PETROCHEMISTRY OF THE QUATERNARY VOLCANIC ROCKS OF HOKKAIDO AND SURROUNDING AREAS

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CONTENTS

I Introduction

Two younger island arcs, the Kuril and the Honshu, are joined together in Hokkaido, and their major geotectonic character controls the arrangement of Quaternary volcanoes in Hokkaido and surrounding areas. Thirty-six Quarternary volcanoes (or volcanic groups) have erupted in Hokkaido, most of them were formed through central eruption, and some of them built gigantic calderas of Kurakatoan type. The volcanic products occupy ca. 20% of the area of Hokkaido, while the pumice-fall and -flow deposits cover almost 50%.

Petrographycally speaking, most of their volcanic rocks are comprised in a basalt-andesite-dacite-rhyolite suite of calcalkali rock series which were usually associated with the folded mountain chains fringing the ocean. Some contrasted differences, however, have been noted in their chemical and mineralogical characters among the rocks of each volcano or volcanic zone. In his earlier papers, the present writer showed that the rocks of the Chôkai zone, along the inner arc of northern Honshu, have higher content of alkalies than those of the other volcanic zones in Japan, especially than those of the Nasu zone lying to its east (KATSUI, 1953 & 1954). Thus, the zonal arrangement of the Quaternary petrographic provinces along the island arcs of Japan were recently established by ISHIKAWA and the writer (ISHIKAWA & KATSUI, 1959). It is true that volcanoes made up of the more calcic lavas are arranged at the outer side not only in the Japanese Islands, but also widely in the circum-Pacific region, such as in Kamchatka (TOMKEIEFF, 1949) and Indonesia (RITTMAN, 1953).

It has long been accepted that calc-alkali volcanic rocks associated usually with the orogenic belts, through ultimate basaltic parentage, have derived in part from sialic contamination. An important suggestion is given here by the fact that alkali olivine-basalt undersaturated in silica actually erupted together with calc-alkali andesites from the Oshima-ôshima volcano of the Chôkai zone (KATSUI, 1954) ; on the other hand such occurrence of mafic andesite of tholeiitic type also associated with calc-alkali rocks was known in the volcanoes of Usu and Towada of the Nasu zone (YAGI, 1953 and KAWANO, 1939). From these facts, the writer has come to the opinion that the marked difference between the calc-alkali rocks of the Chôkai zone and those of the Nasu zone owed its origin to the difference in character of their parental basaltic magmas, i.e. alkali olivine basalt magma and tholeiite magma respectively (KATSUI, 1956). The writer believes that this hypothesis has a good agreement between the zonal arrangement and petrogenesis in the Kuril arc as well as in the northern Honshu arc (KATSUI, 1958).

Very recently, during the preparation of the present paper, KUNO (1959) published "Origin of Cenozoic petrographic provinces of Japan and surrounding areas." KUNO's opinion is much in agreement with the writer's views.

This paper is intended to describe in preliminary manner the work, in which the writer has been engaged for the last ten years in the fields of volcanology and petrology. In this paper, all available data on the chemical compositions of the Quaternary volcanic rocks of Hokkaido are collected, of which one half or more of the chemical analyses were performed by the writer himself; then the chemical and mineralogical characters of these volcanic rocks are described; and lastly, origin of these volcanic rocks and petrographic provinces is considered in view of recent ideas of petrogenesis and geotectonics.

II Acknowledgement

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III Distribution of the Quaternary volanoes in Hokkaido

The total number of the Quaternary volcanoes (or volcanic groups) in Hokkaido is 36, of which 7 are known with historical activity, viz., Shiretoko-iwo-zan, Me-akan-dake, Tokachi-dake, Tarumai, Usu, Komaga-dake and Oshima-ôshima (Fig. 1).

On the distribution of the volcanoes in Hokkaido, different classifications or zonings have been proposed from different points of view. A well known classification, such as the Chishima (Kuril), the Nasu and the Chôkai zones, is based on the geographical view point. Accordingly, this classification does not imply that the volcanoes belonging to a single zone should have a common mineralogical or chemical characteristics. For instance, the writer has shown that the rocks of Rishiri, northwest of Hokkaido, have a high alkali content, yet it lies at the northern end of the Nasu zone, whose rocks are generally characterized by low alkali content (KATSUI, 1953). With the progress of petrographical study, a classification based on the petrographical character has been proposed. Thus, ISHIKAWA and KATSUI (1959) proposed the following classification;

I Volcanoes on the Kuril arc:
- Ia Chishima volcanic zone
- Ib Western subzone of the Chishima volcanic zone (or Daisetsu volcanic zone)
- (Ic Inner subzone of the Chishima volcanic zone)

II Volcanoes on the northern Honshu arc:
- IIa Northern subzone of the Nasu volcanic zone
- IIb Nasu volcanic zone

(IIc South part of the Nasu volcanic zone)
IId Chôkai volcanc zone

Natural or genetic classifications of volcanic zones or chains are most desirable. For this purpose, studies must be make from various point of view, viz., geographical distribution and geotectonic controls, historical evolution, type and scale of volcanic activity, mineralogical and chemical character of the volcanic rocks and their genetic relation, etc. After consideration, the following statement may be made as to the distribution of volcanoes in Hokkaido.

