red volcanic ash again. Lavas are interbedded between these parts.

Below the middle part of these pyroclastics, the upper conglomerate is locally found. The conglomerate is developed well on the north side of Sanuki and is also distributed in a wider area to the southwest. Good outcrops of this conglomerate are found on the coast at Hirado-guchi and Tabira, but in these places no such pyroclastics as observed in the vicinity of Sanuki are developed above the conglomerate.

The upper conglomerate is intercalated with dacitic tuff. The pyroclastics overlying the conglomerate are thickly distributed on the south side of the upper reaches of Shisa-gawa, i.e., in the area between Kunimi-yama and Tsujinodo-toge. Outcrops on the mountain slope south of Sanuki reveal abundant volcanic bombs or blocks, some being as large as 3 m in diameter, occurring in the lower part of the pyroclastic beds. Toward the upper horizons the pyroclastic beds become gradually finer-grained and grade into volcanic ash abundantly containing single crystals of augite and hypersthene (KUNO, 1938).

The Kita-matsuura district is frequented by landslips everywhere, resulting in fresh outcrops one after another. In the vicinity of Ningyoishi-yama in the northeastern area, there is a precipitous cliff formed in the great landslides of 1952 to

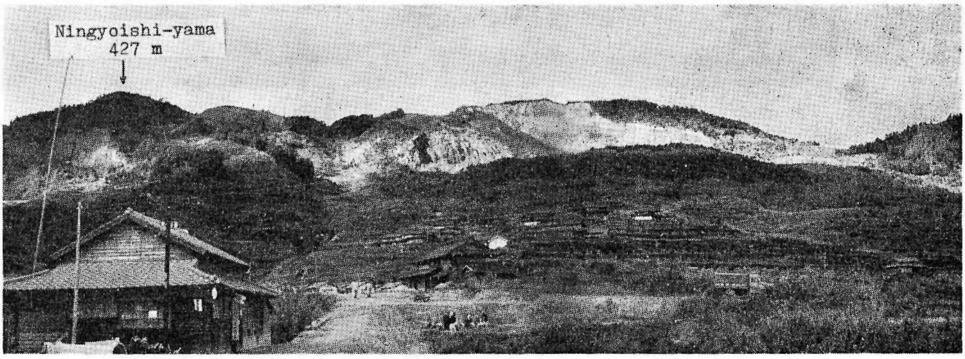


Photo. 9 In the vicinity of Ningyoishi-yama, there is a precipitous cliff formed in the great landslides of 1952 to 1953.

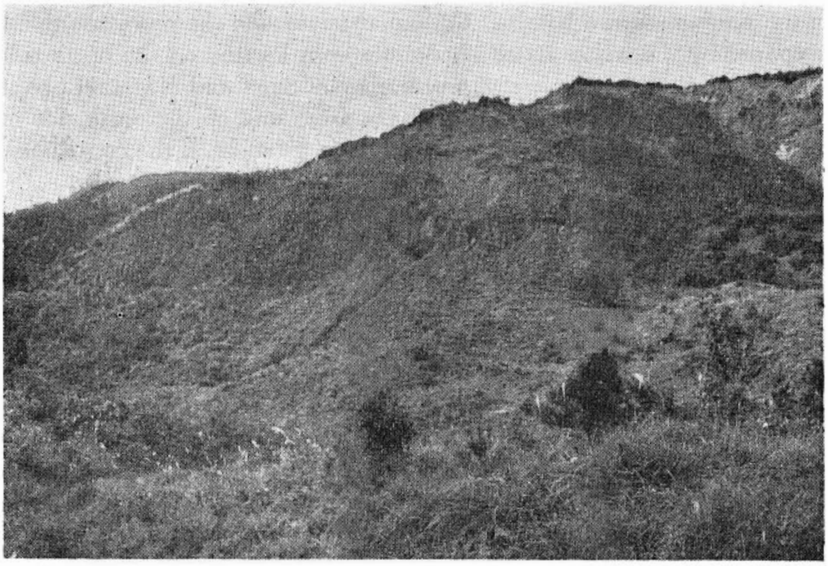


Photo. 10 In the cliff the mode of accumulation of the basalts can be fully Sasebo group, and the overlying alternation of basalt lavas and basement here.

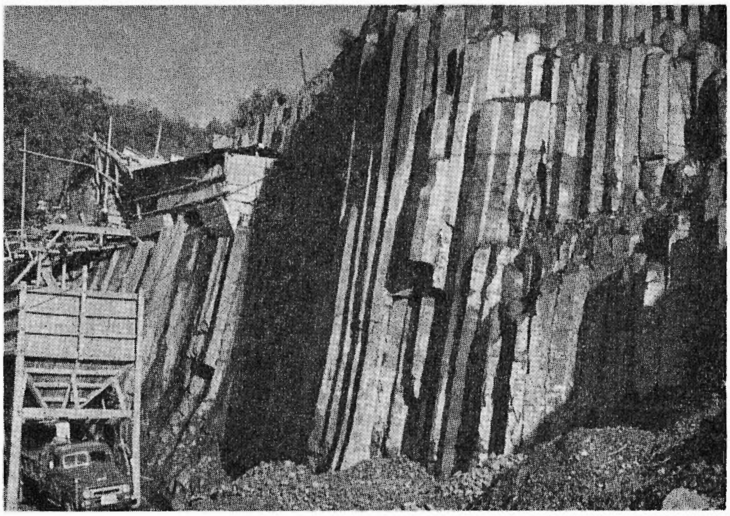
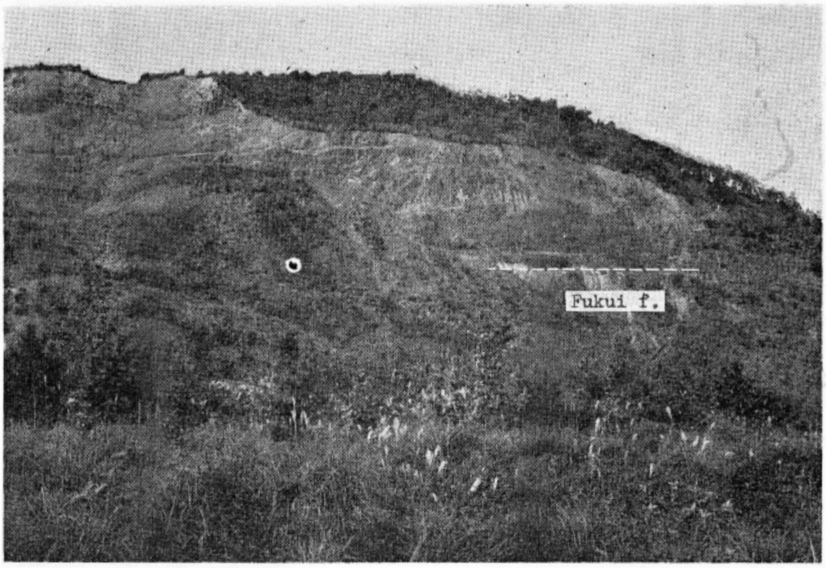


Photo. 12 A section of the basalt of the Group II showing columnar joints, the quarry along the road to the north of Myokanji-toge, 4 km WSW of Eri-ṭoge, the north of Sasebo City.

1953. In this cliff the mode of accumulation of the basalts can be fully observed. The outcrop reveals the sedimentary beds of the Tertiary Sasebo group constituting the basement of this area, and the overlying alternation of basalt lavas and volcanic ash beds (Photo. 9, 10). The stratigraphic succession of these strata is shown by the columnar section in Fig. 6.

Outcrops between Kurinoki-toge south of Kunimi-yama and Yunoki show



observed. The outcrop reveals the sedimentary beds of the Tertiary
volcanic ash beds. Fukui formation belongs to Sasebo group is

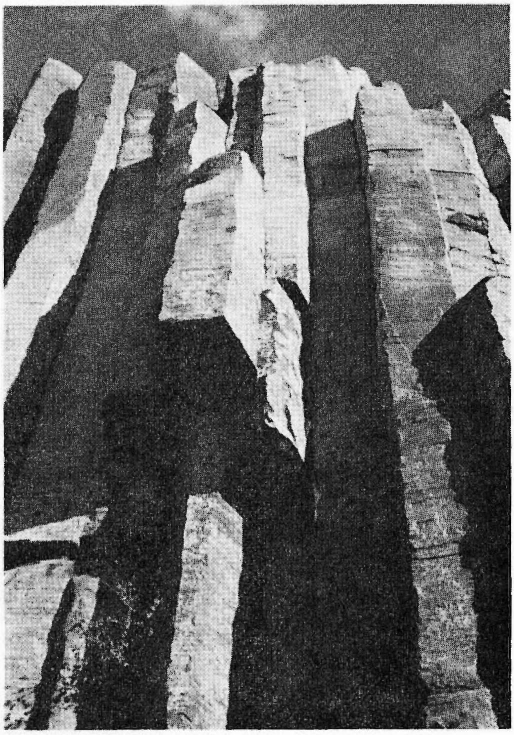


Photo. 13 The splendid columnar joint of the basalt belonging to the Group II.

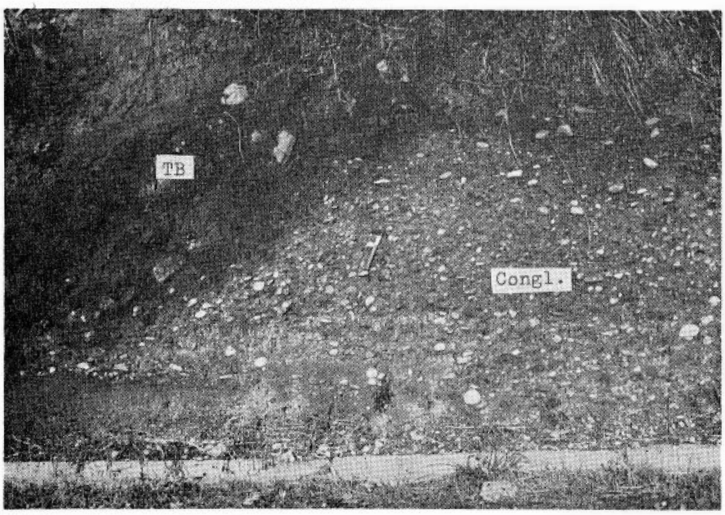


Photo. 14 The boundary between the lower conglomerate (Congl.) and the trachybasalt lava (TB), along the road to the northeast of Myokanji-toge, the north of Sasebo City.

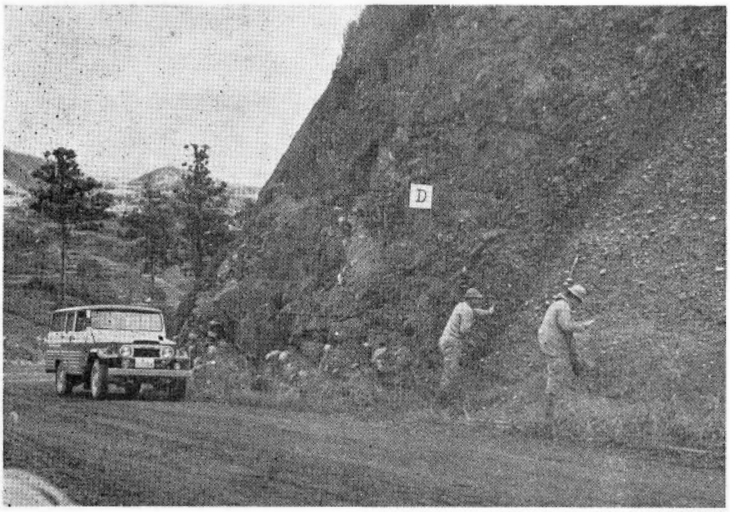


Photo. 15 Showing the lower conglomerate and the basalt dyke (D), along the road to the southwest of Myokanji-toge, the north of Sasebo City.

the following succession: The basement Tertiary system is overlain by basalt lavas; then comes conglomerate intercalated with a thin bed of volcanic ash; above this conglomerate are found basalt lava, dacitic tuff, two layers of basalt lava, volcanic ash, and another basalt lava, in ascending order. The conglomerate is thought to be the lower conglomerate. The stratigraphic position of the dacitic tuff is correlatable with that of the upper conglomerate of the Shisa-gawa drainage area.

The stratigraphic succession at Myokanji-toge is as follows: The Tertiary basement is unconformably covered by conglomerate, and above this conglomerate are found basalt lava having well-developed columnar joints, volcanic ash bed inter-

Photo. 16 A section of the deposit of the dacitic ash fall (F) showing layered bed, one of the key-bed for the volcano-stratigraphic correlation of the basalts, at the southwest of Myokanji-toge, 4 km WSW of Eri-toge, the north of Sasebo City.

calated with dacitic tuff, basalt lava, volcanic ash bed, and basalt lava again, in ascending order. The conglomerate is correlated with the lower conglomerate, and the dacitic tuff corresponds to the upper conglomerate from its stratigraphic position. On the southwest side of the pass, the conglomerate is intruded by a dike which is correlatable lithologically with the basalt lava of the upper horizon (Photo. 15). Columnar sections of the above two areas are given in Fig. 6.

Thus, the Kita-matsuura basalts, with intercalations of the lower conglomerate and the upper conglomerate which is accompanied by the dacitic tuff, can be divided volcano-stratigraphically. However, the conglomerates are not always present, and in such cases the dacitic tuff associated with the upper conglomerate would serve as a very effective key bed.

The basalt lava occurring beneath the lower conglomerate is extremely limited in distribution. To the naked eye the lava is a vitreous or black nonporphyritic rock, easily distinguishable from other lavas.

From the relations so far mentioned, it has become known that the Kita-matsuura basalts comprise, in ascending order, the lowermost basalt lava, the lower conglomerate, the alternation of basalt lavas and volcanic ash beds, the upper conglomerate, and another alternation of basalt lavas and volcanic ash beds. The lower and upper conglomerates seem to represent dormant periods of the volcanic activities in this district.

The Kita-matsuura basalts were thus divided into five groups by the volcano-stratigraphic method. The results are summarized in Table 2.

IV. 1. 2 Correlation of basalts by natural remanent magnetism

In recent years, study of paleomagnetism as a new field of geophysics has made a rapid progress in many countries of the world. This field has been dealing with the migration of magnetic poles from the geophysical standpoint, and the obtained results have agreed well with the results of researches on the same subject based on

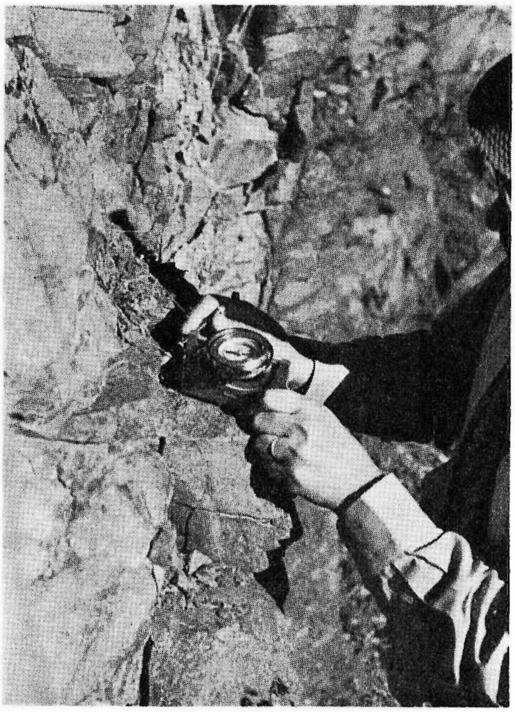


Photo. 17 Oriented specimens were taken from each outcrop.

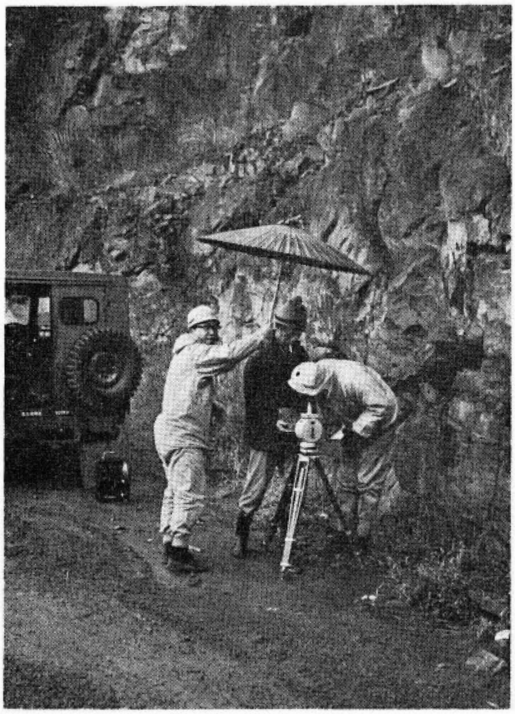
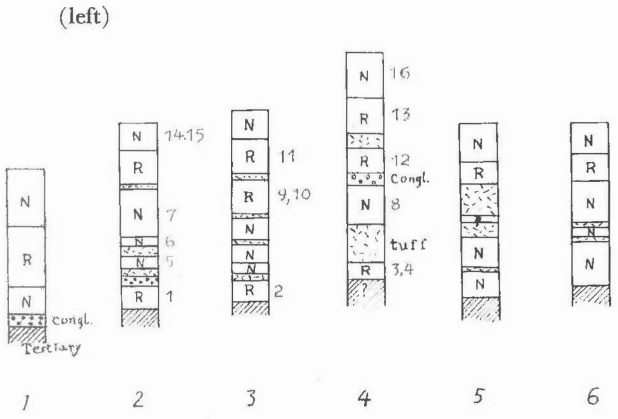
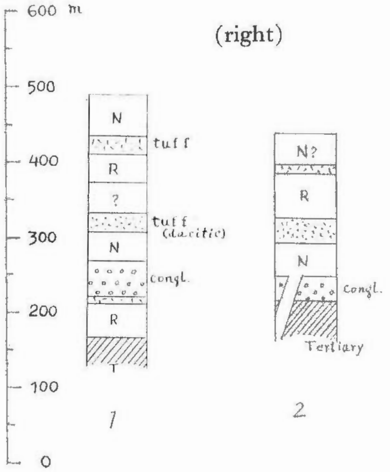


Photo. 18 Natural remanent magnetism was measured by Schmidt's magnetic field balance at each locality.





N: Normal magnetization
R: Reversed magnetization
Nos. 1–16: No. in Table 2
Column 1: Senryu-shira-dake
2: Fuefuki
3: Kawachino
4: Sanuki
5: Tsuji-no-do
6: Ningyoishi-yama

Fig. 6–1 Paleomagnetic correlation of the northeast part of the Kita-matsuura district. (left)

Column 1: Kunimi-yama to Yunoki
2: Myokanji-toge

Fig. 6–2 Paleomagnetic correlation of the central part of the Kita-matsuura district. (right)

the paleoclimatologic data, thus enlarging the reliability of this new method. It has become known, on the other hand, that a key point of paleomagnetic researches lies in the periodical changes of magnetic poles. In the course of the related researches, some rocks were found to have their natural remanent magnetism in a reverse direction to that of the present magnetic field. To explain the cause of this phenomenon, various hypotheses have been presented. As to the mechanism which causes the natural remanent magnetism in a direction reverse to the direction of the external remanent magnetism in a direction reverse to the direction of the external magnetic field, some people attempted to explain the so-called self-reverse only under a definite condition, but none of the hypotheses was able to explain the reversal magnetization for all cases.

In other words, no conclusive evidence has been introduced to verify the occurrence of reversion in the earth's magnetic field. Nevertheless, based on an assumption that the reversion of the earth's magnetic field is taking place periodically, active researches have been made utilizing the reversal magnetization for the purpose of age determination and correlation of rocks.

Table 4 Natural remanent magnetization of the rock samples.

Group I

	Sample No.	Declination	Inclination	Intensity in 10⁻⁴emu/g	S.G.	Locality	No. in Table 3
1*	621216–9–1	S 18.6 W	−42.2	40.5	2.82	Fuefuki	
	621216–9–2	S 02.0 W	−39.1	28.2	2.90		
2	621216–5–1	S 22.5 W	−38.3	43.8	2.85	Kawachino	1
	621216–5–2	S 03.1 W	−49.0	79.6	2.96		
3	621215–8–3	S 00.7 E	−34.4	16.8	2.94	Sanuki	7
	621215–8–4	S 05.7 W	−37.5	16.7	2.99		
4	621215–9–2	S 05.1 E	−50.7	4.0	3.06	Sanuki	
Group II							
5	621216–12a	N 77.5 E	+52.5	80.1	2.84	Fuefuki	40
	621216–12b	N 73.7 E	+43.8	88.2	2.90		
Group III							
6	621216–15–1	N 48.4 E	+15.5	4.9	3.13	Fuefuki	41
	621216–15–2	N 09.9 E	+44.9	1.5	2.95		
7	621216–11–1	N 00.0 E	+33.7	14.9	2.97	Fuefuki	
	621216–11–2	N 39.0 E	+22.1	4.0	3.07		
8	621216–1–1	N 05.7 E	+63.4	2.9	2.84	Sanuki	10
	621216–1–2	N 20.6 E	+43.1	1.6	2.86		
Group IV							
9	621216–8–1	S 19.8 W	−36.6	23.4	3.06	Kawachino	
	621216–8–2	S 25.8 W	−34.6	19.7	3.19		
10	621216–6–1	S 19.2 W	−38.0	4.3	2.77	Kawachino	
	621216–6–2	S 09.9 W	−44.5	8.0	2.90		
11	621216–7–1	S 19.3 W	−50.8	4.5	2.77	Kawachino	4
	621216–7–2	S 03.4 W	−45.0	3.3	2.83		
12	621216–2–2	S 14.9 E	−73.7	7.1	2.97	Sanuki	
13	621216–3–1	S 00.0 W	−45.0	0.9	2.94	Sanuki	12
	621216–3–2	S 45.0 E	−48.8	4.0	2.70		
Group V							
14	621216–14–2	N 00.0 E	+45.0	0.0	2.77	Fuefuki (weathering)	
15	621216–13–1	N 03.2 E	+39.8	3.1	2.99	Fuefuki	
16	621216–4–1	N 39.9 E	+ 4.8	0.7	2.92	Sanuki	(6)

Nos. in Table 3 are the rock specimen numbers.
*The numbers are the same as those in Fig. 6.

The present writer, taking several of these problematical points into consideration, have used the natural remanent magnetism as an effective means for volcano-stratigraphic correlation of the rocks, that is, volcano-stratigraphic correlation by the paleomagnetic methods (KOCHEGURA, 1961).

For the volcano-stratigraphic correlation of the basalts in the Kita-matsuura district, the writer collected specimens referring to the columnar sections of the respective localities (Table 3). Oriented specimens were taken from each outcrop and their natural remanent magnetism was measured by Schmidt's magnetic field balance. The sense of each specimen was determined by intensity of magnetism against the specimen's orientation, i.e., in the directions of north, south, upper plane and lower plane. The sense thus obtained was defined either as normal or reverse, each being strongly or weakly so.

In order to examine the sense of the natural remanent magnetism, the writer made experiments in the laboratory. By the use of an astatic magnetometer, the

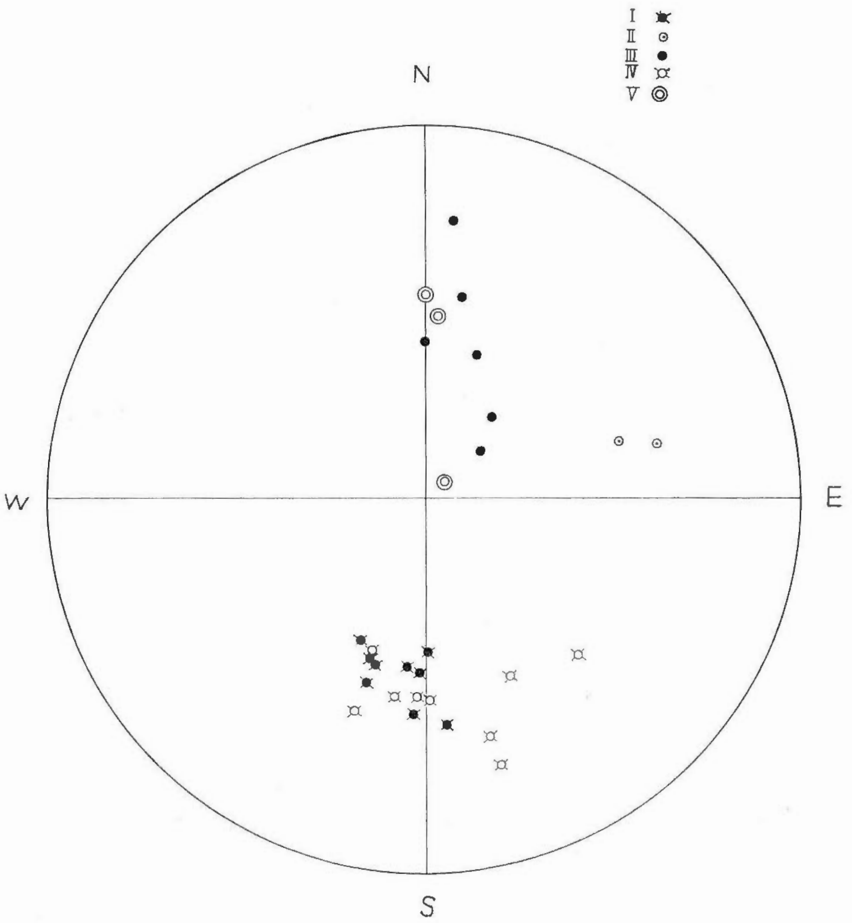


Fig. 7 Direction of natural remanent magnetism of the rocks of the Kita-matsuura district. The symbols represent the classified groups.

intensity, declination and inclination of magnetism of each rock were measured. For this measurement, the specimens were cut into cubes of about (5×5×5) cm^3 according to the orientation. The specimens used in the measurement were taken from the rocks distributed in the drainage basin of Shisa-gawa, the most important area in the Kita-matsuura district. Table 4 shows the results of measurement. The measured values were plotted on Schmidt projection, as illustrated in Fig. 7.

The rock magnetism is controlled by the nature of iron ore among the rock-forming minerals, and in this respect the writer is now making reliability tests.

The above-mentioned measurement using Schmidt's field balance was made on volcanic rocks of the whole region of northwestern Kyushu, including such areas as Kishima, Higashi-matsuura, Goto Islands, Tara-dake, Shimabara Peninsula and Nishi-sonogi Peninsula, in addition to the Kita-matsuura district. With the results thus obtained, a general correlation of these rocks was attempted.

With a few exceptions, a good agreement was recognized between the stratigraphic succession of the basalts divided by the volcano-stratigraphic method and the stratigraphic correlation based on the measured values of natural remanent magnetism of the rocks. Columnar sections of the representative outcrops are given in Fig. 6.

The remanent magnetism of the volcano-stratigraphically classified basalts is as follows: The basalts underlying the lower conglomerate, i.e., Group I, shows strong reversed magnetization (R strong); the basalts above, Group II, shows normal magnetization; the basalts farther above, Group III, shows strong normal magnetization (N strong); the basalts covering the upper conglomerate, Group IV, shows reversed magnetization; and the uppermost basalts, Group V, shows weak normal magnetization (N weak) (Table 2).

The direction measured on Group I, the lowermost member, shows reversed magnetization, but its directional trend turns from S toward SW, with intensity as large as 10^{-3} emu/g. Group II shows normal magnetization but its direction is about N 75° E, so that the sense of normal magnetization is not well expressed in spite of the large value, nearly 10^{-2}, of intensity. Group III is normally magnetized, but its direction varies from N to N 50° E. From such directions Group II and Group III are supposed to have been continuous. In other words, there was not a great time gap between the two groups. The intensity of the rocks of Group III ranges between 10^{-4} and 10^{-3} emu/g. Group IV is reversely magnetized and the direction is predominantly S or SE. The intensity of the rocks of this group is larger than 10^{-4} emu/g. In Group V, directions are concentrated in N, with one exception; intensity of the rocks is very weak, generally less than 10^{-4} emu/g. The results of measurement are given in Table 4.

As seen in Fig. 7, Groups I, II and III show independent distributions of directions but it seems that migration of magnetic poles was continuous in the order of I→II→III. Migration is undoubtedly continuous between II and III. Between Group III and Group IV, migration is discontinuous, and between Group IV and Group V it is also discontinuous. From these results, the mutual relations of the groups can be summarized as follows, in view of paleomagnetism also:

$$\text{Group I} \xrightarrow{\text{continuous}} \text{II} \xrightarrow{\text{continuous}} \text{III} \;—\; *$$

$$* \xrightarrow{\text{discontinuous}} \text{IV} \xrightarrow{\text{discontinuous}} \text{V}$$

Using the natural remanent magnetism of rocks, many researches have been made on the relationship between the stratigraphic succession of volcanic rocks and the period of their activity. The study of paleomagnetism in the Kita-izu and Hakone districts by T. NAGATA et al. (1957), based on the stratigraphy of lavas by H. KUNO, is one of the excellent works among the early researches on this subject.

The volcano-stratigraphic succession of the Kita-izu and Hakone districts is, in ascending order; ejecta of the Usami Volcano overlying the Pliocene Zyo formation, and ejecta of the Taga, Yugawara and Hakone Volcanoes, with erosion intervals between the activities. The Hakone Volcano was active in the latter half of the Pleistocene epoch and activities of other volcanoes occupied the former half, which suggests that the active period of the volcanoes in this area may have been $10^5 \sim 20^5$ years long. The center of the poles of the earth's magnetism in Pleistocene had migrated around the polar axis from 72° N and 86° N and 32° W. The fact that the direction of polarization of the central dipole was reversed in Early Pleistocene is recognized throughout the world. This reversion is observed in the middle period of formation of the Usami Volcano which is the lowermost member of the Kita-izu and Hakone districts.

From the facts in these reports we have to admit that the earth's magnetic field was reversed in the early period of Pleistocene, i.e., about one million years ago.

Consequently, the reversed natural remanent magnetism of the rocks in the upper part of the Kita-matsuura basalts can be correlated with the above-mentioned reversion, and the rocks are considered to have been active during Early Pleistocene. Another reversion occurring in the lower horizon may signify a volcanic activity of 1,000,000–2,000,000 years or even several million years ago.

On the other hand, the Kita-matsuura basalts are intervened with conglomerates as already mentioned, one above Group I and another above Group III, apparently indicating interruption of volcanic activities. Hence, the Kita-matsuura basalts are not the result of a single continuous volcanic activity but must have been accumulated during a long period, probably a few million years, of activities from time to time.

Fig 8 shows the distribution of each group of the Kita-matsuura basalts classified on the basis of the results of geologic, volcano-stratigraphic and paleomagnetic studies.

IV. 1. 3 Dimensions and type of activity of Kita-matsuura basalts

The distribution of the classified basalts is shown in Fig. 8. On the original map based on the 1 :50,000 topographic map which was used as a base map for Fig. 8, the writer calculated the area of distribution of each group. In the calculation the portions apparently eroded away were included. The volume of erupted ma terials was computed from the mean values of the maximum and minimum thicknesses of the ejecta in each group. The volume includes both lavas and pyroclastics. The distribution areas and erupted volumes thus obtained are listed in Table 5.

As is obvious from the volumes of erupted materials, Groups II, III_2 and IV played the principal roles in the activities of the Kita-matsuura basalts. The ac-

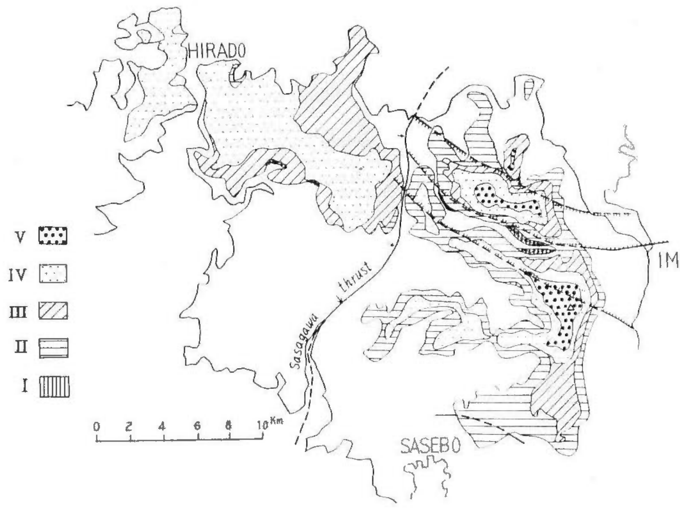


Fig. 8 Distribution of the classified groups of the Kita-matsuura basalts in the Kita-matsuura district.

Table 5 Estimated volume and Distribution Area of the effusive material of the classified groups of the Kita-matsuura basalts, Northwest Kyushu.

Group	km^2	km^3
V	12	0.8
IV	101	15.3
III_2	119	12.5
III_1	6	0.2
II	128	18.0
I	19	2.2
	Total	49.0

tivities of Group I, the lowermost member, and Group V, the uppermost member, can be called parasitic. Group III_1 is distributed only locally, so that this is also defined as a parasitic activity.

The basalts belonging to the lowermost Group I are especially well developed and exposed in the fairly dissected drainage basin of Shisa-gawa. The basalts of Group III_1 are distributed in the vicinity of Ningyoishi-yama to the northeast; those of the uppermost Group V are found in the vicinity of Kunimi-yama to the east and also in the northeastern area. These basalts of parasitic activities are mostly distributed in the east of the Sazagawa thrust.

Table 5 was prepared for comparison of the distributions and erupted volumes of the five groups of the Kita-matsuura basalts. Fig. 8 is the distribution map.

As to the area of distribution, Groups II, III_2 and IV show values more than 100 km^2, whereas Groups I, III_1 and V have much smaller values. Referring to these values and the erupted volume of each group, we find that the basalts widely distributed in both eastern and western areas with the Sazagawa thrust in between are those of Groups III_2 and IV. Group I is distributed in these areas, too, but it is best developed in the Shisa-gawa drainage basin. Group III_1 is distributed only in the vicinity of Ningyoishi-yama in the northeastern area. Group I is distributed in the eastern area.

Inferring from the erupted volumes of the respective groups the characteristics of the activities of the Kita-matsuura basalts are mentioned below.

The first activity is represented by Group I, whose erupted volume is 2.2 km^3, and the constituents are largely lavas. This activity was followed by a time gap during which the conglomerate was deposited. Next, eruption of Group II took place. This group consists mainly of lavas which flowed over the whole area of the Kita-matsuura district and were widely distributed especially in the eastern area. The volume of eruption is as large as 18 km^3.

Group III is subdivided into two groups, III_1 and III_2, by petrological character and distribution. Group III_1 is a parasitic activity, having been active only in the northeastern area, with the erupted volume only 0.2 km^3. As is obvious in the cliff produced by landslip near Ningyoishi-yama, thin beds of lavas are alternating with reddish volcanic ash. The activity of Group III_2, the leading figure of the activity of this stage, is manifested by extensive outflow of lavas accompanied by volcanic ash, the volume of eruption attaining to 12.5 km^3.

Afterwards, the volcanic activity was suspended and conglomerate was deposited locally. At the same time, andesitic to rhyolitic volcanic ash from the adjacent areas accumulated, forming the beds of tuff. It is possible that the activity of the Seira-san andesite or Arita rhyolite, now distributed in the south of Imari City, took place in this period.

After this large interval the activity of Group IV occurred. In the early period of this activity enormous volumes of pyroclastic materials were erupted. This was particularly remarkable on the south side of the upper reaches of Shisa-gawa in the northeastern area. Following the eruption of these pyroclastics, lavas flowed out in abundance. The total volume of these ejecta reaches 15.3 km^3.

The activities of the Kita-matsuura basalts were, as mentioned before, controlled by the tectonic movements accompanied by the fault movement of a NW–SE trend. It seems that the influence of such movements was especially strong in the period of the Group IV activity. Dikes as observed everywhere also reflect the effects of the tectonic movements.

The last volcanic activity in the Kita-matsuura district is represented by Group V. It produced a very small volume, 0.8 km^3, of ejecta.

Thus, the activities of the basalts in the Kita-matsuura district had two time intervals, one between Group I and Group II, and another between Group III and Group IV. The volume of erupted materials was especially larger in the middle period represented by Groups II, III_2 and IV. Other groups, I, III_1 and V, present a parasitic character. With regard to the relations of these activities, refer to Table 2.

IV. 1. 4 Volumes of Kita-matsuura basalts in comparison with basalts of West Japan

The Kita-matsuura basalts are 246 km^2 in distribution area and 49 km^3 in volume. They belong to the Circum-Japan Sea alkali rock province, and their volume attains to two-thirds of 73.9 km^3, total volume of rocks erupted in northwestern Kyushu including the areas adjacent to the Kita-matsuura district. Dimensions of basalts in West Japan inclusive of northwestern Kyushu are given in Table 15.

If northwestern Kyushu is grouped with the neighbouring areas, such as Goto Islands, Tara-dake area and South Shimabara area, into one rock province, the total volume of erupted rocks would become 87 km^3. This value, however, is no more than the volume of one strato-volcano, when compared with 353 km^2 and 96 km^3 of the Hakone Volcano and 896 km^2 and 389 km^3 of the Fuji Volcano (SUGIMURA et al., 1963).

The erupted volume of alkaline suite, which belongs to the Circum-Japan Sea alkali rock province and is widely distributed in West Japan extending from the San-in region to northwestern Kyushu, is calculated as 100 km^3 approximately (Table 15).

IV. 2 Petrography of basalts

The Kita-matsuura district constitutes part of the northwestern Kyushu basaltic region, occupying the southwestern end of the Circum-Japan Sea alkaline province named by TOMITA (1935). Since the district is also extending over the Japanese Islands rock province which is a part of the Circum-Pacific orogenic belt, the basalts of the district comprise various rock series, though differing in erupted volumes.

For example, the basalts occupying the lowermost horizon of the volcanostratigraphic sequence have a tholeiitic character, whereas the basalts of the major activities have the nature of alkali rock series, occasionally accompanied by parasitic activities of a tholeiitic character. The basalts of the latest stage are of calc

-alkali rock series showing obvious effects of contamination.

The basalts of this district are thus divided into tholeiitic rock series, alkali rock series and calc-alkali rock series, in the order of eruption.

Consequently, their petrographic characteristics reflecting the differences of these rock series should differ naturally.

IV. 2. 1 Nomenclature of rock types

Kuno (1954), in his classification of volcanic rocks, divided the rocks of the alkali rock series as follows:

With the color index values 35 and 10 (in wt percent) as the boundaries, Kuno divided the rocks into three groups, proposing the names trachybasalt, trachyandesite and trachyte. Also empirically using the solidification index ($MgO \times 100/MgO+FeO+Fe_2O_3+Na_2O+K_2O$) (Kuno, et al., 1957), he placed boundaries on the index values 20 and 10 to divide the rocks into three groups, namely, trachybasalt, trachyandesitic basalt—trachyandesite, and trachyte—trachyrhyolite—comendite. However, so far as the Kita-matsuura basalts are concerned, the above two classifications are not always applicable.

The present writer has established a nomenclature of rock types on the basis of the standard given below which was compiled from the results of various examinations.

Alkali rock series (sub-alkali rock series)

Solidification index

	40		25		20	
Picritic basalt		Trachybasalt Basalt		Trachyandesitic basalt Trachybasaltic andesite (Mugearite)		Trachy-andesite

Calc-alkali rock series & tholeiitic rock series

Solidification index

	30	
Basalt		Andesite

Names of the rocks near the boundaries were decided after referring to the calculated values of norm and to the color index. Among the basalts, the rocks whose Or content of normative feldspar is $Or \times 100/Or+Ab+An > 15$ were grouped as trachybasalt. If the rocks were remarkably under-saturated in SiO_2 and were rich in normative olivine, they were also regarded as trachybasalt, even when the Or content was more than 12. When the volume of phenocryst olivine exceeded 10 percent, the rocks were called picritic basalt.

Rocks grouped with mugearite are trachybasaltic andesite and trachyandesitic basalt having more than 5.5 percent Na_2O+K_2O; their rock-forming mineral compositions were also taken into account.

According to the above classification, the rocks generally known as the Kita-matsuura basalts are found to include picritic basalt, dolerite, basalt, trachybasalt, trachyandesitic basalt, andesitic basalt, trachybasaltic andesite, basaltic andeiste, mugearite, trachyandesite and andesite. By the term "-bearing" the writer signifies the case where the volume of phenocrysts is less than 0.5 percent. Quartz occurring as xenocrysts is one of such examples.

IV. 2. 2 Petrography of basalts

Volume percentages of rock-forming minerals

Volume percentages of phenocrysts and groundmass minerals of the respective lavas are given in Table 6. The rocks having extremely fine-grained groundmass are denoted with a mark, as the calculated values would involve fairly large errors produced in the process of measurement. In the measurement a mechanical stage was used so as to obtain the volume percentage of each mineral distributed within a given distance. The distance was determined by crosshairs.

Groundmass feldspars are hardly identified into plagioclase, anorthoclase, potash-plagioclase, lime-anorthoclase, etc., hence the values of feldspars in Table 6 are not very accurate. Measurements of xenocrysts were made on plagioclases and quartz crystals that are easily distinguished as exotic material. In a few lavas, olivine is replaced by orthopyroxene and iron ore, which were measured as olivine. In the measurement, micro-phenocrysts were treated as phenocrysts.

Olivine phenocrysts are present in almost all lavas, showing a maximum value of 17 percent in picritic basalt. Phenocrysts of clinopyroxene are found in some lavas, and those of orthopyroxene are very rare.

Plagioclase phenocrysts are contained in about one half of the lavas, with a maximum of 28 percent. Several lavas contain more than 10 percent.

Xenocrysts of plagioclase are recognized in about 30 of lavas. Quartz is 2 percent in maximum.

Rock series

Classification of igneous rocks into tholeiitic rock series, alkali rock series and calc-alkali rock series which is derived from the former two, on the basis of their mineral composition, mutual relations of mafic minerals, reaction system, process of crystallization differentiation and chemical composition, has hitherto been generally accepted. Lately, however, KUNO (1960) proposed a high-alumina basalt magma independent of the above series. As will be mentioned later, in the Kita-matsuura district the present writer has failed to find such high-alumina basalts.

The Kita-matsuura basalts are divided into five groups, as stated already. The majority of the rocks in the Kita-matsuura district belong to the alkali rock series. Judging from the ferromagnesian silicate mineral assemblages, i.e., mutual relations of mafic minerals, in the groundmass, some of the basalts of Group III_1 and Group IV may belong to the tholeiitic rock series. But, the ferromagnesian silicates in the rocks of Group IV do not show a distinct "reaction", so the writer treated the rocks whose chemical compositions do not indicate oversaturation of SiO_2 as alkali rock series, even if a partial reaction relation may exist between olivine and clinopyroxene. In other words, volcanic rocks of the tholeiitic rock series are very rare among the basalts of the Kita-matsuura district.