"Most of volcanoes are divided into two major groups; one comprises those along the Kuril arc, and the other those along the northern Honshu arc. Two volcanic chains along the Kuril arc are recognized; 1) the Shiretoko-Akan in east Hokkaido, and 2) the Daisetsu-Tokachi in the central Hokkaido. In western Hokkaido, volcanoes along the northern

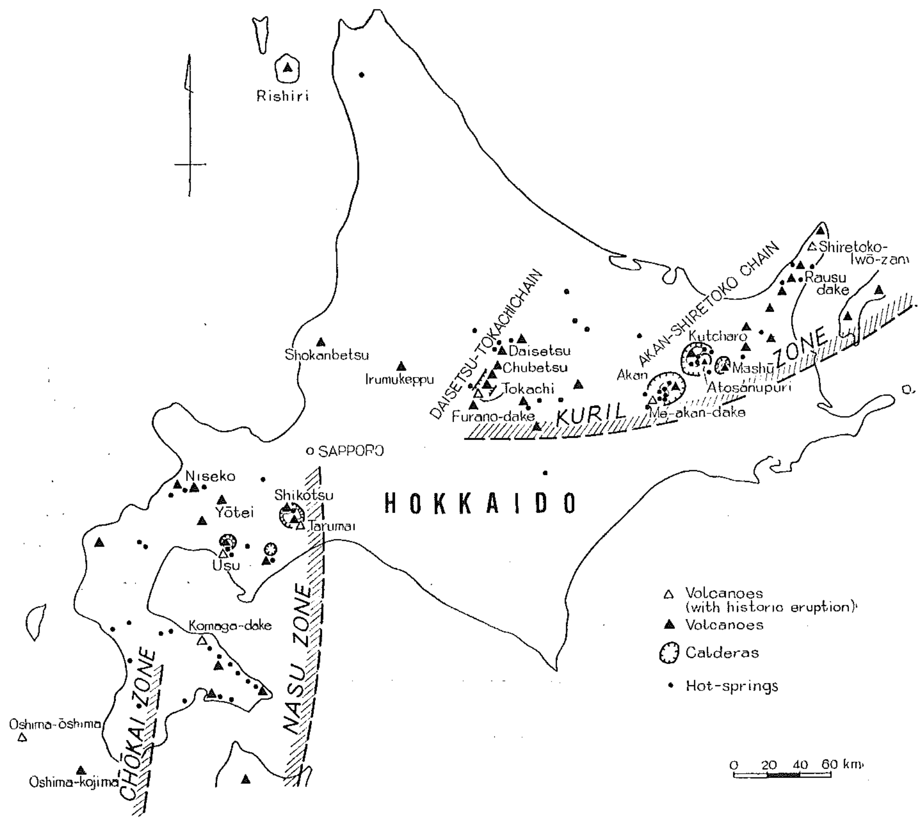


Fig. 1. Distribution of the Quaternary volcanoes in Hokkaido.

Honshu arc are comprised in two parallel volcanic zones; one is called 3) the Nasu zone, and the other 4) the Chôkai zone lying to the west of the former. Beside them, 5) a few volcanoes lie scattered in the inner side of the knot of the above two major arrangements; Irumukeppu, Shokanbetsu and Rishiri" (Fig. 1).

One housld be made aware of some important features of the above distribution.

a) From the geotectonic view point, it has been noticed that the Kuril and northern Honshu arcs are double, composed of inner and outer arcs, respectively (TOKUDA, 1926). Geological units are distributed zonally either in the Kuril arc or in the northern Honhu arc from the west or the inner to the outer sides as follows; 1) Japan Sea basin or Okhotsk Sea basin, 2) Inner arc (green tuff region) with volcanic belt, 3) outer arc and 4) Pacific oceanic basin surrounded by the Japan trough (MINATO, *et al.*, 1956). It is evident that not only the Quaternary volcanoes above mentioned, but also areas of Neogene volcanic activity, so called "green tuff regions", are distributed only in the inner arcs. Accordingly, volcanoes are, and always have been, concentrated chiefly within the inner arcs, since the Neogene period. MINATO and his collaborators published excellent studies on the formation of this green tuff regions bearing igneous activity to the effect that the igneous activity of the green tuff regions in the Pliocene and Quaternary periods can be interpreted as the final ignneous activity correspoding to the geologic history of the formation, filling up, and then finally complete emergece of the geosyncline (MINATO, *et al.* 1956).

b) Amog the Quaternary crustal movements, the most outstanding evidences are manifested by volcanism restricted to the inner arc and by seismic activity concentrated in a zone of the outer arc. From the geophysical view point, the former may be regarded as a mechanism which discharged thermal energy, while the latter was a sudden releasing of kinetic energy. Both endogenetic energies are estimated as having been of nearly equal order in scale (YOKOYAMA, 1958). It is well known that the depth of foci descends gradually from the oceanic side toward the Asiatic continent, and under the active volcanic zones it reaches to about 100-200 km (WADATI, 1935 and TOKAREV, 1958). Intimate relations may be concealed between volcanism and seismic activity; this matter will be treated chapter IX.

c) It goes without saying that among the volcanic zones or chains above mentioned both the Shiretoko-Akan chain and the Nasu zone are situated in the most outer zone which will be called "the front volcanic zone" or simply "the front zone" in the following description. All other volcanoes or volcanic zones are located in another zone or area which is called "the inner volcanic zone" or simply "the inner zone." Following marked differences are recognized between the front volcanic zone and the inner zone. The former includes crowded comparatively younger volcanoes, some of them yet retaining activity. A number of hot springs and solfataric fields are also associated with this zone. The rocks of the front zone are composed mainly of pyroxene-andesite, characterized by low content of alkalies and high content of CaO and Al_2O_3. On the other hand, volcanoes distributed in the inner zone lie scattered, most of them have ceased their activity and generally they are dissected. The rocks of the inner zone are characterized by richness in alkalies and common occurrence of hornblende- and/or biotite-bearing andesite, dacite and rhyolite which scarcely occur in the front zone.