Accordingly, the Kita-matsuura basalts include the following rocks:

Tholeiitic rock series

Basalt

Alkali rock series

Picritic basalt, basalt, trachybasalt, dolerite, trachydolerite, trachyandesitic basalt, trachybasaltic andesite, mugearite, trachyandesite.

Calc-alkali rock series

Basalt, andesitic basalt, basaltic andesite, andesite.

Any rocks belonging to KUNO's high-alumina basalt were not found among

Table 7 Optical properties on constituent minerals of analyzed rocks of the Kita-matsuura district, Northwest Kyushu. (each group)

	Feldspar	Olivine	Clinopyroxene	Orthopyroxene	Other minerals	Accessory minerals
I Phenocrysts						
2.	Plagioclase $\gamma = 1.572$, $\alpha = 1.560$ An 68–62	$2V\alpha = 89°–85°$ $\alpha = 1.678$, $\gamma = 1.725$ Fa 23–28				
I Groundmass						
2.	Plagioclase $\gamma = 1.569$, $\alpha = 1.558$ An 62–57	$2V\alpha = 86°–80°$ Fa 27–35	Titanaugite $2V\gamma = 51°–49°$ $\beta = 1.697–1.700$			Magnetite, Ilmenite Chlorite Brown glass
II–1 Phenocrysts						
5.	Plagioclase $\gamma = 1.572$, $\alpha = 1.558$ An 68–57	$2V\alpha = 89°–87°$ $\alpha = 1.660$, $\gamma = 1.711$ Fa 14–22	Titanaugite $2V\gamma = 54°–48°$ $\beta = 1.706–1.710$ $c \wedge Z = 45°–41°$		Magnetite	
13.		$2V\alpha = 89°–86°$ $\alpha = 1.666$, $\gamma = 1.723$ Fa 17–27	Titanaugite $2V\gamma = 50–44$ $\beta = 1.698–1.706$ $c \wedge Z = 54°–48$			
15.	Plagioclase $\gamma = 1.573$, $\alpha = 1.560$ An 70–62	$2V\alpha = 89°–85°$ Fa 18–26	Titanaugite	Corroded hypersthene rimmed with augite ($2V\gamma = 50°$) $2V\gamma = 70°–64°$		
II–1 Groundmass						
5.	Plagioclase $\gamma = 1.566$, $\alpha = 1.555$ An 58–52 Potash-plagioclase $\gamma = 1.555$, $\alpha = 1.532$ Anorthoclase	$2V\alpha = 85°–83°$ $\beta = 1.710–1.720$ Fa 28–32	Titanaugite $2V\gamma = 55°–47°$			Magnetite, Ilmenite Apatite, Chlorite Phlogopite
13.	Plagioclase $\gamma = 1.567$, $\alpha = 1.557$ An 60–56 Potash-plagioclase Lime-anorthoclase?	$2V\alpha = 83°–73°$ Fa 32–46	Titanaugite $2V\gamma = 52°–50°$ $\beta = 1.696–1.711$ Soda-augite $2V\gamma = 51°$			Magnetite Ilmenite Apatite Chlorite
15.	Plagioclase $\gamma = 1.568$, $\alpha = 1.558$ An 61–58 Anorthoclase	$2V\alpha = 86°–78°$ Fa 26–38	Titanaugite $2V\gamma = 51°–49°$ $\beta = 1.706–1.712$			Magnetite Ilmenite, Chlorite (Brown glass) Apatite

II–2 Phenocrysts

5.	Plagioclase $\gamma = 1.572$, $\alpha = 1.560$ An 67–62	2Vα = 89°–82° $\alpha = 1.674$, $\gamma = 1.734$ Fa 21–32	Titanaugite 2Vγ = 54°–49° $\beta = 1.704$–1.708 c$\wedge$Z = 48°			
12.	Plagioclase $\gamma = 1.572$, $\alpha = 1.556$ An 68–53	2Vα = 89°–86° $\alpha = 1.668$, $\gamma = 1.725$ Fa 18–27	Titanaugite 2Vγ = 53°–47° $\beta = 1.702$–1.708			

II–2 Groundmass

5.	Plagioclase n.d. Anorthoclase?	2Vα = 88°–77° βmax. = 1.740 Fa 24–40	Titanaugite 2Vγ = 49°–45° $\beta = 1.708$–1.712			Magnetite Ilmenite, Chlorite Brown glass
12.	Plagioclase $\gamma = 1.566$, 1.554 An 58–50 Potash-plagioclase $\gamma = 1.548$, $\alpha = 1.530$ Anorthoclase	2Vα = 80°–75° $\beta = 1.748$–1.726 Fa 35–44	Titanaugite 2Vγ = 53°–48° $\beta = 1.710$–1.714			Magnetite Ilmenite Apatite

III$_1$ Phenocrysts

3.	Plagioclase $\gamma = 1.574$, $\alpha = 1.561$ An 72–63	2Vα = 89°–83° $\alpha = 1.673$, $\gamma = 1.729$ Fa 21–29	Augite	Corroded hypersthene rimmed with augite (2Vγ = 52°) 2Vα = 62° $\alpha = 1.696$, γ=1.709 Fs 38 r>v		
4.		2Vα = 87°–86° $\alpha = 1.663$, $\gamma = 1.715$ Fa 16–23				
5.	Plagioclase $\gamma = 1.572$, $\alpha = 1.559$ An 68–59	2Vα = 89°–88° $\alpha = 1.664$, $\gamma = 1.708$ Fa 17–20	Augite			

III$_1$ Groundmass

3.	Plagioclase $\gamma = 1.569$, $\alpha = 1.556$ An 62–54 Anorthoclase	2Vα = 82°–78° Fa 33–38	Augite 2Vγ = 51°–47°			Magnetite Ilmenite Apatite Chlorite

	Feldspar	Olivine	Clinopyroxene	Orthopyroxene	Other minerals	Accessory minerals
4.	Plagioclase $\gamma = 1.569$, $\alpha = 1.557$ An 62–56 Anorthoclase	$2V\alpha = 85°–78°$ βmax. = 1.734 Fa 30–39	n.d.			Magnetite Ilmenite, Apatite Chlorite Brown glass
5.	Plagioclase $\gamma = 1.567$, $\alpha = 1.556$ An 60–54	$2V\alpha = 88°–83°$ $\beta = 1.701–1.719$ Fa 24–31	Augite $2V\gamma = 53°–48°$ $\beta = 1.703–1.712$			Magnetite, Ilmenite Apatite, Chlorite Brown glass

III_2 Phenocrysts

4.	(Plagioclase)	$2V\alpha = 85°$ Fa 28				
10.	Plagioclase $\gamma = 1.571$, $\alpha = 1.559$ An 66–59	$2V\alpha = 88°–84°$ $\alpha = 1.678$, $\gamma = 1.730$ Fa 23–30			Magnetite	
12.	Plagioclase $\gamma = 1.574$, $\alpha = 1.563$ An 71–67	$2V\alpha = 89°$ Fa 22			Magnetite	
13.	Plagioclase $\gamma = 1.572$, $\alpha = 1.556$ An 67–54	$2V\alpha = 89°–87°$ Fa 18–26			Magnetite	
16.		$2V\alpha = 89°–86°$			Magnetite	

III_2 Groundmass

4.	Plagioclase $\gamma = 1.568$, $\alpha = 1.557$ An 61–56 Potash-plagioclase Anorthoclase	$2V\alpha = 78°$ Fa 38	Titanaugite $2V\gamma = 53°–50°$ $\beta = 1.700–1.706$			Magnetite Ilmenite Apatite, Chlorite Phlogopite $\gamma = 1.570–1.576$
10.	Plagioclase n.d. Potash-plagioclase Lime-anorthoclase ~anorthoclase $\gamma = 1.530$	$2V\alpha = 82°$ Fa 32	Titanaugite $2V\gamma = 54°–46°$ Soda-augite $2V\gamma = 50°$			Magnetite Ilmenite Apatite, Chlorite Phlogopite

12.	Plagioclase $\gamma = 1.567$, $\alpha = 1.554$ An 59–50 Potash-plagioclase Anorthoclase	$2V\alpha = 77°$ Fa 39	Titanaugite $2V\gamma = 53°–49°$			Magnetite Ilmenite Apatite, Chlorite Brown glass
13.	Plagioclase $\gamma = 1.565$, $\alpha = 1.554$ An 56–50 Potash-plagioclase Lime-anorthoclase	$2V\alpha = 76°–73°$ βmax. = 1.753 Fa 42–46	Titanaugite $2V\gamma = 51°–45°$ $\beta = 1.696–1.702$			Magnetite Ilmenite Apatite
16.	Plagioclase $\gamma = 1.570$, $\alpha = 1.558$ An 64–58 Potash-plagioclase $\gamma = 1.540$, $\alpha = 1.532$ Anorthoclase $\gamma = 1.535$, $\alpha = 1.525$	$2V\alpha = 82°–79°$ $\beta = 1.730–1.720$ Fa 33–37	Titanaugite $2V\gamma = 54°–51°$			Magnetite Ilmenite Apatite Brown glass

IV Phenocrysts

4.	(Plagioclase)	$2V\alpha = 89°–88°$ $\alpha = 1.666$, $\gamma = 1.715$ Fa 17–23				
5.	Plagioclase n.d.	$2V\alpha = 88°$ $\alpha = 1.658$, $\gamma = 1.718$ Fa 13–24	Augite $2V\gamma = 52°, 49°$ $\beta = 1.680, 1.683$			
7.		$2V\alpha = 88°–85°$ $\alpha = 1.663$, $\gamma = 1.728$ Fa 16–29	Titanaugite $2V\gamma = 50°–44°$ $\beta = 1.708–1.718$		Magnetite	
13.		$2V\alpha = 88°–83°$ Fa 24–31			Magnetite	
16.		Olivine n.d.		Bronzite-hypersthene (an initimate aggregate with magnetite in olivine) $2V\alpha = 68°–60°$	Magnetite	

IV Groundmass

4.	Plagioclase $\gamma = 1.572$, $\alpha = 1.559$ An 67–60 Anorthoclase	$2V\alpha = 89°–81°$ $\beta = 1.725–1.700$ Fa 23–34	Titanaugite $2V\gamma = 54°–46°$ $\beta = 1.694–1.698$			Magnetite Ilmenite Apatite

	Feldspar	Olivine	Clinopyroxene	Orthopyroxene	Other minerals	Accessory minerals
5.	Plagioclase $\gamma = 1.572$, $\alpha = 1.558$ An 68–58 Potash-plagioclase Anorthoclase	2Vα = 86°–81° βmax. = 1.720 Fa 26–32	Titanaugite 2Vγ = 49°–45°			Magnetite Ilmenite Apatite Chlorite
7.	Plagioclase $\gamma = 1.569$, $\alpha = 1.557$ An 63–56 Potash-plagioclase Lime-anorthoclase	2Vα = 85°–77° β = 1.735–1.710 Fa 28–38	Augite 2Vγ = 48°–44°			Magnetite Ilmenite Apatite
13.	Plagioclase $\gamma = 1.570$, $\alpha = 1.559$ An 64–60 Potash-plagioclase $\gamma = 1.555$, $\alpha = 1.535$ Anorthoclase	2Vα = 84°–76° Fa 30–42	Titanaugite 2Vγ = 51°–46°	Bronzite 2Vα = 70°–65° r>v Fs 26–30		Magnetite Ilmenite Apatite Cristobalite?
16.	Plagioclase $\gamma = 1.566$, $\alpha = 1.553$ An 58–49 Potash-plagioclase $\gamma = 1.558$, $\alpha = 1.538$ Anorthoclase	replaced with orthopyroxene and magnetite	Augite 2Vγ = 55°–43° β = 1.698–1.702			Magnetite Ilmenite Apatite Cristobalite Tridymite
24.	Plagioclase $\gamma = 1.562$, $\alpha = 1.550$ An 50–43 Potash-plagioclase Anorthoclase	2Vα = 81°–78° $\alpha = 1.702$, $\gamma = 1.763$ Fa 35–45	Titanaugite (purple-augite) 2Vγ = 53°–59° β = 1.696–1.705			Magnetite Ilmenite Brown glass

V Phenocrysts

1.	Plagioclase $\gamma = 1.571$, $\alpha = 1.558$ An 66–58	2Vα = 89°–80° $\alpha = 1.674$, $\gamma = 1.740$ Fa 21–35	Titanaugite 2Vγ = 54°–46° β = 1.702–1.708 Pigeonite (reaction rim around olivine) 2Vγ = 5°–18°		Magnetite	
2.	Plagioclase $\gamma = 1.574$, $\alpha = 1.559$ An 72–59	2Vα = 88°–82° $\alpha = 1.682$, $\gamma = 1.735$ Fa 25–32	Titanaugite 2Vγ = 53°–48° c$\wedge$Z = 45°–43°		Magnetite	

4.		Olivine n.d.	Titanaugite $2V\gamma = 52°–49°$ $c \wedge Z = 44°$ Pigeonite (reaction rim) around olivine) $2V\gamma = 0°–12°$		Magnetite	
5.		Olivine n.d.	Titanaugite $2V\gamma = 53°–48°$ Pigeonite-augite (reaction rim around olivine) $2V\gamma = 5°–30°$		Magnetite	

V Groundmass

1.	Plagioclase $\gamma = 1.565, \alpha = 1.553$ An 56–48 Anorthoclase	$2V\alpha = 81°–77°$ βmax. = 1.740 Fa 34–40	Augite $2V\gamma = 50°–42°$	Bronzite $2V\alpha = 71°–68°$ r>v Fs 25–28		Magnetite Ilmenite Apatite Cristobalite Tridymite
2.	Plagioclase $\gamma = 1.567, \alpha = 1.553$ An 60–48 Potash-plagioclase $\gamma = 1.560, \alpha = 1.542$ Anorthoclase $2V\alpha = 58°–50°$	$2V\alpha = 82°–79°$ βmax. = 1.728 Fa 32–36	Titanaugite $2V\gamma = 50°–44°$ $\beta = 1.692–1.700$			Magnetite Ilmenite Apatite
4.	Plagioclase $\gamma = 1.569, \alpha = 1.554$ An 62–50 Potash-plagioclase $2V\gamma = 75°–120°$ Anorthoclase $\gamma = 1.535–1.520$	Olivine n.d.	Titanaugite $2V\gamma = 53°–48°$ Soda-augite $2V\gamma = 54°$			Magnetite Ilmenite Apatite Cristobalite Tridymite Quartz Brown glass
5.	Plagioclase $\gamma = 1.566, \alpha = 1.551$ An 58–45 Potash-plagioclase Anorthoclase	Olivine n.d.	Titanaugite $2V\gamma = 52°–47°$			Magnetite Ilmenite Apatite Calcite Brown glass

the Kita-matsuura basalts, as already mentioned.

It must be noted here that the alkali rock series has a wide range, since the mineral composition, mutual relations of mafic minerals and chemical composition would reveal that some rocks are typical alkali rocks while others have subalkalic characters closer to the tholeiitic rock series.

Mineralogy

All the refractive indices were measured by the oil immersion methods. The accuracy of measurement is 0.001–0.002. Errors in measurement are larger in the minerals of higher index. Axial angles were measured with a universal stage, with accuracy ± 3° max.

Compositions of olivines, orthopyroxenes and clinopyroxenes were inferred from their optical properties, by the use of diagrams prepared by POLDERVAART (1950), KUNO (1954) and MUIR (1951). For plagioclases, the diagram by CHAYES (1952) was used and the compositions were determined from the refractive indices. The diagram showing the relationship between the optical properties and the chemical compositions of alkali-feldspars is after TUTTLE (1952). However, anorthoclases in the volcanic rocks of this district are of lime-rich type, showing high values of α, β, γ and $2V\alpha$, so that we are unable to determine their chemical compositions from the above diagram (AOKI, 1954). To determine the compositions of titanaugites and alkali-pyroxenes by optical properties, there remain some problems. For example, the pyroxenes of this district are rich in R_2O_3, TiO_2 and alkalis, consequently having high values of refractive indices than pyroxenes poor in alkalis, and inevitably give rise to errors 0.005—0.007 on the average (ISHIBASHI, 1962).

As to the signs of refractive indices, notation of γ means α max., α means α min., and β means its range, unless some special notes are given.

The compositions of feldspars are expressed in weight percentage.

Table 7 lists the optical properties of rock-forming minerals of the rock representatives of each group.

Plagioclase

Plagioclase, occurring as phenocrysts and in the groundmass, is the principal constituent of the volcanic rocks of this district.

The composition of plagioclase in the basalts belonging to the tholeiitic rock series distributed in this district is An 75–54; in the rocks of the alkali rock series it is An 73–43; it is An 66–45 in the rocks of the calc-alkali rock series.

Plagioclase phenocrysts in the basalts of the tholeiitic rock series are less than 3 volume percent, the value being smallest of all rock series. Rocks belonging to the alkali rock series are restricted to intermediate and basic rocks, and plagioclase phenocrysts contained in them are sometimes as much as 28 volume percent, but generally around 10 volume percent or even below 5 volume percent. The size of phenocrysts does not exceed 5.0 mm in all rock series. In the rocks of the calc-alkali rock series, phenocrysts are larger than in the other two series, attaining to 10 mm in maximum, and the content is less than 15 percent. In the rocks formed by contamination, i.e., the rocks of the calc-alkali series, phenocrysts of plagioclase increase in both size and amount.

Groundmass of the rocks contains plagioclase which is the most abundant of all rock-forming minerals. However, its amount decreases as the rock grow acidic, as exemplified by trachyandesite or mugearite of the alkali rock series. Also with increasing acidity, anhedral plagioclase increases, occasionally filling interstices between plagioclase laths and mafic minerals. The zonal structure of plagioclase shows Carlsbad twinning, but no polysynthetic twinning, is observed.

Potash-plagioclase has smaller refractive index than does common plagioclase, and is found to surround plagioclase laths or fill the interstices.

Alkali feldspar

Alkali feldspars in the volcanic rocks of this district are represented by anorthoclase which is an important rock-forming mineral of the rocks belonging to the alkali rock series. This mineral does not occur as phenocrysts in this district where acidic rocks are absent, but it is contained in the groundmass of almost all lavas, occurring unexceptionally as anhedral crystals filling the interstices of plagioclase laths. In many cases, its mineral components form mesostasis as a groundmass glass. Cross-hatched twinning is not observed in the groundmass anorthoclase.

Lime-anorthoclase shows, unlike anorthoclase, cross-hatched twinning in thin sections prepared at right angles with the crystal's crystallographic axis *a*. Besides, it has the optical properties of high albite-oligoclase. The writer tried to measure the volume percentage of alkali feldspars, but the measurement along with discrimination of feldspars was a very difficult task and the writer could not obtain accurate values.

Silica minerals

The majority of volcanic rocks distributed in this district are devoid of quartz phenocrysts. Groundmass silica minerals are found in the rocks of Group V and in some rocks of Group IV. It is probable that they occur as silica components in the interstices-glass which is a mesostasis of the groundmass of lavas produced by contamination. The more or less tholeiitic rocks of Group III_1 contain much glass in which silica components are included, so the silica components may not be recognized as definite minerals. In the basalts of this district, occurrence of silica minerals is very rare. Tridymite is often crystallized out into drusy cavities, especially in the lavas of Groups IV and V.

Quartz xenocrysts are found in basalts or andesites of the alkali rock series or the calc-alkali rock series, especially in the lavas of high silica content belonging to Group IV and the lavas of Group V showing remarkable contamination. The volume percentage of quartz xenocrysts does not exceed 2 percent, usually less than 1 percent. In most cases, these silica minerals are surrounded by reaction rim of minute augite or by brown glass.

Olivine

Olivine occurs as phenocrysts in the rocks of the alkali rock series. It is found also in the groundmass of such rocks. This mineral is most abundant in the basic rocks of this district. The amount of olivine phenocrysts is 13–17 percent in picritic basalts and 1–8 percent in basalts. Olivine in the groundmass of trachybasalts is generally 7–12 percent; this percentage is somewhat small, because microphenocrystic minerals were counted as phenocrysts, as shown in Table 6. The amount of olivine phenocrysts decreases rapidly as the rock becomes acidic. The longer diameter of olivine phenocrysts is generally less than 5 mm; in the lavas of Groups III_1 and III_2 it is less than 2 mm.

Some phenocrysts of olivine are completely replaced by aggregates of bronzite-hypersthene and magnetite, as exemplified by the phenocrysts in the olivine basalt of Senryu-shira-dake (No. 16 of Group IV).

The composition of olivine is Fa 13–35 in the case of phenocryst, and Fa 23–46 in groundmass. Olivine phenocrysts of Group IV are generally poor in Fa.

In basalts and andesites of the calc-alkali rock series, olivine occurs as phenocrysts but in the groundmass it is very scarce, and in some andesites it is absent.

Olivine phenocrysts including spinel are noticeable in the rocks of Group IV, especially in picritic basalts.

Olivine nodules are not found in this district but are abundant in the vicinity of Karatsu-shi to the northeast, particularly in the lavas and pyroclastics of Takashima Island, Saga Prefecture (KOBAYASHI et al., 1956).

Clinopyroxene

Clinopyroxene is found in rocks of all rock series. It comprises augite, titanaugite, soda-augite and aegirine-augite. Titanaugite is especially abundant in the rocks of the alkali rock series; soda-augite is also found in these rocks very often. Aegirine-augite occurs in cognate xenoliths and in porous segregate pipes that are often found in some lavas.

The amount of clinopyroxene phenocrysts is 5 volume percent at most, usually 1–2 volume percent, but in picritic basalts it attains to as much as 11–14 volume percent.

Groundmass clinopyroxene is abundant in the lavas of Groups II and IV belonging to the alkali rock series. In trachybasalts, for example, the amount of holocrystalline clinopyroxene ranges from 11 to 28 percent. The amount, however, decreases rapidly as the rock becomes more acidic or gets closer to the calc-alkali rock series.

The composition of titanaugite, as estimated from the optical angles and refractive indices, ranges between $Wo_{40}En_{40}Fs_{20}$—$Wo_{40}En_{30}Fs_{30}$. But, according to ISHIBASHI (1962), the refractive indices are affected by Ti, Al, Na and K contained in pyroxenes of alkali rocks. Chemical analysis and optical properties of separated pyroxenes have revealed that the refractive indices of titanaugite are 0.05–0.07 higher on an average, due to the influence of the Ti content. Therefore, in the above-mentioned range of pyroxene compositions, the value of the Fs content is supposed to be 4–6 percent smaller. This problem requires further and detailed examinations.

Zoning of clinopyroxene is often recognized, as seen in the case where titanaugite is grading into the aegirine composition toward the outer margin of the crystal.

Clinopyroxene in the groundmass of lavas often shows a subophitic texture where it is intercalated with plagioclase laths or minute minerals of olivine or magnetite, and grows into subhedral crystals. Titanaugite and aegirine-augite show a weak or a little strong pleochroism, the latter being purple in color. Soda-augite shows a pale green–green color.

Pigeonite occurs in basalts and andesites of the calc alkali rock series, crystallizing as reaction rim in the margin of olivine phenocryst. It suggests that pigeonite was crystallized when the basaltic rocks belonging to the alkali rock series suffered contamination. This problem was discussed also by FUKUYAMA (1960–1961).

Orthopyroxene

Orthopyroxene is common in the rocks of the calc-alkali rock series, especially in their groundmass.

As stated before, olivine phenocrysts in trachybasalts and basalts are often replaced by aggregates of hypersthene and magnetite.

In many cases, phenocrysts of orthopyroxene are surrounded by reaction rim of augite; this is conspicuous in the lavas of the calc-alkali rock series. Orthopyroxene phenocrysts are found also in the trachybasalts of the alkali rock series, but its occurrence is rare and the amount never exceeds 2 volume percent and the size is under 2 mm in diameter.

Groundmass orthopyroxene is found in the lavas of the calc-alkali rock series. In some of the lavas, it occurs in a large amount, occasionally exceeding 10 volume percent, but the amount is generally very small.

In the basalts of the calc-alkali rock series, reaction rim of hypersthene is observed to surround olivine phenocrysts.

In most case, phenocrystic or microphenocrystic orthopyroxenes are showing parallel intergrowth with clinopyroxenes or are surrounded by the latter.

Judging from the optical evidence, there is a general tendency that these orthopyroxenes occur as hypersthene in phenocryst and as bronzite in the groundmass.

In the thick pyroclastics distributed below the lavas of Group IV, single crystals of hypersthene and augite are abundant, the crystals sometimes being as large as 2 cm.

Hornblende

In the Higashi-matsuura district and Iki Island adjacent to this district, kaersutite occurs as phenocrysts, and hornblende is found in the groundmass and cavities of trachybasalts (Aoki, 1959), but no such minerals have been observed in this district.

Hornblendes are absent in the Kita-matsuura basalts, except that the Seira-san andesites to the east belonging to the calc-alkali rock series contain a large amount of hornblendes occurring as phenocrysts.

Accessory minerals

Biotite: Biotite occurs often as irregular anhedral flakes in the groundmass of trachybasalts and trachyandesites. Some biotites show a deep reddish-brown color, looking like titanbiotite, but many are colorless phlogopite. They are frequently seen also in the cavities of rocks, having a hexagonal form.

Magnetite: Magnetite is contained in all rocks. Its amount as phenocrysts does not exceed 1 volume percent and the longer diameter is almost always less than 1mm. In the groundmass it occurs as octahedral or skeletal crystals, the amount seldom exceeding 5 volume percent.

Magnetite phenocrysts, as large as 0.5–1.5 cm, are found in Iki Island, containing TiO_2 11.46 percent and Al_2O_3 11.13 percent (Matsui, 1958), but no such large crystals are known in this district.

As mentioned before, this mineral is found in the aggregates that replaced olivine phenocrysts.

Ilmenite: In the groundmass of nearly all rocks ilmenite is contained as minute hexagonal plates or slender prismatic crystals. This mineral is black or opaque. Very often it coexists with magnetite.

Apatite: Apatite occurs in a very small amount in the groundmass of rocks of all rock series. In many cases it is included in plagioclase phenocrysts.

Picotite and spinel: Picotite and spinel occur in very small amounts as minute octahedral crystals in olivine. Occurrence of these minerals in olivine phenocrysts is conspicuous in the lavas of Group IV, as mentioned before.

Zeolite: Zeolite occurs as radial crystals often in the cavities of altered or slightly altered rocks.

Chlorite: Chlorite is found replacing mafic minerals in altered or slightly altered rocks among the older members of the Kita-matsuura basalts.

Brown glass: In nearly all rocks brown glass is found though in a very small amount. Some of the basalts belonging to Group III_1 contain brown glass as much as 50 volume percent, resulting in the small values of color index (Table 6).

IV. 3 Petrochemistry of basalts

IV. 3. 1 Range of chemical composition

As regards the chemical compositions, this section deals only with the Kita-matsuura basalts, and the associated Seira-san andesites and Arita rhyolites are considered separately.

Table 8 shows that the content of SiO_2 ranges from 44.44 % to 54.46 %, accompanied by 2.76 % to 6.53 % alkalis. On the other hand, the Al_2O_3 content is 13 $\sim$ 19 %, total FeO is 7 $\sim$ 12 %, CaO is 6 $\sim$ 11 %, MgO is 3.5 $\sim$ 14 %, TiO_2 is 0.5 $\sim$ 3 %, MnO is 0.08 $\sim$ 0.25 %, and P_2O_5 is 0.3 $\sim$ 0.9 %.

IV. 3. 2 Range of composition of each group

The range of chemical compositions of the respective groups arranged in the order of eruption reveals noticeable differences in the contents of Na_2O+K_2O, MgO and total FeO, as shown below (Group I was omitted due to scarcity of data).

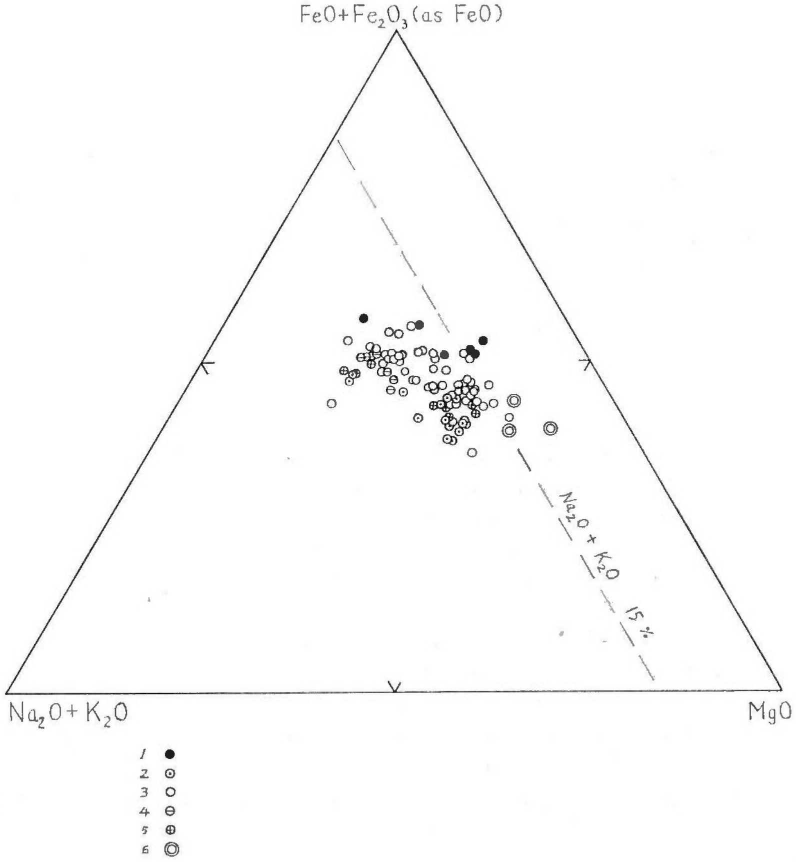
SiO_2:		
	Group II	44.5 - 53.4 (%)
	Group III_1	45.7 - 51.4
	Group III_2	44.2 - 51.7
	Group IV	45.1 - 54.0
	Group V	51.4 - 54.5
Na_2O+K_2O:		
	Group II	3.3 - 6.2 (%)
	Group III_1	2.8 - 4.8
	Group III_2	4.5 - 6.5
	Group IV	2.7 - 5.1
	Group V	4.4 - 6.9
MgO:		
	Group II	3.5 - 9.8 (%)
	Group III_1	6.0 - 7.7
	Group III_2	4.0 - 6.5
	Group IV	6.5 - 13.7
	Group V	3.5 - 5.5
Total FeO:		
	Group II	8.5 - 11.3 (%)
	Group III_1	9.7 - 12.0
	Group III_2	9.6 - 12.4
	Group IV	7.0 - 10.8
	Group V	8.3 - 9.0

The above values indicate a general tendency, except for Group V, as follows: The SiO_2 content varies little, becoming slightly abundant in Group IV; Na_2O+K_2O gradually increase from Group II to Group III_2; MgO is poorest in Group III_2, but becomes richer in Groups II and IV, especially in the members of IV; total FeO is abundant in Groups III_2 and III_1 but is poor in IV.

IV. 3. 3 Consideration on variation diagrams

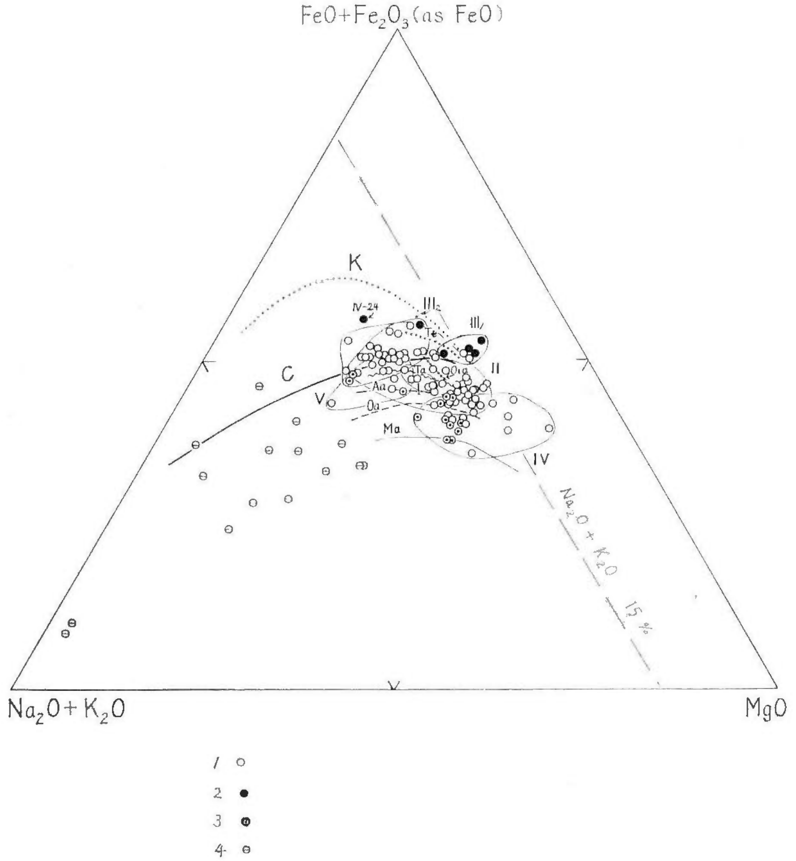
The Kita-matsuura basalts were plotted on the $MgO-FeO$ (total) $-Na_2O+K_2O$ diagrams (Figs. 10, 11). These rocks indicate an iron-rich fractionation trend as compared with the basalts of the western part of San-in and Tottori districts. For example, the latter basalts show the values of $FeO+Fe_2O_3$ (as FeO) distributed in the field less than 50, whereas the Kita-matsuura basalts are distributed in the field of relatively higher values, attaining to more than 50.

The fractionation trend of each group of the Kita-matsuura basalts reveals the following facts: Group IV occurs closer to MgO and occupies a position poor in iron. The area closest to MgO is occupies by picritic basalts. Some rocks of Group IV are of advanced differentiation and comprise basalts that were formed



1. c and b→c type (Kuno's ferromagnesian silicate mineral assemblage)
2. d and a→d type
3. b type
4. Mugearites
5. Conspicuous undersaturated rocks
6. Picritic basalts

Fig. 10 Variation diagram of the rocks of the Kita-matsuura district as plotted in the ternary diagram $MgO-FeO+Fe_2O_3-Na_2O+K_2O$.



1. Alkali rock series (b type)
2. Tholeiitic rock series (c and b→c type)
3. Calc-alkali rock series (d and a→d type)
4. Andesites and rhyolites in the adjacent area

Ma: Alkali rock series of Mi-shima district
Oa: Alkali rock series of Otsu district
Aa: Alkali rock series of Abu district
Oia: High-iron alkali rock series of Otsu district
San-in region
Ta: Alkali rock series of Tara-dake district
Tt: Tholeiitic rock series of Tara-dake district
C: Circum-Japan Sea alkali rock province
K: Kami-goto rook series

Fig. 11 Variation diagram of the rocks of the Kita-matsuura district as plotted in the ternary diagram.

by contamination; these basalts occupy a position where the content of FeO+Fe$_2$O$_3$ is poorest, suggesting a contamination of magma whose crystallization differentiation is less advanced. The majority of Group III$_1$ and a small part of the tholeiitic basalts of Group II show a trend richest in FeO+Fe$_2$O$_3$.

Most of the Group V rocks are a derivative of contamination of a magma of the middle stage where crystallization differentiation is advanced.

The majority of the rocks are plotted in the field of $Na_2O + K_2O > 15\%$, the rest being the basalts of tholeiitic rock series of Group III$_1$ and the picritic basalts of Group IV.

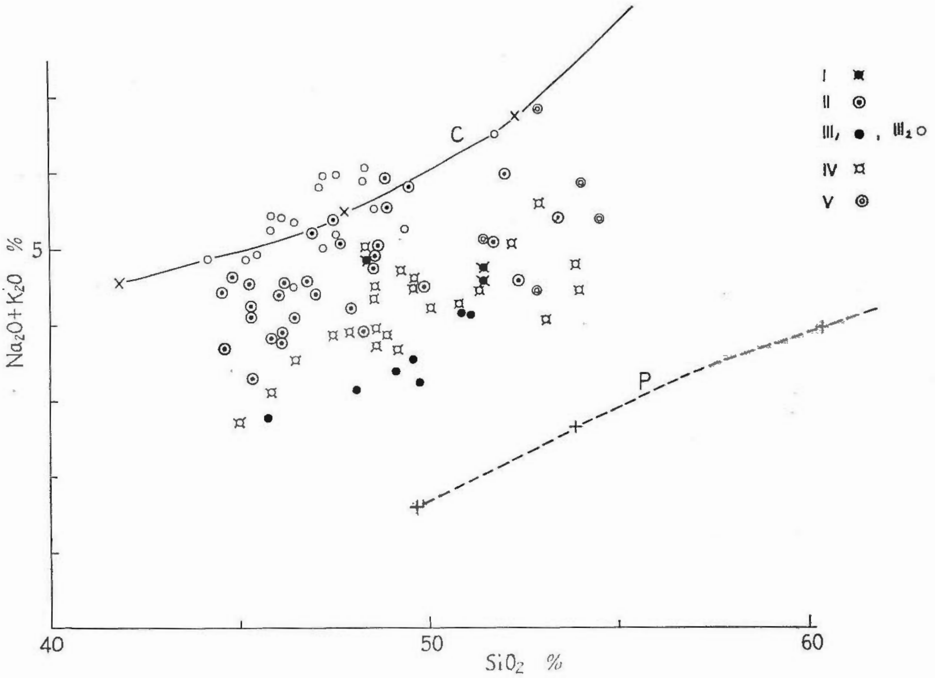


Fig. 12 Total alkalis of the rocks of the Kita-matsuura district plotted against SiO_2. Symbols are the classified groups.

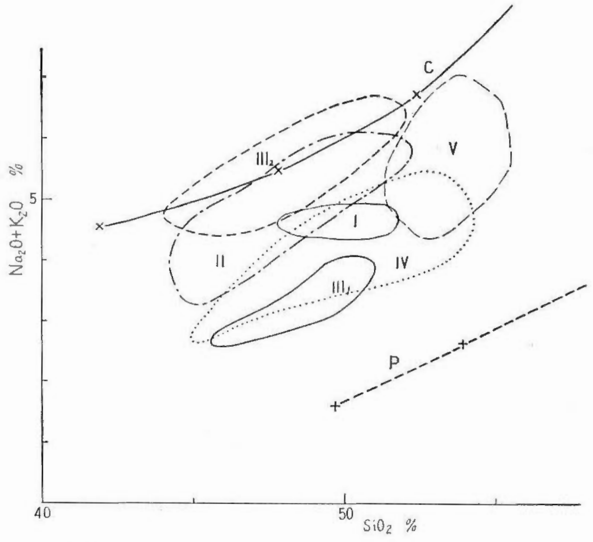


Fig. 13 Simplified diagram for the each group of the Kita–matsuura basalts in Fig. 12.

The relationship between Na_2O+K_2O and SiO_2 is mentioned below.

Fig. 12 is a diagram in which the Kita-matsuura basalts were plotted by groups. The diagram is simplified in Fig. 13 by bounding the groups with lines. When the lines are averaged, characteristics of each group become clear, as seen in Fig. 14.

From these figures we realize that Group III_1 is poorest in alkalis which increase toward Group II and Group III_2 but decrease again in Group IV. Group V, member of the last activity, occupies the independent position of $SiO_2 > 51\%$, showing a character of the calc-alkali rock series marked with contamination.

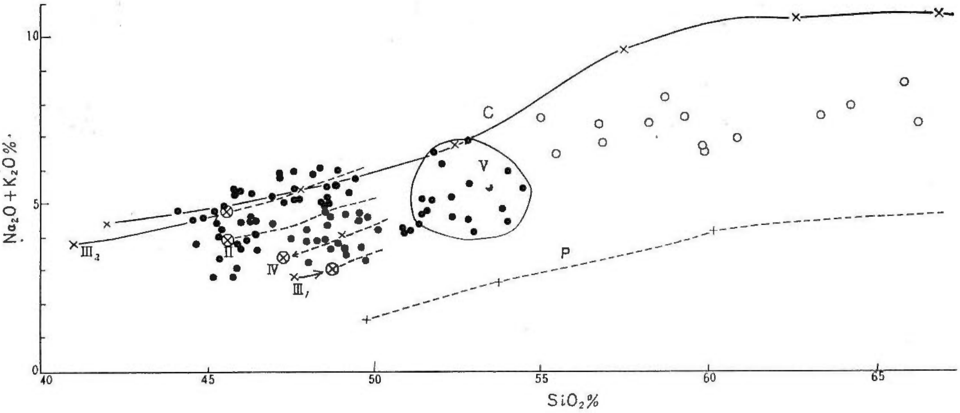


Fig. 14 Total alkalis of the Kita-matsuura basalts plotted against SiO_2. The curves for each group that for the average basalt groups. The variation diagram represents the curves for the trend of the Circum-Japan Sea alkali rock province (C) and pigeonitic rock series (P) for the comparison between the Kita-matsuura basalts. Open circles represent Seira-san andesites and Arita rhyolites.

Thus, judging from the behaviour of alkalis against SiO_2, the Kita-matsuura basalts seem to represent one cycle of volcanism ranging from the lowermost group to the uppermost group.

The content of alkalis increases gradually from Group I to Group III_2 until the latter comes to have the chemical composition typical of alkaline suite. Group IV, on the contrary, shows the alkali-poor character. Group V of the final activity is characterized by a striking contamination of basalt magma with granitic materials.

Group III_1 is composed, for the most part, of tholeiitic basalts and is much richer in alkalis than the tholeiitic rock series of the Izu and Hakone districts, one of the alkali-poor members among the tholeiitic basalts of the world. The same thing can be said about tholeiitic rocks in other parts of West Japan.

Fig. 15 shows the relation of K: Na versus SiO_2. The ratio shows the lowest value in Group III_1, being about 0.2. Group II and Group III_2 show nearly the same values, 0.4–0.5, although the rocks of Group II have a wider range of values. In Group IV the value is intermediate between III_1 and III_2, being about 0.3. The value in Group V is about 0.5.

The relationship between SiO_2 and MgO is given in Fig. 16. From Group I to Group III_2, MgO shows relatively small values, but in Group IV it becomes most

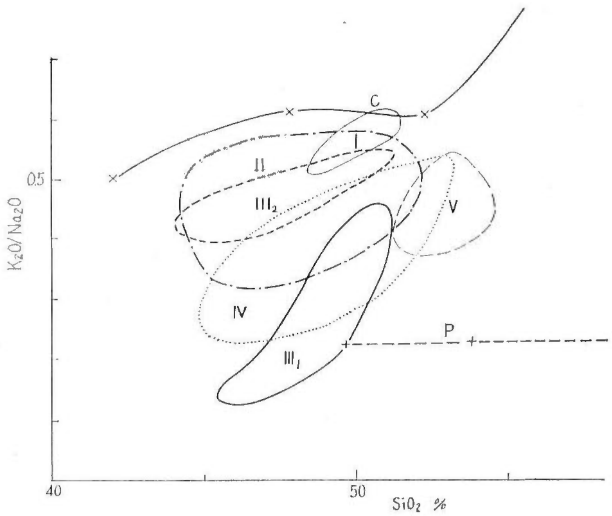


Fig. 15 Simplified diagram of K_2O: Na_2O of the Kita-matsuura basalts as plotted against SiO_2.

abundant and its distribution reveals a character different from that of the suite of alkali rock series of Group II and Group III_2. Group V occupies a position of small values of both SiO_2 and MgO. From these facts it is pointed out that Groups I–III_2 are direct magmatic products while Groups IV and V were affected by some other factors.

Similar relationship is noticed between FeO/MgO+FeO and SiO_2, as shown in Fig. 17. In view of the sequence of eruptions of the Kita-matsuura basalt groups, the ratio becomes gradually larger from Group I to Group III_2, but is much smaller in Group IV. Group V shows an isolated distribution, occupying the position evidently rich in SiO_2.

Fig. 18 was prepared to explain the relationship between the solidification index and the behaviour of chemical composition. In the figure were plotted mean values of the representative rock series, such as the pigeonitic rock series of the Izu and Hakone districts (KUNO, 1950) and the alkali rock series of the Circum-Japan Sea alkali rock province (TOMITA, 1935).

The tholeiitic basalts of Group III_1 of the Kita-matsuura basalts are rich in SiO_2, $FeO+Fe_2O_3$ and MnO, and poor in Na_2O+K_2O, especially K_2O. Rocks of the alkali rock series of Group II show a wide range of fractionation trend and are poor in SiO_2. In the early stage of solidification, this group is poor in SiO_2 and rich in $FeO+Fe_2O_3$, CaO and TiO_2; CaO further increases in the later stage.

Group III_1 is of a type of advanced differentiation, and is poorer in SiO_2 and CaO than Group II and richer in $FeO+Fe_2O_3$ and Na_2O+K_2O.

Group IV is of an olivine-rich type, and is poor in $FeO+Fe_2O_3$, CaO, TiO_2 and MnO, as compared with the trend of the early stage of Group II, but is richer in SiO_2.

From the behaviour of chemical compositions of the Kita-matsuura basalts, the following facts are known: Tholeiitic basalts abound in SiO_2 and iron, but are poor in Al_2O_3, Na_2O+K_2O, especially in K_2O. The suite of basalt, trachybasalt and trachyandesite of alkali rock series is abundant in Group II; SiO_2 in these rocks

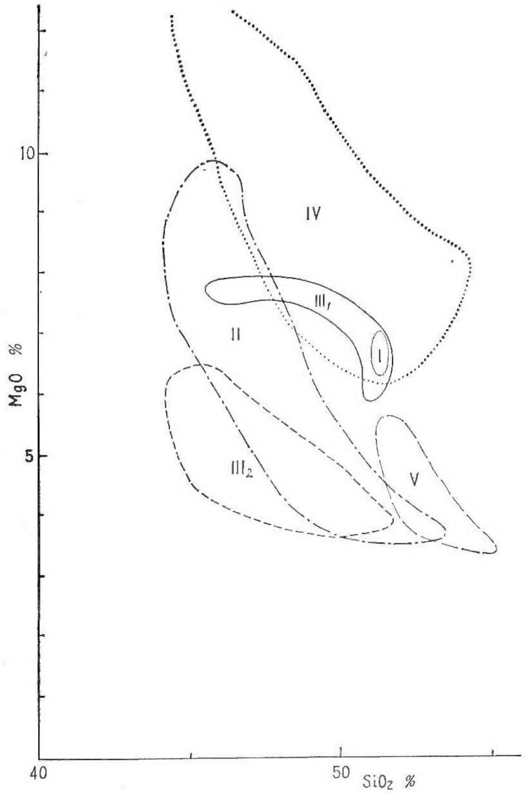


Fig. 16 MgO of the basalts as plotted against SiO_2.

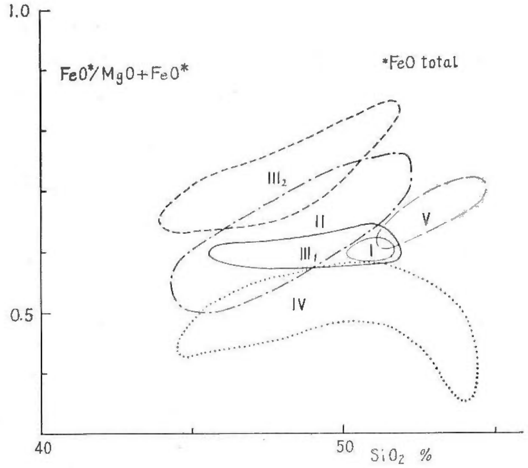


Fig. 17 FeO (total) : MgO+FeO (total) of the basalts as plotted against SiO_2.

is about 45 percent and gradually increases with progress of fractionation, sometimes attaining to more than 50 percent. Iron shows an increase near the value 30 of the solidification index, but decreases as fractionation advances. CaO shows a slight decrease with progress of fractionation, and in the middle stage it decreases conspicuously.

In Group III_2, fractionation is more advanced that in the above-mentioned suite of alkali rock series; the solidification index is 28–19 and shows a SiO_2–poor iron-rich trend. The alkali rock suite of this group includes mugearite-trachyandesite, showing more alkalic nature than the trachybasalt-trachyandesite alkali rock suite which is characteristic to Group II.

The solidification index of each group is listed below.

Group II	40 - 17
Group III_1	35 - 29
Group III_2	28 - 19
Group IV	50 - 33
Group V	28 - 19

By comparing these values, it would be recognized that the suite of tholeiitic rock series is the fractionation product of the early stage, the suite of alkali rock series of Group II is that of early to middle stage, and the strong alkali rock suite characteristic to Group III_2 is of middle stage.

Part to Group IV is rich in olivine, as exemplified by picritic basalts. The diagram shows that those rocks are of the type rich in SiO_2 and poor in iron, CaO and TiO_2, but the alkali contents are not much different from other alkali rocks. Hence, the olivine-rich rocks of Group IV belong to a suite having less alkalis than in the suite of the alkali rock series of Group II. In the rocks are found residual olivine and some influence of contamination.

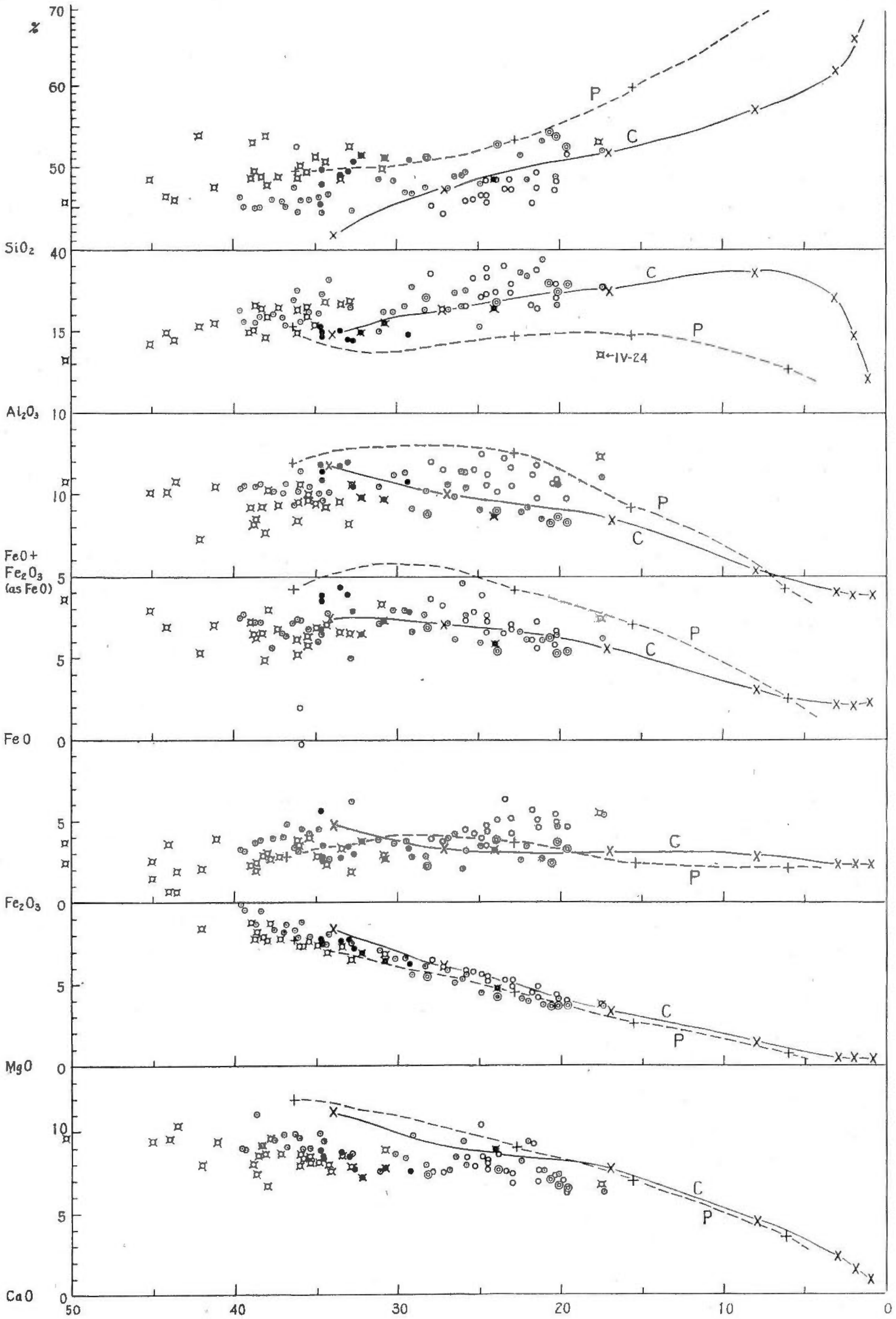
Group V shows the middle stage of fractionation, with high content of SiO_2 and low contents of iron and CaO. The majority of the rocks of this group are products of strong contamination. Variation of SiO_2, most important component in the solidification index versus oxides relationship, was simplified in the diagram of Fig. 19 for each group. Fig. 20 shows the relationship between $Na_2O + K_2O$ and the solidification index.

To consider the high-alumina basalt magma proposed by KUNO (1960), Fig. 21 was prepared. The figure shows the position occupied by high-alumina basalts containing SiO_2 in the range of 47.51–52.50 percent. Occurring in this position are augite-olivine trachybasalt (No. 2 of Group II–1) and augite-olivine-bearing andesite (No. 15 of Group II–2); the former, having 44.62 percent SiO_2, is an undersaturated rock and belongs to alkali rock series, while the latter, with 53.36 percent SiO_2 and solidification index 21.1, is advanced in fractionation and so cannot be treated as basalt. Augite-olivine basalt (No. 1 of Group II–1) occurring near the lower limit of the distribution area of high-alumina basalt has 45.36 percent SiO_2 and is a markedly undersaturated rock.

These confusing rocks do not apply to KUNO's high-alumina basalt, from the above facts as well as from their petrographic properties. Thus, the Kita-matsuura basalts are found to contain no rocks corresponding to high-alumina basalts.

In this diagram, Group III_1 and part of Group IV seem to correspond to tholeiitic basalt.

Among the rocks of this district, Group III_1 has, in general, a character closest to tholeiitic rock, as mentioned before, but the diagram reveals that this group


%
70
60
50
SiO$_2$
40
P
C
40
15
C
P
¤←IV-24
Al$_2$O$_3$
10
10
P
C
FeO+
Fe$_2$O$_3$
(as FeO)
5
5
P
C
FeO
0
0
5
C
P
Fe$_2$O$_3$
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50
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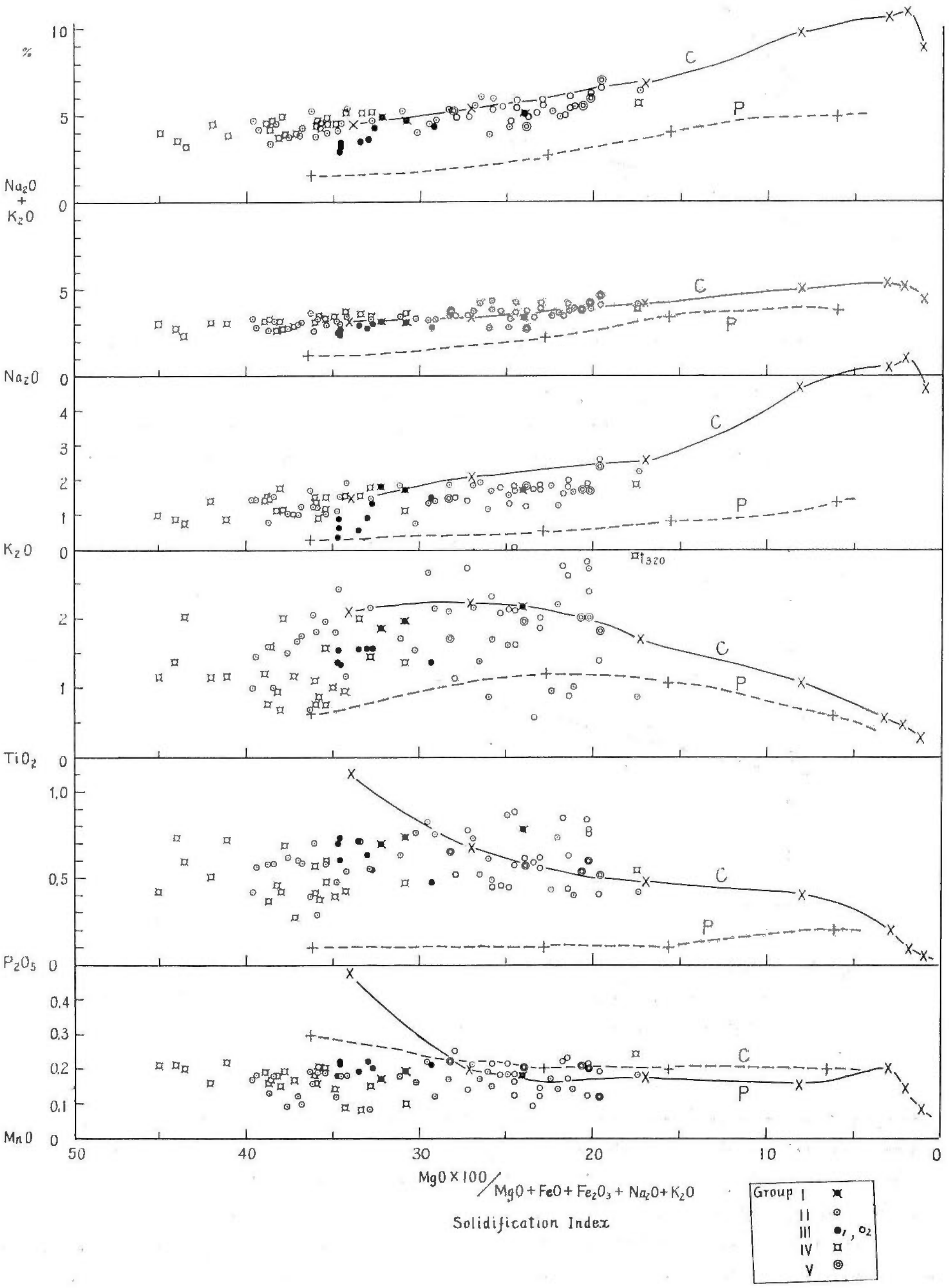


Fig. 18 Variation diagrams of the rocks of the Kita-matsuura district as plotted against the value $MgO \times 100/MgO+FeO+Fe_2O_3+Na_2O+K_2O$ (the solidification index value proposed by KUNO, 1954, 1957). The curves for the Circum-Japan Sea alkali rock province (C) and Pigeonitic rock series (P) are plotted in the diagram.

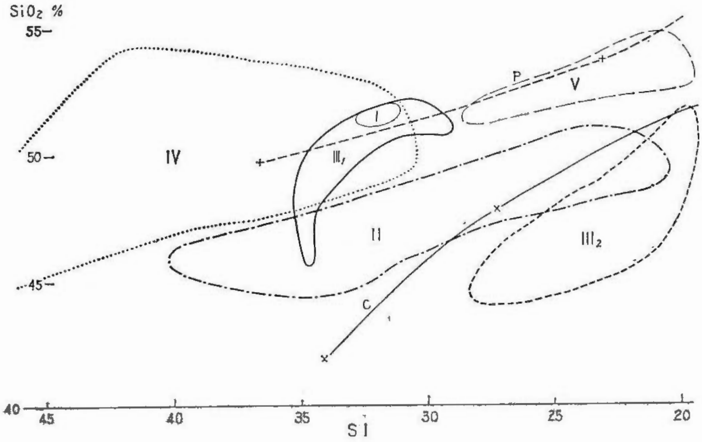


Fig. 19 Simplified variation diagram of the Kita-matsuura basalts as plotted against the solidification index. The method of plotting is the same as Fig. 18. The ordinate represents the weight percentage of SiO_2.

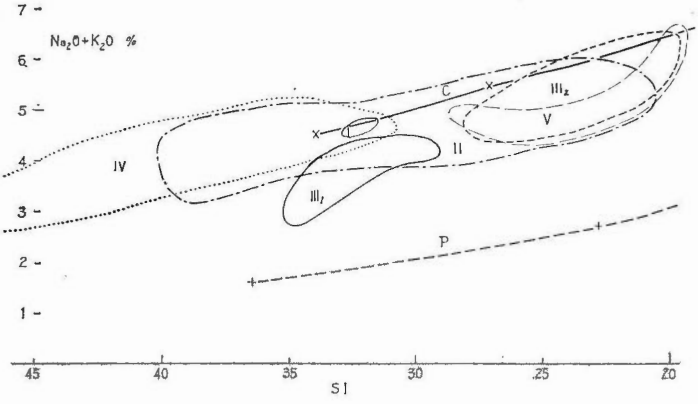
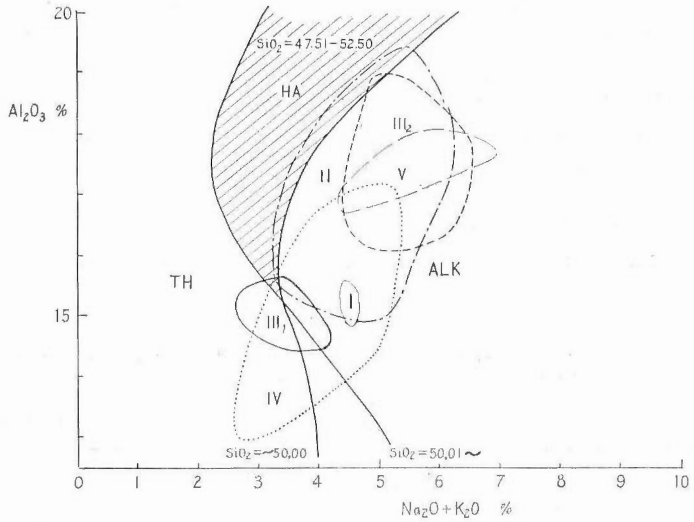


Fig. 20 Variation diagram of the Kita-matsuura basalts. Total alkalis of the rocks as plotted against the solidification index. The method of plotting is the same as Fig. 18.

occupies the position extending over tholeiitic basalt and alkali olivine basalt. Those plotted in the position of tholeiitic basalt are Nos. 1–5 basalts, and those in the position of alkali olivine basalt are Nos. 6 and 7 olivine basalts. That is, these basalts are not distinctly tholeiitic basalts but are close to alkali rock series.

Nos. 1, 2, 3 and 7 of Group IV are plotted in the position of tholeiitic basalt, but they are picritic basalts containing 44–48 percents SiO_2, and accordingly are different from tholeiitic basalt.

No. 24 augite-olivine dolerite is a segregate pipe (schliere), enriched with volatile matter, occurring in olivine basalt of No. 4 of Group IV, and is probably a fractional part of lava. Therefore, almost all basalts of this district are fractionation products derived from alkali olivine basalt magma.



TH: Aphyric tholeiite field
HA: Aphyric high-alumina basalt field
ALK: Alkali basalt field

Fig. 21 Al_2O_3—total alkalis—SiO_2 relation of the Kita-matsuura basalts.

IV. 3. 4 Norm

Norms of the respective basalt groups are given in Table 9. Normative quartz occurs characteristically in Groups I, III_1 and V; it is recognized also in some parts of Groups II and IV, especially in the latter where the rocks suffered contamination. Fig. 24 shows the relationship between normative quartz and SiO_2.

Normative Ne occurs characteristically in Groups II and III_2. The highest value of normative Ne in this district is 5.97 percent in augite-olivine trachybasalt of Group II. Normative Ne is detected in more than one half of the rocks of Group

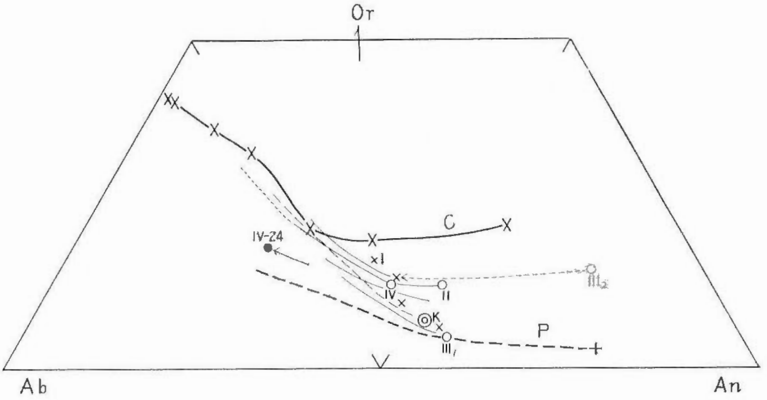


Fig. 22 Composition of the normative feldspar of the Kita-matsuura basalts. The average curves of the classified groups represents in the diagram. Open circles represent the composition of the normative feldspar of the extrapolated parental magma of the classified groups of the Kita-matsuura basalts.

III$_2$. Rocks in which Ne is calculated are those having less than 5 percent SiO_2 and more than 4 percent deficiency of normative quartz.

Normative olivine is generally less than 20 percent excepting picritic basalt in which normative olivine exceeds 25 percent.

Fractionation trend of normative feldspars shows increasing Or content from Group II to Group III$_2$, as seen in Fig. 22.

IV. 3. 5 Alkali-lime index

The alkali-lime index of the Kita-matsuura basalts is given in Table 11.

Table 11 PEACOCK's alkali-lime indices of each group of Kita-matsuura basalts, Northwest Kyushu, Southwest Japan.

	Indices	$CaO = Na_2O + K_2O$
Group V	55.0～56.2	6.0～7.0
IV	57.0	6.75
III$_2$	50.5	6.15
III$_1$	58.5	6.85
II	54.2	6.75

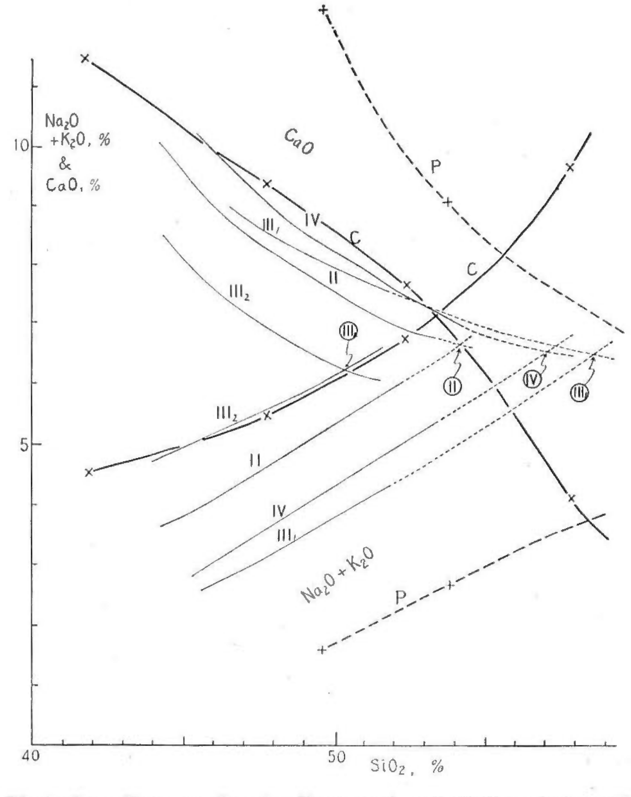


Fig. 23 Variation diagram for the PEACOCK's alkali-lime index of the each group of the classified basalts. The curves for the average of the Kita-matsuura basalts and that the classified groups are shown.

Value of the alkali-lime index is 58.5 in Group III_1 which is poorest in alkalis, and 54.2 and 50.5 respectively in Groups II and III_2 of alkali rock series. Group IV shows a large value, 57.0, which is close to 59.3 of the western part of San'in belonging to the calc-alkali rock series which was derived from the alkali olivine basalt magma, or to 58.0 of the Tottori district in central San-in, or to 57.5 of Iki Island and Higashi-matsuura Peninsula (Table 12).

These values are lower than 60, the value of the Quaternary volcanic rocks of the Chokai Volcanic Zone (KATSUI, 1954) in Tohoku region and the Daisen Volcanic Zone of West Japan, both being still active on a large scale.

The value of $CaO = N_2O + K_2O$ in the alkali rock series of the Kita-matsuura basalts in lowest, 6.15, in Group III_2, and $6.75 \sim 7.0$ in other groups. The value is 7.0 in western San-in and 6.5 in the Tottori district, respectively (Table 12).

Table 12 PEACOCK's alkali-lime indices of various regions of Japan.

Kami-goto Islands	Subalkali rock series	55.0
Fukué-jima, Goto Islands	Tholeiitic rock series	57.0
	Younger stage alkali rock series	53.5
	Older stage alkali rock series	51.0
Western part of San-in region	Calc-alkali rock series	58.0 ~ 60.5
	Abu district alkali rock series (younger stage)	53.0
	Otsu district alkali rock series (older stage)	51.5
Tottori area of San-in region	Calc-alkali rock series	59.5
	Alkali rock series	55.0
Tara-dake and Minami Shimabara alkali rock series		50.0 ~ 53.0
Iki islands and Higashi-matsuura district (K.A., 1958)		51.0
Circum-Japan Sea alkali rock series (T.T., 1935)		53.1
Japan and surrounding area (K.Y., 1959)		51.6
Pigeonitic rock series of Izu and Hakone districts (H.K., 1954)		66.0

V. Discussion and Conclusion

V. 1 Parental magmas of the Kita-matsuura basalts

In order to presume the parental magma of the Kita-matsuura basalts, the writer studied the respective basalt groups from the viewpoint that the sequence of eruptions is an important clue to elucidate the generation of magma and its development processes.

Table 13 shows the chemical compositions of the rocks of Groups II–IV, which are highest in the value of solidification index. Group I was not dealt with, because of scarcity of specimens. Group V was also excluded as being contamination products. The solidification index is 35.8 in Group III_1 whose character is most tholeiitic of all rocks in this district, 40.5 in Group II, 28.2 in Group III_2, and 46.5 in Group IV. The very high index value of Group IV is due to picritic basalts. The low value of Group III_2 indicates that fractionation from the parental magma was fairly advanced in this group.

Table 13 Compositions of the eariest stage of the solidification of the Kita-matsuura basalts, North-west Kyushu.

	II	III_1	III_2	IV
SiO_2	45.6	48.1	45.5	47.2
TiO_2	1.4	1.5	2.0	1.2
Al_2O_3	15.9	15.2	17.7	14.2
Fe_2O_3	3.8	3.0	4.2	2.9
FeO	7.7	9.0	8.5	7.8
MnO	0.1	0.2	0.2	0.2
MgO	10.2	9.0	6.7	12.0
CaO	9.8	9.3	8.3	9.5
Na_2O	2.8	2.4	3.4	2.6
K_2O	1.1	0.6	1.4	0.8
P_2O_5	0.6	0.7	0.6	0.6
H_2O	1.0	1.0	1.5	1.0
Total	100.0	100.0	100.0	100.0
FeO tot.	44.0	51.1	51.7	40.3
MgO	40.5	35.8	28.2	46.5
Alk.O	15.5	13.1	20.1	13.2
Q	(−9.85)	(−6.55)	(−7.57)	(−8.53)
Or	6.68	3.34	8.35	5.01
Ab	18.87	20.43	26.22	22.02
An	27.54	28.93	28.93	24.48
Ne	2.56	—	1.42	—
Wo	7.43	5.46	2.32	8.01
En	5.02	5.02	1.41	7.23
Fs	1.85	3.30	0.79	2.77
Fo	14.35	10.69	10.69	15.90
Fa	5.30	6.72	6.52	5.91
Mt	5.56	4.40	6.02	4.17
Il	2.73	2.88	3.79	2.28
Ap	1.35	1.68	1.35	1.35

In the past, numerous hypotheses and definitions have been made on basaltic magma (parental magma). The present writer holds a view that a parental magma in a strict sense should be the one with the solidification index value near 40, as was pointed out by KUNO (1954).

Among the lavas actually existent in the Kita-matsuura basalts the following can be enumerated as closest to parental magma:

Group II:	(II–1–7)*	Olivine trachybasalt	(36.8)**
Group III_1:	(III_1–2)	Augite-olivine basalt	(34.6)
Group III_2:	(III_2–1)	Augite-olivine trachybasalt	(27.2)
Group IV:	(IV–5)	Augite-olivine trachybasalt	(37.8)

* Refer to Table 8.

** Solidification index.

In the above list the value of solidification index is lowest in the trachybasalt of Group III_2. The trachybasalt of Group II contains 5 percent olivine phenocrysts. The trachybasalt of Group III_2 and that of Group IV are porphyritic, abundantly containing phenocrysts of plagioclase, olivine and augite. A general composition of parental magma would be known from the above result.

Table 14 Compositions of the extrapolated parental magmas of the Kita-matsuura basalts, Northwest Kyushu.

	II	III_1	III_2	IV
SiO_2	45.6	47.6	41.0	49.0
TiO_2	1.4	1.3	2.0	1.3
Al_2O_3	15.9	14.5	15.8	15.7
Fe_2O_3	3.8	3.1	3.9	3.0
FeO	7.7	9.2	9.4	7.3
MnO	0.1	0.2	0.2	0.2
MgO	10.2	9.6	11.8	9.0
CaO	9.8	10.1	10.0	8.9
Na_2O	2.8	2.3	2.9	2.9
K_2O	1.1	0.4	0.9	1.2
P_2O_5	0.6	0.7	0.6	0.5
H_2O	1.0	1.0	1.5	1.0
Total	100.0	100.0	100.0	100.0
FeO tot.	44.0	49.4	45.3	43.3
MgO	40.5	39.5	41.4	39.0
AlK.O	15.5	11.1	13.3	17.7
Q	(−9.85)	(−3.18)	(−18.10)	(−4.69)
Or	6.68	2.23	5.57	7.23
Ab	18.87	19.40	5.77	24.64
An	27.54	28.09	27.26	26.15
Ne	2.56	—	10.23	—
Wo	7.43	7.43	7.90	6.16
En	5.02	16.46	5.22	10.44
Fs	1.85	8.44	2.11	4.35
Fo	14.35	5.21	17.03	8.30
Fa	5.30	3.26	6.93	3.67
Mt	5.56	4.40	5.56	4.40
Il	2.73	2.43	3.79	2.43
Ap	1.35	1.68	1.35	1.35

Table 14 shows the chemical compositions of extrapolated parental magma obtained for each group by placing the solidification index at about 40. Among these compositions, that of Group II is actually existent as a lava, and that of Group IV was obtained from a lava proximate to parental magma. As to Groups III_1 and III_2, their compositions are a result of extrapolation from Figs. 14 and 18 and from several variation diagrams.

The extrapolated parental magma of Group III_1 is poorest in alkalis, as compared with other groups, and contains −3.18 percent normative quartz. Although excess normative quartz was not detected, Group III_1 has the most tholeiitic character among the rocks of this district. Normative nepheline is found in Group II and Group III_2, attaining to more than 10 percent in the latter; normative olivine in these groups is about 24 percent, and deficiency of normative quartz is as much as 18 percent.

Thus, the magma of Group III_2 is an extremely undersaturated suite containing 41 percent SiO_2, and no rocks corresponding to such magma are found in the Kita-matsuura district. The least-differentiated member of Group III_2 is the alkali-rich trachybasalt as shown in Table 13. If we regard a magma near 40 of solidification index as corresponding to parental magma, then we must accept this strongly undersaturated suite (Table 14, column III_2) as the magma. A rock to be deduced from the chemical composition of this parental magma is limburgite, but it would be of the type somewhat abounding in Al_2O_3, poor in alkalis and rich in olivine, as indicated by III_2 in Table 14.

From the foregoing points it is concluded as follows: The rocks of these groups are fractionation products of such parental magmas as tholeiitic basalt for Group III_1, alkali olivine basalt for Group II, limburgite–alkali olivine basalt for Group III_2 and alkali olivine basalt for Group IV.

V. 2 Summary on the Kita-matsuura basalts

The erupted volume of the Kita-matsuura basalts reaches 49 km^3 which is the largest of all basalts erupted in West Japan including northwestern Kyushu.

The activities of these basalts began in the early period of Pliocene, along with the peneplanation which had been taking place since the end of Miocene. The peneplanation was succeeded by the orogenic folding accompanied by the faulting of NW–SE trend. The basalts were erupted through fissures along the fault lines; the presently observed monadnocks on the lava plateau tell the location of the centers of such fissure eruptions.

The Kita-matsuura basalts were divided volcano-stratigraphically into five large groups, on the basis of the correlation of lavas ascertained by the field works and the paleomagnetic method. The groups were denoted with volcanic ash, scoria and bombs. The kinds of the lavas are variable, ranging from picritic basalt to andesite, of which trachybasalt is the most dominant.

The sequence of the Kita-matsuura basalt activities can be ideally presented as follows:

V
IV
III_1, III_2
II
I

From geological and paleomagnetic evidence (Table 4, Fig. 7, etc.) it is known that there was a time interval between I and II, another between IV and V, and the longest interval between III and IV, but no conspicuous interval between II and III.

Comparison of the erupted volumes of the respective groups reveals that the major activities were accomplished by Groups II, III_2 and IV; activities of Groups I, III_1 and V are subordinate, even parasitic (Table 5). Lavas of Groups I and III_1 are the most tholeiitic ones of this district, and lavas of Group V are, for the most part, contamination products belonging to the calc-alkali rock series.

Almost all rocks of Groups II, III_2 and IV belong to the alkali rock series. However, examination in detail reveals that the members of III_2 are more alkalic, i.e. strongly undersaturated, than those of II. The members of IV are rich in olivine and pyroxene phenocrysts, and at the same time their alkali contents are the smallest of all rocks belonging to the alkali rock series. In other words, the rate of undersaturation rises in the order of IV $\rightarrow$II$\rightarrow$$III_2$. The volumes of erupted rocks are roughly equivalent in these three groups, as mentioned before.

Differences in petrographical and chemical properties of the groups are reflected also by the differences in their parental magmas including some extrapolated ones (Table 14). Such relations would become clear by comparing the value of normative quartz against SiO_2 (Fig. 25). As seen in the figure, the rate of undersaturation

Table 15 Dimension of the basaltic rocks of various districts, Southwest Japan.

Northwest Kyushu

Districts	(km^2)	Thickness max. (m)	(km^3)
Kita-matsuura	246.0	400	49.0
Iki islands	127.0	100	6.8
Higashi-matsuura	125.0	70	6.2
Kishima	25.0	200	2.5
Nishi-sonogi	72.0	250	9.0
Fukuoka	11.0	70	0.4
Total	606.0		73.9
Seira-san andesites	7.0	400	1.4
Arita rhyolites	19.0	500	5.0
Total	26.0		6.4

Kami-goto islands

Districts	(km^2)	Thickness max. (m)	(km^3)
Uku island	24.5	80	0.9
Ojika islands	12.5	50	0.6
Total	37.0		1.5

Fukué island, Goto islands

Districts	(km^2)	Thickness max. (m)	(km^3)
Fukué	45.2	70	0.9
Tomié	13.8	40	0.2
Miiraku	28.0	80	0.7
Kishuku	9.5	50	0.2
Southeast islands	3.5	50	0.1
Total	100.0		2.1

South Shimabara and Tara-dake districts

Districts	(km^2)	Thickness max. (m)	(km^3)
South Shimabara	8.0	100	0.3
East Tara-dake	19.0	150	1.5
West Tara-dake	54.0	200	2.7
Total	81.0		4.5

Western part of San-in region

Districts	(km^2)	Thickness max. (m)	(km^3)
Mi-shima	8.0	100	0.6
Otsu	20.0	100	1.0
Abu	49.0	150	3.7
Total	77.0		5.3

Tottori district of San-in region

District	(km^2)	Thickness max. (m)	(km^3)
Tottori Pref.	100.0	150	3.3
Total	100.0		3.3

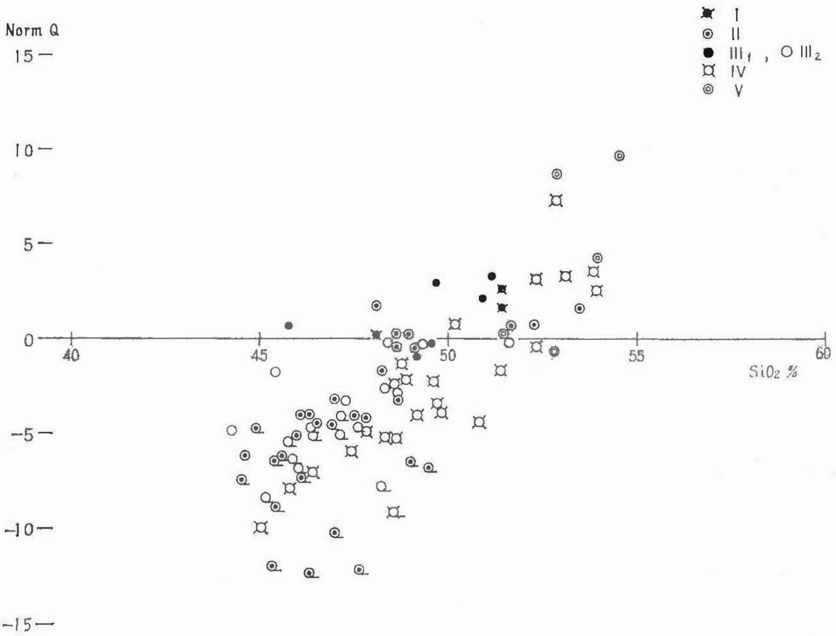


Fig. 24 The normative quartz plotted against SiO_2 for the Kita-matsuura basalts. The under-lined symbols represent the normative nepheline rocks.

lowers in the order of $III_2 \rightarrow II \rightarrow IV \rightarrow III_1$ (I). In particular, the parental magma of III_2 should have the composition of limburgite, as it shows strong undersaturation.

V. 3 Comparison between parental magmas of the Kita-matsuura basalts and magmas of other districts

For a comparison between the deduced parental magmas for the rocks of the Kita-matsuura district and other parental magmas of the adjacent areas and the well-known parental magmas, the present writer studied the relationship between normative quartz and SiO_2 (Fig. 25).

The parental magmas treated here were not compared under one and the same definition, since the parental magmas of the Kita-matsuura district were deduced from the lavas near 40 in the value of solidification index, and some were obtained by extrapolation. For the purpose of comparison, however, it will be all right to use parental magmas of somewhat different criterion.

In the figure are given the compositions of Hawaiian magmas, parental magmas of the western San-in region, those of Japan and surrounding areas (KUNO, 1954, 1960), parental magma of the Kami-goto rock series, and the earliest stage compositions of actually existent lavas in each group of the Kita-matsuura basalts.

Parental magma of Group I was not obtained due to lack of analytical data, as stated already, but its composition is probably near that of III_1.

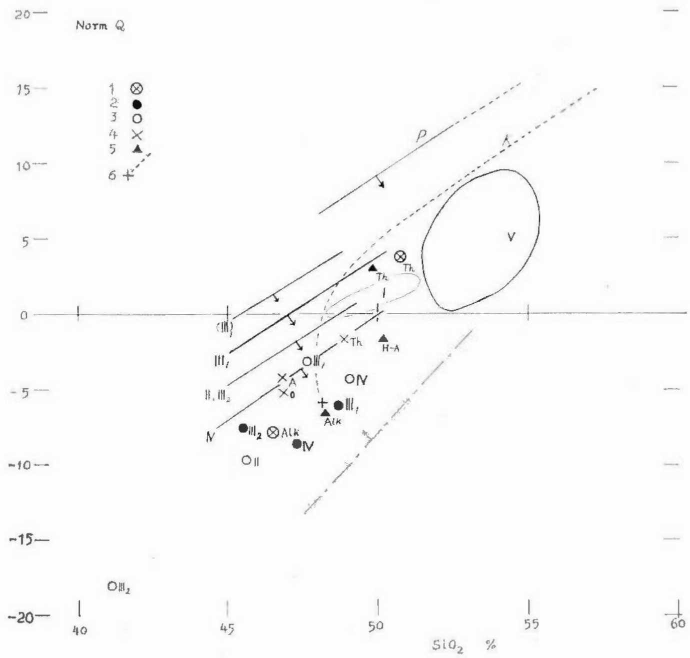
Parental magmas of the Kita-matsuura basalts were deduced for each group and it has been clarified that each group had an independent magma.

From Group I to Group III_2 SiO_2 and normative quartz show a positive correlation, and the composition changes gradually to that of a parental magma having less normative quartz. The magma of Group III_2, in particular, occupies the field of SiO_2 41.0 percent and normative quartz −18.10 percent, isolated from other groups, and indicates the state of strong undersaturation. Even when the magma of III_2 did not occupy this field, it might be ranked intermediate between Group III_2 and Group II.