IV Mineral composition of the Quaternary volcanic rocks of Hokkaido

TABLE 1. Quaternay volcanic rocks of Hokkaido. (1)

Rocks \ Volcanoes	Shiretoko-Akan chain	Nasu zone	Daisetsu-Tokachi chain	Niseko	Irumukeppu & Shokanbetsu	Rishiri	Chōkai zone
Basalt & Mafic andesite	IVc 1 Vc 2 Ic 1		IVb→c 1 Vc→d 2 Vd 1	(Vc)	(IVb) (IVc)	IVb 6	IVb 2 (IVc)
Color index 30 — Color index 10	c 1 Vd→c 1 Vd 5 V 2	Vc 1 Vd→c 1 Vd 8 V 8	Vd 3 VId 2 XVId 1 (XVII)	VId 1	V 1 V-VI 3 VId 2 VI 3 VIII 1 XVIII 1	Vd 1 Ie 1 (Ve) (VId) (VIe)	VId 2 XVId 1 (IVd) (Vd) (IXd) (XIX)
Dacite Or<An	Vd 3 Vd-e 1 Ve 1 V 3	V 1 Ie 3 I 1 VI 2	(XVI)				
Rhyolite Or>An		VI 1	(XVI)				

Figure of classification indicated in Table 2. Open figures and their numbers show the analysed rocks listed in Table 3. Figures closed by ( ) show the other representative rocks in each volcanic field.

All of the Quaternary volcanic rocks of this area, analysed and not analysed, are made up of a wide range of basalt-andesite-dacite-rhyolite as shown in Table 1. Their respective mineral composition represented on Kuno's classification of the ferro-magnesian silicate mineral assemblage, are shown in Table 2.

TABLE 2. Quaternary volcanic rocks of Hokkaido. (2)

Groundmass / Phenocrysts	Olivine Mono. Py. Ortho. Py.	Olivine Mono. Py.	Mono. Py.	Mono. Py. Ortho. Py.	Ortho. Py.	Glassy	Groundmass + Phenocryst Biotite
Ortho. Py.	Ia	Ib	Ic ○	Id	Ie ○ ○○○ ●	I ○	XI
Olivine Ortho. Py.	IIa	IIb	IIc	IId	IIe	II	XII
Olivine	IIIa	IIIb	IIIc	IIId	IIIe	III	XIII
Olivine Mono. Py.	IVa	IVb ●●●● ●●●● ●	IVc ○ ■	IVd ■	IVe	IV ■	XIV
±Olivine Mono. Py. Ortho. Py.	Va	Vb	Vc ○○	Vd ○ ←○○ ○○○○○ ○○○○○ ○○○○○ →●● ●●●●● ○	Ve ○ ■	V ○○○○○ ○○○○○ ○○○○ ● ●●	XV ●
±Olivine Mono. Py. Ortho. Py. Hornblende	VIa	VIb	VIc	VId ●●●●●●●	VIe ■	VI ○○○ ●●●●	XVI ●●
±Olivine Ortho. Py. Hornblende	VIIa	VIIb	VIIc	VIId	VIIe	VII	XVII ■
±Olivine Hornblende	VIIIa	VIIIb	VIIIc	VIIId	VIIIe	VIII ●	XVIII ●
±Olivine Mono. Py. Hornblende	IXa	IXb	IXc	IXd ■	IXe	IX ■	XIX ■
Mono. Py.	Xa	Xb	Xc	Xd	Xe	X	XX
None	a	b	c ○○	d	e		x

Classification made according to the ferromagnesian silicate mineral assemblage proposed by KUNO (1950). Open circles: analysed rocks listed in Table 3 of the front volcanic zone which comprises the Shiretoko-Akan volcanic chain and the Nasu volcanic zone; solid circles: analysed rocks listed in Table 3 of the inner volcanic zone which comprises the Daisetsu-Tokachi volcanic chain, the volcanoes Irumukeppu, Shokanbetsu, Rishiri and Niseko and the Chôkai volanic zone; solid squares: other representative rocks of the inner zone.

The nature of the leading rock types will be briefly described in the following.

Basalts of type IVb (Table 3, columns 44-49, 79 & 80), comprise most mafic members of the rocks of this area; they are characterized by the presence of olivine as phenocryst and groundmass minerals and also by the undersaturation of silica.

Occurrence of the basalts of this type are restricted to the Japan Sea region (or the inner volcanic zone), such as the volcanoes of Rishiri and Oshima-ôshima where these basalts are found together with hornblende- and rarely biotite-bearing pyroxene-andesites. Phenocryst consists of olivine, augite and plagioclase; while the groundmass is composed of lath-shaped plagioclase, augite (rarely with titan-augite), olivine, iron ore, interstitial alkali-feldspar and apatite, showing usually intersertal or intergranular textures. It is evident that olivine formed consistently during both phenocryst and groundmass crystallizations, without reaction relation to monoclinic pyroxene. Biotite as a deuteric mineral is also found, but no silica minerals in any specimen. Rare occurrence of groundmass anhydrite, as a primary pyrogenetic mineral, was reported in the olivine-basalt dyke of the Rishiri volcano. (KATSUI, 1958b).

Basalt of type IVb→c (Table 3, column 29), occurs only from Furano-dake of the Tokachi volcano in central Hokkaido. The nature of the basalt of this type resembles that of type IVb, except for groundmass mineral composition. Groundmass consists of plagioclase, augite∼pigionitic augite, iron ore, alkali-feldspar, cristobalite, olivine and apatite, showing fine intersertal texture. The presence of pyroxene-rimmed olivine and cristobalite distinguishes the basalt of this type from that of type IVb in which olivine is entirely free from the reaction-rim and no silica mineral can be found.