In contrast with this trend of changes in composition from I to III_2, the magma of Group IV has a composition similar to that of III_1, showing a reverse direction to the above trend, that is, the magma of IV changes its nature toward the lower rate of undersaturation. Group V, characterized by rocks of intense contamination, generally occupies the field of oversaturation, and the constituent rocks are considered to have assimilated acidic material.

According to KUNO, in Japan and surrounding areas are found three types of parental magmas, tholeiite, high-alumina basalt and alkali olivine basalt. The tholeiite magma occupies the completely oversaturated field, and the high-alumina basalt magma is situated between the former and the alkali olivine basalt magma. The high-alumina basalt resembles the tholeiite basalt magma of the western part of San-in region.

In Hawaii, on the other hand, there are two types of magmas, one is similar

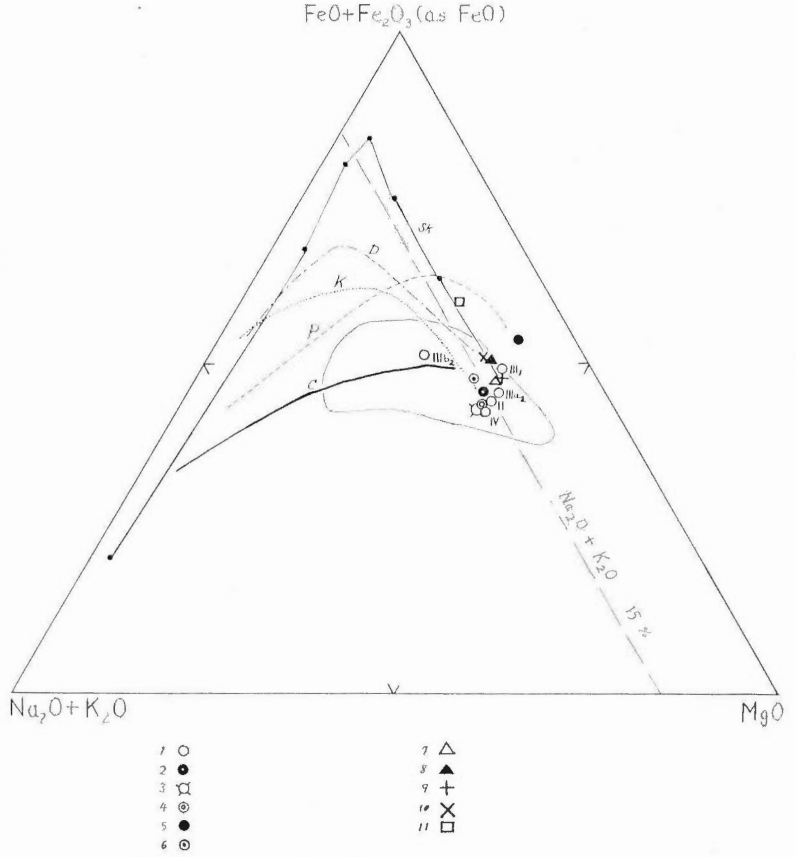


1. Hawaiian magmas 2. Composition of the eariest stage of the solidification index of the Kita-matsuura basalts 3. The extrapolated parental magmas of the classified groups 4. The parental magmas of the western part of San-in region (A: Abu district, O: Otsu district, Th: Tholeiitic basalt magma of the Otsu district) 5. The tholeiite, high-alumina basalt and alkali olivine basalt magmas proposed by KUNO (1954, 1960) 6. The curve for the Kami-goto rock series reported by KURASAWA (1961)

Fig. 25 Variation diagram for the comparison between the extrapolated parental magmas and various magmas. The symbols (I～V) represent the classified groups of the Kita-matsuura basalts.

to the above-mentioned tholeiite magma, and the other is a little more undersaturated than the alkali olivine basalt magmas of Japan.

The alkali olivine basalt magmas of western part of San-in region have a character similar to that of III_1 or to the intermediate character between IV and



1. The extrapolated parental magmas of the Kita-matsuura basalts 2. The parental magma of the Kami-goto rock series 3. The parental magma of the alkali rock series of the western part of San-in region, West Japan 4. The parental magma of the alkali rock series of Japan and the surrounding area proposed by YAGI (1959) 5. The parental magma of the pigeonitic rock series of Izu and Hakone districts proposed by KUNO (1954) 6. The parental magma of the high-alumina basalt proposed by KUNO (1960) 7. The parental magma of the alkali rock series of Hawaii (KUNO, 1957) 8. The tholeiite magma of Hawaii (KUNO, 1957) 9. The parental magma of the Skaergaard intrusion 10. The parental magma of the Dillsburg diabase-granophyre, Pennsylvania (HOTZ, 1953) 11. The composition of the Deccan basalt plateau.

Fig. 26 Variation diagram of the extrapolated parental magmas of the Kita-matsuura basalts and that for the comparison among the several rock series in the world.

II of the Kita-matsuura district, and do not show any stronger undersaturation than the parental magmas of northwestern Kyushu. The extrapolated parental magma of the Kami-goto rock series bears some resemblance to the alkali olivine basalt magmas of Japan (KURASAWA et al., 1961).

Referring to these facts, the following relation can be recognized among the parental magmas of the Kita-matsuura basalts, in view of the rate of undersaturation, i.e. the alkali degree.

Silica saturation←——————————→Undersaturation
Magmas: I——III_1———IV———II——————III_2

When the above relation is translated into the SiO_2/alkalis relation, the parental magmas of the Kita-matsuura basalts are plotted between the mean curve of the pigeonitic rock series of the Izu and Hakone districts and the mean curve of the Circum-Japan Sea alkali rock province, as shown in Fig. 27. The rate of undersaturation of the magmas, inclusive of those in the Kita–matsuura district, indicates a negative correlation in the figure.

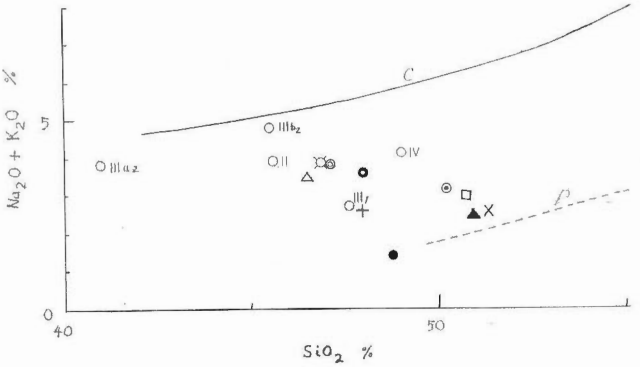


Fig. 27 Total alkalis for the comparison between the parental magma of the Kita-matsuura basalts and other magmas in the world as plotted against SiO_2. The symbols are the same as Fig. 26.

V. 4 Kita-matsuura magmas versus Hawaiian magmas

Most of the Kita-matsuura basalts belong to the alkali rock series, whereas tholeiitic basalts, represented by the members of Group I and Group III_1, are only several percents in volume.

The volcanic activities of the Kita-matsuura district present one cycle of magmatic evolution, beginning with the activity of tholeiitic basalts, succeeded by the activity of alkaline suite, and then grading into the alkali-poor activity again.

In the Hawaiian suite, on the other hand, a magmatic evolution from tholeiite to alkali olivine basalt, becoming more alkaline with the lapse of time, is observed. The majority of the Hawaiian suite belong to the tholeiitic rock series, and only several percents are attributed to the alkali rock series.

Thus, the observed sequences in the Kita-matsuura district and Hawaiian volcanoes are similar in the mode of evolution from one type to another type of magma.

However, in the former the alkali olivine basalt magma played a leading role, and the tholeiitic basalt magma took merely a subordinate part, while in the latter the tholeiitic basalt magma represents the major activity, with a subordinate activity of the alkali olivine basalt magma. In other words, the volcanic activities of the two areas are similar in the observed sequence, but are reverse in the relation of principal and subordinate activities.

This reverse relation may be ascribed to the difference of rock province. The Hawaiian Islands region belongs to the oceanic rock province, while the northern Kyushu region belongs to the continental rock province or is situated at its margin. It is possible, therefore, that the different sources of magmas in different rock provinces are reflected in the relationship between the sequence of the above-mentioned two magma types and the volume of erupted materials.

It goes without saying that the volume of products derived from the tholeiite magma of the oceanic region is much larger than that of the continental region products. In Japan and surrounding areas, too, a great quantity of tholeiite magma has been active on the Pacific Ocean side, whereas on the continental side the activity of a much smaller quantity of magma, i.e., alkali olivine basalt magma, is observed (SUGIMURA et al., 1963).

These facts tell that, for genetical elucidation of volcanic rocks, a full study of the relationship between the observed sequence and the erupted volume in one region is as important as correlation rock provinces.

V. 5 Problems on the origin of parental magma

Various hypotheses have hitherto been proposed on parental magma. In recent years, two magma types, tholeiitic basalt magma and alkali olivine basalt magma, have been most popular. In addition to these, KUNO (1960) has proposed another type which he named high-alumina basalt magma. In the content of alkalis and the rate of silica saturation, this magma is intermediate between the above two types but is rich in alumina. These three types of parental magmas are generally accepted by investigators except some.

However, as to the mechanism of generation of these parental magmas, views are diversified. Along with the progressing researches on the structure of the earth's crust and the increasing geophysical data concerning the upper mantle, study of the generation mechanism of parental magmas has become active lately. Besides, efforts are being made to clarify the reaction relation of silicates by means of high-temperature high-pressure experiments.

DALY (1933) considered a layer of liquid basalt as a depth about 60 km from the ground surface. This depth, however, is too shallow for the basalt to exist as a stationary liquid. In other words, the temperature at this depth cannot be the melting temperature of basalts. Also, the speed of seismic waves, Vp = 8.0—8.2 km/sec., which is the presently known value, cannot be satisfactorily explained by a basaltic magma at the depth of 60 km (18–20 kb). DALY, in an attempt to explain the extravagant volume of plateau basalts, may have presumed a stationarily melted magma. The present writer would like to point out here that the accumulation of plateau basalt lavas was not accomplished within a short period but is a result of repeated eruptions through long geologic times, that is, the volume of lavas produced by one eruption cannot be very large.

The Mohorovicic discontinuity representing the lower limit of the earth's crust lies at an average depth of 35 km from the ground surface in the continental region, 5–6 km from the sea bottom in the oceanic region. This discontinuity is considered to be a boundary of rocks strikingly differing in nature. The rocks constituting the earth's crust above the M-discontinuity are generally granitic rocks. Some investigators maintain that a substratum of gabbroic rocks exists at the base of the crust. The mantle beneath the M-discontinuity is composed undoubtedly of peridotitic rock, as was discussed by Ross (1954) and others. Possible existence of eclogite pockets scattered in this peridotite layer has also been discussed.

A view that a parental magma originates in partial melting of the mantle is now generally held. This idea was already discussed by BOWEN (1928). According to VERHOOGEN (1954), a basaltic magma is generated at a depth of 100–150 km.

As to the mechanism of generation of a parental magma due to partial melting within the mantle, there are the hypothesis of thermal convection in the mantle advocated by VERHOOGEN (1954) and the hypothesis of stress relief at a great depth proposed by UFFEN (1959). Either of these theories can explain the generation mechanism of magma. In the case of a basaltic magma, partial melting of 5 percent (or less) of peridotite would suffice for its generation (KUNO, 1957).

It is also reasonable to assume that a magma can be generated accompanying an outbreak of earthquakes or that earthquakes can be caused by the activity of a magma generated by thermal convection, as there is no doubt in the intimate relationship between the outbreak of earthquakes and the generation of magmas (KUNO, et al., KUNO, 1957, 1959b, 1960; SUGIMURA, 1960; and others).

Lately, KUNO (1957) has explained the generation of two types of Hawaiian magmas, tholeiite basalt and alkali olivine basalt, by the different depths in the mantle. He holds a view that different types of magmas are originated independently. POWERS (1955), in his study of the Mauna Loa and Kilauea Volcanoes of Hawaii, has set a depth of seismic foci at about 60 km. This also suggests that magmas are generated in the peridotite substratum.

From the fact that incongruent melting of enstatite in peridotite takes place under a pressure less than 10 kb, KUSHIRO (1960) considers that a tholeiite magma can be generated by partial melting of the peridotite substratum at a depth shallower than 35 km, or by bodily melting of a basaltic layer—or gabbroic layer—at the base of the earth's crust. He opines that tholeiite of TiO_2-poor plateau basalt was formed by bodily melting of the basaltic layer.

At great depths under the ground, forsterite and enstatite are in a cotectic relation which gives rise to generation of an undersaturated magma. Chromium diopside occurring in peridotite contains (Na, K) $AlSi_2O_6$, and melting of these alkalis is accelerated under a high pressure at depth so as to generate an alkaline magma (KUNO et al., 1957).

YORDER & TILLEY (1962), through their recent experiments under high temperature and high pressure, have explained the generation of two magma types as follows:

"From the study of the eclogites, eclogite melts in a 'eutectic-like' fashion, loosely speaking, suggesting that eclogite itself is the partial melting product of a more primitive rock (e.g. garnet peridotite). The distribution of normative components between the major mineral phases of a simple eclogite provides a mechanism for generating the tholeiitic and alkali basalt magma types from a single parent. The deduced phase relations at both high and low pressures in simple systems pertaining to basalt indicate that a single parent may evolve the two major basalt magma types depending on the pressure."

From the classification of magmas attempted by many investigators and from various researches on the origin of magmas, we find that two views are now prevailing; one maintains that parental magmas of different nature, such as tholeiitic basalt magma and alkaline basalt magma, were derived from a single magma by undergoing some processes, while the other view is that each magma was generated independently under the control of temperature and pressure.

As mentioned above, KUNO established the high-alumina basalt magma in addition to the hitherto-known two magmas, and connected the geographical distribution of these magmas with the petrographical classification of volcanic rocks and the generation of earthquakes (KUNO, 1959b, 1960). He related the seismic foci in the oceanic front of the volcanic zones of the Japanese Islands and surrounding areas with those in the continental region, the former lying at a depth about 50 km under the ground and the latter at about 500 km.

By relating the depth of seismic foci with the generation of parental magmas, KUNO inferred the depths where the above three types of parental magmas are generated. Pertaining to the magma-generating depth, SUGIMURA (1960) reached a conclusion similar to KUNO's.

V. 6 Origin of the Kita-matsuura basalts

The activities of the Kita-matsuura basalts extended from Early Pliocene to Pleistocene, so that at least one half of the Pliocene's 10 million years must have been involved. During this period there were five stages of volcanic activities, intervened by two conglomerates. In this paper the five stages were classified as five groups of rocks.

The time intervals among the five groups have been mentioned in the preceding section; the interval between Group III and Group IV is great, but between II and III no conspicuous interval is recognized.

Volumes of erupted rocks of the respective groups, as listed in Table 5, indicate that Groups II, III_2 and IV, belonging to the alkali rock series, constitute the major part of the Kita-matsuura basalts. Group I and Group III_1 which were erupted in the early stage, are of parasitic activities and have characteristics closer to tholeiite basalt. Group V of the last stage activity is characterized by the rocks produced by contamination with the crustal materials, and is also of a parasitic activity.

As has been mentioned many times, Group III_2 consists of the rocks having the strongest rate of undersaturation in this district. The volume of these rocks is 12.5 km^3, showing similar abundance ratios to Group II of the preceding activity and Group IV of the later activity. That is to say, the rocks of Group III_2 have more abundant alkalis than those of other groups. This fact cannot be explained by enrichment of volatile matter containing alkalis, as maintained by BARTH (1952), because the volume is too large.

The characteristics of the rocks of the five groups, defined from their time relations, volumes, lithology, changes in rock series and from the paleomagnetic features, tell that the Kita-matsuura basalts were not derived from a definite single parental magma.

The parental magmas of the respective groups are given in Table 14. To know differences among these magmas, comparison of their values of normative quartz would be the most important factor.

The SiO_2/normative quartz diagram (Fig. 25) clearly shows the differences of the parental magmas. This relation agrees well with the distribution of intermediate to deep-seated seismic foci in the Japanese Islands (WADATI, 1935). In recent years the relationship between seismic focus and source of parental magma has become the subject of discussion by many investigators (KUNO 1952b, 1960, SUGIMURA 1960, etc.).

KUNO thinks that 200 km is the boundary between the depth of source of alkali olivine basalt magma and that of tholeiite magma. Also, he sets the boundary between the depth of source of tholeiite magma and that of high-alumina basalt magma at 175 km.

According to WADATI (1935), the depth of intermediate to deep-seated seismic foci in West Japan is 85 km along the cast margin of Kyushu and 200–300 km along the west margin; in East Japan, it is 85 km along the east margin and 300–400 km in the western central Honshu. A view that East Japan and West Japan have different geologic structures has become prevalent lately. Recent occurrences of shallow and intermediate earthquakes are concentrated at shallow depths in West Japan and at considerable depth in East Japan. In other words, shallow and intermediate earthquakes in West Japan occur mainly at the depth of 40–50 km and those in East Japan at deeper places. This may be ascribed to the relationally differing geologic structure, such as West Japan being situated in a region of block structure and East Japan in arc structure. Consequently, it is not advisable to make a hasty correlation of the nature of volcanic rocks between East Japan and West Japan.

The nature of the rocks constituting the Kita-matsuura basalts is controlled essentially by the difference in depth of the source of the parental magma in each stage of the volcanic activities. It is recognized that with the progress of the volcanic activities the depth of the source of parental magmas become gradually deeper, and in the latter half of the period the depth become shallower again. In other words, the source of magma originated first at relatively shallow depths.

Petrographically speaking, the sequence of the volcanic activities is as follows: In the former half of the period, the rocks derived from a tholeiitic basalt magma were erupted first, then the activity graded into that of an alkaline basalt magma, i.e., the rocks derived from a strongly undersaturated magma; in the latter half, the rocks derived from an alkaline basalt magma of a low rate of undersaturation were erupted, succeeded by the last stage activity of the rocks belonging to the calc-alkali rock series produced by contamination with the crust-constituting materials.

Such cycle of volcanic activities as above was recognized within one district (rock province), namely Kita-matsuura district. This cycle is considered to present a fundamental type of a certain volcanic activity (igneous activity).

In the alkali rock series of the Kita-matsuura basalts are found two series, Groups II·IV and Group III_2, i.e., the trachybasalt→trachyandesite series which is a differentiation product of a normal alkali olivine basalt magma and the limburgitê→trachybasalt→mugearite→ trachyandesite series showing a strong rate of undersaturation.

Normative nepheline is detected in alkaline basalts and trachyandesites, but nepheline does not occur as a rock-forming mineral. This may be explained as that nepheline molecule in undersaturated magmas enters into albite molecule, as was indicated by BARTH (1936)'s equation,

$$\underset{\text{En}}{4\,MgSiO_3} + \underset{\text{Ne}}{NaAlSiO_4} \rightleftarrows \underset{\text{Fo}}{2\,Mg_2SiO_4} + \underset{\text{Ab}}{NaAlSi_3O_8}$$

but, it is also possible that Na atom enters into the pyroxene lattice, thus unabling nepheline to crystallize out.

V. 7 Relationship between the volcanic activities of the Kita-matsuura basalts and those of the adjacent areas

As mentioned in the foregoing sections, a cycle of magmatic evolution is recognized in the Kita-matsuura basalts. Volcanic activities bearing some resemblance to this magmatic evolution are observed in the areas adjacent to the Kita-matsuura district.

In the western part of San-in region, for example, the first activity is represented by a very small amount of tholeiitic basalt, which was followed by the activity of the older stage alkali rock series as observed in the Otsu district, and by that of the younger stage alkali rock series in the Abu district, the former being more alkaline than the latter. After these activities, the rocks of the calc-alkali rock series produced by marked contamination were erupted (KURASAWA et al., 1960).

Rocks of the alkali rock series are found also in Fuké-jima of the Goto Islands, and are divided into two members, older stage and younger stage. The older stage rocks are more alkaline. At the end of the period of these activities, influence of remarkable contamination makes its appearance.

Besides these areas, similar types of volcanic activities are observed in various parts of West Japan. However, the type is not always so simple. Where the type of volcanic activity is complex, the tectonic movement of the area is also intricate.

The depth of source of the parental magmas in the Kita-matsuura district was deduced from the basis that a magma ranked near 40 of solidification index is the parental magma. Therefore, if we failed to obtain the composition of the magma even by means of extrapolation, we should not attempt a hasty correlation.

From the above viewpoints, it is concluded that the chronological changes in the Circum-Japan Sea alkaline suite which was active in West Japan is controlled fundamentally by the changes in the composition of the parental magmas of the erupted materials, as typically manifested by the rocks of the Kita-matsuura district. And, the changes in the composition of magma are attributed to the difference in the depth of the magma's source. In this respect, the present writer agrees with KUNO (1957).

Appendix A

I. Basalts in the Adjacent Areas

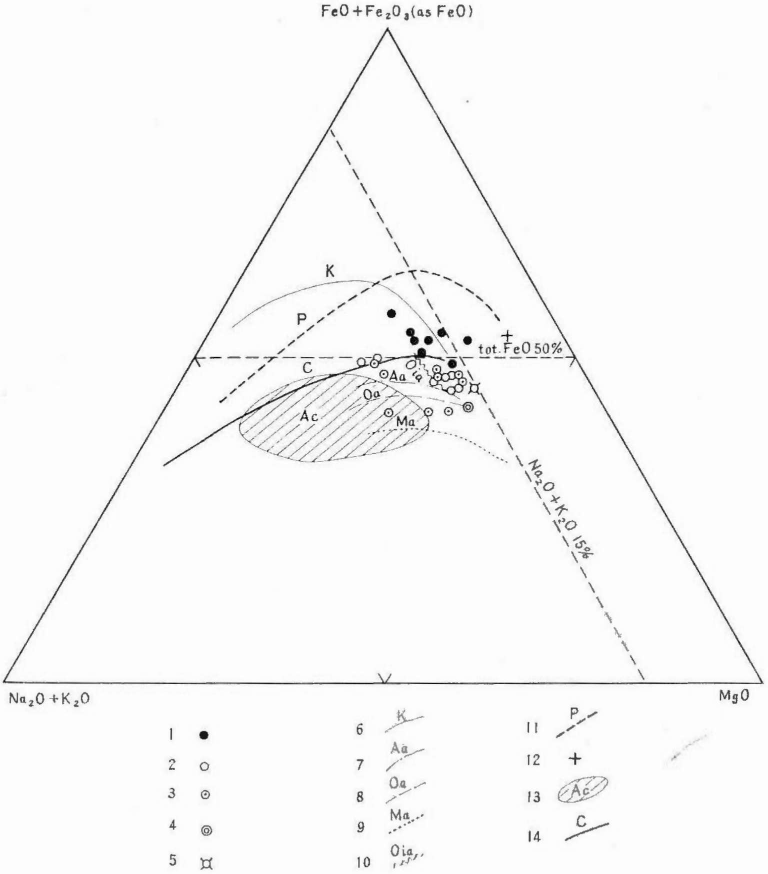
Basalts which lie sporadically in Southwest Japan, forming a part of the Circum-Japan Sea alkali rock province, i.e., the volcanic rocks related to alkali olivine basalt magma are erupted extending over a vast area through the San-in district and northern Kyushu. The volcanic activities in each area are described in the following (Table 15).

1. Northwestern provinces in Kyushu

1. 1 Tara-dake area (TAKAHASHI and KURASAWA, 1960)

In the base of the Tara-dake volcano of the Quaternary system overing Nagasaki and Saga prefectures in the western central Kyushu, there are erupted basalts covering the volcanic body. Such a distribution of basalts divides the area into the eastern and western parts, which form the lava plateau accompanied with volcanic clastics.

In the eastern area, there are distributed basalts overing the area of 19 km^2 and of a thickness of 150 m in maximum. In the lower part, there is a activity of tholeiitic basalts intercalating trachybasalt lava. This tholeiitic basalt lava is not



1. Tholeiitic rock series (c and b→c type)
2. Alkali rock series (b type)
3. Calc-alkali rock series (d and a→d type)
4. The parental magma of the alkali rock series of the western part of San-in region
5. The parental magma of the Kami-goto rock series
6. The Kami-goto rock series
7. Alkali rock series of the Abu district of the western part of San-in region
8. Alkali rock series of the Otsu district of the western part of San-in region
9. Alkali rock series of the Mi-shima district of the western part of San-in region
10. High-iron alkali rock series of the Otsu district of the western part of San-in region
11. Pigeonitic rock series in Izu and Hakone districts
12. The parental magma of the pigeonitic rock series in Izu and Hakone districts
13. The calc-alkali rock series of the Abu district of the western part of San-in region
14. The Circum-Japan Sea alkali rock province

Fig. 28 Variation diagram of the rocks of the Tara-dake and South Shimabara districts of the northwest Kyushu as plotted in the ternary diagram $MgO-FeO+Fe_2O_3-Na_2O+K_2O$.

typical and except for slightly over-saturation of SiO_2, it has no remarkable characteristics. After these activities, there is erupted basaltic andesite lava of calc-alkali rock series.

In the western area, there is formed the lava plateau composed of basalts having a thickness of 200 m in maximum and a area of about 54 km^2. In this area there is recognized younger volcanic activity than that of the Tara-dake volcano. In the area there are distributed alkali olivine basalt-type lava as observed in the eastern area and so-called quartz basalts of calc-alkali rock series covering the Tara-dake volcano in part, but tholeiitic lava is not recognized.

In this area, there is a mixed activity of tholeiitic basalt and trachybasalts, and are erupted basalts of calc-alkali rock series at time intervals. These volcanic activities are during Pliocene, the end of Tertiary to Quaternary in age.

1. 2 South Shimabara area (Kurasawa et al., 1965)

The Unzen volcano is situated in the south of the Tara-dake mentioned above,

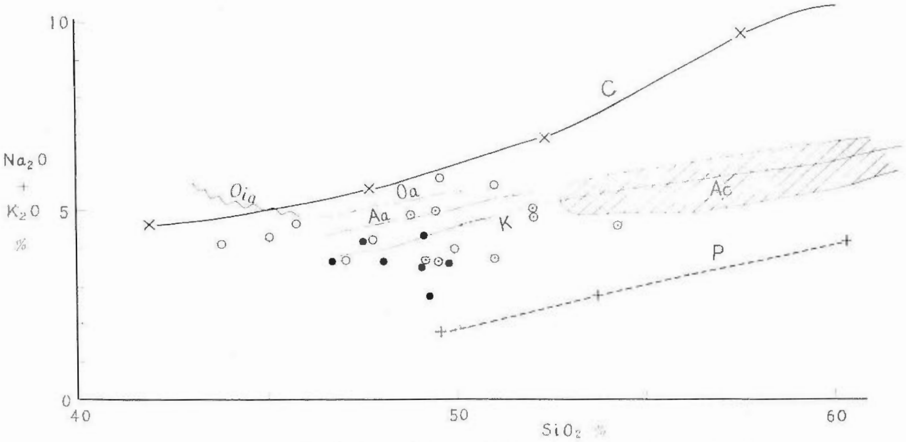


Fig. 29 Total alkalis of the Tara-dake and South Shimabara districts of the northwest Kyushu as plotted against SiO_2. Symbols are the same as Fig. 28.

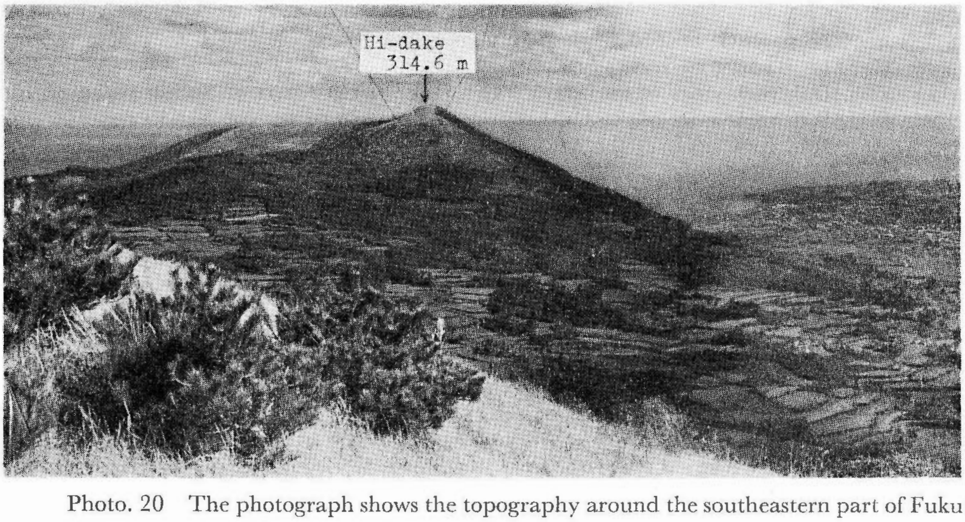


Photo. 20 The photograph shows the topography around the southeastern part of Fukué-

and in the formation of sedimentary rocks of Neogene $I_1 \sim I_2$, there are intercalated basalts. Among them the lower is alkali olivine basalt lavas in mostly unsaturation of SiO_2 intercalating trachybasalt. In the uppermost part of the lower group, there is recognized a lava which may be considered tholeiitic basalt being scanty in alkalis, and in the upper part, basalt of calc-alkali rock series is in active.

And after these activities during Pliocene ~ Pleistocene, there is a activity of andesite lava of calc-alkali rock series forming a dipping tableland. The activity of Unzen volcano in Quaternary starts in succession to those activities.

In this area, there are activities in order of alkali olivine basalt, tholeiitic basalt and basalt of calc-alkali rock series, and this is transitive to the Quaternary volcanism (Figs. 28, 29). The thickness of basalts is 100 m in maximum, but is thin, in general, about 20 m and they are distributed in the area of 8 km^2.

1. 3 Kumamoto-Kimpo-san area (KURASAWA et al., 1963)

Basalt lava crops out partially forming a base of volcano on the southwestern foot of Kimpo volcano in the central Kyushu. It is placed under a category of the high-alumina basalt. Judging from the ferromagnesian silicate mineral assemblage, it is basalt of calc-alkali rock series.

1. 4 Fukué-jima in Goto islands (KURASAWA et al., 1962a, 1964)

In four areas, Fukué (the east part of the isle), Tomié (south part), Miiraku (northwest part) and Kishuku (north part) of the Fukué-jima situated at the southern end of Goto islands ranging northeast and southwest in the west of Kyushu and islets being dotted on the southeastern sea, there are distributed basalts.

In the Fukué isle, there is an activity of basalts belonging to older and younger alkali rock series, and tholeiitic rock series classified petrologically.

In the Fukué area, there are trachybasalts of the younger alkali rock series which are somewhat differentiated in advance, and gigantic cinder cones are formed, too. In these lavas there are remarkably composed quartz of xenocryst and plagioclase.

In the Tomié area, there is formed a flat topography by one or two eruptions of tholeiitic basalt lava. And there are recognized outcrops of older basalts in part.

In the Miiraku area, there is formed a gently dipped lava plateau of younger alkali rock series, intercalating tholeiitic basalt in part. In scoria from the northern

jima, Nagasaki Prefecture, Southwest Japan. The cinder cones as seen from On-dake.

part of Sagano-shima located 5 km in the west, there yield crystals of hematite.

In the Kishuku area, there is a activity of trachybasalts of older alkali rock series.

In the isles dotted in the southeast of Fukué-jima, there are distributed undifferentiated basalts of younger alkali rock series. These basalts have a characteristics being poor in alkalis than those of younger alkali rock series in other areas.

These volcanic activities mentioned above can be interpreted as follows: there is

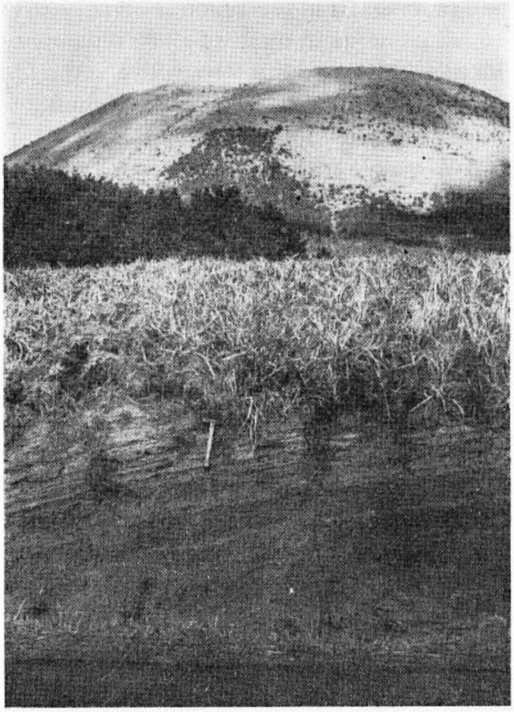


Photo. 21 Showing the cinder cone and scoria bed of On-dake volcano in Fukué-jima, Goto Islands of Nagasaki Prefecture.

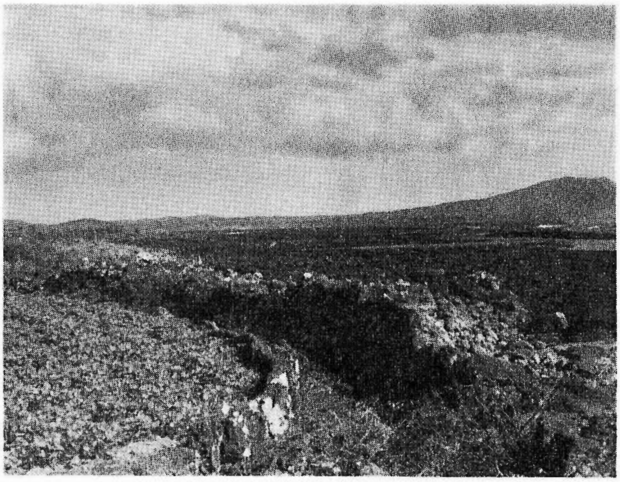


Photo. 22 On-dake and Hi-dake tower in the center with a bulge at the northern flank

the first activity of trachybasalts being rich in alkalis of older alkali rock series. This activity is considered to be Pliocene at the end of Tertiary in age. And there is the second activity of trachybasalts of younger alkali rock series and of basalts of type being poor in alkalis, intercalating tholeiitic basalt in part. Lastly, there are erupted tholeiitic basalts. In a part of younger alkali rock series, there is recognized xenocryst, but not strong contamination.

Judging from the facts mentioned above, it may be deduced that in this area there is a tendency of decrease in alkalis in the volcanic activities, from the magma having an important factor of alkali rock series, through continuous series, to tholeiitic basalt magma being scanty in alkalis (Figs. 30, 31).

Trachybasalts of older alkali rock series have a thickness of 50 m in maximum and are distributed in the area of 9.5 km^2. Trachybasalts and basalts of younger alkali rock series have a thickness of 80 m in maximum and are distributed in the area of 15 km^2. On the contrary, tholeiitic basalts have a thickness of 40 m in maximum and are distributed in the area of 14 km^2. Judging from the fact, it is evident that this area is mainly formed by the volcanic activity having an important factor of alkali rock series.

1.5 Kami-goto area (KURASAWA et al., 1961b)

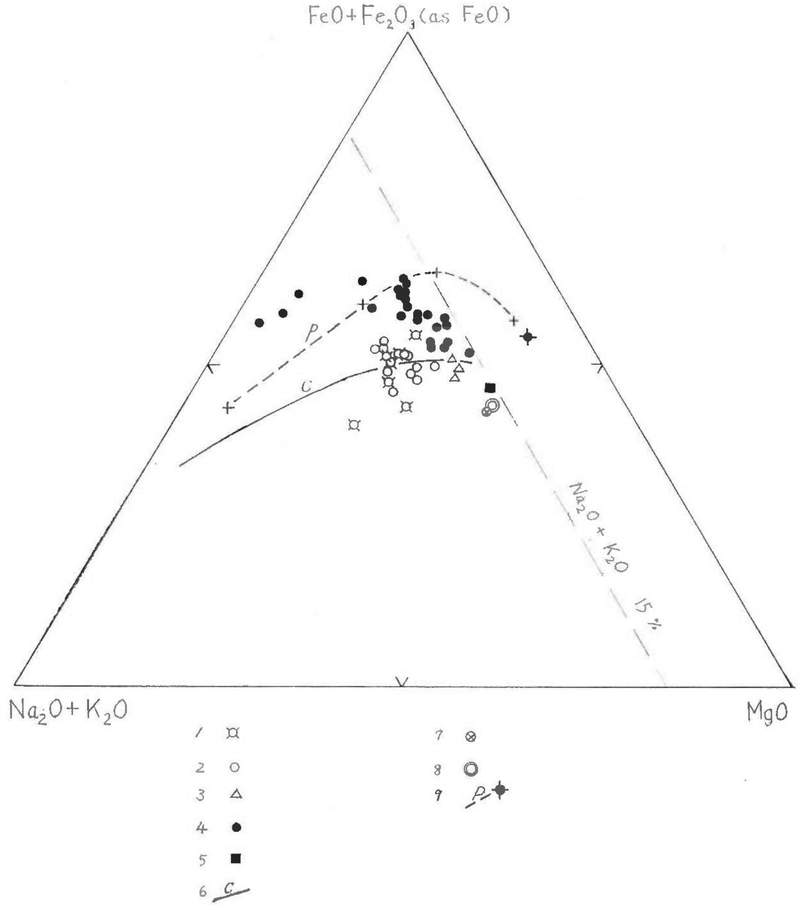
The Kami-goto area described in this paper includes the Uku-shima, Ojika-jima and the isles dotted in the adjacent seas, belonging to Kita-matsuura-gun, Nagasaki Prefecture. These isles are situated about 60 km in the west of Sasebo City at the northern end of Goto islands.

The volcanic rocks in this area have various characteristics, such as basalts ~ andesite (dacitic in part) differentiated in advance. These rocks are generally distributed in two areas, Uku and Ojika; andesitic rocks in the Uku area are formed by the first volcanic activity, and basalts in the Ojika area successively. Especially, the latter is accompanied with over 20 cinder cones, and its activity continues to recent times.

These lavas have a thickness of 80 m in maximum in the Uku area and are distributed in the area of 24.5 km^2, and in the Ojika area, a thickness of 50 m in maximum and in the area of 13 km^2. Estimated by the solidification index (KUNO,

(left). Another cinder cone, Usu-dake is nearly on the southern foot (extreme right).

1954), basaltic rocks, more undifferentiated (characteristically distributed in the Ojika area), occupy about 40～50 percents of andesitic rocks differentiated in advance (distributed in the Uku area) in the middle age of magmatic differentiation. However, considering that the islets on the sea are mainly formed by basaltic



1. Older stage alkali rock series of the Fukué–jima, Goto islands, Northwest Kyushu
2. Younger stage alkali rock series of the Fukué-jima
3. Tholeiitic rock series of the Fukué-jima 4. The Kami-goto rock series
5. Parental magma of the Kami-goto rock series
6. Circum-Japan Sea alkali rock province
7. The parental magma of the western part of San-in region
8. The parental magma of the alkali rock series of Japan and the surrounding area 9. The parental magma of the pigeonitic rock series of Izu and Hakone districts and their fractional trend

Fig. 30 Variation diagram of the rocks of the Goto islands district in the northwest Kyushu as plotted in the ternary diagram $MgO-FeO+Fe_2O_3-Na_2O+K_2O$.

rocks and there are many parts eroded and lacked, it is deduced that the above-mentioned both rocks may be at the rate of 1 : 1. A considerable parental magma is not formed yet, but materials obtained by extrapolation resemble the source of magma of alkali rock series in the Pacific region, especially Hawaii, except being rich in SiO_2 and Al_2O_3. In other words, it is subalkaline.

These volcanic rocks are considered to be the products formed by a successive magmatic differentiation. In the middle age of this differentiation, there is recognized a remarkable enrichment of iron. And there is crystallized a large quantity of ore minerals in groundmass under the microscope. In the chemical composition, there is observed ferric content, characteristically. Judging from the occurrence of this ore mineral, it is presented that the magma has a characteristics of subalkali as stated above and is differentiated into ore form with the increase of

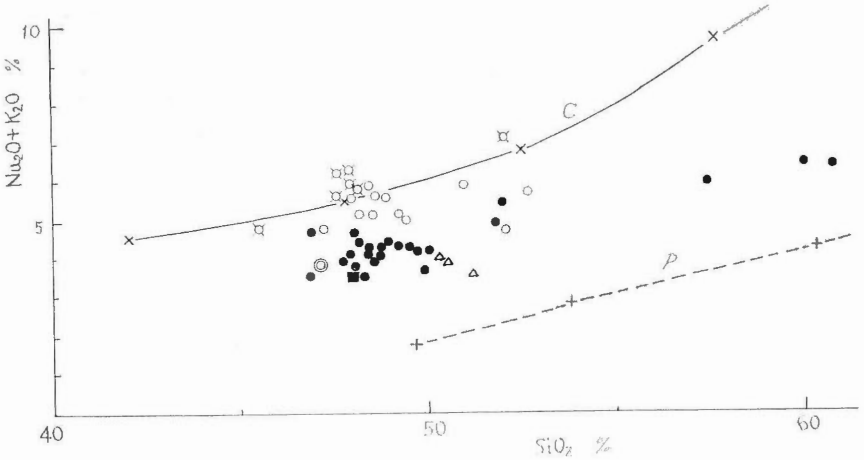


Fig. 31 Total alkalis of the rocks of the Goto islands district as plotted against SiO_2. The symbols are the same as Fig. 30.