Basalts and mafic andesites of types IVc, Vc, Ic, and c (Table 3, columns 3, 4, 8, 9, 14, 20 and 67), are rather common rocks in the front volcanic zone, viz., somma lavas of Kutcharo, Mashû, Akan and Usu, but never appear in the inner volcanic zone. Phenocryst is variable in composition; that is, in most mafic rocks combinations of plagioclase+olvine+augite (type IVc) are representatives, but in the others combinations of plagioclase+augite+hypersthene (type Ic) are common. Aphyric or nearly aphyric rocks are also found (type c). On the contrary, groundmass is consistently composed of lath-shaped plagioclase, augite∼pigionitic augite, iron ore, silica minerals (cristobalite or tridymite) and apatite, showing usually intersertal texture. Olivine and hypersthene phenocrysts are always framed by a narrow reaction rim of pigionitic augite. Thus, it is easy to estimate that in the intratelluric stage olivine, augite and hypersthene might have continued crystallization, but in the effusive condition they were replaced only by the crystallization of the monoclinic pyroxene.

Plagioclase phenocryst in the rocks of this type is usually calcic; large anorthite or calcic bytownite crystals larger than 1 cm or more in diameter are occasionally found in some rocks. (ISHIKAWA, 1951; YAGI, 1953 & KATSUI, 1955).

Andesites of type Vd→c (Table 3, columns 10 & 63), occurs also from the front volcanic zone, such as from the volcanoes Mashû and Yôtei, accompanied with the rocks of type Vc. The nature of andesite of this type is much like that of the andesites of type Vc, except for the presence of groundmass hypersthene which is usually surrounded by pigionitic augite. In this type, crystallization of hypersthene continued until early stage of the effusive condition.

Basalts and mafic andesites of type Vc→d (Table 3, columns 28 & 30), are found in central Hokkaido, where they build up extensive lava flows of the Tokachi and Chubetsu volcanoes. Phenocryst contains plagioclase, augite, hypersthene, olivine and magnetite. Groundmass is composed of lath-shaped plagioclase, augite, hypersthene, iron ore, tridymite, alkali-feldspar and a small amount of apatite and brown glass, showing intersertal texture. Olivine and hypersthene phenocrysts and a part of groundmass (or microphenocrystic) hypersthene are surrounded by reaction-rim of monoclinic pyroxene. Accordingly, it can be said that in the rocks of this type, monoclinic pyroxene replaced the crystallization of olivine and hypersthene only at the early stage of groundmass formation, but in the following stage both monoclinic and rhombic pyroxenes continued parallel crystallization without mutual reaction relation.

Plagioclase phenocryst which includes zoned dust, corroded sodic core and aggregations of pyroxene and magnetite grains as pseudomoph after hornblende, are frequently found; they indicate contamination of the magma.

Andesites (partly dacites) of type Vd (Table 3, columns 1, 2, 5, 12, 13, 16, 19, 22, 23, 24, 25, 31, 50, 52, 57, 58, 60, 61, 64, 65 & 66), are the predominant rocks throughout this area. For instance, most of lavas and fragments of the volcanoes of Shiretoko-iwo-zan, Tarumai, Yôtei and Komaga-dake are comprised of andesites of type Vd.

The rocks of this type always show strong porphyritic structure, owing to abundant presence of plagioclase phenocrysts which show various zonal textures; some of them have calcic or sodic cores. Large anorthite or calcic bytownite crystals are occasionally found in the rocks of the front volcanic zone. Olivine is frequently present, usually in the mafic members. The ratio between the amounts of hypersthene and augite phenocrysts is widely varied, but in most of the rocks the former is more abundant than the latter. Groundmass shows various textures, and is characterized by the presence of both augite and hypersthene, as a result of parallel crystallization free from reaction relation. Silica minerals are found in considerable amounts in groundmass, rearely up to about 37% in dacite. Alkali-feldspar, usually found as an intertitial mineral, is generally more abundant in the rocks of the inner volcanic zone than in those of the front zone.

Most of the pumice and welded tuff from the front volcanic zone are comprised in andesite and dacite of type V, having glassy groundmass (Table 3, columns 6, 7, 11, 18, 21, 53, 59, 62, 72, 73, 74, 75, 76 & 77). Presumably, most of these rocks would have resulted in type Vd, due to complete equilibrium.

Aggregations of pyroxene or magnetite as a pseudomorph after hornblende are frequently found, mainly in the rocks of the inner volcanic zone. The rocks including such aggregations are of transitional type from VId to Vd.

Felsic andesites and dacites of types Ie and Ve (Table 3, columns 15, 17, 51, 68, 69 & 71), are characterized by the presence of hypersthene as the only ferromagnesian silicate mineral in groundmass. Phenocrysts may contain augite beside hypersthene, but not olivine in any specimen in this area. Silica minerals and alkali feldspar are usually found as interstitial minerals. Most of the rocks included in type Ie or Ve are more felsic than those of type Vd and frequently erupted in the later stage of the volcanism, building up viscous lava domes or lava tongues. The well-known new dome lava (erupted in 1943-1945) of Showa Shinzan, one of the lava domes of the Usu volcano, is comprised of a representative dacite of type Ie. (YAGI, 1953).

Andesites of type VId (Table 3, columns 26, 27, 34, 36, 43, 78, 81 & 82), are characterized by the presence of hornblende in addition to pyroxenes in phenocrysts. Their occurrences are restricted to the inner volcanic zone. In other words, all of the volcanic fields of the inner zone are always possess rocks of this type.

The most striking feature seen in the rocks of this type is that phenocrystic minerals are very complicated; that is, plagioclase, augite, hypersthene, hornblende and magnetite are always contained, often together with olivine and quartz, contrasting to their rather simple groundmass which is like those of type Vd. Such feature is very similar to one possessed by the rocks of the Norikura volcanic zone in central Japan (ISHIKAWA, 1958) and of the San Juan region in Colorado (LARSEN *et al.*, 1936-

1938). Presumably, all of the phenocrysts did not crystallize from a magma simply through complete equilibrium, but must have been derived from the partial assimilation of other rocks and/or by the mixing of two magmas. This is obvious in view of the following features.