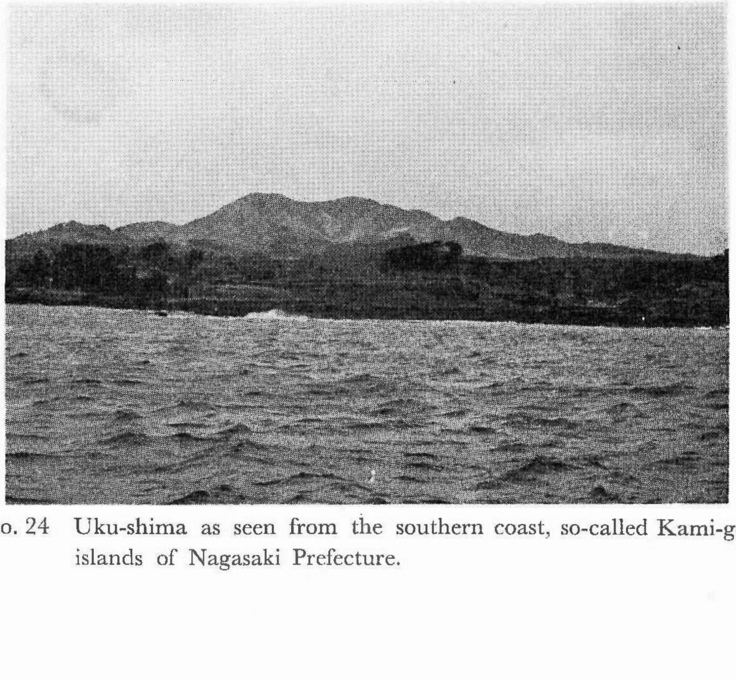


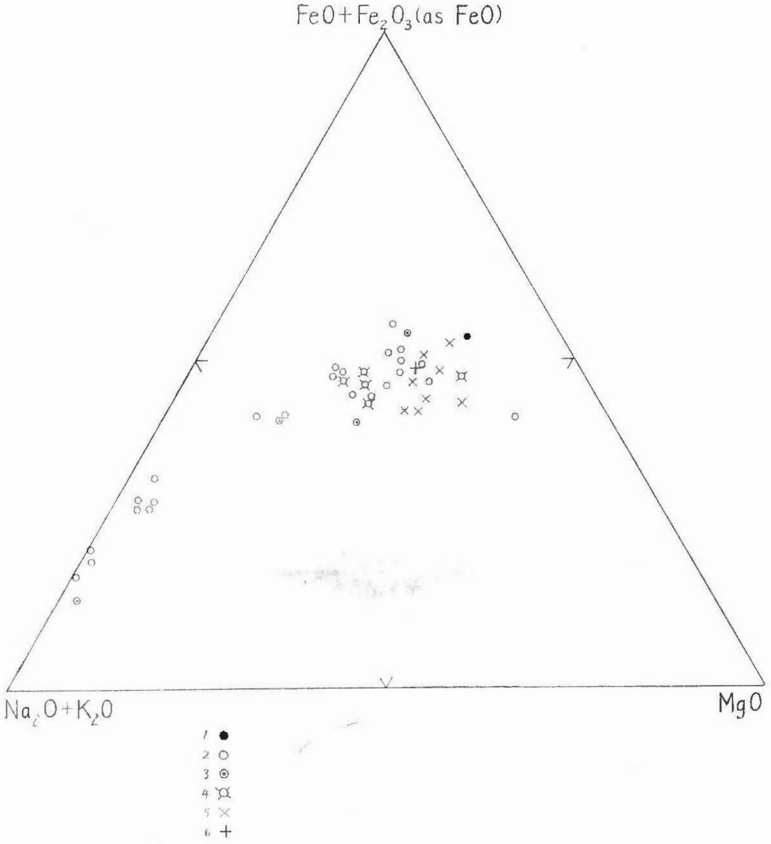
Photo. 24 Uku-shima as seen from the southern coast, so-called Kami-goto islands of Nagasaki Prefecture.

oxygen pressure without taking the formation of Fe-silicate for so-called silica-under-saturated magma. And in lavas, there is contained quartz xenocryst, and this exotic material may be possible to relate to oxygen pressure in the occurrence of the ore mentioned above.

Judging from a remarkable characteristics of differentiation which is different from the differentiation trend of volcanic rocks in the western Japan, these volcanic rocks are called "Kami–goto rock series" (KURASAWA et al., 1961) (Figs. 30, 31).

1. 6 Iki islands and Higashi-matsuura district (AOKI, 1959; MATSUI, 1958)

In this area, there are distributed various volcanic rocks which are active during Pliocene ~ Pleistocene.



1. Tholeiitic rock series 2. Alkali rock series
3. Calc-alkali rock series derived from the tholeiitic basalt magma
4. Calc-alkali rock series derived from the alkali olivine basalt magma
5. The Kita-matsuura basalts (Analyst: K. TAKAHASHI) (I. IMAI, K. SAWAMURA and T. YOSHIDA, 1958)
6. Trachybasalt of Nanatsu-gama in Karatsu City (N. AOYAMA, 1952)

Fig. 32 Variation diagram of the rocks of the Iki islands and Higashi-matsuura district of the northwest Kyushu as plotted in the ternary diagram $MgO-FeO+Fe_2O_3-Na_2O+K_2O$.

Among the volcanic rocks in Pliocene, there are basic~acidic volcanic rocks of tholeiitic rock series and calc-alkali rock series. In Pleistocene of the Quaternary period, trachybasalts in the first stage is formed covering most of the whole area and secondly in the area there are erupted trachy-andesites. In Iki islands, there is partially formed hornblende andesite of calc-alkali rock series after the above-stated volcanic rocks, and there are distributed pyroxene andesites covering these rocks in the northern part.

In the southern half of Iki islands, there are formed trachybasalts in the second stage, and are erupted trachy-andesites in the second stage, successively. In the area of the Higashi-matsuura peninsula, there are observed trachybasalts, and the present topography of the area is nearly perfected by the eruption of these rocks.

The volcanic activity ends after the last activities of trachybasalts and trachy-andesites in the third~fourth stages on a small scale in the Iki islands.

Judging from the times of volcanic activities stated above, it is considered that basalts in these area are rich in alkali contents, in ascending order, in general, successively poor in alkali contents. And it seems that the basalts are affected by contamination stronger and in ascending order.

It is found that parental magma, i.e., two kinds of tholeiitic magma and alkali olivine basalt magma are composed in the volcanic rocks of calc-alkali rock series in this area.

The activities of volcanic rocks in Iki islands and Higashi-matsuura district are large activities on a scale. The former has a thickness of 100 m in maximum and has the area of 127 km^2; the latter a thickness of 70 m in maximum and the area of about 125 km^2. Both are nearly equal and amount to 250 km^2 in total.

The variation diagram of chemical compositions of the rocks in this area is given in the following.

From MgO–FeOtot.–Na_2O+K_2O diagram (Fig. 32), it is considered that the products of alkali rock series in succession show nearly a consistent stage of differentiation. Especially, rocks show the locality resembled that of the Kita-matsuura basalts. And tholeiitic basalt is plotted at the locality being poor in alkalis.

According to the relation diagram of SiO_2 to Na_2O+K_2O, the rocks of alkali rock series show the trend near the Circum-Japan Sea alkali rock province (Fig.

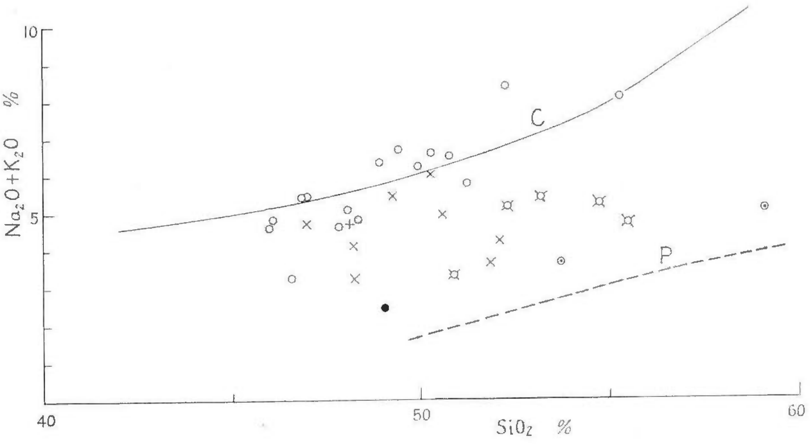


Fig. 33 Total alkalis of the rocks of the Iki islands and Higashi-matsuura district as plotted against SiO_2. Symbols are the same as Fig. 32.

33). Especially, the rocks being scanty in SiO_2 are liable to variation in alkalis, and are within the limits of compositions, 3∼6 percents.

In the rocks of calc-alkali rock series, there are two kinds of rocks derived from tholeiitic magma and alkali olivine basalt magma, and the latter is rich in alkalis than the former, in general.

1. 7 Fukuoka area in the northern Kyushu (Oji, 1956, 1957, 1962)

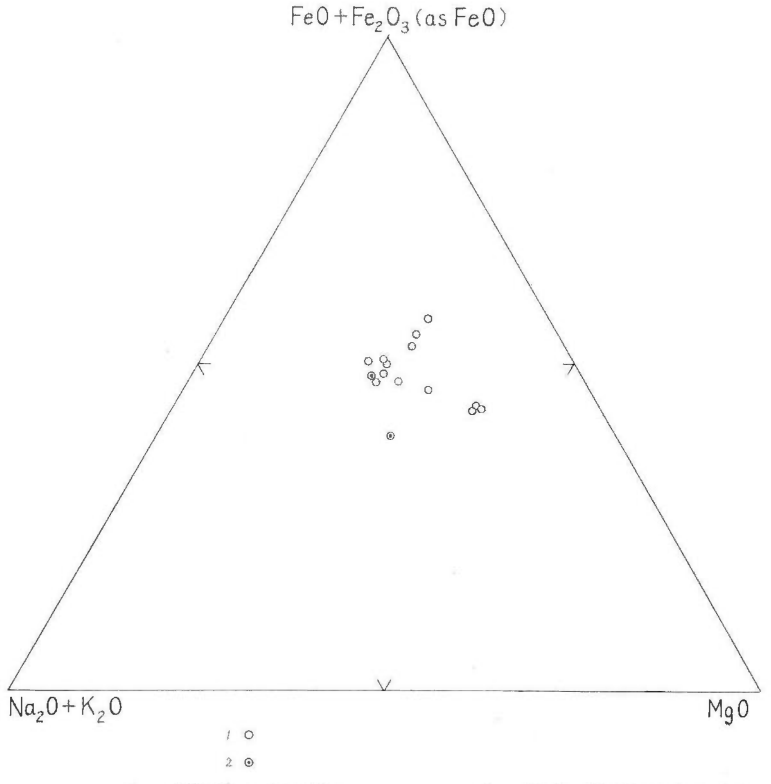
This area is situated at the northern end of Kyushu. Basalts are distributed sporadically, in the direction of NE–SW, in the coast area and isles on adjacent seas, and, in the trend of S–N, in the inland of about 20 km, on a small scale.

A part of those basalts is active at the end of Tertiary and most in the Quaternary period.

This activity is mainly caused by trachybasalts and trachyandesites of alkali rock series, and basalt and andesite of calc-alkali rock series are active accompanying with them. In this calc-alkali rock series, there are two kinds originated from tholeiitic basalt magma and alkali olivine basalt magma.

In trachybasalts there are composed those being rich in ore minerals. Volcanic rocks in this area have a thickness of 70 m in maximum and are distributed in the area of about 11 km².

Based on the chemical compositions of volcanic rocks in this area, Figs. 34 and



1. Alkali rock series 2. Calc-alkali rock series

Fig. 34 Variation diagram of the rocks of the Fukuoka and adjacent area of the northern Kyushu as plotted in the ternary diagram $MgO-FeO+Fe_2O_3-Na_2O+K_2O$.

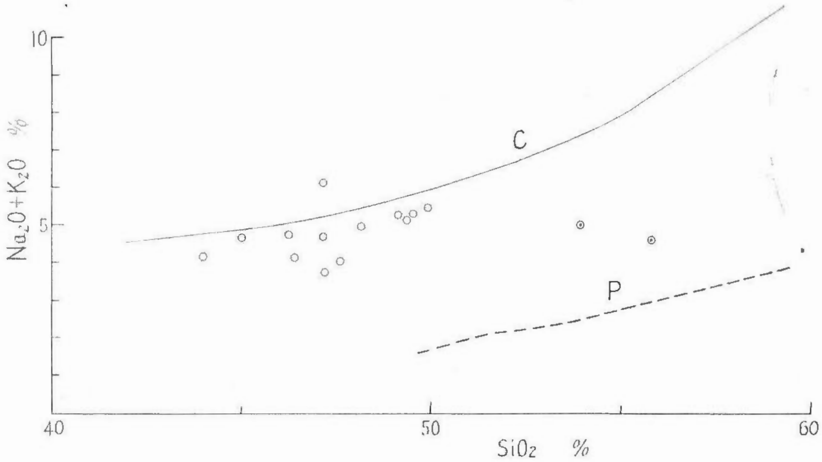


Fig. 35 Total alkalis of the rocks of the Fukuoka and adjacent area of the northern Kyushu as plotted against SiO_2. Symbols are the same as Fig. 34.

35 are drawn up. According to the figures, among the basalts widely distributed in the northern Kyushu there exist the series in high grade of iron comparable with the basalts of the Kami-goto rock series from Kami-goto islands. In general, the rocks of alkali rock series contain SiO_2 less than 50 percent and Na_2O+K_2O of 3.5 ~ 5.5 percents in common, and they resemble those of the Circum-Japan Sea alkali rock province. The rocks of calc-alkali rock series are contamination products derived from alkali olivine basalt magma.

1. 8 Kishima area in Saga Prefecture (Y. MATSUMOTO, 1960, 1961a, b, c, 1963, 1964)

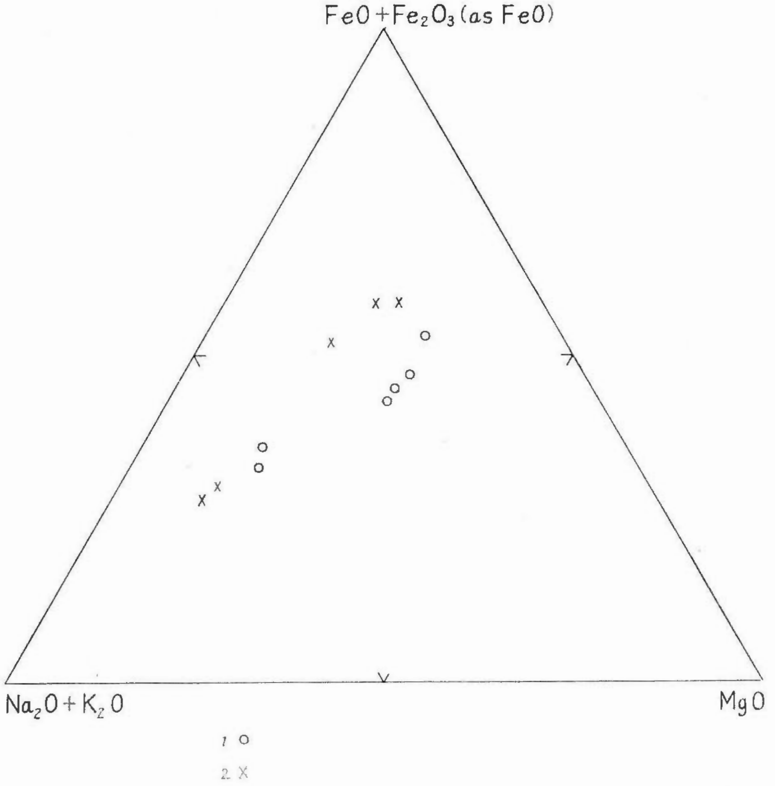
Basalts of this area are distributed in the area of about 15 km in width of E–W, extending 15 ~ 30 km in the east of the Kita-matsuura district in which basalts are distributed, forming the mesa topography with scattered small tablelands.

The detailed researches on basalts in this area were already done (MATSUMOTO, 1960 ~ 64), and basalts in the area are divided into B_0, $B_1 \sim B_6$ roughly. B_0 is called "older basalts," and is in close relation to Hizen dolerite and Sanukite of late Miocene in age. And $B_1 \sim B_4$ are called Matsura basalts, which are divided into B_1, B_2 and B_3, B_4. In the B_2 there is included trachybasalts. Basalts, B_5 upper than B_2, are called "Futago-yama volcanic rocks," which are accompanied with andesite and rhyolite. These $B_1 \sim B_5$ are formed by the activity in Pliocene, late Tertiary.

Secondly, basalts B_6 are active in the Diluvium of Quaternary. These volcanic activities are very complicated, and that the basalts are rich in alkalis, generally, in ascending order, and have constituents of alkali rock series. But in the last stage of the activity there are erupted basalts of series being scanty in alkalis.

The volcanic rocks in this area have a thickness of 200 m in maximum and a half of them intercalates clastics and acidic tuff. They are distributed in the area of about 25 km². Older basalts and sanukitic rocks are considered to be of Miocene in age. And they are shown in the figures 36 and 37.

It is presumed that these rocks belong to the calc-alkali rock series derived from alkali olivine basalt magma. In the Fig. 36, there is shown that the rocks are in the



1. Older basalts and sanukitic rocks
2. Futago-yama volcanic rocks

Fig. 36 Variation diagram of the rocks of the older basalts and Futago-yama of the Kishima district of the northwest Kyushu as plotted in the ternary diagram.

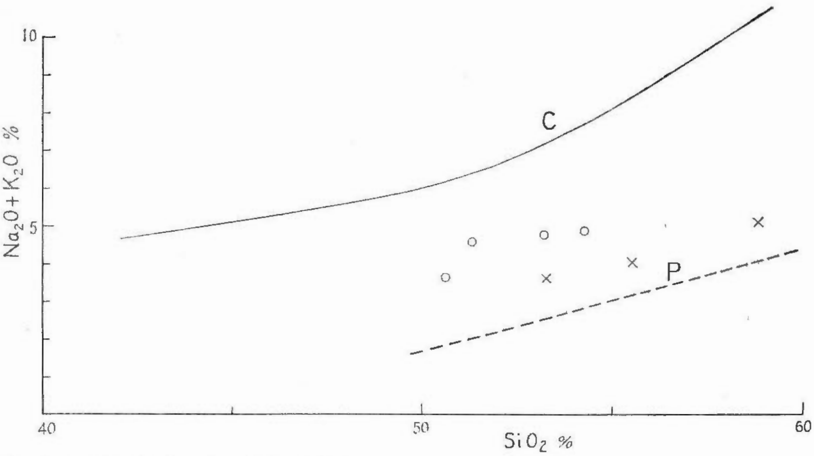
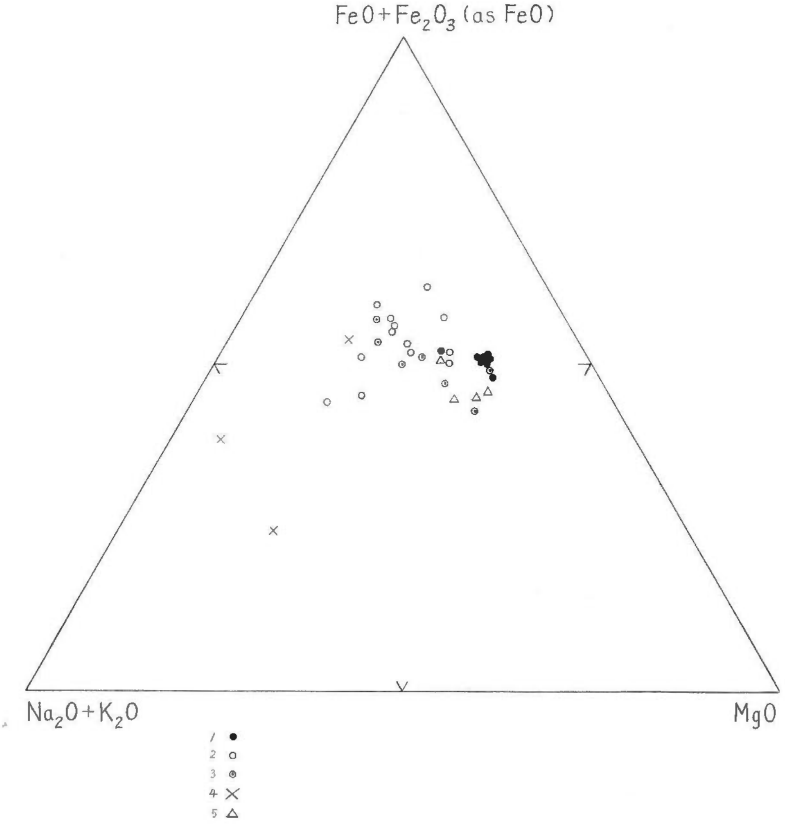


Fig. 37 Total alkalis of the Futago-yama and older basalts of the Kishima district as plotted against SiO_2. Symbols are the same as Fig. 36.

differentiated stage nearer to MgO than the general alkali rock series, and in Fig. 37, there is shown that the values of SiO_2 in the rocks are in the middle between the average value of the Circum-Japan Sea alkali rock province which contains SiO_2 of 50 percent or more and that of the pigeonitic rock series in Izu and Hakone districts. And it is considered that the Futago-yama volcanic rocks in the later stage of Pliocene rather belong to the rocks of calc-alkali rock series derived from tholeiitic magma. The Fig. 36 shows that they are low in MgO and high in iron, and the Fig. 37 shows that they contain over 53 percent of SiO_2, but are low in alkalis.

The Matsura basalts distributed in abundance in the Kishima area are of Pliocene in age, and are lower than the Futago-yama volcanic rocks. These are shown in the Figs. 38 and 39.

The basaltic rocks of alkali rock series in this area have a tendency to contain



1. Pigeonitic rock series
2. Alkali rock series
3. Hypersthenic rock series
4. Plio-Pleistocene volcanic rocks

(MATSUMOTO, 1960 ~ 1963)

5. Average composition of the Matsuura basalts proposed by FUKUYAMA (1961)

Fig. 38 Variation diagram of the rocks of the Kita-matsuura district and the Matsuura basalts as plotted in the ternary diagram $MgO-FeO+Fe_2O_3-Na_2O+K_2O$.

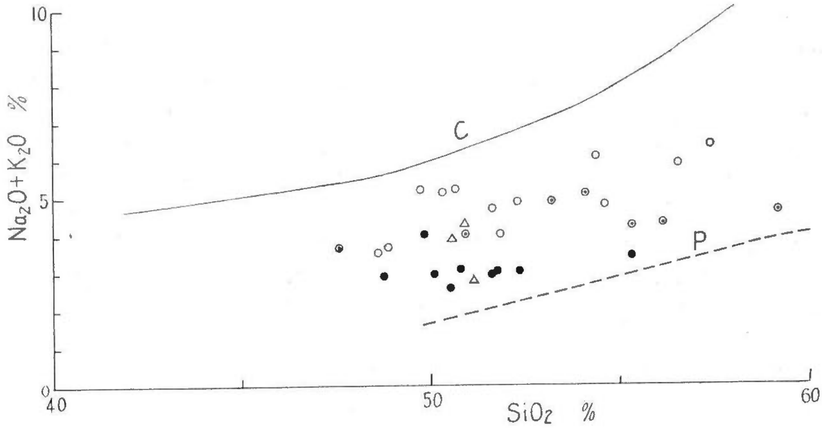


Fig. 39 Total alkalis of the rocks of the Kita-matsuura district and the Matsuura basalts as plotted against SiO_2. Symbols are the same as Fig. 38.

high iron, and especially in the figure showing the relation between Na_2O+K_2O and SiO_2, it is shown that they are richer in SiO_2 than those of other areas in the northern Kyushu and are scanty in alkalis. The writer does not interprete distinctly whether this is a characteristics of the Pliocene basalts in this area or not. As shown in Fig. 39, the rocks of alkali rock series are between the Circum-Japan Sea alkali rock province and Izu and Hakone districts, which do not show the enrichment of alkalis. This characteristics rather resembles that of the fractional trend of the Kami-goto rock series. And the basaltic rocks of the pigeonitic rock series in MATSUMOTO's papers have contents distinctly low in alkalis. From Fig. 39 it is considered that the products of calc-alkali rock series less than 55 percent of SiO_2 derived from alkali olivine basalt magma, and those over 55 percent of SiO_2, relate to tholeiitic basalt magma.

1. 9 Other area in the northwestern Kyushu

Basalts in the northwestern Kyushu which are not described in the Nishisonogi peninsula, etc. situated 10 km south of the area of which the Kita-matsuura district are distributed, and they are presumed to have been formed by the volcanic activity, accompanying with scoriae.

2. San-in provinces in the western Japan

2. 1 Western part of the San-in region (KURASAWA et al., 1960)

This area is situated in the north of Yamaguchi Prefecture, the western end of Honshu. Volcanic rocks are distributed extending over the area of about 80 km in width of E–W (Fig. 40).

Judging from the distribution of these volcanic rocks and petrological, chemical characteristics, this area is divided into three areas, i.e., the eastern area, Abu-gun (Abu district), the western area, Otsu-gun (Otsu district) and Mi-shima (Mi-shima district), about 45 km NNW of Hagi City in Yamaguchi Prefecture. The volcanic rocks are described, classifying into each area.

At the end of Tertiary, there is activity in basalts and dyke of andesite of tholeiitic rock series, in an only part of Mi-shima and Otsu districts on a small scale. Other volcanic rocks, except those rocks, are almost formed in the Diluvium of Quaternary.

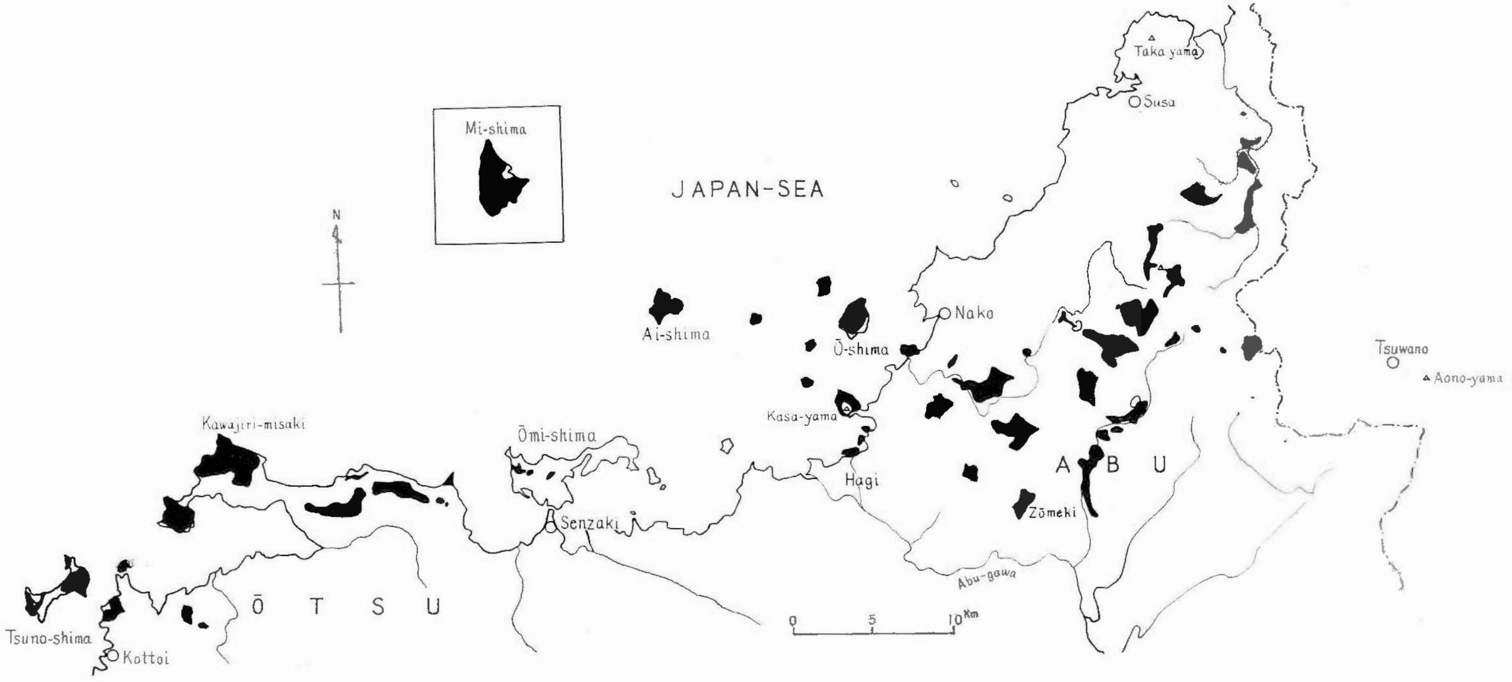


Fig. 40 Distribution of the Quaternary volcanic rocks of the western part in San-in region, West Japan.

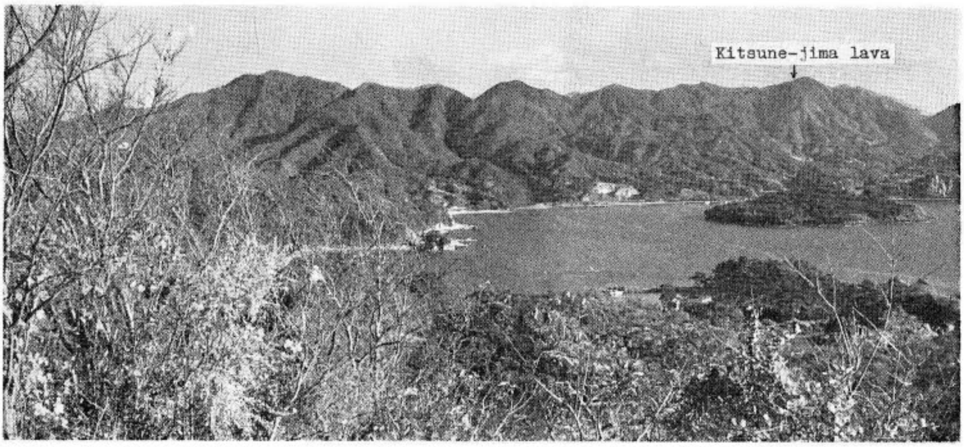
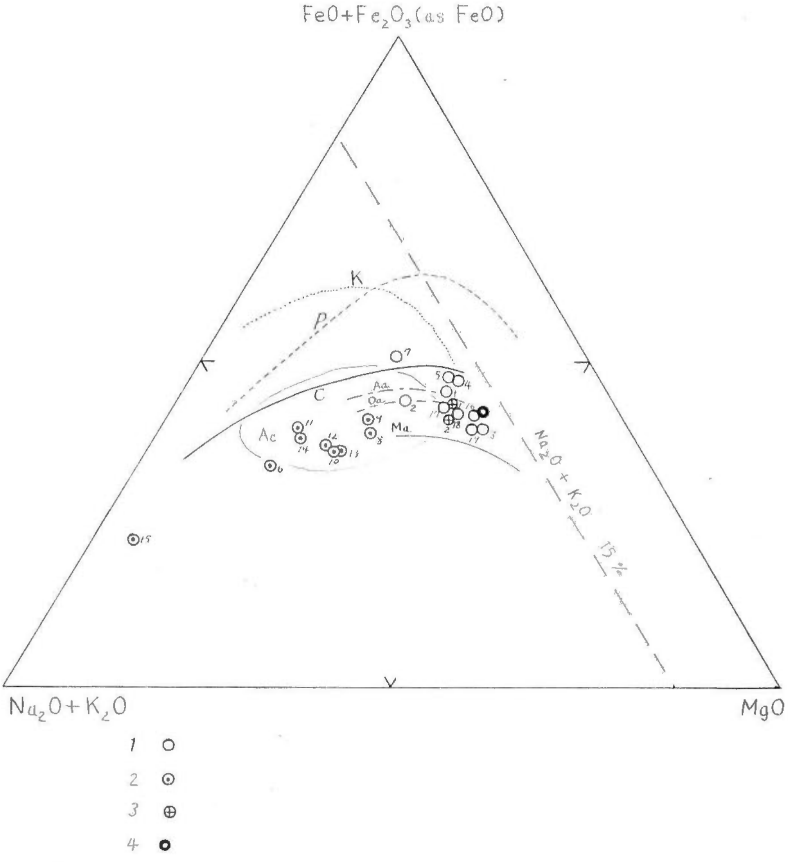
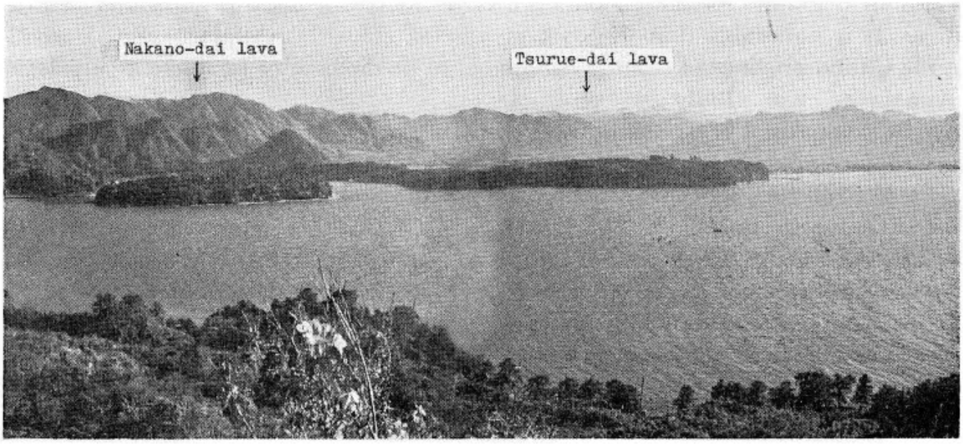


Photo. 25 The photograph shows the topography of the small lava plateaus as seen



1. Alkali rock series 2. Calc-alkali rock series
3. Alkali rock series in the Yonago district
4. Parental magma of the alkali rock series in the western part of San-in region (KURASAWA et al., 1960)

Fig. 41 Variation diagram of the rocks of the Tottori district in San-in region of the southwest Japan as plotted in the ternary diagram $MgO-FeO+Fe_2O_3-Na_2O+K_2O$.



from Kasa-yama cinder cone, the northern part of Yamaguchi Prefecture, West Japan.

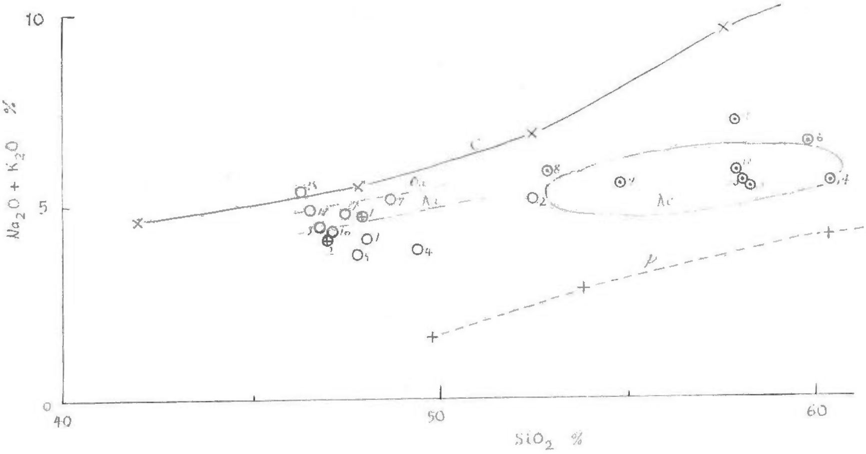


Fig. 42 Total alkalis of the Tottori district in San-in region as plotted against SiO_2. Symbols are the same as Fig. 41.

The volcanic rocks, which are firstly active in Quaternary, are trachybasalts of alkali rock series in the Otsu district, and among those rocks, there are included rock series being rich in iron. These lavas have a thickness of 100 m in maximum and are distributed in the area of 20 km^2. Secondly in the Abu district, there are the activities of trachybasalts and basalts of calc-alkali rock series accompanying with cinder cones. On some of these basalts, there is recognized a little influence of contamination. After these activities, there are erupted andesites mainly of calc-alkali rock series, i.e., well-known pyroxene andesite of Kasa-yama, formed by the contamination of alkali olivine basalt magma and granitic materials. These lavas have a thickness of 150 m in maximum and are distributed in the district of about 49 km^2. And andesites of the latter amount to about 60 percent of the former in effusive quantity. In the volcanic rocks of the Abu district, there are frequently confined strange materials, which are xenoliths of gneissose rock in abundant, and are affected remarkably by pyrometamorphism. The origin of those materials is granitic or amphibolitic gneissose rock, but there is not found in this area. It is noticeable that the rock mentioned above is resemble "Hida gneiss" in the Chubu province of Honshu considered to be the base of Japanese archipelago (KURASAWA et al., 1961).

By comparison of basalts in three districts above, it is found that trachybasalts formed formerly in the Otsu district (older stage) are richer in alkalis, and are more of alkali rock series than trachybasalts and basalts formed laterly in the Otsu district (younger stage).

In the Figs. 28, 29, 41 and 42, there are shown simplifying alkali rock series in the three districts and calc-alkali rock series in the Abu district, from the chemical composition of volcanic rocks in this district. As shown in Fig. 41, the components of each rock are all less 50 percent in total FeO, and in order of Mi-shima, Otsu and Abu districts, there are shown the differentiation stage of high iron. In Fig. 42, there is shown that the alkali rock series of the Otsu district is rich in alkali than that of the Abu district, and a characteristic close to the Circum-Japan Sea alkali rock province.

2. 2 Tottori area (MURAYAMA et al., 1961, 1963; KURASAWA et al., 1963)

This area is situated in the middle of the San-in region and is devided into the coast area, mountainous area and central area. The volcanic rocks distributed in these area are basalt to andesite. And those volcanic rocks are considered to be of Pliocene of Tertiary in age, judging from the fact that they unconformably overlie the Miocene formation in the southern part of Tottori, the upper Miocene formation in the Kurayoshi area and the uppermost Miocene or the Ningyo formation of lower Pliocene conformably near Okutsu of the mountainous area, and the uppermost part is overlain with the Daisen volcanic materials in Quaternary unconformably. The lavas form a tableland topography eroded.

All the basaltic rocks in this area belong to the alkali rock series. Trachybasalts are mainly distributed in the mountainous area, basalts in the coast area, and in the central area, there are developed trachyandesites and dacites.

Especially, in the basic rocks of the mountainous area, there is the activity from lower basalts to upper trachybasalts rich in alkalis, and is a tendency of which the factor of alkali rock series becomes high with the times. Other andesitic rocks except trachyandesites are formed by the contamination of alkali olivine basalt magma and granitic materials.

The thickness of volcanic materials is over 500 m including andesites, basalts and volcanic clastics which distribute in the area of about 300 km^2. Basaltic rocks have a thickness of 150 m and are distributed in the area of about 150 km^2; they are as 20 percent of the whole.

From the variation diagrams of components in these rocks, it is found that volcanic rocks of this area, especially basaltic rocks are similar to the fractional trend in the western part of the San-in region (Figs. 41, 42).

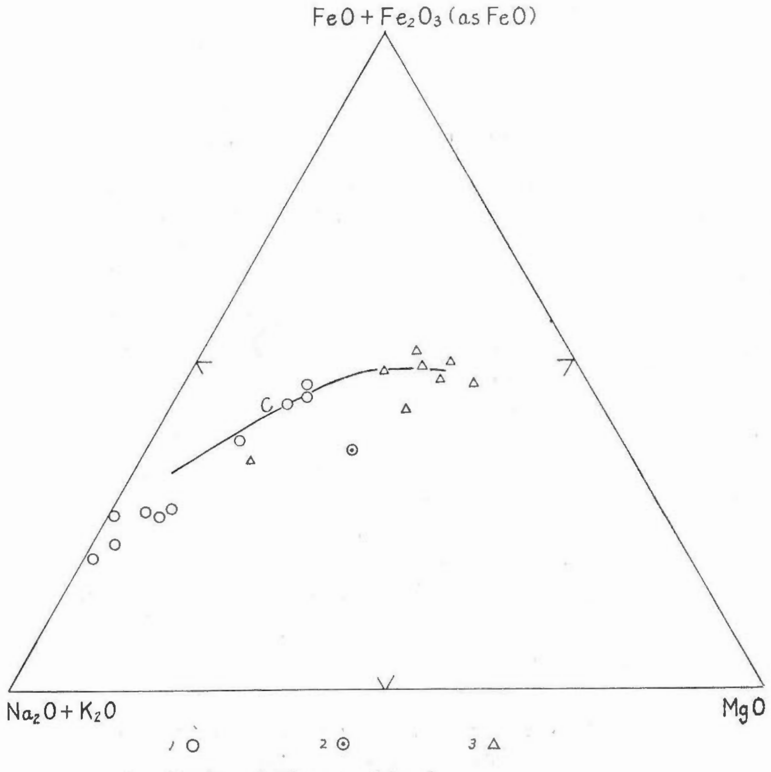
3. Other areas in the San-in provinces and adjacent area

In Hamada, Shimane Prefecture, there are distributed a well-known melilite-nepheline basalt extremely undersaturated in SiO_2 on a small scale (HARUMOTO, 1952). And in the northern part of Hyogo Prefecture, east of Hamada, there are sporadically, widely distributed trachybasalt and basalt commonly called "Gembudo" basalts, which flow down from summits of mountain to ravines. It is generally said that those phenomena are caused by the activities in Pliocene to Pleistocene.

Especially in the eastern part of Setouchi area (Inland Sea region), there are trachybasalts related to sanukite on a small as well.

4. Oki islands

The islands are situated on the northern sea of the San-in region, the western Honshu. In the islands, there are considered to be the states of Oki-dogo and Oki-dozen islands. Especially these are energetically studied by Tomita (1935, etc). He starts the studies of the Circum-Japan Sea alkali rock province. Roughly speaking, the volcanic activity of the Oki-dogo group of upper Miocene to lower Pliocene in age; in the lower there exist pyroxene andesites and rhyolites of calc-alkali rock series, and in the upper, trachybasalts, basalts, trachyandesites, alkali-trachytes and alkali-rhyolites of alkali rock series, and especially in Quaternary there are activities of trachybasalts and basalts of basic rocks. Describing about the volcanic activity in this area, Tomita (1936) attaches importance to the following; after sedimentation of the Dogo group mentioned above, there is recognized to be a great variation in the rock series, and Tomita calls "petrological revolution" for this phenomenon. (Recently reported by Uchimizu, 1966)



1. Rocks of Utsuryo island
2. Rocks of the north Manchuria district (average of 10 specimens)
3. Rocks of Kisshu-Meisen district of Korea

Fig. 43 Variation diagram of the rocks of the west Japan and the surrounding areas as plotted in the ternary diagram $MgO-FeO+Fe_2O_3-Na_2O+K_2O$.