Various types of zoning; normal, oscillatory and reverse, are found in plagioclase phenocrysts. Some of them have a dust core, and include fine aggregates of plagioclase and pyroxene grains presumably formed through hornfels of argillaceous rock origin. Olivine and quartz are usually corroded. Nearly all hornblende phenocrysts included in the moderately crystalline groundmass show brown—reddish brown in color, some of them released magnetite as a result of intense oxidation (magmatic resorption) which must have occurred after the eruption, and the others converted into aggregates of pyroxene and magnetite grains which possibly were favored by the near-surface conditions without oxidation. Green hornblende phenocrysts may occur in the rapid fixed glassy base (type VI); they are found as pumice, bombs and glassy dome lavas. Groundmass usually contains both augite and hypersthene, but no hornblende in any specimen, except for rare presence of pargasite of pneumatolytic origin which is found in druses of dome lava of the Daisetsu volcano. Interstitial silica minerals, cristobalite or tridymite, and alkali-feldspar are also found in considerable amount.

Various types of xenoliths which are granite, slate, sandstone and of other origin and of autoliths, are occasionally included in the rocks of this type.

Andesite with groundmass which contains hypersthene as the only ferromagnesian silicate mineral, has been found from the Rishiri volcano (type VIe).

Andesites of types XV, XVI, XVII, XVIII and XIX (Table 3, columns 32, 40, 42 & 83), are characterized by the presence of biotite phenocrysts, and their occurrences are also restricted to the inner volcanic zone. Unfortunately, most of these rocks are not clarified as to what type of mineral assemblage of groundmass they are comprised of, owing to their glassy base; but, so far as identified on the fairly crystalline groundmass, they belong to type d or e. Generally speaking, these rocks are more felsic than those of other types in which biotite is not included; but all features seen in these biotite-bearing rocks are much like those of andesite of type VI as already described. Resorption of hornblende and biotite are also found as in the rocks of type VId. Xenoliths and autoliths are also abundant.

Dacite and rhyolite of type XVI (Table 3, column 33), occur only from central Hokkaido, as Pleistocene welded tuff of the Daisetsu-Tokachi volcanic chain, constituting a vast pyroclastic plateau. The rocks of this type are comprised in most felsic members of the inner volcanic zone. Essential phenocrystic minerals are plagioclase, quartz, biotite, hornblende, hypersthene, iron ore and augite. Groundmass is usually glassy and fairly welded, but sometimes shows cryptocrystalline texture, due to the secondary crystallization of felsic minerals. Propylite, slate, hornfels, andesite, dacite, rhyolite and other lithic fragment are included in the welded tuff.

Dacite and rhyolite of type VI (Table 3, columns 54, 55 & 56), are representatives of most felsic rocks in the front volcanic zone, and are comparable to dacite and rhyolite of type XVI in the inner zone. These rocks were erupted from the Shikotsu volcano as a pumice-fall and following pumice-flows, just before the depression of the Shikotsu caldera in late Pleistocene. Small amounts of plagioclase, hypersthene, augite, green hornblende and magnetite are usually found in phenocrysts; besides, quartz is frequently attained. Groundmass is composed of highly vesicular glass, and a part of the pumice-flow shows welded texture.

The most striking feature seen in the above descriptions is the presence of regularity in the assemblage of ferromagnesian silicate minerals. (See Table 2). All mafic rocks in this area include phenocrysts of combined olivine+augite (type IV) or olivine+augite+hypersthene (type V) in most cases, and hypersthene (type I) in a few. Other assemblages are entirely lacking in this area, while types II and III may occur. The groundmass of mafic rocks is constricted to type b or c in most cases, a few of them show transitional types b→c or c→d. Intermediate to felsic rocks are most abundant throughout the present area; they are comprised in two groups; one is pyroxene-andesite and -dacite, and the other is hornblende- and/or biotite-bearing andesite~rhyolite. The former group is composed mainly of so-called "two pyroxene-andesite and -dacite" (type V) together with some little hypersthene-andesite and -dacite (type I). Groundmasses belonging to this group are type d or e, rarely c or c→d, and usually contain considerable amounts of excess silica minerals. On the contrary, the latter group ranges through various types of VI, VII, XV, XVI, XVII, XVIII and XIX, and their groundmass is always classified in type d or e, with considerable amount of alkali-feldspar as well as silica minerals. Non-occurrence of type b and c in this group has an important suggestion on the genesis of hornblende- and/or biotite-bearing rocks.

It must also be noted as significant that the rocks of the front volcanic zone are composed mainly of pyroxene-andesites and -dacites (types V and I) together with oversaturated basalts (types IVc and Vc); on the contrary, those of the inner zone include hornblende- and/or biotite-bearing andesites (rarely dacites and rhyolites) associated with undersaturated basalts (types IVb and IVb→c). (See Table 1). Such petrographical aspects evidence the consanguinity of rocks in each zone as well as in each petrographic province; this will be discussed later.

V Chamical composition of the Quaternary volcanic rocks of Hokkaido

All available data on the chemical composition of the Quaternary volcanic rocks from Hokkaido are listed in the following table (Table 3). The items of analytical data contained in Table 3 number 83, of which 50 analyses were performed by the writer himself, while the remainder were taken from litratures published during the 30 years since 1930. The older data published before 1930 were omitted, because they may be unreliable due to the infriority of analytical technique in those days.

TABLE 3. Chemical composition of the Quaternary volcanic rocks of Hokkaido.