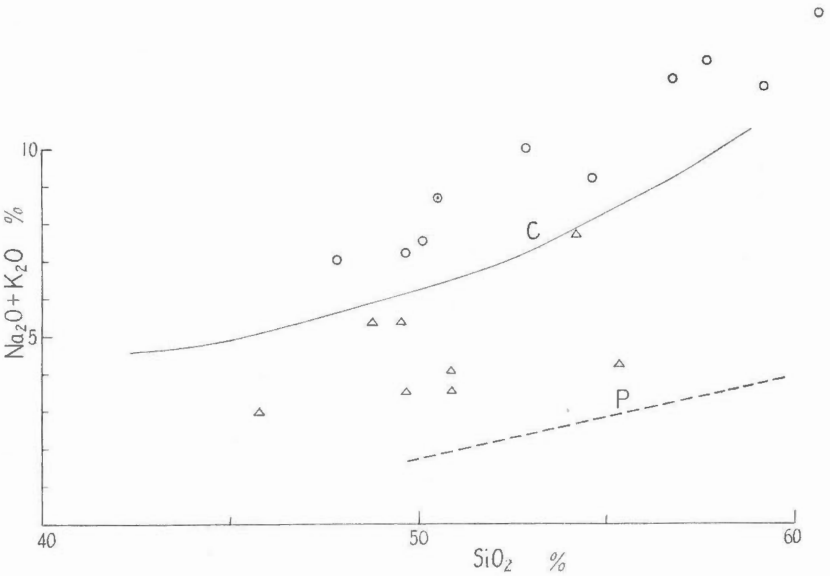


Fig. 44 Total alkalis of the rocks of the west Japan and the surrounding areas as plotted against SiO_2. Symbols are the same as Fig. 43.

5. Alkali rocks in environs

The Fig. 43 and 44 are drawn on a basis of the analytical data of those in the Utsuryo island of Korea (HARUMOTO, 1932), Kisshu-Meisen of the northern Korea (HARUMOTO, 1956) and Manchuria (GORAI, 1940), from the alkali basalts in the continental region and its environs.

According to the Fig. 43, the rocks in the Kissu-Meisen district of the northern Korea are the differentiation products in earlier stage than the alkaline suite of the Utsuryo island. In this figure, generally, they show the fractionation trend resembling the mean value of the Circum-Japan Sea alkali rock province, but the rocks in Manchuria are plotted in the position being different from this trend. In the alkaline basalts of the Kisshu-Meisen district of the northern Korea, there are observed two types of series being rich and poor in alkalis as shown in the Fig. 44.

Alkaline basalts in the Utsuryo island of Korea are the rocks in later stage, and have alkalis in same grade as alkaline basalts in the northern Manchuria. It is considered that in the basalts of the northern Manchuria, there appears an influence of contamination by granitic materials. The alkaline basalts in the continental region are distinctly high in the undersaturation rate.

II. Tentative Consideration on the Origin of the Kita-matsuura Magmas

As mentioned in the foregoing chapter (V), difference of parental magma is reflected especially in the silica-saturation rate, and this rate is represented by excess or deficiency of normative quartz.

KUNO (1959b, 1960) bounded the source depths of parental magmas by the values mentioned above, and the present writer is inclined to think that KUNO's values were deduced from the arcuate distribution of seismic foci in East Japan.

The depth of seismic foci of West Japan is 200–300 km in the west margin of Kyushu. The writer tried to obtain the source depths of the parental magmas of the Kita-matsuura basalt groups, by introducing the SiO_2–normative quartz relation (Fig. 25). From the things mentioned in the foregoing paragraphs, we can assume that the deepest seismic foci, in the region where the Kita-matsuura basalts were erupted, are at about 300 km below the ground surface. Thereupon, the writer arranged the parental magmas, setting the lower limit on the normative quartz (−18.1 percent) of Group III_2 whose parental magma is most strongly undersaturated among the groups of the Kita-matsuura basalts, and the upper limit on the famous tholeiite magma (3.40 percent) of Hawaii, and correlated this arrangement with the distribution of seismic foci.

Thus, based on an assumption that the relationship between each of these parental magmas and the intermediate to deep-seated earthquakes is reflected by the SiO_2–normative quartz relation in Fig. 25, the following equation was introduced:

$$\mathrm{Dm\ (km)} = [10-(\pm\ \text{normative quartz})]\times 10$$

where Dm (km) is the depth of the source of the parental magma, and normative quartz is a C.I.P.W. normative mineral.

The depths calculated from this equation are given in Table 16. The tholeiitic magma of Japan and surrounding areas and the Hawaiian tholeiite magma show depths of 60∼70 km, and alkali olivine basalt magmas show 170∼180 km. These values are reasonable.

Table 16 Tentatively calculated depth of the source of the parental magmas of various regions.

Japan and surrounding area (H. KUNO)	Tholeiite magma High-alumina basalt magma Alkali olivine basalt magma	70 km 120 170
Hawaii (H. KUNO)	Tholeiite magma Alkali olivine basalt magma	60 180
Kami-goto, Kyushu (H. KURASAWA)	Alkali olivine basalt magma	160
Western part of San-in region (H. KURASAWA)	Tholeiitic basalt magma Alkali olivine basalt magma	110 150
Kita-matsuura district, Northwest Kyushu (This paper)	Group I Group II Group III_1 Group III_2 Group IV	(100) 200 130 280 150

The depth of the source of the parental magma of each group of the Kita-matsuura basalts ranges from 100 km to 280 km. Although the values are not conclusive they may serve as a guide to determine the source depth.

It has been mentioned already that Groups I and III_1 have a tholeiitic character and are of parasitic activities, and that the extrapolated parental magma of Group III_2 has a character of limburgite. Limburgite does not occur in the Kita-matsuura district but is found in the western part of the San-in region, as seen at Oguso-yama in Misumi-machi, Shimane Prefecture, West Japan.

On the basis of what has been stated so far, the writer proposed the origin of the Kita-matsuura basalts as follows:

As an antecedent activity of the volcanism in this district, the tholeiitic basalts were erupted, originating at or near the top of the peridotite substratum. The depth of the source was about 100 km. The activity was of a small scale (Group I).

After this forerunning activity, the major activity of the alkali olivine basalt magma began, ejecting the fractionation products (Group II). The depth of the source of this magma was about 200 km. The volume of the ejecta was much larger than the former and attained to 18 km^3.

Then came the activity of the limburgitic parental magma which originated at a greater depth, and trachybasalt and mugearite were erupted out as the fractionation products (Group III$_2$). The volume of the ejecta was nearly the same as that of Group II, but the depth of the source was about 280 km or even deeper. During the period of this activity, a tholeiitic basalt magma was generated and locally erupted, performing a parasitic activity (Group III$_1$). Its source lay at a depth similar to that of the tholeiitic basalt magma of the first stage.

These activities were followed by a very long time interval (Table 2). The activity that succeeded the time interval is characterized by remarkable pyroclastics (Group IV). The parental magma which participated in this activity was generated at a depth about 150 km. During this period, local contamination took place. Among the lavas are found picritic basalts, indicating the crystal settling of olivine and pyroxene that are the early stage crystallization products. The volume of erupted materials is larger than the preceding group.

After the activities related to the alkali olivine basalt magma were terminated, the rocks characterized by strong contamination were erupted as the final products (Group V). Their activity was parasitic and the volume was very small. Contamination was performed mainly by acidic rocks.

The intimate relationship between the above-mentioned volcanic activities and the NW–SE trending faults developed in the Kita-matsuura district is worthy of notice, since the tectonic movement is also related to the source of the parental magmas.

Appendix B

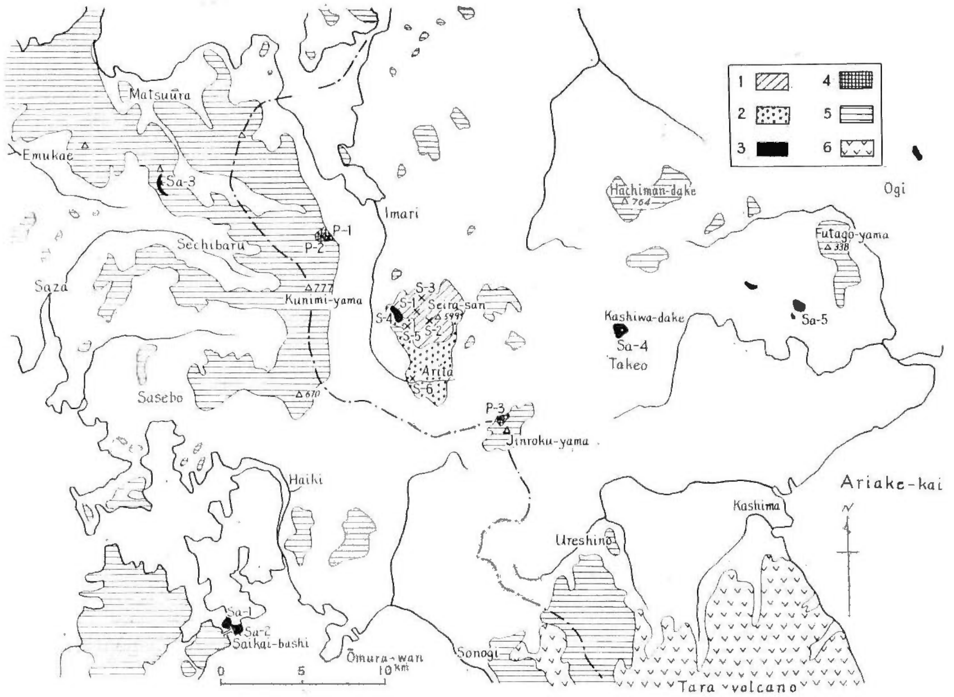
I. Volcanic Rocks from the Kita-matsuura District Nearby

The Kita-matsuura basalts are widely distributed in the center of the Karatsu and Sasebo coal fields, northwestern Kyushu. The volcanic rocks of the Seira-san andesites, Arita rhyolites, Sanukitic glassy andesites and Pliocene andesites are distributed south and west of Imari City are considered to have been erupted during a certain stage of the long period of the Kita-matsuura basalts (Teble 1).

Seira–san andesites cover the Arita rhyolites, and construct of semicircular ridge (559 m high). At the center of the circle, a thick bed of volcanic breccia of hypersthene-augite-olivine andesite well develops. The upper part of the bed is composed of thin lava flows of hypersthene-olivine-augite-hornblende dacitic andesite.

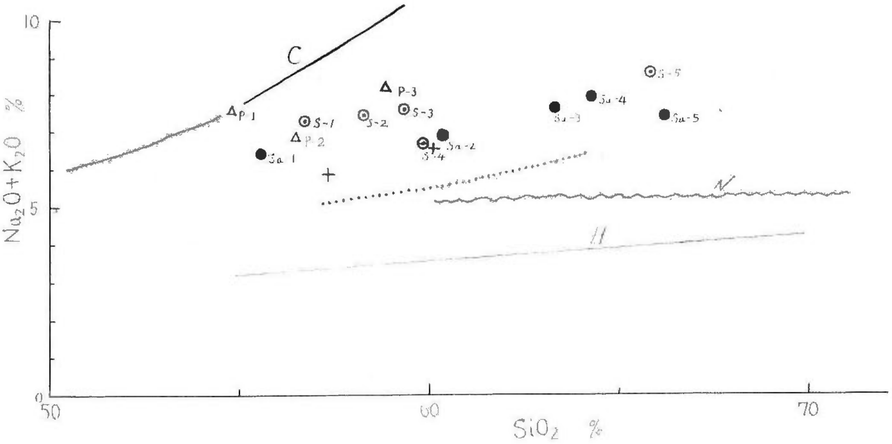
Arita rhyolites consist of pyroclastics and many lava flows. These rocks formed a tableland (200～250 m high). Then on the table, alternation of aphyric rhyolite and its pyroclastics, formed the semicircular ridge (518 m high). On the margin of thick lava or dome, and in contact with the pyroclastics, black or white-coloured obsidians show rapid cooling phenomenon (Imai, Sawamura and Yoshida, 1958).

The distribution of the sanukitic glassy andesites and Pliocene andesites is



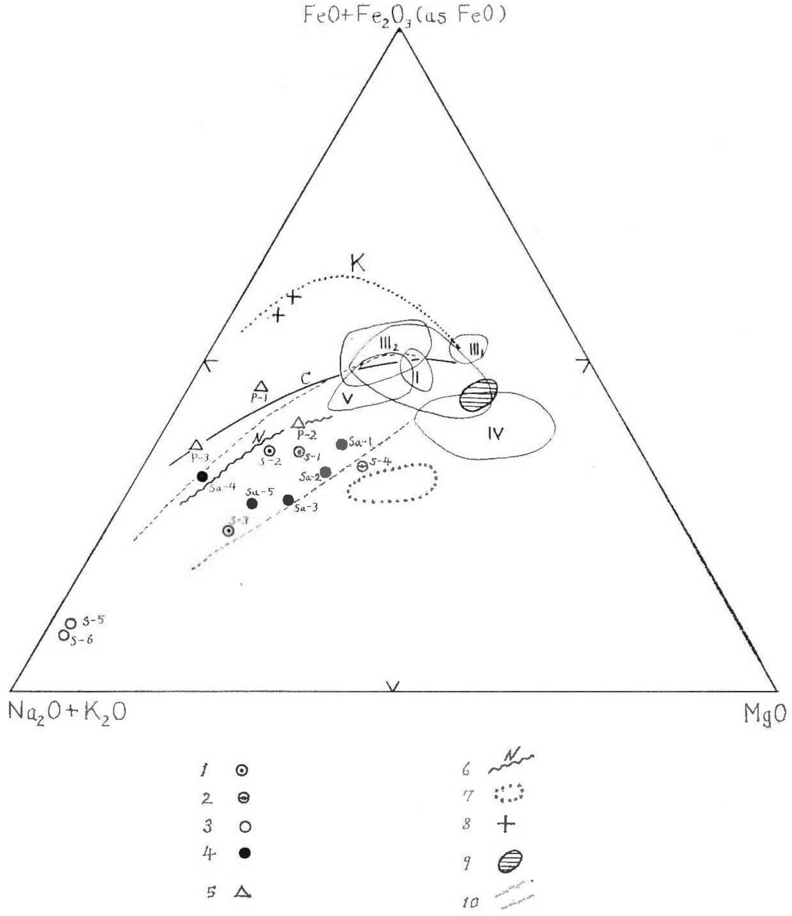
1. Seira-san andesites (S–1–4)
2. Arita rhyolites (S–5 and 6)
3. Sanukitic glassy rocks (Sa–1–5)
4. Pliocene andesites (P–1–3)
5. Distribution of the basalts of the Kita-matsuura district and adjacent area
6. Tara-dake volcano

Fig. 45 Distribution of the andesitic and rhyolitic rocks of the Kita-matsuura district nearby of the northwest Kyushu.



H: Hypersthenic rock series of Izu and Hakone districts

Fig. 46 Total alkalis of the andesitic and rhyolitic rocks of the Kita-matsuura district and adjacent area as plotted against SiO_2. Symbols are the same as Fig. 46.



1. Seira-san andesites
2. Glassy rock of the Seira-san andesites
3. Arita rhyolites
4. Sanukitic glassy rocks of the Kita-matsuura and Kishima districts
5. Pliocene andesites of the Kita-matsuura and Kishima districts
6. Rocks of the Nijo-san in Central Japan (MORIMOTO et al., 1957)
7. Rocks of the Oto-zan of the Setouchi (Inland Sea) region (YAMAGUCHI, 1958)
8. Glassy rocks of the Kami-goto district
9. Basalts of the Setouchi (Inland Sea) region
10. The field of the Daisen Volcanic Zone

Fig. 47 Variation diagram of the andesites and rhyolitic rocks of the Kita-matsuura districts nearby as plotted in the ternary diagram.

shown in Fig. 45 with above-mentioned volcanic rocks. Numbers in Fig. 45 refer to the specimens chemically analyzed showing in Table 17. The discussion on the volcanic rocks will be reported elsewhere (Tables 17, 18, 19, 20, 21; Figs. 46, 47).

Table 17 Chemical compositions of the volcanic rocks from the Kita-matsuura district nearby.

Seira-san area

S-	1	2	3	4	5	6
	54 1) sy-6 Vd** Ayao	53 sy-5 VId Ayoah	52 sy-4 VIId Ahyo	49 sy-1 (V)d Aoay	55 sy-7 R	56 sy-8 (X)? Rgb
SiO_2	56.74	58.24	59.34	59.78	65.84	72.02
TiO_2	0.85	0.75	0.72	0.72	0.09	0.10
Al_2O_3	16.11	17.03	16.37	14.99	12.17	13.74
Fe_2O_3	1.68	2.87	1.60	0.75	0.53	0.70
FeO	4.37	3.01	3.78	5.40	0.51	0.22
MnO	0.17	0.14	0.13	0.17	0.07	0.03
MgO	3.16	2.39	2.48	5.10	0.28	0.30
CaO	5.79	4.88	4.53	4.84	0.70	0.73
Na_2O	3.89	4.52	4.18	3.71	3.60	3.74
K_2O	3.39	2.87	3.39	2.94	4.97	5.35
P_2O_5	0.34	0.31	0.29	0.36	0.28	0.22
H_2O+	1.27	1.62	1.32	0.48	4.45	0.78
H_2O-	1.82	1.17	1.60	0.72	5.96	1.80
Total	99.58	99.80	99.73	99.96	99.45	99.78
FeOtot.	36.0	36.4	24.2	34.0	10.1	8.4
MgO*	19.3	15.5	16.2	28.6	2.8	2.9
Alk.O	44.7	48.1	59.6	37.4	87.1	88.7

Analyst: Hajime KURASAWA

* Solidification index

** KUNO's ferromagnesian silicate mineral assemblage 1) Rock number

Sanukitic rocks

Sa-	1	2	3	4	5
	68 sb-1 d A	69 sb-2 d A	36 ko-2 IId Ay	81 kw-1 II(b→)c Aoy	82 kh-1 VIId Ahy
SiO_2	55.48	60.36	63.32	64.24	66.22
TiO_2	0.87	0.60	0.67	0.44	0.45
Al_2O_3	17.41	15.16	15.02	17.02	14.89
Fe_2O_3	2.86	1.60	1.50	1.44	0.94
FeO	3.64	4.00	3.16	3.12	2.98
MnO	0.09	0.12	0.09	0.13	0.09
MgO	4.03	4.03	3.40	1.21	2.42
CaO	7.10	5.91	4.11	3.09	3.16
Na_2O	4.10	4.05	4.14	4.72	3.81
K_2O	2.36	2.87	3.49	3.20	3.53
P_2O_5	0.32	0.27	0.40	0.30	0.31
H_2O+	0.77	0.34	0.31	0.32	0.48
H_2O-	0.85	0.68	0.47	0.58	0.65
Total	99.88	99.99	100.08	99.81	99.93
FeOtot.	37.2	33.2	29.0	32.6	28.2
MgO*	24.2	24.6	21.9	8.9	17.8
Alk.O	38.6	42.2	49.1	58.5	54.0

Pliocene andesites

P-	1	2	3
	19 ke-7 V? Aoya	18 ke-6 Vd? Aay	95 jy-5 Xc? Aa(o)
SiO_2	54.94	56.80	58.74
TiO_2	1.57	1.40	1.55
Al_2O_3	17.59	17.66	16.10
Fe_2O_3	4.77	3.39	4.69
FeO	3.52	3.49	1.14
MnO	0.18	0.18	0.22
MgO	1.48	2.64	0.75
CaO	5.30	5.45	3.53
Na_2O	4.55	3.76	4.55
K_2O	3.01	3.02	3.62
P_2O_5	0.50	0.48	0.39
H_2O+	1.31	0.97	1.96
H_2O-	0.92	0.39	2.27
Total	99.64	99.48	99.51
FeOtot.	46.4	41.0	37.5
MgO*	8.8	16.5	5.4
Alk.O	44.8	42.5	57.1

Table 18 Norms of the analyzed rocks in Table 17.

Seira-san area

Norms	1	2	3	4	5	6
Q	4. 57	7. 21	8. 41	7. 51	25. 16	28. 65
C	—	—	—	—	0. 41	1. 02
Or	20. 03	17. 25	20. 03	17. 25	29. 50	31. 72
Ab	33. 03	38. 27	35. 13	31. 46	30. 41	31. 46
An	16. 41	17. 52	16. 13	15. 58	1. 67	2. 23
Wo	4. 41	1. 97	1. 86	2. 56	—	—
En	7. 83	5. 92	6. 22	12. 75	0. 70	0. 70
Fs	5. 41	2. 24	4. 75	8. 31	0. 53	—
Fo	—	—	—	—	—	—
Fa	—	—	—	—	—	—
Mt	2. 55	4. 17	2. 32	1. 16	0. 70	0. 70
Il	1. 67	1. 37	1. 37	1. 37	0. 15	0. 15
Hm	—	—	—	—	—	0. 16
Ap	0. 67	0. 67	0. 67	1. 01	0. 67	0. 50
Or	29	24	28	27	48	49
Ab	48	52	49	49	49	48
An	23	24	23	24	3	3
Wo	25	19	14	11	0	0
En	44	59	48	54	57	100
Fs	31	22	38	35	43	0

Sanukitic rocks

Norms	1	2	3	4	5
Q	3. 36	8. 35	12. 67	15. 26	19. 04
C	—	—	—	0. 92	—
Or	13. 91	17. 25	20. 03	18. 92	21. 15
Ab	34. 60	34. 08	35. 13	39. 85	32. 51
An	22. 25	14. 74	11. 96	13. 35	12. 79
Wo	4. 53	5. 11	2. 44	—	0. 35
En	10. 04	10. 04	8. 43	3. 01	6. 02
Fs	3. 03	5. 28	3. 69	3. 96	4. 09
Fo	—	—	—	—	—
Fa	—	—	—	—	—
Mt	4. 17	2. 32	2. 08	2. 08	1. 39
Il	1. 67	1. 37	1. 21	0. 91	0. 91
Hm	—	—	—	—	—
Ap	0. 67	0. 67	1. 01	0. 67	0. 67
Or	20	26	30	26	32
Ab	49	51	52	55	49
An	31	23	18	19	19
Wo	26	25	17	0	3
En	57	49	58	43	58
Fs	17	26	25	57	39

Pliocene andesites

Norms	1	2	3
Q	5. 71	8. 59	11. 53
C	—	—	—
Or	17. 81	17. 81	21. 15
Ab	38. 27	31. 98	38. 27
An	18. 91	22. 25	13. 07
Wo	1. 74	0. 70	0. 81
En	3. 71	6. 63	1. 91
Fs	0. 26	1. 72	—
Fo	—	—	—
Fa	—	—	—
Mt	6. 95	4. 86	—
Il	3. 04	2. 73	2. 88
Hm	—	—	4. 63
Ap	1. 20	1. 20	0. 85
Or	24	25	29
Ab	51	44	53
An	25	31	18
Wo	30	7	30
En	65	74	70
Fs	5	19	0

Table 19 Modal compositions of analyzed rocks in Table 17.

Seira-san area (%)

S-	1	2	3	4	5	6
1)	52	53	52	49	55	56
Phenocryst						*)
Plagioclase	1	2	2			+
Oilvine	+	+	+	+		
Monoclinic pyroxene	+	+		+		
Rhombic pyroxene	+	+	+			
Hornblende		2	+			
Iron-ore	+	+	+			
Xenocryst Quartz						
Plagioclase	+	+	+			

* Biotite and garnet-bearing 1) Rock numbers refer to Table 6

Sanukitic andesites

Sa-	1	2	3	4	5
1)	68	69	36	81	82
Phenocryst					
Plagioclase					
Olivine		+		+	
Monoclinic pyroxene					
Rhombic pyroxene			+	+	+
Amphibole					+
Iron-ore					

Pliocene andesites

P-	1	2	3
1)	19	18	95
Phenocryst			
Plagioclase	18	31	3
Olivine			2
Monoclinic pyroxene	1	3	2
Rhombic pyroxene	1	1	
Amphibole			
Iron-ore	2	3	1
Xenocryst			
Quartz Plagioclase	+	+	+

Table 20 Rock name and locality of the analyzed rocks of the Kita-matsuura district nearby, Northwest Kyushu.

Seira-san area

1. Hypersthene-augite-olivine andesite (Ku 60120102)
   750 m W. from a top of Seira-san, Imari City, Saga Pref.
2. Hypersthene-olivine-augite-hornblende andesite (Ku 60120103)
   S. W. mountain-side of a top of Seira-san, Imari City.
3. Hornblende-hypersthene-olivine andesite (Ku 60120101)
   S. of Okawachi-yama, Imari City.
4. Olivine-augite-hypersthene andesite (KT 59110103)
   1 km E. from Oki, Nishi-arita-mura, Nishi-matsuura-gun, Saga Pref.
5. Rhyolite-obsidian (Ku 59102601)
   500 m N. from Hiroseyama, Nishi-arita-mura, Nishi-matsuura-gun, Saga Pref.
6. Garnet-bearing biotite rhyolite (Ku 60120105)
   E. of Arita Station, Arita-machi, Nishi-matsuura-gun, Saga Pref.

Sanukitic rocks

1. Andesite (Ku 60120701)
   A coast cliff of Saikai-bashi (bridge), Sasebo City.
2. Andesite (Ku 60120702)
   East coast of Saikai-bashi (bridge), Sasebo City.
3. Hypersthene andesite (Ku 60120506)
   750 m S. from a top of Kohochi-dake, Yoshii-machi, Kita-matsuura-gun, Nagasaki Pref.
4. Olivine-hypersthene trachytic andesite (Ku 60112002)
   Kashiwa-dake, Takeo City, Saga Pref.
5. Hornblende-hypersthene trachytic andesite (Ku 60112808)
   W. of Kamioda, Kohoku-machi, Kishima-gun, Saga Pref.

Pliocene andesites

1. Olivine-hypersthene-augite trachytic andesite (KT 60121007)
   N. mountain-side of a top of Eboshi-dake, Imari City.
2. Augite-hypersthene andesite (KT 60121006)
   500 m N. W. from a top of Eboshi-dake, Imari City.
3. Olivine-bearing augite trachytic andesite (Ku 60120802)
   A pebble in tuff, 500 m N. from a top of Jinroku-yama, Yamauchi-mura, Kishima-gun, Saga Pref.

Table 21 PEACOCK's Alkali-lime Indices of the analyzed rocks* of the Kita-matsuura district and associated volcanic rocks of Southwest Japan.

Northwest Kyushu	
Seira-san andesites*	53.5
Sanukitic glassy andesites*	56.7
Older basalts and Sanukitic rocks from Kishima area, Northwest Kyushu (MATSUMOTO)	60.7
Setouchi region	
Oto-zan (YAMAGUCHI)	59.8
Nijo-san (MORIMOTO)	61.0
So-called Daisen volcanic zone	
Daisen (OTA)	59.5
Sanbe (YAMAGUCHI)	60.5
Aono-yama	59.5
Tokushima-kimpo	59.0
Shikuma & Take-yama	57.5
Kuju (ONO)	59.5
Tara-dake	61.0
Unzen (KURASAWA)	61.5
Kumamoto-kimpo	62.3
Futago (KAWANO)	63.0
Aso (HONMA)	58.1
Calc-alkali rock series of the western part of San-in district	59.3
Kirishima volcanic zone	
Kirishima (SAWAMURA)	61.3
Sakura-jima (YAMAGUCHI)	65.0
Chokai volcanic zone (KATSUI)	60.0
Nasu volcanic zone (KAWANO et al.)	64.8
Hypersthenic rock series of Izu and Hakone districts (KUNO)	68.0
Amagi (KURASAWA)	65.5

* in this paper

REFERENCES

AKAGI, T. (1935): Explanatory text of the Geol. Map of Japan, Omuta sheet, Scale 1: 75,000. Geol. Surv. Japan (in Japanese with English abstract).

AKAGI, T. (1935): Explanatory text of the Geol. Map of Japan, Ogi sheet, Scale 1: 75,000. Geol. Surv. Japan (in Japanese with English abstract).

AKAGI, T. (1935): Explanatory text of the Geol. Map of Japan, Shimabara sheet, Scale 1: 75,000. Geol. Surv. Japan (in Japanese with English abstract).

AKAGI, T. (1936): Explanatory text of the Geol. Map of Japan, Kuchinotsu sheet, Scale 1: 75,000. Geol. Surv. Japan (in Japanese with English abstract).

AOKI, K. (1959): Petrology of alkali rocks of the Iki Islands and Higashi–matsuura district, Japan. Fac. Sci. Tohoku Univ., Ser. 3, vol. 6, no. 2, p. 261–310.

AOKI, K. (1960): Differentiation of quartz dolerite dyke of the hypersthenic rock series, Kabeshima Island, Saga Prefecture (in Japanese with English abstract). Jour. Jap. Assoc. Min. Petr. Econ. Geol., vol. 44, p. 47–53.

AOYAMA, N. (1952): Petrography, I (in Japanese). Kobutsu Syumino Kai, Kyoto.

ARIYOSHI, M. & TASHIRO, N. (1962): On so-called Kunimi-yama fault in Matsuura coalfield area, Kyushu (in Japanese). Kyushu Tanko Gijutsu Rengokai, vol. 15, p. 138–142.

BAILEY, E. B., CLOUGH, C. T., WRIGHT, W. B., RICHEY, J. E. & WILSON, G. V. (1924): Tertiary & post–tertiary geology of Mull, Loch Aline, and Oban. Mem. Geol. Surv. Scotland, p. 1–445.

BARTH, Tom. F. W. (1936): The crystallization process of basalt. Am. Jour. Sci., vol. 31, p. 321–351.

BELOUSSOV, V. V. & RUDITCH, E. M. (1961): Island Arcs in the Development of the Earth's Structure (Especially in the Region of Japan and the Sea of Okhotsk). Jour. Geol. vol. 69, p. 647–658.

BENSON, W. N. (1941): Cainozoic petrolographic provinces in New Zealand and their residual magma. Am. Jour. Sci., vol. 239, p. 537–552.

BENSON, W. N. (1944): The basic igneous rocks of eastern Otago and their tectonic environment. Royal Soc. New Zealand, Tr., vol. 74, p. 71–123.

BERMAN, H. (1937): Constitution & Classification of the Natural Silicates. Am. Miner., vol. 22, p. 342–408.

BOBRIEVITCH, A. P., Smirnov, G. I. & Sobolev, V. S. (1960): On the mineralogy of xenolites of the grossularite-pyroxene-dishene rock (gross-Rydite) in kimberlite of Yokutia. Geol. Geophys. Acad. Sci. U.S.S.R., no. 3, p. 18–24.

BOWEN, N. L. (1928): The evolution of the igneous rocks. Princeton, p. 1–332.

BOYD, F. R. & England, J. L. (1958): Melting of diopside under high pressure. Carnegie Inst. Washington Year Book, vol. 57, p. 83–87.

BOYD, F. R. & England J. L. (1959): Experimentation at high pressures and temperatures. Carnegie Inst. Washington Year Book, vol. 58, p. 82–89.

CHAPMAN, R. W. & Williams, C. R. (1935): Evolution of the White Mountain magma series. Am. Miner., Vol. 20, p. 502–530.

CHAYES, F. (1951): Relations between composition and indices of refraction in natural plagioclase. Am. Jour. Sci., Bowen Volume, p. 85–105.

CHRISTLE, O. H. J. (1959): Crystallization experiments with alkali olivine basaltic glass from Egersund. Norsk Geol. Tidsskr., vol. 39, p. 271–273.

CHUJO, J., KONDO, N. & KURASAWA, H. (1961): Marine Sonic Survey and Land Geological Survey on the Shimabara Kaiwan (in Japanese with English abstract). Bull. Geol. Surv. Japan, vol. 12, p. 247–283.

COATS, R. R. (1952): Magmatic Differentiation in Tertiary and Quaternery Volcanic

Rocks from Adak and Kanaga Islands, Aleutian Islands, Alaska. Bull. Geol. Soc. Am., vol. 63 p. 485–520.

Cornwall, H. R. (1951): Differentiation in magma of the Keweenwan series. Jour. Geol., vol. 59, p. 151–172.

Daly, R. A. (1933): Igneous rocks and the depth of the earth, New York, p. 1–598.

Daly, R. A. (1933): Volcanism and petrogenesis as illustrated in the Hawaiian Islands. Bull. Geol. Soc. Am., Vol. 55, p. 1363–1400.

Domen, H. (1960): Some Magnetic Properties of the Early Pleistocene Basalts in the Northern Part of Yamaguchi Prefecture, West Japan. Bull. Fac. Educ. Yamaguchi Univ., vol. 9, p. 31–42.

Eaton, J. P. & Murata, K. J. (1960): How volcanoes grow. Science, vol. 132, p. 925–938.

Edwards, A. B. (1935): Three olivine basalt-trachyte provinces and some theories of petrogenesis. Royal Soc. Victoria Proc., vol. 48, p. 3–26.

Edwards, A. B. (1942): Differentiation of the dolerite of Tasmania. Jour. Geol., vol. 50, p. 451–480, 579–610.

Ewing, M. & Press, F. (1955): Physical contrast between continents and ocean basin ("Crust of the earth," Sympo.). Spec. Pap. Geol. Soc. Am., vol. 62, p. 1–6.

Fermor, L. L. (1934): On the chemical composition of the Deccan traps of Linga, Chindwara District, Central Provinces. Geol. Surv. India Rec., vol. 68, p. 344–360.

Fukuyama, K. (1960, 1961): Abnormal olivine basalts in the Senryu area of northern Kyushu, Japan, (1), (2). Fac. Sci. Kumamoto Univ. Sec. 1, Geology, vol. 4, p. 30–72, 73–89.

Fukuyama, K. (1961a): Drusy pigeonite in the olivine basalt from the Hirado-shiratake hill, Nagasaki Prefecture, Japan (1). Fac. Sci. Kumamoto Univ., Sec. 1, Geology, vol. 4, no. 2, Supplement, p. 1–18.

Fukuyama, K. (1961b): Drusy pigeonite in the olivine basalt from the Senryu-shiratake hill, Nagasaki Prefecture, Japan (2). Fac. Sci. Kumamoto Univ., Sec. 1, Geology, vol. 4, no. 2, Supplement, p. 18–24.

Funahashi, M. (1953): The problem of the basalt (in Japanese). Jour. Assoc. Geol. Collab. Japan, no. 10, p. 1–14.

Geological Survey of Japan (1951): The Geological Map (1: 500,000) of Fukuoka.

Geological Survey of Japan (1953): The Geological Map (1: 500,000) of Kagoshima.

Geological Survey of Japan (1959): The Geological Map (1: 200,000) of Karatsu.

Geological Survey of Japan (1965): The Geological Map (1: 200,000) of Nagasaki.

Gast, P. W. (1960): Limitations on the Composition of the Upper Mantle. Jour. Geophys. Res., vol. 65, p. 1287–1297.

Gilluly, J. (1937): The water content of magmas. Am. Jour. Sci. 5th ser., Vol. 33, p. 430–441.

Gorai, M. (1940): On genesis of alkali basalts of Wutalienchih Volcano, North Manchuria (in Japanese with English abstract). Jour. Geol. Soc. Japan, vol. 47, p. 457–467, 481–498.

Gorai, M. (1951): On the origin of the diversity of igneous rocks. Jour. Geol. Japan, vol. 57, p. 387–397.

Gorai, M. (1955, 1957, 1958): The genetical theory of igneous rocks (in Japanese). I–III, Asso. Geol. Collab. Japan, Tokyo.

Gorskov, G. S. (1956): On the depth of the magmatic focus of the Kliuchevsky volcano. C. R. Acad. Sci. U.S.S.R., vol. 106, No. 4, p. 703–705.

Green, J. & Poldervaart, A. (1955): Some basaltic provinces. Geochim. et Cosmochim. Acta, vol. 7, p. 177–188.

Green, J. & Poldervaart, A. (1958): Petrochemical fields and trends. Geochim. et Cosmochim. Acta, vol. 13, p. 87–122.

Hamilton, W. B. & Neuerburg, G. J. (1956): Olivine-sanidine trachy-basalt from the

Sierra Nevada. Am. Miner., vol. 41, p. 851–873.

Harris, P. G. & Rowell, J. A. (1960): Some geochemical aspects of the Mohorovicic discontinuity. Jour. Geophys. Res., vol. 65, p. 2443–2459.

Harumoto, A. (1932): On the chemical compositions of the volcanic rocks from Utsuryo Island, Japan (Abstract in Japanese). Jour. Geol. Soc. Japan, vol. 41, p. 352–354.

Harumoto, A. (1952): Melilite-mepheline-basalt, its olivinenodules and other inclusions from Nagahama, Japan. Mem. Coll. Sci. Kyoto Univ., Ser. B, vol. 20, no. 2, p. 69–88.

Harumoto, A. (1953): Nepheline basalt of the Chihsia District, Shantung, North China. Mem. Coll. Sci. Kyoto Univ., Ser. B, vol. 20, no. 4, p. 311–322.

Harumoto, A. (1956): Basalts of the Kissu-Meisen District, Korea (in Japanese with English abstract). Jubilee Pub. in the Commem. of Prof. Jun Suzuki, M.J.A., Sixtieth Birthday, Sapporo, p. 227–236.

Hatae, N., Ariyoshi, M. & Tashiro, N. (1961): On the geology, especially the abnormal development of the Kase formation, of the basin of the Shisa River in Sasebo Coal-field (in Japanese with English abstract). Jour. Mini. Inst. Kyushu, vol. 29, p. 167–178.

Hatae, N., Ariyoshi, M. & Tashiro, N. (1962): On the geology of the Sechibaru district in Sasebo Coal-field (in Japanese with English abstract). Jour. Mini. Inst. Kyushu, vol. 30, p. 124–139.

Hess, H. H. (1941): Pyroxenes of mafic magmas, 1, 2. Am. Miner., vol. 26, p. 515–534, 573–594.

Hess, H. H. (1949): Chemical composition and optical properties of common clinopyroxenes I. Am. Miner., vol. 34, p. 621–661.

Holmes, A. (1936): Contribution to the petrology of Kimberlite and its inclusions. Trans. Geol. Soc. S. Afr., vol. 39, p. 379–428.

Hoppe, H. J. (1938): Chemische und mikroskopiche untersuchungen an islandischen Gesteinen. Chemie. der Erde, vol. 11, p. 457–479.

Hotz, P. E. (1953): Petrology of granophyre in diabase near Dillsburg, Pennsylvania. Bull. Geol. Soc. Am., vol. 64, p. 675–704.

Hytonen, K. (1961): The plane enstatite-anorthite-diopside and its relation to basalts. Carnegie Inst. Washington Year Book, vol. 60, p. 125–141.

Imai, I., Sawamura, K. & Yoshida, T. (1958): Explanatory text of the Geol. Map of Japan, Imari sheet, Scale 1: 50,000. Geol. Surv. Japan (in Japanese with English abstract).

Ishibashi, K. (1962): Alkali-pyroxene in doleritic basalt flow from the Higashi-Matsuura districts, Saga Prefecture (in Japanese with English abstract). Jour. Jap. Assoc. Min. Petr. Econ. Geol., vol. 47, p. 213–222.

Ishibashi, K. (1964): Large phenocrystic pyroxenes in basaltic rocks of Northern Kyushu, Japan (in Japanese with English abstract). Facu. Sci. Kyushu Univ., vol. 7, p. 47–56.

Ishikawa, T. & Katsui, Y. (1959): Some considerations on the relation between the chemical character and the geographical position of the volcanic zones in Japan. Jour. Fac. Sci. Hokkaido Univ., ser. IV, vol. 10, p. 163–182.

Iwahashi, T. (1961): On the Hachinokubo gravel bed in Sasebo Coal-field and its surrounding area, Kyushu, Japan (in Japanese with English abstract). Sci. Rep. Fac. Sci., Kyushu Univ., vol. 5, p. 80–97.

Iwasaki, I., Kokubu, N. & Katsura, T. (1956): Geochemical investigations of volcanoes in Japan, 32, Residual magmatic waters in cavities of trchyandesitic basalt in Imari district, Saga Prefecture, Japan. Bull. Chemi. Soc. Japan, vol. 29, p. 379–387.

Kano, H. (1955): High temperature optics of natural plagioclase. Min. Jour., vol. 1, p. 255–277.

KATSUI, Y. (1954): Chemical composition of the lavas from the Chokai Volcanic Zone, Japan (in Japanese with English abstract). Jour. Geol. Soc. Japan, vol. 60, p. 185–191.

KAWAI, M. (1957): Explanatory text of the Geol. Map of Japan, Tsuyama-Tobu sheet, Scale 1: 50,000. Geol. Surv. Japan (in Japanese with English abstract).

KENNEDY, W.Q. (1933): Trends of differentiation in basaltic magma. Am. Jour. Sci., vol. 25, p. 239–256.

KENNEDY, W. Q. & ANDERSON, E. M. (1938): Crustal layers and the origin of magmas. Bull. volcano., Ser 3, vol. 3, p. 24–82.

KENNEDY, G. C. (1948): Equilibrium between volatiles and iron oxides in igneous rocks. Am. Jour. Sci., vol. 246, p. 529–549.

KENNEDY, G. C. (1955): Some aspects of the role of water in rock melts. Geol. Soc. Am., Special Paper, vol. 62, p. 489–504.

KENNEDY, G. C. (1959): The origin of continents, mountain ranges, and ocean basins. Am. Sci., vol. 47, p. 491–504.

KOBAYASHI, I., IMAI, I. & MATSUI, K. (1953): On several problems in the geological sheet maps of Karatsu and Yobuko (in Japanese with English abstract). Bull. Geol. Surv. Japan, vol. 4, p. 215–218.

KOBAYASHI, I., IMAI, I. & MATSUI, K. (1955): Explanatory text of the Geol. Map of Japan, Yobuko sheet, Scale 1; 50,000. Geol. Surv. Japan (in Japanese with English abstract).

KOBAYASHI, I., IMAI, I. & MATSUI, K. (1956): Explanatory text of the Geol. Map of Japan, Karatsu sheet, Scale 1 :50,000. Geol. Surv. Japan (in Japanese with English atbstract).

KOCHEGURA, V. V. (1961): Paleomagnetic methods for correlating the age of rocks (in Russian). Sovetskaya Geologiya, no. 4, p. 47–59.

KOZU, S. (1912): Fukue-gan from Fukue-jima, Northwest Kyushu, Japan (in Japanese). Rep. Geol. Surv. Japan, no. 35.

KOZU, S. (1913): Petrological notes on the igneous rocks of the Oki Islands. Sci. Rep. Tohoku Imp. Univ., ser. 2, vol. 1.

KOZU, S. (1914): Riebeckite-bearing soretite-trachyandesite and its allied glassy variety (monchiquitic) from Kozaki, Prov. Bungo, Japan. Sci. Rep. Tohoku Imp. Univ., ser. 2, vol. 1, no. 5, p. 75–81.

KOZU, S. & YOSHIKI, B. (1929): Mica basalt from Mutsure-Jima, Japan (in Japanese). Jour. Jap. Assoc. Min. Petr. Econ. Geol., vol. 1, p. 153-161.

KOZU, S. & YOSHIKI, B. (1933): Mica basalt from Mutsure Jima. Proc. Imp. Acad., vol. 9, p. 265–268.

KUNO, H. (1938): Occurrence of the augite at Nishiga-dake, Hizen, Northwest Kyushu, Japan (Abstract in Japanese). Jour. Geol. Soc. Japan, vol. 45, p. 879–880.

KUNO, H. (1950): Petrology of Hakone Volcano and adjacent areas. Bull. Geol. Soc. Am., vol. 61, p. 957–1019.

KUNO, H. (1952a): Chemical composition of hypersthene and pigeonite in equilibium in magma. Am. Miner., vol. 37, p. 1000–1006.

KUNO, H. (1952b): Cenozoic volcanic activity in Japan and surrounding areas. New York Acad. of Sci., Ser. II, vol. 14, p. 225–231.

KUNO, H. (1954a): Study of orthopyroxene from volcanic rocks. Am. Miner., vol. 39, p. 30–46.

KUNO, H. (1954b): Volcanoes and volcanic rocks (in Japanese). Iwanami & Co., Tokyo.

KUNO, H. (1954c): Geology and petrology of Omuro-yama volcano group, North Izu. Jour. Fac. Sci. Univ. Tokyo, Sect. II, Part II, p. 241–265.

KUNO, H., YAMASAKI, K., IIDA, C. & NAGASHIMA, K. (1957): Differentiation of Hawaiian magmas. Jap. Jour. Geol. Geogr., vol. 28, p. 179–218.

KUNO, H. (1959a): Discussion of Toru TOMITA's paper on "Chemical distinctions between the three principal series of basaltic rocks" (in Japanese with English abstract). Jour. Geol. Soc. Japan, vol. 65, p. 385–389.

Kuno, H. (1959b): Origin of cenozoic petrographic provinces of Japan and surrounding areas. Bull. Volcano., Ser. II, vol. 20, p. 37–76.

Kuno, H. (1960): High-alumina basalt. Jour. Petr., vol. 1, p. 121–145.

Kuno, H. (1962): Frequency distribution of rock types in Oceanic, Orogenic and Kratogenic Volcanic Associations. Geophys. Monograph., no. 6, p. 135–139.

Kuno, H. (1964): Dike swarm in Hakone Volcano. Bull. Volcano., vol. 27, p. 1–7.

Kurasawa, H. (1959): Petrology and chemistry of the Amagi Volcanic Rocks, Izu Peninsula, Japan (in Japanese with English abstract). Jour. Assoc. Geol. Collab. Japan, no. 44, p. 1–18.

Kurasawa, H. & Takahashi, K. (1960): Petrology and chemistry of the Cenozoic Volcanic Rocks on the Western Part of the San-in Region, Southwest Japan (in Japanese with English abstract). Bull. Volc. Soc. Japan, Second Series, vol. 5, p. 110–127.

Kurasawa, H., Nozawa, T. & Takahashi, K. (1961): Inclusions of Gneissose Rocks in Basalt from Northern Part of Yamaguchi Prefecture, Japan (in Japanese). Jour. Geol. Soc. Japan, vol. 67, p. 184–185.

Kurasawa, H. & Takahashi, K. (1961a): Basalts of the West Japan, I (in Japanese). Monthly of Geology, no. 79, p. 6–11, Geol. Surv. Japan.

Kurasawa, H. & Takahashi, K. (1961b): Petrology and chemistry of the volcanic rocks from the Kami-goto district in Nagasaki Prefecture, Southwest Japan (in Japanese with English abstract). Bull. Volc. Soc. Japan, Second Series, vol. 6, p. 86–101.

Kurasawa, H. and Takahashi, K. (1962a): Petrology and chemistry of the volcanic rocks from the Fukuê-jima in the Goto Islands of Nagasaki Prefecture, Southwest Japan (in Japanese with English abstract). Bull. Geol. Surv. Japan, vol. 13, p. 195–210.

Kurasawa, H. & Takahashi, K. (1962b): Basalts of the West Japan, II (in Japanese). Monthly of Geology, no. 90, p. 7–13, Geol. Surv. Japan.

Kurasawa, H. & Takahashi, K. (1962c): Basalts of the West Japan, III (in Japanese). Monthly of Geology, no. 94, p. 20–25, Geol. Surv. Japan.

Kurasawa, H. (1962): Differentiation and genesis of the Kita-matsuura basalts, Southwest Japan (Abstract in Japanese). Bull. Volc. Soc. Japan, Second Series, vol. 7, p. 112.

Kurasawa, H., Isshiki, N., Ozawa, A., Yamada, N. & Murayama, M. (1963): Chemical composition of the Pliocene volcanic rocks of the San-in region, Tottori Prefecture, Japan (Abstract in Japanese). Jour. Geol. Soc. Japan, vol. 69, p. 325.

Kurasawa, H. & Takahashi, K. (1963): Petrology and chemistry of rocks of Kimpo volcano in Kumamoto, Kyushu, Southwest Japan (in Japanese with English abstract). Bull. Geol. Surv. Japan, vol. 14, p. 364–376.

Kurasawa, H. (1963): Basalts of the West Japan, IV (in Japanese). Monthly of Geology, no. 108, p. 18–22, Geol. Surv. Japan.

Kurasawa, H. & Matsui, K. (1964): Basaltic rocks from Southeastern Islands of the Fukuê-jima Island, Nagasaki Prefecture, Southwest Japan (in Japanese with English abstract). Bull. Geol. Surv. Japan, vol. 15, p. 775–782.

Kurasawa, H. (1965a): Genesis of the Kita-matsuura basalts, Southwest Japan (Abstract in Japanese). Jour. Jap. Assoc. Min. Petr. Econ. Geol., vol. 53, p. 115–116.

Kurasawa, H. (1965b): Petrology and chemistry of Quaternary volcanic rocks in the Western part of Chugoku provinces, Southwest Japan (in Japanese with English abstract). Bull. Geol. Surv. Japan, vol. 16, p. 217–226.

Kurasawa, H. & Takahashi, K. (1965): Petrology and chemistry of the Unzen volcano and its basement, Kyushu, Southwest Japan (in Japanese with English abstract). Bull. Geol. Surv. Japan, vol. 16, p. 258–274.

Kushiro, I. (1961): A possible origin of Tholeiitic magma. Jap. Jour. Geol. Geogr., vol. 32, p. 31–37.

Kushiro, I. & Kuno, H. (1963): Origin of primary basalt magmas and classification of basaltic rocks. Jour. Petr., vol. 4, p. 75–89.

LARSEN, E. S. (1942): Alkalic rocks of Iron Hill, Gunnison County, Colorado. U.S. Geol. Surv., Profes. Paper, 197A, p. 1–64.

LE BAS, M. J. (1962): The role of Aluminium in igneous clinopyroxenes with relation to their parentage. Am. Jour. Sci., vol. 260, p. 267–288.

LESSING, P., DECKER, R. W. & REYNOLDS, R. C. Jr. (1963): Potassium and rubidium distribution in Hawaiian lavas. Jour. Geophys. Res., vol. 68, p. 5581–5855.

LOVERING, J. F. (1958): The nature of the Mohorovicic discontinuity. Trans. Am. Geophys. Un., vol. 39, p. 947–955.

MACDONALD, G. A. (1944a): Pyroxene in Hawaiian lavas. Am. Jour. Sci., vol. 242, p. 626–629.

MACDONALD, G. A. (1944b): Hawaiian petrographic province. Bull. Geol. Soc. Am., vol. 60, p. 1541–1596.

MACDONALD, G. A. (1960): Dissimilarity of continental and oceanic rock. Jour. Petr., vol. 1, p. 172–177.

MACKENZIE, W. S. & SMITH, J. V. (1956): The alkali feldspars, III. An optical and X-ray study of high-temperature feldspars. Am. Miner., vol. 41, p. 405–427.

MASUDA, A. (1964): Lead isotope composition in volcanic rocks of Japan. Geochim. et Cosmochim. Acta, vol. 28, p. 291–303.

MATSUI, K. (1958): Explanatory text of the Geol. Map of Japan, Katsumoto Gonoura Ashibe sheets, Scale 1:50,000. Geol. Surv. Japan (in Japanese with English abstract).

MATSUMOTO, T. (1963): Pressure effects on phase equilibria in some principal rock-forming minerals. —Proposal of a modal regarding the origin of primary magmas— Jour. Geosci., Osaka Univ., vol. 7, Art. 3, p. 81–95.

MATSUMOTO, T. (1963): On the origin of the Neogene volcanic series in Southern Japan. Jour. Geosci., Osaka City Univ., vol. 7, p. 49–79.

MATSUMOTO, Y. (1960): Matsura basalts in the Kishima area of the Northern Kyushu, Japan (in Japanese). Sci. Rep. Seisan Kagaku Inst., Kyushu Univ., no. 28, p. 36–73.

MATSUMOTO, Y. & YAMASAKI, T. (1960): Volcanic activities of the Karatsu coal-field of Kyushu with particular reference to the Hizen dolerites (in Japanese). Jour. Assoc. Mini. Kyushu, vol. 28, p. 312–325.

MATSUMOTO, Y., YAMASAKI, T. & TOMITA, T. (1960): Hizen dolerites and associated rocks in the central area of the Karatsu coal-field, North Kyushu (in Japanese). Sci. Rep. Seisan Kagaku Inst., Kyushu Univ., p. 4–35.

MATSUMOTO, Y. (1961a): Older basalts and Sanukitic rocks in the Kishima area, Saga Prefecture, Japan (in Japanese). Sci. Rep. Seisan Kagaku Inst., Kyushu Univ., no. 29, p. 1–25.

MATSUMOTO, Y. (1961b): Futagoyama volcanic rocks in the Kishima area, Saga Prefecture, Japan (in Japanese). Sci. Rep. Sesan Kagaku Inst., Kyushu Univ., no. 29, p. 26–47.

MATSUMOTO, Y. & TOMITA, T. (1961): Average chemical composition of the Post-Miocene basaltic rocks in Northern Kyushu, Japan (in Japanese with English abstract). Jour. Assoc. Mini. Kyushu, vol. 29, p. 190–199.

MATSUMOTO, Y. (1961c): Petrological studies on the Matsura basalts from Northern Kyushu, Japan (in Japanese). Sci. Rep. Seisan Kagaku Inst., Kyushu Univ., no. 30, p. 1–99.

MATSUMOTO, Y. (1963): The late Cenozoic volcanizm in northern and central Kyushu, Japan (in Japanese with English abstract). Sci. Rep. seisan Kagaku Inst., Kyushu Univ., no. 34, p. 1–21.

MATSUMOTO, Y. (1964): On the so-called high-alumina basalts of post-Miocene time from Northern Kyushu, Japan (in Japanese with English abstract). Sci. Rep. Fac. Sci., Kyushu Univ., vol. VIII, p. 1–9.

MIYAMOTO, H. (1952): Explanatory text of the Geol. Map of Japan, Tsuwano sheet, Scale 1:75,000. Geol. Surv. Japan.

MORIMOTO, R., HUJITA, K. & KASAMA, T. (1957): Cenozoic volcanism in southwestern Japan with special reference to the history of the Setouchi (Inland Sea) geologic province. Bull. Earthq. Inst. Tokyo Univ., vol. 35, p. 35–45.

MUAN, A. and OSBORN, E. F. (1956): Phase equilibria at liquidus temperatures in the system $MgO–FeO–Fe_2O_3–SiO_2$. Jour. Am. Ceram. Soc., vol. 39, p. 121–140.

MUELLER, R. F. (1961): Oxidation in high temperature petrogenesis. Am. Jour. Sci., vol. 259, p. 460–480.

MUIR, I. D. (1951): The clinopyroxenes of Skaergarrd intrusion, eastern Greenland. Min. Mag., vol. 29, p. 690–714.

MUIR, I. D. & TILLEY, C. E. (1957): Contributions to the petrology of Hawaiian basalts: I The picrite-basalts of Kilauea. Am. Jour. Sci., vol. 255, p. 241–253.

MUIR, I. D. & TILLEY, C. E. (1961): Mugearites and their place in alkali igneous rock series. Jour. Geol., vol. 69, p. 186–203.

MUIR, I. D. & ERNST, W. G. (1963): Contributions to the petrology of Hawaiian Basalts: II The tholeiitic basalts of Mauna Loa and Kilauea. Am. Jour. Sci., vol. 261, p. 111–128.

MUKAE, M. (1958): Volcanostratigraphical study on the Miocene volcanism in Shimane Prefecture, Japan. Jour. Sci. Hiroshima Univ., Ser. C, vol. 2, p. 129–172.

MURATA, K. J. (1960): A new method of plotting chemical analyses of basaltic rocks. Am. Jour. Sci. p. 258–A, p. 247–252.

MURAYAMA, K. (1930): Explanatory text of the Geol. Map of Japan, Susa sheet, Scale 1:75,000. Geol. Surv. Japan (in Japanese with English abstract).

MURAYAMA, M. & OZAWA, A. (1961): Explanatory text of the Geol. Map of Japan, Aoya · Kurayoshi sheets, Scale 1:50,000. Geol. Surv. Japan (in Japanese with English abstract).

MURAYAMA, M., ISSHIKI, N. & SAKAMOTO, T. (1963): Explanatory text of the Geol. Map of Japan, Tottori-hokubu · Tottori-nanbu sheets, Scale 1:50,000. Geol. Surv. Japan (in Japanese with English abstract).

NAGAHAMA, H. & MATSUI, K. (1958): Explanatory text of the Geol. Map of Japan, Kakinoura sheet, Scale 1:50,000. Geol. Surv. Japan (in Japanese with English abstract).

NAGAHAMA, H. (1962): Yobikonoseto faulting in the Seto-Matsushima coal field, Nagasaki Prefecture, Kyushu, Japan (in Japanese with English abstract). Jour. Geol. Soc. Japan, vol. 68, p. 199–208.

NAGASHIMA, K. (1953): Geochemistry of the Kita-Izu and Hakone volcanic rocks, and Hamada nepheline basalt (in Japanese). Bull. Fac. Agric., Tokyo Univ. Agric. Tech., vol. 1, p. 1–39.

NAGATA, T. (1953): Rock magnetism. Maruzen & Co., Tokyo.

NAGATA, T., AKIMOTO, S., UYEDA, S., SHIMIZU, Y., OJIMA, M., KOBAYASHI, K. & KUNO, H. (1957): Palaeomagnetic studies on a Quaternary volcanic region in Japan. Jour. Geomagn. Geoelc., vol. 4, p. 23–41.

NOCKOLDS, S. R. & ALLEN, R. (1953): The geochemistry of some igneous rock series, 1. Geochim. et Cosmochim. Acta, vol. 4, p. 105–142.

NOCKOLDS, S. R. & ALLEN, R. (1954): The geochemistry of some igneous rock series, 2. Geochim. et Cosmochim. Acta, vol. 5, p. 245–285.

NOCKOLDS, S. R. & ALLEN, R. (1956): The geochemistry of some igneous rock series, 3. Geochim. et Cosmochim. Acta, vol. 9, p. 34–77.

NOCKOLDS, S. R. (1954): Average chemical composition of some igneous rocks. Geol. Soc. Am. Bull., vol. 65, p. 1007–1032.

NODA, M. & MUTA, K. (1957): The geological structure of the Nishisonogi Peninsula, Nagasaki Prefecture. (in Japanese with English abstract). Rep. Earth Sci., Dep. Gener. Edu., Kyushu Univ., vol. 4, p. 17–21.

NODA, M. & MUTA, K. (1959): The limonite beds in the Kawatana and Sonogi districts, Nagasaki Prefecture (in Japanese with English abstract). Rep. Earth Sci., Dep. Gener. Edu., Kyushu Univ., vol. 6, p. 9–20.

OGURA, T. (1919): Tara-dake volcano (in Japanese). Rep. Earthq. Inv. Comm., no. 90,

p. 1–49.

Ohashi, R. (1935): Chemical composition of pyroxene from Nishi-gatake, Hizen, Kyushu, Japan (Abstract in Japanese). Jour. Geol. Soc. Japan, vol. 44, p. 201.

Oji, Y. (1956): Cenozoic basaltic rocks of the Northern Kyushu (in Japanese). Bull. Fukuoka Gakugei Univ., vol. 7, p. 75–87.

Oji, Y. (1957): Cenozoic basaltic rocks of the Northern Kyushu (in Japanese). Bull. Fukuoka Gakugei Univ., vol. 8, p. 55–68.

Oji, Y. (1960): Petrological studies of the Cenozoic basaltic rocks from the western Sanin district, 1 (in Japanese with English abstract). Jour. Jap. Assoc. Min. Petr. Econ. Geol., vol. 44, p. 74–82.

Oji, Y. (1960): Petrological studies of the Cenozoic basaltic rocks from the western Sanin district, 2 (in Japanese with English abstract). Jour. Jap. Assoc. Min. Petr. Econ. Geol., vol. 44, p. 129–141.

Oji, Y. (1961): Petrological studies of the Cenozoic basaltic rocks from the western Sanin district, 3 (in Japanese with English abstract). Jour. Jap. Assoc. Min. Petr. Econ. Geol., vol. 45, p. 1–8.

Oji, Y. (1961): Petrology of the Cenozoic basaltic rocks of western San-in and north Kyushu, Japan. Bull. Fukuoka Gakugei Univ., Special vol., no. 1, p. 1–89.

Oji, Y. (1962): Petrological studies on the Cenozoic basaltic rocks from North Kyushu (in Japanese with English abstract). Jour. Jap. Assoc. Min. Petr. Econ. Geol., vol. 47, p. 23–35.

Okamoto, K. (1961): Cenozoic formations of Tsuno-shima (Island), Hohoku-cho, Toyoura-gun, Yamaguchi Prefecture (in Japanese with English abstract). Jour. Geol. Soc. Japan, vol. 67, p. 476–483.

Osborn, E. F. (1959): Role of oxygen pressure in the crystallization and differentiation of basaltic magma. Am. Jour. Sci., vol. 257, p. 609–647.

Osborn, E. F. (1962): Reaction series for subalkaline igneous rocks based on different oxygen pressure conditions. Am. Miner., vol. 47, p. 211–226.

Ota, R. (1962a): Explanatory text of the Geol. Map of Japan, Yumoto sheet, Scale 1: 50,000. Geol. Surv. Japan (in Japanese with English abstract).

Ota, R. (1962b): Explanatory text of the Geol. Map of Japan, Akasaki Daisen sheets, Scale 1:50,000. Geol. Surv. Japan (in Japanese with English abstract).

Ota, R. (1962c): Explanatory text of the Geol. Map of Japan, Yonago sheet, Scale 1: 50,000. Geol. Surv. Japan (in Japanese with English abstract).

Otsuki, Y. (1910): The Geological Map (1:200,000) of Iki. Geol. Surv. Japan.

Otsuki, Y. (1917): The Geological Map (1:200,000) of Hirado. Geol. Surv. Japan.

Patterson, E. M. & Swaine, D. J. (1955): A petrochemical study of tertiary tholeiitic basalt: The middle lavas of the Antrim plateau. Geochim. et Cosmochim. Acta, vol. 8, p. 173–181.

Peacock, M. A. (1931): Classification of igneous rock series. Jour. Geol., vol. 39, p. 54–67.

Poldervaart, A. (1947): The reletionship of orthopyroxene to pigeonite, Miner. Mag., vol. 28, p. 164–172.

Poldervaart, A. (1949): Three methods of graphic representation of chemical analyses of igneous rocks. Royal Soc. South Afr., Tr., vol. 32. p. 177–188.

Poldervaart, A. (1950): Correlation of physical properties and chemical composition in the plagioclase, olvine and orthopyroxene series. Am. Miner., vol. 35, p. 1067–1079.

Poldervaart, A. (1951): Pyroxenes in the crystallization of basaltic magma. Jour. Geol., vol. 59, p. 472–489.

Poldervaart, A. & Elston, W. E. (1954): The calc-alkaline series and trend of fractional crystallization of basaltic magma: A new approach at graphic representation. Jour. Geol., vol. 62, p. 150–162.

Powers, H. A. (1955): Composition and origin of basaltic magma of the Hawaiian Islands. Geochim. et Cosmochim. Acta, vol. 7, p. 77–107.

RINGWOOD, A. E. (1958): The constitution of the mantle, Parts II and III. Geochim. et Cosmochim. Acta, vol. 15, p. 18–29; 195–212.

ROSS, C. S., FOSTER, M. D. & MYERS, A. T. (1954): Origin of dunites and of olivine-rich inclusions in basaltic rocks. Jour. Miner. Soc. Am., vol. 39, p. 693–737.

SAWATA, H., SAWAMURA, K., IMAI, I. & NAGAHAMA, H. (1955): Explanatory text of the Geol. Map of Japan, Hirado sheet, Scale 1:50,000. Geol. Surv. Japan (in Japanese with English abstract).

SAWATA, H. (1956): Some notes on the "Sasagawa thrust" in the Northwestern Kyushu (in Japanese with English abstract). Bull. Geol. Surv. Japan, vol. 7, p. 29–32.

SAWATA, H. (1958): Explanatory text and the Geol. Maps of the Hokusho coal field (in Japanese with English abstract). Geol. Surv. Japan.

SAWAMURA, K. (1952): Basalts and faults in the Hokusho coal field district, Kyushu, Japan (Abstract in Japanese). Jour. Geol. Soc. Japan, vol. 58, p. 308.

SCHAIRER, J. F. (1950): The alkali-feldspar join in the system $NaAlSiO_4$–$KAlSiO_4$–SiO_2. Jour. Geol., vol. 58, p. 512–517.

SHIBATA, I. (1952): Tertiary basalts in Japan and its surrounding areas (in Japanese). Shinsei-dai no Kenkyu, nos. 15–16, p. 9–16.

SHIMAZU, Y. (1959): A thermodynamical aspect of the earth's interior-physical interpretation of magmatic differentiation process. Jour. Earth Sci., Nagoya Univ., vol. 7, p. 1–34.

SHIMAZU, Y. (1960): Path of fractional differentiation of basaltic magmas and frationation diagram (in Japanese with English abstract). Bull. Volc. Soc. Japan, vol. 5, l. 25–34.

SIMON, A. (1947): On the gradual development of the basaltic parent magma during the course of the geological periods. Bull. Comm. Geol. Finland, vol. 140, p. 193–198.

SMITH, J. V. & MACKENZIE, W. S. (1958): Alkali feldspars: IV, The cooling history of high temperature sodium rich feldspars. Am. Miner., vol. 43, p. 872–889.

SUGI, K. (1942): Petrological studies on the basaltic rocks from San-in and northern Kyushu, southwestern Japan. Mem. Fac. Sci. Kyushu Imp. Univ., Ser. I, vol. 1, p. 69–90.

SUGIMURA, A. (1959): Geographische verteilung der charakter-stendenzen des Magmas in Japan (in Japanese with German abstract). Bull. volc. Soc. Japan, Second series, vol. 4, p. 77–103.

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

SUGIMURA, A., MATSUDA, T., CHINZEI, K. & NAKAMURA, K. (1963): Quantitative distribution of late Cenozoic volcanic materials in Japan. Bull. Volc., vol. 26, p. 125–140.

SUKHESWALA, R. N. & POLDERVAART (1958): Deccan basalts of the Bombay area, India. Geol. Soc. Am. Bull., vol. 69, p. 1475–1494.

TAKAHASHI, K. & KURASAWA, H. (1960): Petrological and chemical characteristics of Tara-dake volcano and its basement rocks in the central Kyushu, Southwest Japan (in Japanese with English abstract). Bull. Geol. Surv. Japan, vol. 11, p. 631–651.

TANEDA, S. (1952): New average chemical composition of Japanese effusive rocks. Jour. Geol. Soc. Japan, vol. 58, p. 517–521.

TANEDA, S. (1962a): Chemical compositions of granitic and volcanic rocks in Japan. Jour. Geol. Soc. Japan, vol. 68, p. 118–124.

TANEDA, S. (1962b): Frequency distribution and average chemical composition of the volcanic rocks in Japan. Mem. Fac. Sci. Kyushu Univ., Ser. D, vol. 12, p. 237–255.

TATEL, H. E. & ADAMS, L. H. (1953): Studies of the earth's crust using waves from explosions. Proc. Am. Philos. Soc., vol. 97, p. 658–669.

TATEL, H. E. & TUVE, M. A. (1955): Seismic exploration of a continental crust ("Crust of the earth" Sympo.). Spec. Pap. Geol. Soc. Am., vol. 62, p. 35–50.

TILLEY, C. E. (1950): Some aspects of magmatic evolution. Quart. Jour. Geol. Soc. London. vol. 106, p. 37–61.

TILLEY, C. E. (1955): Discussion on the "Origin of the earth". Proc. Geol. Soc. London, vol. 1521, p. 48–50.

TILLEY, C. E. (1960): Differentiation of Hawaiian basalts: Some variants in lava suites of dated Kilauean eruptions. Jour. Petr., vol. 1, p. 47–55.

TILLEY, C. E., GITTINS, J. & SCOON, J. H. (1961): Igneous nepheline-bearing rocks of the Haliburton-Bancroft province of Ontario. Jour. Petr., vol. 2, p. 38–48.

TOMITA, T. (1927–1932): Geological and petrological studi of Dogo, Oki Islands (in Japannese), 1–20. Jour. Gol. Soc. Japan, vol. 34–39.

TOMITA, T. (1933a): On the so-called leucite-basalt from Ryudo, Kankyo-hokudo, Korea. Jour. Shanghai Sci. Inst., Sec. 2, vol. 1, p. 25–39.

TOMITA, T. (1933b): Olivine trachyandesitic basalt from Hsuenhuashan Hill, Chinghsing district, north China. Jour. Shanghai Sci. Inst., Sec. 2, vol. 1, p. 1–10.

TOMITA, T. (1934): On the kaersutite from Dogo, Oki Islands, Japan, and its magmatic alteration and resorption. Jour. Shanghai Sci. Inst., Sec. 2, vol. 1, p. 99–136.

TOMITA, T. (1935): On the chemical composition of the cenozoic alkaline suite of the circum-Japan Sea region. Jour. Shanghai Sci. Inst., Sec. 2, vol. 1, p. 227–306.

TOMITA, T. (1936): Geology of Dogo, Oki Islands, in the Japan Sea. Jour. Shanghai Sci. Inst., Sec. 2, vol. 2, p. 37–146.

TOMITA, T. & SAKAI, E. (1939): Cenozoic geology of the Huginakimati district, Izumo province, a contribution to the igneous geology of the east Asiatic Province of cenozoic alkaline rocks. Jour. Shanghai Sci. Inst., Sec. 2, vol. 2, p. 147–204.

TOMITA, T. (1951): Types of magmatic evolution (in Japanese with English abstract). Mem. Fac. Sci., Kyushu Univ., vol. 3, p. 77–104.

TOMITA, T. (1958): Chemical distribution between the three principal series of basaltic rocks (in Japanese with English abstract). Jubilee Publ. Comm. Sixtieth Birthday Prof. Jun Suzuki, p. 193–211, Sapporo.

TOMKEIEFF, S. I. (1937): Petrochemistry of Scotish Carboniferous Permian igneous rocks. Bull. Volc., Ser. 2, vol. 1, p. 59–87.

TSUYA, H. (1934): On the configurations of the granite masses and the distribution of the quaternary volcanoes in the Tyugoku district, Japan. Bull. Earthq. Res. Inst., vol. 12, p. 249–259.

TURNER, F. J. & VERHOOGEN (1941): Igneous and metamorphic petrology. p. 1–602, New York.

TSUBOI, C. (1954): Gravity survey along the lines of precise levels throughout Japan by means of a Wordon gravimater, a chart attached to Bull. Earthq. Res. Inst., vol. 4, Suppl.

TUTTLE, O. F. (1952): Optical studies on alkali feldspars. Am. Jour. Sci., Bowen Volume, p. 553–567.

TYRRELL, G. W. & SANDFORD, K. S. (1933): Geology and petrology of the dolerites of Spitsbergen. Proc. Roy. Soc. Edimburgh, vol. 53, p. 284–321.

UCHIMIZU, M. (1966): Geology and Petrology of Alkali Rocks from Dōgo, Oki Islands. Jour. Fac. Sci. Tokyo Univ., 2, vol. 16 p. 85–159.

UEDA, Y. (1961): A study of the Goto group. Mem. Fac. Sci., Kyushu Univ., vol. 5, p. 51–61.

UFFEN, R. J. (1959): On the origin of rock magma. Jour. Geophys. Res., vol. 64, p. 117–122.

VERHOOGEN, J. (1954): Petrological evidence on temperature distribution in the mantle of the earth. Trans. Am. Geophys. Union, vol. 35, p. 85–92.

WADATI, K. (1935): On the activity of deep-focus earthquakes in the Japan Islands and neighbourhoods. Geophys. Mag., vol. 8, p. 305–325.

WADATI, K. & IWAI, Y. (1954): The minute investigation of seismicity in Japan. Geophys. Mag., vol. 25, p. 167–173.

WAGER, L. R. & DEER, W. A. (1939): The petrology of Skaergaard intrusion, Kangerdlugssuaq, east Greenland. Med. om Greenland, Bd. 105, no. 4, p. 1–352.

WAGER, L. R. (1956): A chemical definition of fractionation stages as a basis for comparison of Hawaiian, Hebridean, and other basic lavas. Geochim. et Cosmochim. acta, vol. 9, p. 217–248.

WAGER, L. R. (1960): The major element variation of the layered series of the Skaergaard intrusion and a re-estimation of the average composition of the hidden layered series and of the successive residual magmas. Jour. Petr., vol. 1, p. 364–398.

WALKER, F. (1940): Differentiation of the Palisade diabase, New Jersey. Geol. Soc. Am. Bull., vol. 51, p. 1059–1106.

WALKER, F. & POLDERVAART, A. (1949): Karoo dolerites of the Union of South Africa. Geol. Soc. Am. Bull., vol. 60, p. 591–706.

WALKER, F. (1952): Mugearites and oligoclase basalts. Geol. Mag., vol. 89, p. 337–345.

WALKER, F. (1953): The magmatic differentiates of the basic sheet. Am. Jour. Sci., vol. 251, p. 41–60.

WASHINGTON, H. S. (1917): Chemical analyses of igneous rocks. U.S.G.S. Prof. Pap., no. 99, p. 1–1201.

WASHINGTON, H. S. (1922): Deccan traps and other plateau basalts. Geol. Soc. Am. Bull., vol. 33, p. 765–803.

WATANABE, K. (1951): The chronological significance of coal (in Japanese with English abstract). Bull. Geol. Surv. Japan, vol. 2, p. 353–396.

WATERS, A. C. (1955): Volcanic rocks and the tectonic cycle ("Crust of the earth" Symp.). Spec. Pap. Geol. Soc. Am., vol. 62, p. 703–722.

WELLS, A. K. (1954): Mugearites and oligoclase basalts. Geol. Mag., vol. 91, p. 14–16.

WESTERVELD, J. (1952): Quaternary volcanism on Sumatra. Bull. Geol. Soc. Am., vol. 63, p. 561–594.

WILKINSON, J. F. G. (1956): Clinopyroxene of alkali-olivine basalt magma. Am. Miner., vol. 41, p. 724–743.

WILLIAMS, H. (1950): Volcanoes of the Paricutin region, Mexico. Bull. U.S.G.S., 965–B, p. 165–279.

YAGI, K. (1953): Petrochemical studies on the alkali rocks of the Morotu district, Sakhalin. Bull. Geol. Soc. Am., vol. 64, p. 769–809.

YAGI, K. (1959): Petrochemistry of the Cenozoic alkalic rocks of Japan and surrounding areas. Bull. Volc. Soc. Japan, Second series, vol. 3, p. 63–75.

YAMADA, N. (1961): Explanatory text of the Geol. Map of Japan, Okutsu sheet, Scale 1:50,000. Geol. Surv. Japan (in Japanese with English abstract).

YAMAGUCHI, M. (1958): Petrography of the Otozen flow on Shodo-shima island, Setouchi inland sea, Japan. Mem. Fac. Sci., Kyushu Univ., Ser. D, Geology, vol. 6, p. 218–238.

YAMAGUCHI, M. (1964): Petrogenic significance of ultrabasic inclusions in basaltic rocks from southwest Japan. Mem. Fac. Sci., Kyushu Univ., Ser. D, Geology, vol. 15, p. 163–219.

YAMAMOTO, T. (1960): Chemical studies of the volcanic rocks of Unzen district (in Japanese with English abstract). Bull. Volc. Soc. Japan, Second series, vol. 5, p. 69–74.

YAMANARI, F. (1922): Soda-pyroxene in the Tertiary and post-Tertiary alkaline rocks from the environs of the Sea of Japan. Jap. Jour. Geol. Geogr., vol. 1, p. 105–111.

YAMASAKI, T. (1959): Geologic structure and its relation to the volcanic activities of the Karatsu coal-field, Kyushu, 1 (in Japanese). Sci. Rep. Seisan Kagaku Inst., Kyushu Univ., vol. 26, p. 33–53.

YAMASAKI, T. (1960): Geologic structure and its relation to the volcanic activities of the Karatsu coal-field, Kyushu, 2 (in Japanese). Sci. Rep. Seisan Kagaku Inst., Kyushu Univ., vol. 27, p. 8–53.

YODER, H. S. Jr. (1952): Charge of melting point of diopside with pressure. Jour. Geol., vol. 60, p. 365–374.

YODER, H. S. Jr. & CHINNER, G. A. (1954): Phlogopite synthesis and stability range. Geochim et Cosmochim. Acta, vol. 6, p. 157–185.

YODER, H. S. Jr. & TILLEY, C. E. (1957): Basalt magmas. Carnegie Inst. Washington Year Book, vol. 56, p. 206–214.

YODER, H. S. Jr. & TILLEY C. E. (1962): Origin of basalt magmas: An experimental study of natural and synthetic rock systems. Jour. Petr., vol. 3, p. 342–532.

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北西九州・北松浦玄武岩類の岩石学的研究

倉沢　一

要　旨

西日本，北西九州・北松浦玄武岩類の分布地域は，環日本アルカリ岩石区の南西端に位置する。本地域の古期岩類からなる基盤は，南西方に分布する西彼杵半島の結晶片岩類，北東方の三郡変成岩類および花崗閃緑岩類である。これらを基盤とする第三系は，下位から相知層群，杵島層群，佐世保層群，野島層群および田平層（平戸層）の順に，東方から西方に向って順次上位の地層が露出している。それらの地質時代は漸新世から中新世に及んでいる。第三系は，東部の微褶曲地帯と，西部の盆状構造とに分けられる。後者の地域には佐々川断層がみられる。

褶曲構造がほぼ完成した後に，著しい北西—南東方向の断層運動が行なわれ，この構造線に沿って玄武岩類の噴出が行なわれた。玄武岩類は休止期を挾んで幾度もの噴火活動を行なって累積した。玄武岩類の厚さは，火山砕屑物を含めて最大 300 m，分布面積は 250 km^2 そして噴出量はおよそ 49 km^3 に及び，西日本玄武岩類の半分に達している。

これらの玄武岩類は，火山層序学的ならびに古地磁気学的方法によって，5つのグループに分類された。火山層序学的方法に対しては，玄武岩類に挾まれている上・下砂礫層および石英安山岩質凝灰岩層が重要な鍵層となっている。また，岩石の自然残留磁性を用いた古地磁気学的方法による熔岩類の対比は，2，3の例外を除いてよい一致をみた。5つのグループは下位から上位に，逆（強）・正・正（強）・逆および正（弱）の帯磁を示している。これらの残留磁性によってえられた各グループの磁極の方向，あるいは礫岩層の存在などによって示される火山活動の休止期などから，玄武岩類が単純な連続的噴火活動によって形成されたものではないことが認められた。つまり，それらは鮮新世中期から洪積世にかけて，かなり長い時代を通じて活動したものと考えられる。

計算された各グループの玄武岩類の噴出量から，グループのⅡ，Ⅲ$_2$ およびⅣがおよそ12〜18 km^3 の噴出量をもって，本地域の主要な活動となっており，またグループのⅠ，Ⅲ$_1$ およびⅤがおよそ2 km^3 以下の噴出量をもって，寄生的活動にすぎないことを示していることが認められた。

本地域は環日本海アルカリ岩石区と環太平洋造山帯とにまたがっているために，噴出量の違いはあっても種々の岩系の岩石が分布している。すなわち，火山層序学的に最下位のソレイアイト質な特徴をもった極少量の玄武岩類（グループⅠ）の活動にはじまり，次いで本格的な火山活動に入って，主要な活動のアルカリ岩系に属する火山岩類が数度の休止期を挾んで噴出した（グループⅡ〜Ⅳ）。最後は，強い混成作用の影響を受けて生成されたカルク・アルカリ岩系の火山岩類の活動で終っている（グループⅤ）。

換言すれば，この一連の火山活動において，過飽和玄武岩マグマの活動にはじまり，次第に強い不飽和玄武岩マグマの活動に移行し，次いで逆に弱い不飽和玄武岩マグマの活動を経て，最後に混成作用によって生成されたマグマの活動で終るという一つの火山活動の輪廻が認められた。

玄武岩類の主体をなすアルカリ岩系玄武岩類の主要構成鉱物は，斜長石，アノーソクレース，かんらん石，チタン輝石，アルカリ輝石および磁鉄鉱であり，また石基にはしばしばチタン黒雲母あるいは金雲母が産出する。ソレイアイト質岩系玄武岩類の構成鉱物は，斜長石，かんらん石，普通輝石および磁鉄鉱である。カルク・アルカリ岩系の構成鉱物は，斜長石，普通輝石，紫蘇輝石および磁鉄鉱であり，西日本の同岩系との間に大きな差は認められない。各岩系とも分化の著しく進んだ岩石は産出しない。ピジオン輝石は，カルク・アルカリ岩系の玄武岩あるいは安山岩中の斑晶かんらん石の周縁部に反応縁として晶出している。すなわち，アルカリ岩系の玄武岩マグマと異質物質との混成作用によって，ピジオン輝石が晶出する場合がある。

北松浦玄武岩類について，およそ100個の化学分析を行なった。玄武岩類のSiO_2は44～54％にわたっている。前述の方法で分類された玄武岩類の各グループは，化学成分において著しい差が認められる。とくにSiO_2に対するアルカリの成分変化では，グループⅠおよびⅢ$_1$は最も低く，Ⅲ$_2$において最も高い価を示している。つまり，グループⅠからⅡ，Ⅲ$_2$の順にアルカリに富む傾向が認められる。またグループⅣは逆にアルカリに乏しくなっている。最後の活動による噴出物のグループⅤは，それらから離れた位置，すなわちSiO_2およびアルカリに富んだカルク・アルカリ岩系の性質を示している。

結晶分化尺度（SI）でみた各化学成分の分化経路は，各グループによって異なっている。本地域のグループⅠおよびⅢ$_1$に属するソレイアイト質玄武岩類は，伊豆・箱根地方のピジオン輝石岩系に比較して，Al_2O_3，Na_2O，K_2OおよびTiO_2に富み，Fe_2O_3+FeO，CaOおよびMnOに乏しい。また，アルカリ岩系に属し最も強い不飽和岩系であるグループⅢ$_2$は，環日本海アルカリ岩石区の平均値に比較してSiO_2およびK_2Oに乏しく，Al_2O_3およびFe_2O_3に富む傾向が認められる。この他のアルカリ岩系のグループは大きな違いがみられない。

玄武岩類の各グループについてみると，グループⅢ$_2$の強い不飽和岩系は他のグループに比較して，SiO_2に乏しく，Fe_2O_3およびTiO_2に著しく富んでいる。また，そのグループのFe_2O_3およびTiO_2は分化の中期に濃集している。玄武岩類のアルカリ・石灰指数は各グループごとに異なるが，ソレイアイト質岩系は59，アルカリ岩系は50～54そしてカルク・アルカリ岩系は55～56である。このアルカリ岩系の指数は，西日本新生代火山岩類の指数（50～55）とよく一致している。高アルミナ玄武岩は本地域には見出されなかった。

北松浦玄武岩類は前述のように5つのグループに分類され，かつそれぞれ異なった性質を持っている。玄武岩類の噴出量，古地磁気学的性質，あるいは火山活動の連続・不連続性などから，それぞれのグループは独立したマグマから生成されたものと考えられる。そこで，各種の変化図から推定あるいは外挿して本源マグマの成分を求めた。グループⅠの本源マグマは，試料が少ないためにえられなかった。それらの本源マグマはすべて不飽和玄武岩マグマである。寄生的活動として噴出して，ソレイアイト質玄武岩と呼称している岩石は，きわめて弱い下飽和本源マグマに由来するものかもしれない。

それぞれの本源マグマの化学成分から，その飽和度を求める手段として，C.I.P.W.ノルム計算のSiO_2成分，つまり，ノルム石英の過・不足量を用いた。アルカリ岩系に属する各グループの本源マグマの不飽和度，すなわちノルム石英の不足量は，グループⅣ，ⅡそしてⅢ$_2$の順に大きくなっている。

ハワイ火山の研究によると，火山層序学的に，ソレイアイト岩系の活動に続いてアルカリ岩系の活動が行なわれたことが認められている。このマグマの発生した位置は，地球物理的な研究からおよそ地下60 kmにあると考えられている。さらに，上記2つの岩系の本源マグ

マは，それぞれ独立に異なった深さで生成され，後期に噴出したアルカリ岩系の本源マグマはさらに深所で生成されたと考えている研究もある。ハワイ地域でのこの活動順序は，北松浦玄武岩類の活動輪廻の前半と類似している。

北松浦玄武岩類の各グループは，独立に発生した本源マグマから生成され，またそれらの本源マグマは独立に異なった深さで発生したと考えられる。日本付近とくに北西九州付近の中・深発地震の分布から，その深さはおよそ数10 kmから300 kmであり，この深さと玄武岩類の本源マグマとの関連について考察した。これは，地震発生と本源マグマの生成とは密接な関係があるという立場に立脚したためである。前述の各本源マグマのノルム石英の不足量すなわち不飽和度と地震分布とを関連づけて2，3の考察をこころみた。

また，本地域の火山活動の輪廻の後半に認められた弱い不飽和アルカリ岩系とそれに続くカルク・アルカリ岩系の活動が，ハワイには認められていないこと，さらに両地域のソレイアイト（あるいはソレイアイト質）とアルカリ岩系の岩石との量比が逆，つまりハワイにおいてはソレイアイト岩系が活動の主体であるのに対して，本地域ではアルカリ岩系のそれが主要な活動であるという大きな相違点がある。これは，本地域が大陸地域の一部であり，しかも環太平洋造山帯との混合岩石区であることと，ハワイ地域が海洋地域であるという，岩石区の違いによるものと考えられる。

北松浦地域において認められたこの火山活動の一輪廻は，西日本玄武岩類の成因究明のための一つの手がかりとなるであろう。

PLATES
AND
EXPLANATIONS

(with 20 Plates)

Figs. 1 ~ 20 : Lower nicol only. × 20.
Figs. 1′ ~ 20′: Crossed nicols. × 20.
Ol: Olivine Au: Augite Pl: Plagioclase Hy: Hypersthene
Ag: Aggregate with magnetite and hypersthene in olivine
Mt: Magnetite

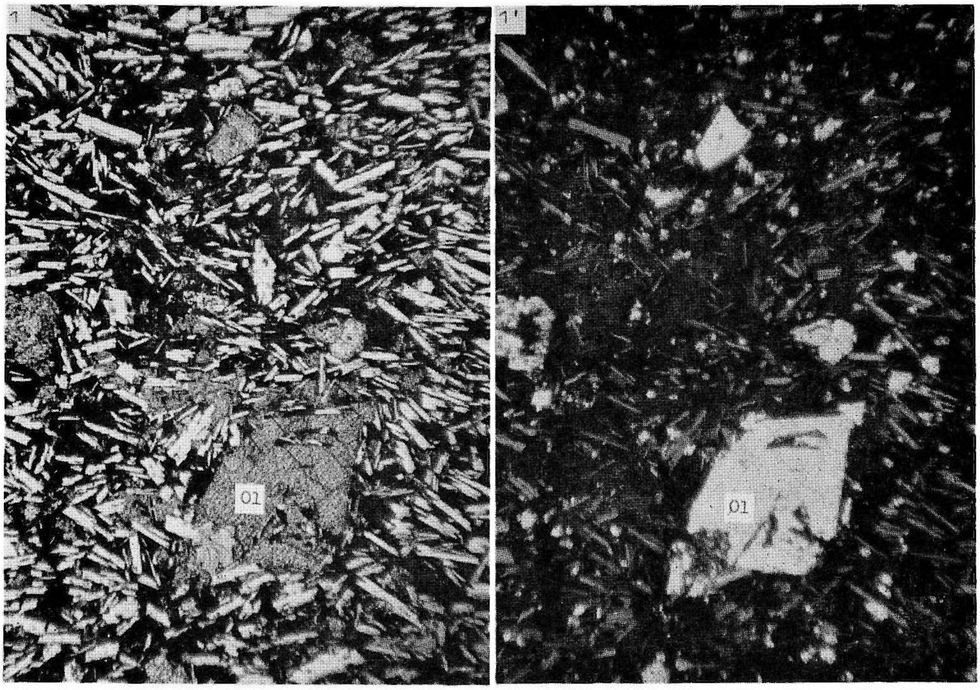

Fig. 1 Olivine basalt (Ku 60120207), Group I–2*. (*Refer to Tables 7, 8 and 10.)