Volcano	Shiretoko-iwo-zan	Rausudake	Kutcharo		
No.	1	2	3	4	5
Type of mineral assemblage*	Vd	Vd	c	Vc	Vd ?
SiO_2	60.69	61.76	48.52	54.14	60.40
TiO_2	.71	.80	1.19	1.21	1.01
Al_2O_3	16.72	16.38	20.89	15.71	16.71
Fe_2O_3	3.60	3.14	3.91	3.41	3.54
FeO	3.96	4.04	6.11	9.19	3.61
MnO	.09	.12	.09	.22	.08
MgO	2.44	2.08	3.49	3.26	2.11
CaO	5.83	5.81	12.37	8.93	5.90
Na_2O	3.51	3.40	1.52	2.31	3.25
K_2O	1.57	1.39	.41	.41	1.44
P_2O_5	.15	.18	.06	.08	.17
H_2O (+)	.27	.34	.60	.48	.61
H_2O (−)	.19	.13	.72	.41	.70
Total	99.73	99.57	99.88	99.76	99.53
Analyst	KATSUI	KATSUI	KATSUI	KATSUI	KATSUI

* Sign of Kuno's classification by the ferromagnesian silicate mineral assemblage (KUNO 1950). *cfr*. Table 2.

1 Augite-hypersthene-andesite, a lava of Naka-dake, one of the central cones of the Shiretoko-iwo-zan volcano. Loc., summit of Naka-dake. (New analysis).

2 Augite-hypersthene-andesite, a dome lava of the Rausu-dake volcano. Loc., summit of Rausu-dake. (New analysis).

3 Andesite (with abundant large calcic plagioclase phenocrysts), a dyke intruded in the somma lava of the Kutcharo volcano. Loc., summit of Mokoto-yama. (KATSUI, 1958a).

4 Augite-hypersthene-basalt, a somma lava of the Kutcharo volcano. Loc., south of Kamisattsuru. (KATSUI, 1958a).

5 Augite-hypersthene-andesite, a somma lava of the Kutcharo volcano. Loc., Bihoro-tôge. (KATSUI, 1958a).

TABLE 3. continued.

Volcano	Kutcharo		Mashû		
No.	6	7	8	9	10
Type of mineral assemblage	V	V	Ic	Vc	Vd→c
SiO_2	71.25	71.92	52.78	55.08	60.05
TiO_2	.50	.59	.77	1.19	.51
Al_2O_3	14.31	12.65	19.01	15.92	17.07
Fe_2O_3	1.22	1.11	2.48	3.83	2.25
FeO	1.48	1.85	7.15	8.16	6.18
MnO	.10	.12	.18	.22	.14
MgO	.89	.67	3.78	3.19	2.33
CaO	3.13	2.89	11.08	9.02	7.90
Na_2O	4.06	3.59	2.21	2.48	2.66
K_2O	1.91	1.62	.30	.44	.50
P_2O_5	.11	.09	.25	.21	.25
H_2O (+)	.68	2.55	.19	.25	.28
H_2O (−)	.16	.46	.18	.14	.10
Total	99.80	100.11	100.36	100.13	100.22
Analyst	KATSUI	KATSUI	KATSUI	KATSUI	KATSUI

6 Augite-bearing hypersthene-dacitic welded tuff, welded part of the first pumice-flow deposits of the Kutcharo volcano. Loc., a quarry of Furume, south of Bihoro. (KATSUI, 1958a).

7 Augite-bearing hypersthene-dacite, a pumice from the second pumice-flow deposit of the Kutcharo volcano. Loc., near Yobito, north of Bihoro. (KATSUI, 1958a).

8 Hypersthene-andesite, a somma lava of the Mashû volcano. Loc., foot of the western part of the Mashû caldera. (KATSUI, 1955).

9 Augite-bearing hypersthene-andesite, a somma lava of the Mashû volcano. Loc., foot of the western part of the Mashû caldera. (KATSUI, 1955).

10 Augite-hypersthene-andesite, a somma lava of the Mashû volcano. Loc., western part of the Mashû caldera. (KATSUI, 1955).

TABLE 3. continued

Volcano	Mashû		Atosanupuri and other post-caldera volcanoes of the Kutcharo		
No.	11	12	13	14	15
Type of mineral assemblage	V	Vd	Vd	c	Ve?
SiO_2	65.53	72.96	57.82	64.26	66.90
TiO_2	.36	.33	.91	.91	.69
Al_2O_3	14.72	12.54	17.65	14.87	14.72
Fe_2O_3	2.48	2.01	2.90	2.18	2.18
FeO	3.21	2.09	4.94	5.03	2.25
MnO	.10	.08	.12	.14	.08
MgO	1.49	.99	2.75	1.76	1.37
CaO	4.42	3.29	7.86	5.49	4.22
Na_2O	3.54	3.66	2.89	3.70	3.59
K_2O	.85	1.07	1.01	.83	1.35
P_2O_5	.20	.29	.14	.20	.15
H_2O (+)	2.71	.41	.32	.25	1.87
H_2O (−)	.20	.30	.29	.36	.34
Total	99.81	100.02	99.60	99.98	99.71
Analyst	KATSUI	KATSUI	KATSUI	KATSUI	KATSUI

11 Augite-hypersthene-andesite, a pumice of the Mashû pumice-fall deposits. Loc., southern slope of the Mashû volcano. (KATSUI, 1955).

12 Augite-hypersthene-dacite, a dome lava of Kamuishu, a central lava dome of the Mashû caldera. Loc., Kamuishu island. (KATSUI, 1955).

13 Olivine-bearing augite-hypersthene-andesite, a dome lava of Oyakotsu in the Kutcharo caldera. Loc., Wakoto peninsula. (KATSUI, 1958a).

14 Aphyric andesite, a somma lava of the Atosanupuri volcano. Loc., eastern part of the Atosanupuri caldera-wall. (KATSUI, 1958a).

15 Augite-hypersthene-dacite, a pumice of the Nakajima pumice-fall deposit. Loc., east of the Nakajima volcano. (KATSUI, 1958a).