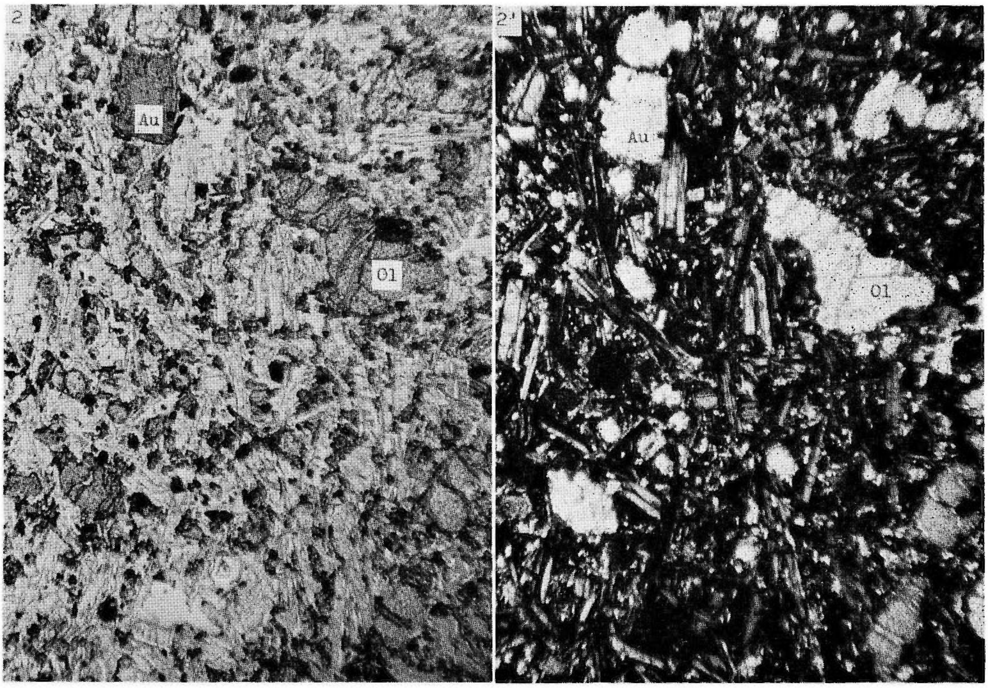

Fig. 2 Augite-olivine trachybasalt (Ku 59110408), Group II–1–5.

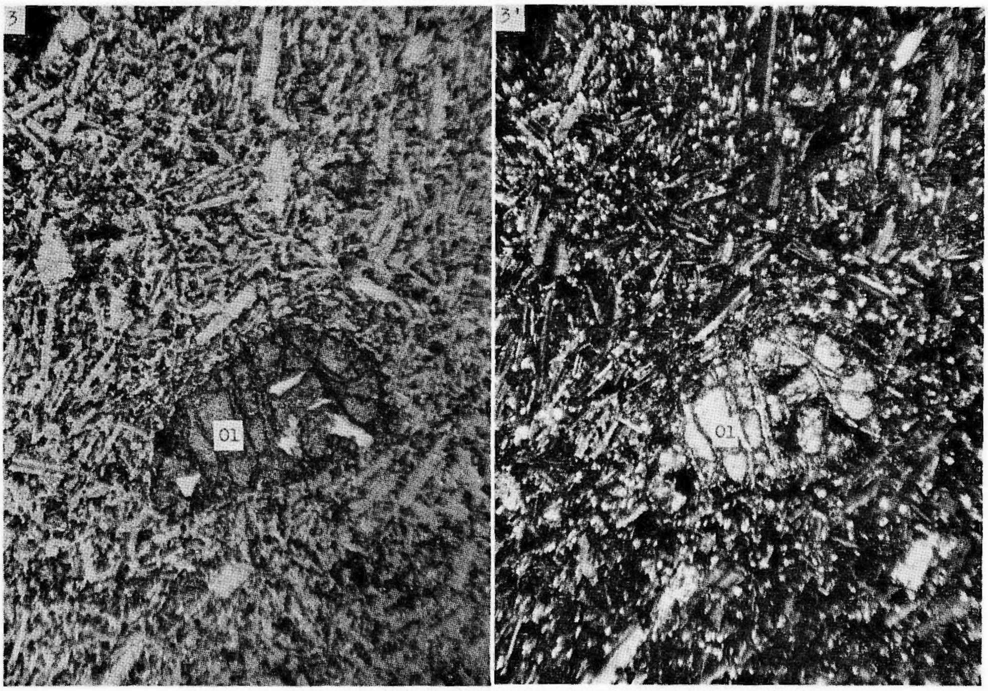

Fig. 3 Augite-olivine basalt (Ku 59103104), Group II–1–13.

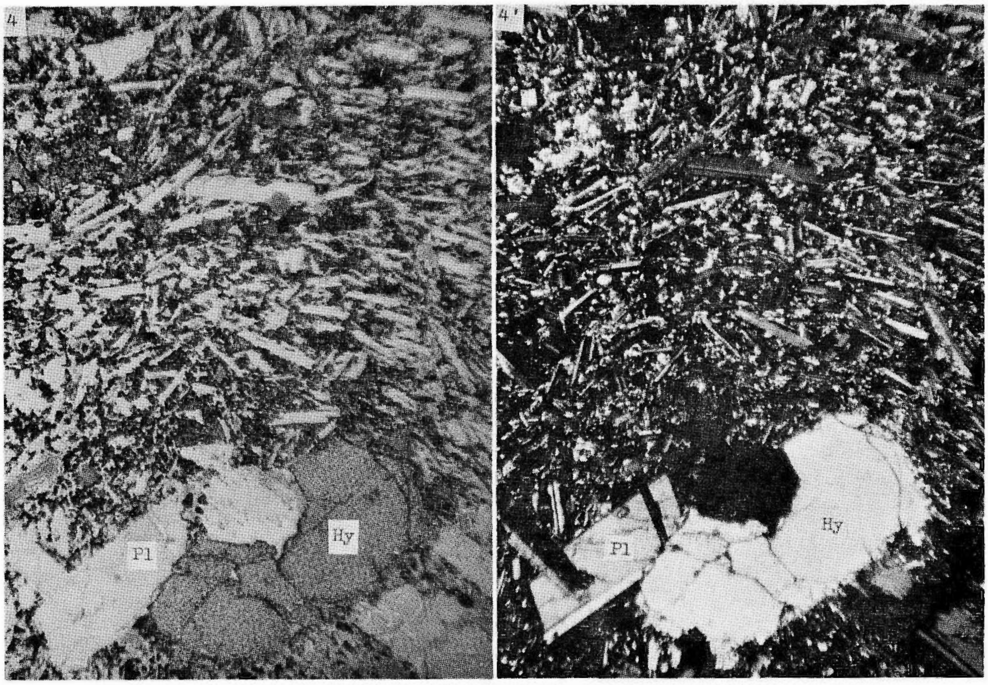

Fig. 4 Olivine-augite-bearing hypersthene basalt (KT 60121003), Group II–1–15.

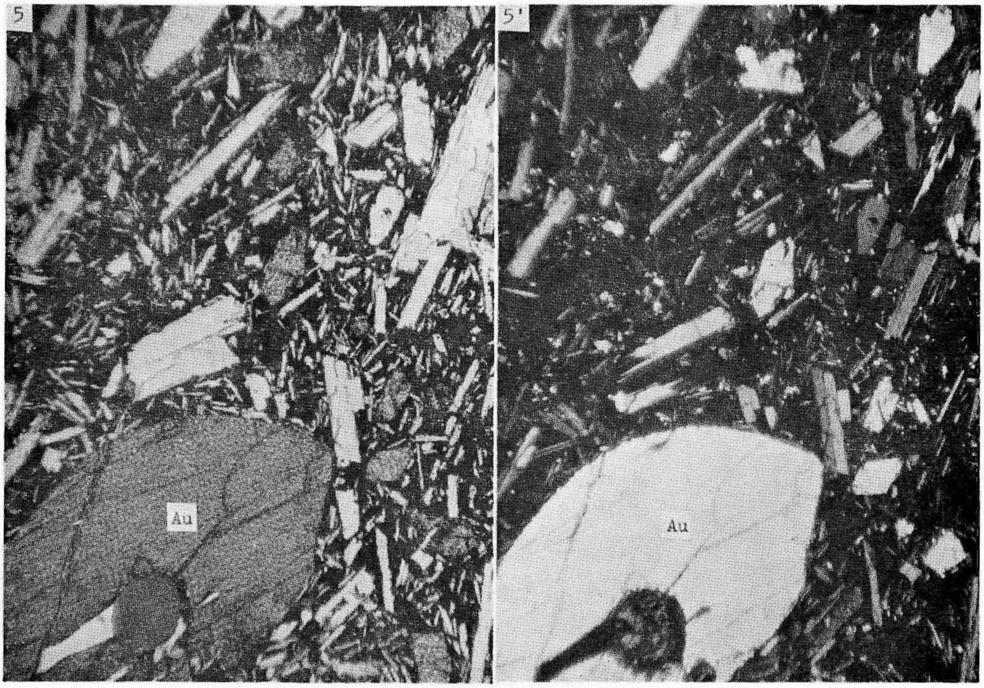

Fig. 5 Augite-olivine trachybasalt (Ku 60120507), Group II–2–5.

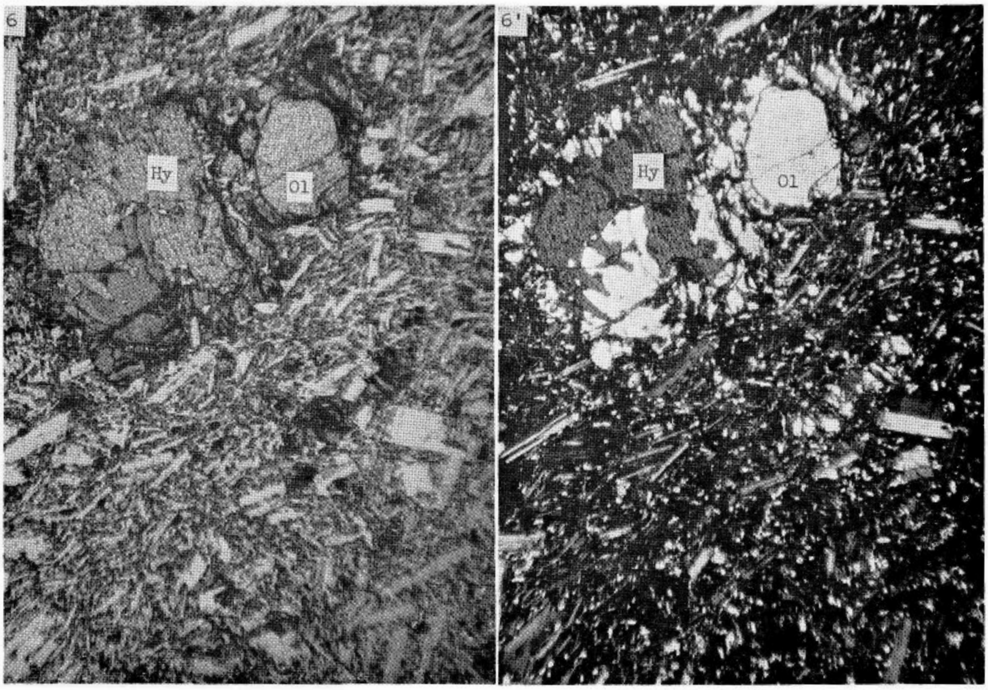

Fig. 6 Augite-hypersthene-olivine basalt (Ku 59102801), Group III$_1$–3.

Fig. 7 Olivine basalt (KT 59103106), Group III_1–4.

Fig. 8 Augite-olivine basalt (Ku 60120602), Group III_1-5.

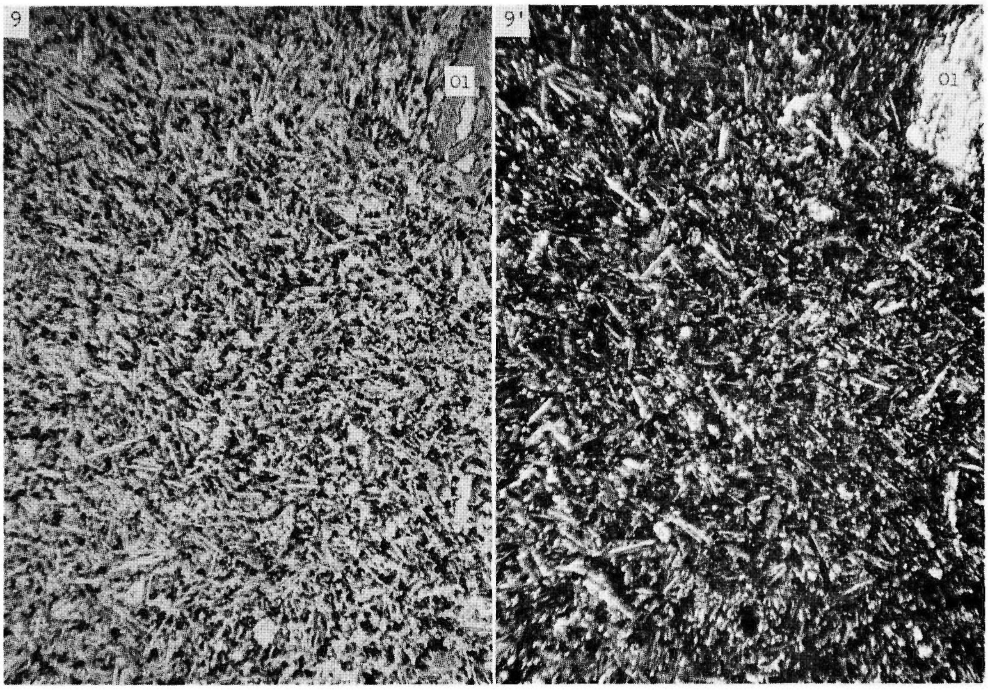

Fig. 9 Olivine-bearing trachybasalt (Ku 59102910), Group III_2–4.

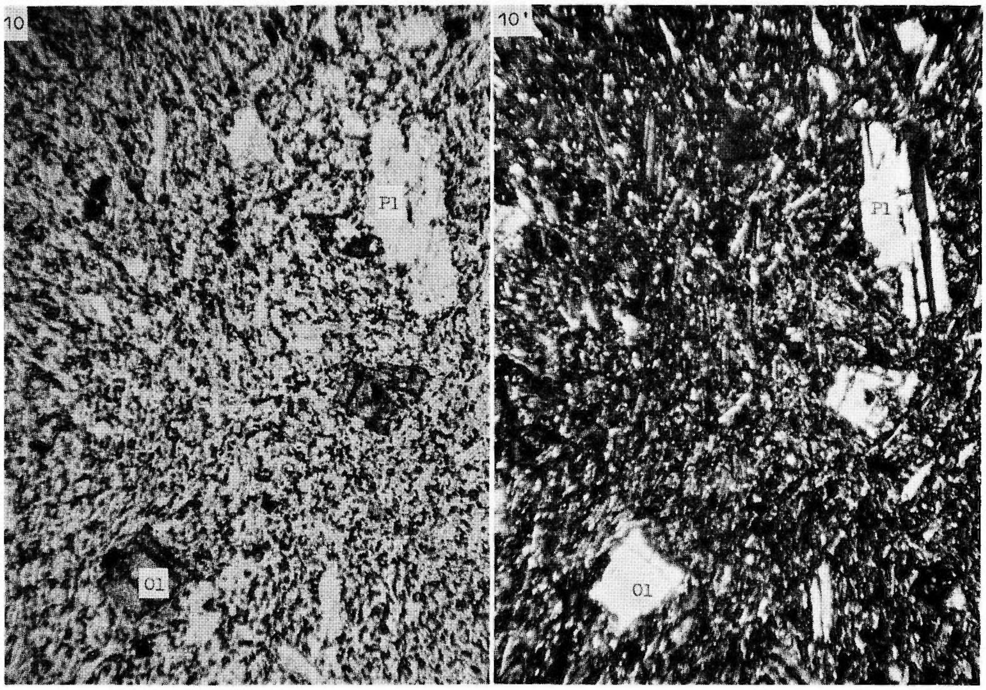

Fig. 10 Olivine mugearite (Ku 59103001), Group III_2–10.

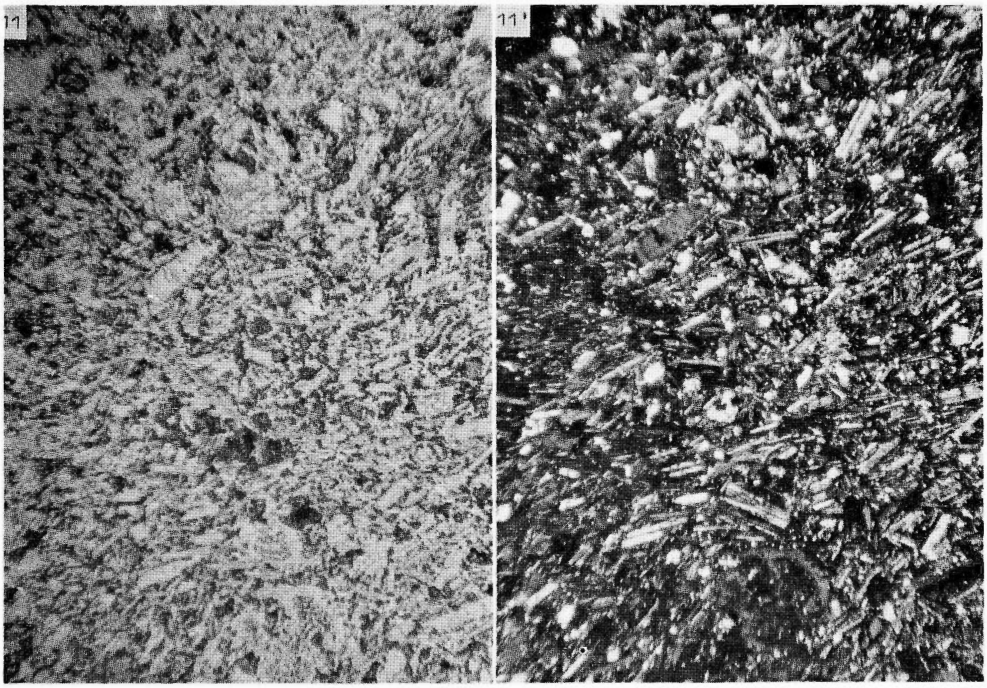

Fig. 11 Olivine mugearite (Ku 60121004), Group III_2–13.

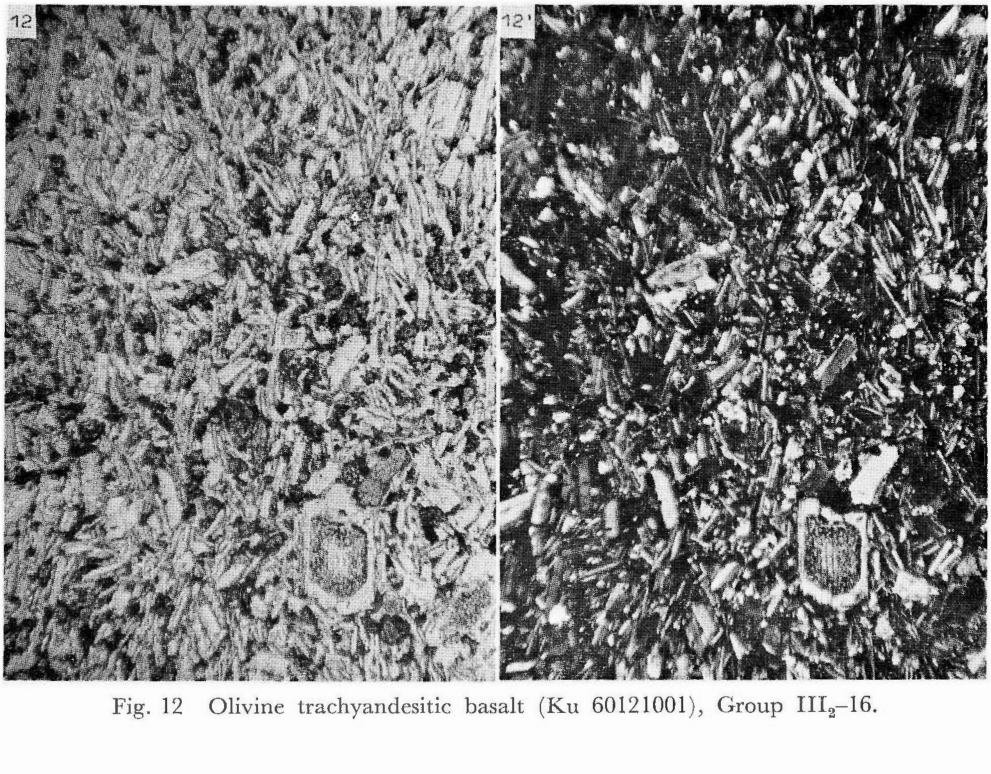

Fig. 12 Olivine trachyandesitic basalt (Ku 60121001), Group III_2–16.

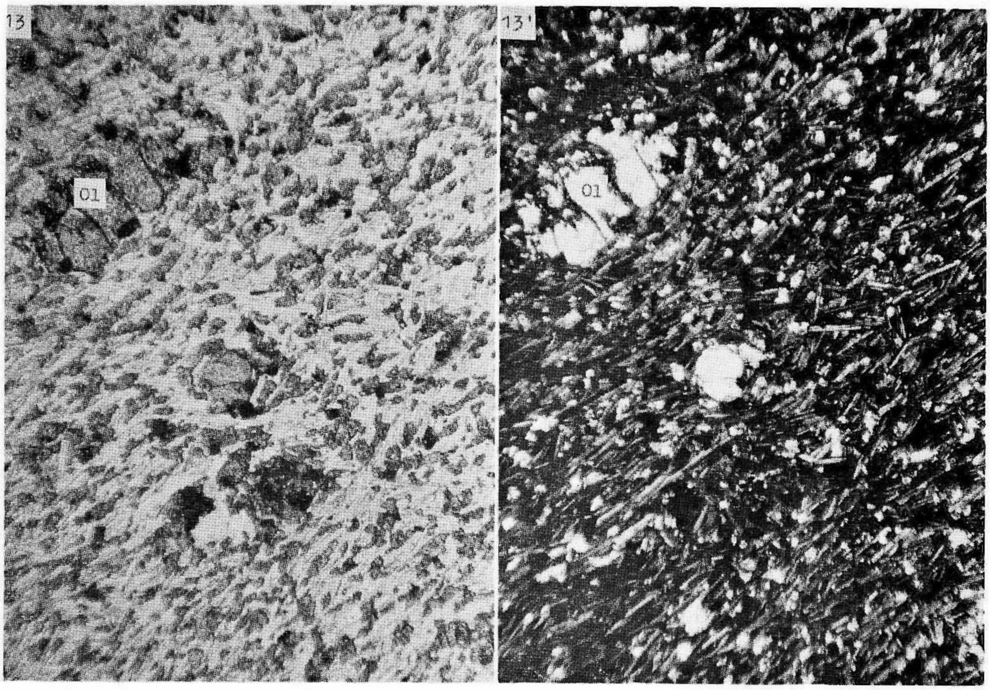

Fig. 13 Olivine basalt (Ku 60120901a), Group IV–4.

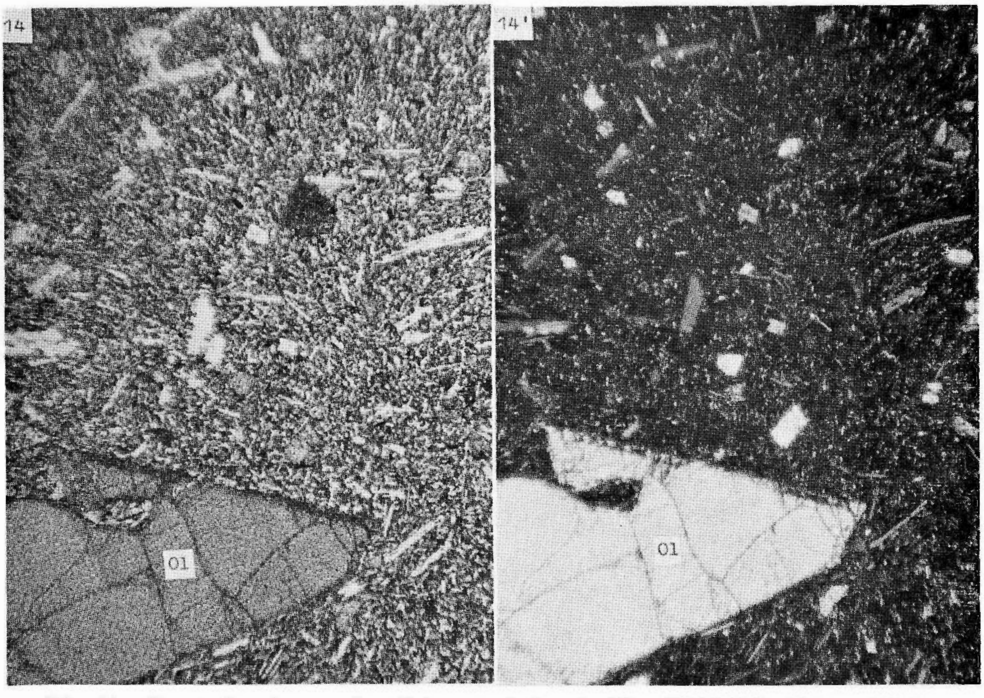

Fig. 14 Quartz-bearing augite-olivine trachybasalt (Ku 60120204), Group IV–5.

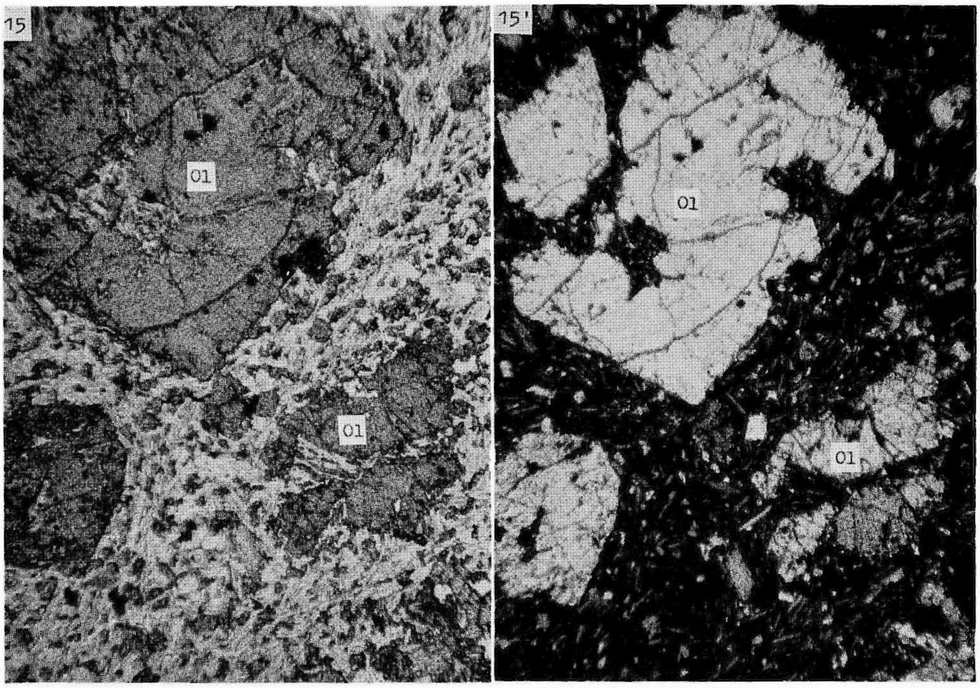

Fig. 15 Augite-olivine picritic basalt (Ku 59110403), Group IV–7.

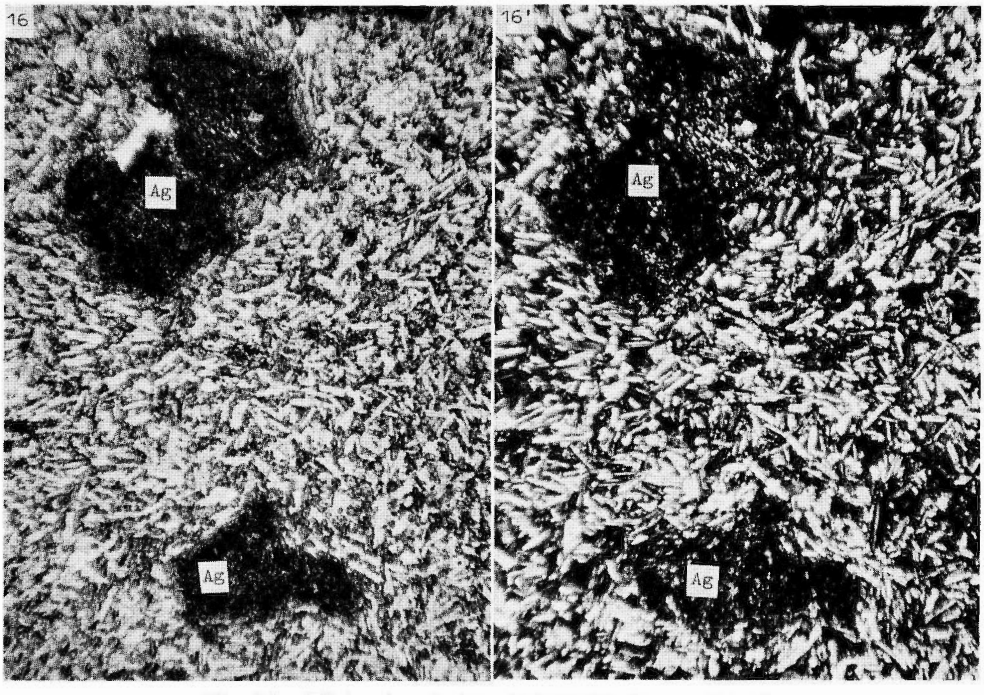

Fig. 16 Olivine basalt (Ku 59110402), Group IV–16.

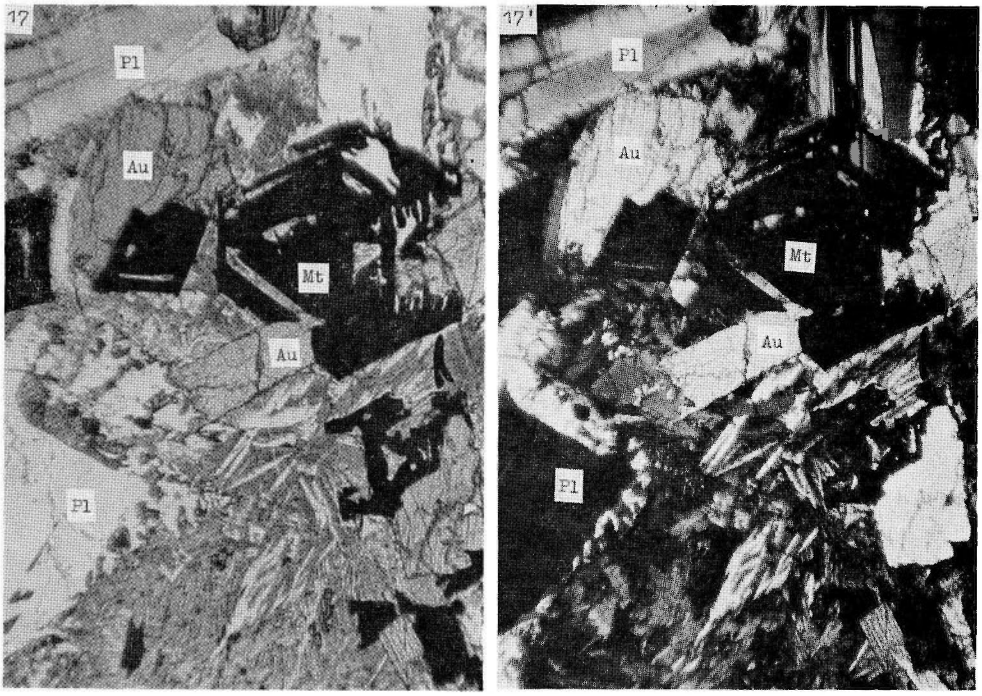

Fig. 17 Olivine-augite dolerite (Ku 60120901c), Group IV–14.

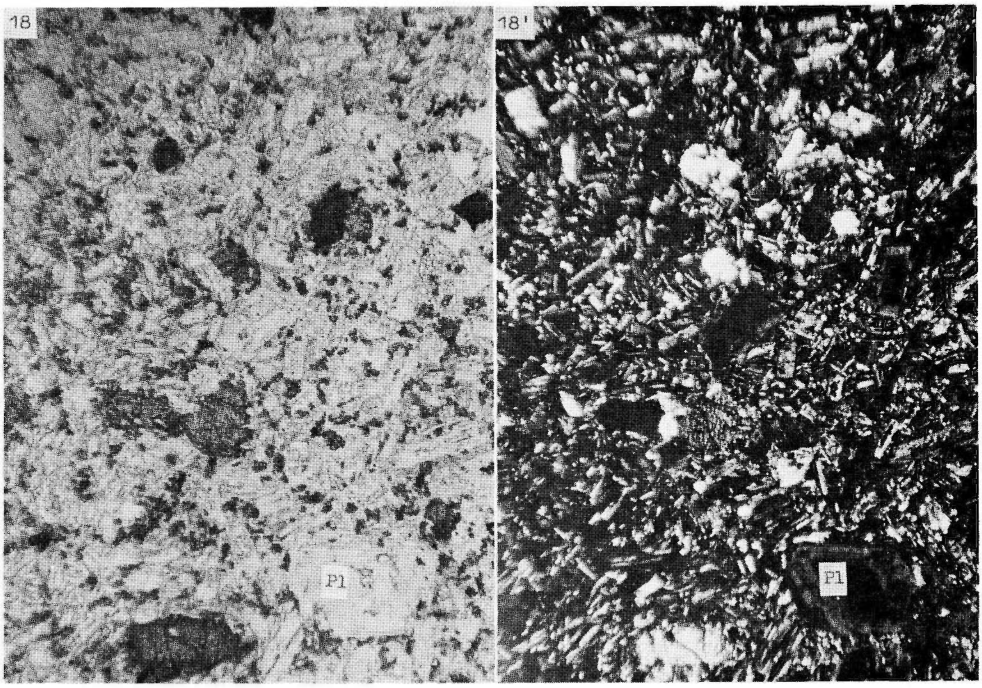

Fig. 18 Augite-olivine andesitic basalt (Ku 59103003), Group V–1.

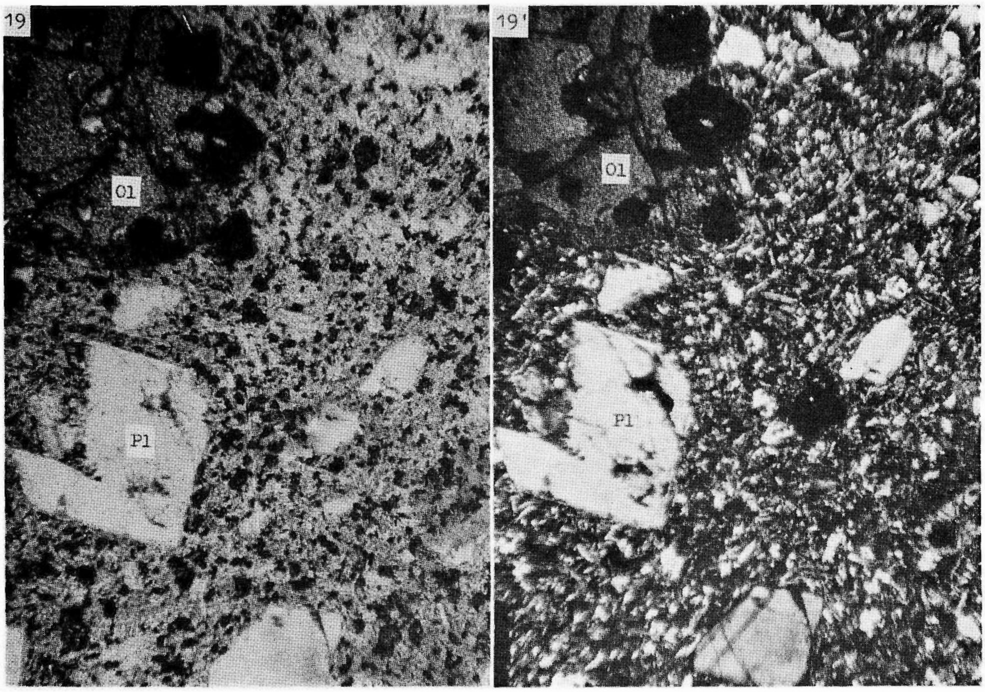

Fig. 19 Augite-olivine trachyandesite (Ku 59103002), Group V–2.

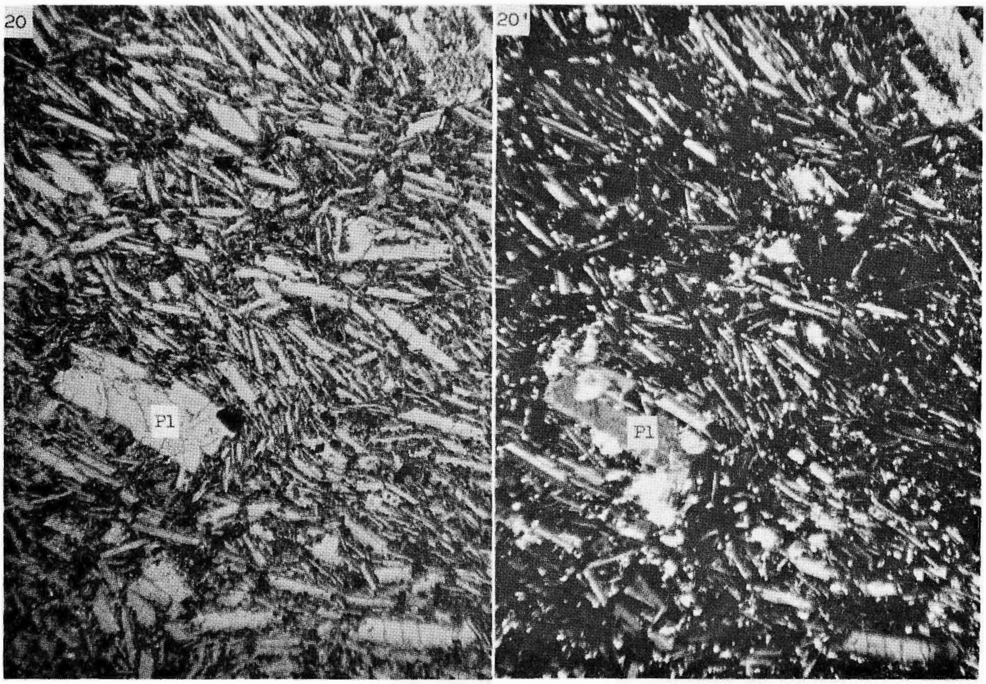

Fig. 20 Augite-olivine-bearing andesite (Ku 60120203), Group V–5.

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  - 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

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  - b. Petrology and Mineralogy
  - c. Paleontology
  - d. Volcanology and Hot spring
  - e. Geophysics
  - f. Geochemistry
- B. Applied geology
  - a. Ore deposits
  - b. Coal
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  - d. Underground water
  - e. Agricultural geology and Engineering geology
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- C. Miscellaneous
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Kurasawa, H.

Petrology of the Kita-matsuura Basalts in the Northwest Kyushu, Southwest Japan

Hajime, Kurasawa

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47 illus., 20 pl., 21 tab., 26 photo.

The Kita-matsuura basalts of the northwest Kyushu, Japan were classified into five groups, I through V, by the volcano-stratigraphic and paleomagnetic methods. The basaltic activities covered a long period, probably between Pliocene to Pleistocene. This serial volcanic activities can be regarded as one cycle of volcanism in a certain area. The variance of the basalts of this district was ascribed to different compositions of their parental magmas, that is, the parental magma of each group was generated independently.

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