TABLE 3. continued

Volcano	Atosanupuri and other post-caldera volcanoes of Kutcharo caldera				Akan
No.	16	17	18	19	20
Type of mineral assemblage	Vd	Vd→e	V	Vd	IVc
SiO_2	67.51	69.65	69.81	72.64	52.43
TiO_2	.69	.59	.58	.68	1.01
Al_2O_3	15.23	13.91	13.23	12.92	17.67
Fe_2O_3	1.94	2.46	2.07	1.52	3.08
FeO	2.43	1.92	1.79	1.93	7.28
MnO	.09	.07	.07	.07	.19
MgO	1.23	1.16	.94	1.14	3.86
CaO	4.49	3.63	3.31	2.53	10.34
Na_2O	3.63	3.55	3.79	4.03	2.22
K_2O	1.34	1.45	1.49	1.62	.51
P_2O_5	.18	.14	.09	.04	.11
H_2O (+)	.53	.77	2.73	.61	.42
H_2O (−)	.38	.42	.33	.15	.32
Total	99.67	99.72	100.23	99.88	99.44
Analyst	KATSUI	KATSUI	KATSUI	KATSUI	KATSUI

16 Augite-hypersthene-dacite (with a few phenocrystic hornblende), a somma lava of the Nakajima volcano. Loc., eastern part of the somma. (KATSUI, 1958a).

17 Augite-hypersthene-dacite, a central dome lava of the Nakajima volcano. Loc., summit of the dome. (KATSUI, 1958a).

18 Augite-hypersthene-dacite, a pumice of the Atosanupuri pumice-flow deposit. Loc., Sattekinai, west of the Atosanupuri volcano. (KATSUI, 1958a).

19 Augite-hypersthene-dacite, a dome lava of Iwo-zan, one of the lava domes of the Atosanupuri volcano. Loc., summit of Iwo-zan. (KATSUI, 1958a).

20 Augite-bearing olivine-basaltic andesite, a somma lava of the Akan volcano. Loc., Senpoku-tôge. (KATSUI, 1958a).

TABLE 3. continued

Volcano	Akan	Me-akan-dake	Daisetsu		
No.	21	22	23	24	25
Type of mineral assemblage	V	Vd	Vd	Vd	Vd
SiO_2	65.87	57.54	54.73	56.72	56.99
TiO_2	.78	.81	.91	.64	.75
Al_2O_3	14.53	18.37	17.84	16.58	17.01
Fe_2O_3	2.43	2.07	2.79	3.27	3.73
FeO	3.51	5.54	6.02	4.84	4.28
MnO	.13	.11	.11	.10	.07
MgO	1.38	3.21	4.70	3.94	3.59
CaO	4.75	7.55	8.13	7.28	8.21
Na_2O	3.51	2.66	2.86	3.03	2.72
K_2O	1.46	1.07	1.45	1.65	1.47
P_2O_5	.34	.09	.17	.24	.17
H_2O (+)	.75	.64	.35	.64	.56
H_2O (−)	.44	.43	.12	.96	.39
Total	99.88	100.09	100.18	99.89	99.94
Analyst	KATSUI	KATSUI	KATSUI	KATSUI	KATSUI

21 Augite-hypersthene-andesitic welded tuff of Akan volcano. Loc., north of the Akan caldera. (KATSUI, 1958a).

22 Augite-hypersthene-andesite, a lava of Ponmachineshiri, one of the cones of the Me-akan-dake volcano. Loc., northwest of the summit of Ponmachineshiri. (KATSUI, 1958a).

23 Olivine-bearing augite-hypersthene-andesite, a spindle-shaped bomb of Asahi-dake, one of the cones of the Daisetsu volcano. Loc., summit of Asahi-dake. (KATSUI & TAKAHASHI, 1960).

24 Olivine-bearing augite-hypersthene-andesite, a lava of Mikurasawa of the Daisetsu volcano. Loc., Mikurasawa. (KATSUI & TAKAHASHI, 1960).

25 Augite-hypersthene-andesite, a lava of Chuô-kakô, the central crater of the Daisetsu volcano. Loc., west of the crater wall. (KATSUI & TAKAHASHI, 1960).

TABLE 3. continued

Volcano	Daisetsu		Chubetsu	Tokachi-dake	
No.	26	27	28	29	30
Type of mineral assemblage	VId	VId	Vc→d	IVb→c	Vc→d
SiO_2	60.44	64.67	55.59	46.79	51.90
TiO_2	.55	.62	1.11	1.61	1.05
Al_2O_3	15.67	16.24	16.30	18.03	17.69
Fe_2O_3	2.80	2.62	2.78	4.98	2.50
FeO	4.08	2.60	6.70	7.52	7.72
MnO	.08	.09	.07	.19	.52
MgO	3.12	2.10	4.27	5.76	4.96
CaO	6.50	4.80	8.84	10.55	9.35
Na_2O	3.31	3.77	2.69	2.67	3.04
K_2O	1.73	1.97	1.22	.79	1.20
P_2O_5	.17	.12	.22	.08	.15
H_2O (+)	.75	.46	.19	.55	.46
H_2O (−)	.51	.15	.22	.38	.11
Total	99.71	100.21	100.20	99.90	100.65
Analyst	KATSUI	KATSUI	KATSUI	KATSUI & TAKAHASHI	TANAKA

26 Quartz- and olivine-bearing honrblende-augite-hypersthene-andesite, the dome lava of Keigetsu-dake, one of the lava domes of the Daisetsu volcano. Loc., summit of Keigetsu-dake. (KATSUI & TAKAHASHI, 1960).

27 Quartz-bearing augite-hypersthene-hornblende-andesite, the dome lava of Kuro-dake, one of the lava domes of the Daisetsu volcano. Loc., southern flank of Kuno-dake. (KATSUI & TAKAHASHI, 1960).

28 Olivine-augite-hypersthene-andesite, a lava of the Chubetsu volcano. Loc., Takanegahara. (KATSUI & TAKAHASHI, 1960).

29 Augite-olivine-basalt, a lava of Furano-dake, one of the cones of the Tokachi volcano. Loc., summit of Furano-dake. (KATSUI & TAKAHASHI, 1960).

30 Olivine-hypersthene-augite-basalt (olivine-pyroxene-andesite according to TADA & TSUYA), a lower lava of the Tokachi volcano. (TADA & TSUYA, 1927).

TABLE 3. continued

Volcano	Tokachi-dake			Irumukeppu	
No.	31	32	33	34	35
Type of mineral assemblage	Vd	XVId	XVI	VI	V
SiO_2	53.93	60.67	71.57	56.94	56.99
TiO_2	1.25	.79	.29	.78	.69
Al_2O_3	18.39	15.44	13.11	18.30	18.26
Fe_2O_3	3.11	4.72	2.62	3.10	2.98
FeO	6.21	2.67	.78	3.59	3.64
MnO	.19	.10	.07	.12	.11
MgO	4.10	2.53	.64	3.63	3.83
CaO	8.83	5.45	2.19	7.69	7.54
Na_2O	2.40	3.35	3.89	2.82	2.83
K_2O	1.43	2.93	3.39	1.56	1.57
P_2O_5	.15	.12	.06	.20	.20
H_2O (+)	.14	.79	.60	.26	.44
H_2O (−)	.03	.32	.42	.60	.49
Total	100.16	99.88	99.63	99.59	99.57
Analyst	TANAKA	TAKAHASHI	TAKAHASHI	MAEDA	MAEDA

31 Olivine-augite-hypersthene-andesite, a bomb (erupted in 1926) of the Tokachi-dake volcano. Loc., near Shin-fun-kako (New crater) of the Tokachi-dake volcano. (TADA & TSUYA, 1927).

32 Biotite- and hornblende-bearing augite-hypersthene-andesite, the dome lava of the Tokachi-dake volcano. Loc., summit of Tokachi-dake. (KATSUI & TAKAHASHI, 1960).

33 Augite- and hypersthene-bearing hornblende-biotite rhyolitic welded tuff, a lower welded tuff (Tokachi welded tuff) of the Tokachi volcano. Loc., east of Kamifurano. (KATSUI & TAKAHASHI, 1960).

34 Hornblende-bearing augite-hypersthene-olivine-andesite, a lava of the 7th ejecta bed (Okirika-yama upper lava) of the Irumukeppu volcano. Loc., Okirika-yama. (KAWANO, MATSUI & SHIMIZU, 1956).

35 Olivine-bearing augite-hypersthene-andesite, a lava of the 5th ejecta bed (Irumukeppu-yama lava) of the Irumukeppu volcano. Loc., Irumukeppu-yama. (KAWANO, MATSUI & SHIMIZU, 1956).

TABLE 3. continued

Volcano	Irumukeppu				
No.	36	37	38	39	40
Type of mineral assemblage	VI	(VI→)V	(VI→)V	VI	XVIII
SiO_2	57.28	57.34	57.70	58.99	59.44
TiO_2	.78	.78	.78	.63	.63
Al_2O_3	17.79	17.54	17.89	18.53	17.46
Fe_2O_3	3.07	3.56	3.07	3.89	4.14
FeO	3.66	3.30	3.44	2.20	2.54
MnO	.13	.13	.13	.13	.13
MgO	3.92	4.06	3.85	2.55	2.38
CaO	7.51	7.16	7.11	6.13	6.14
Na_2O	2.83	2.85	3.01	3.14	2.81
K_2O	1.45	1.47	1.60	1.39	1.47
P_2O_5	.20	.19	.20	.20	.19
H_2O (+)	.54	.47	.30	1.24	1.44
H_2O (−)	.46	.72	.52	.64	.80
Total	99.62	99.57	99.60	99.66	99.57
Analyst	MAEDA	MAEDA	MAEDA	MAEDA	MAEDA

36 Horblende-bearing olivine-augite-hypersthene-andesite, a lava of the 6th ejecta bed (Okirika-yama lower lava) of the Irumukeppu volcano. Loc., northern foot of Okirika-yama. (KAWANO, MATSUI & SHIMIZU, 1956).

37 Olivine-angite-hypersthene-andesite (with a few phenocrystic hornblende), a lava of the 8th ejecta bed (800 m-yama lava) of the Irumukeppu volcano. Loc., 800 m-yama. (KAWANO, MATSUI & SHIMIZU, 1956).

38 Augite-hypersthene-olivine-andesite (with a few phenocrystic hornblende), a lava of the 9th ejecta bed (Otoe-yama lava) of the Irumukeppu volcano. Loc., Otoe-yama (or Okirika?) . (KAWANO, MATSUI & SHIMIZU, 1956).

39 Augite-hypersthene-hornblende-andesite, a lava of the 2nd ejecta bed (805 m-yama lava) of the Irumukeppu volcano. Loc., Irumukeppu-yama. (KAWANO, MATSUI & SHIMIZU, 1956).

40 Quartz-biotite-hornblende-andesite, a lava of the first ejecta bed (Okirika-kosenzawa lava) of the Irumukeppu volcano. Loc., northern slope of Irumukeppu-yama. (KAWANO, MATSUI & SHIMIZU, 1956).

TABLE 3. continued

Volcano	Irumukeppu		Shokan betsu	Rishiri	
No.	41	42	43	44	45
Type of mineral assemblage	VI	VIIIe?	VId	IVb	IVb
SiO_2	59.60	60.85	55.41	49.26	49.58
TiO_2	.63	.63	.64	1.25	1.41
Al_2O_3	17.10	17.97	17.38	17.71	16.88
Fe_2O_3	5.20	3.30	3.36	2.67	4.19
FeO	1.61	2.45	4.16	7.12	5.97
MnO	.11	.13	.15	.05	.25
MgO	2.56	2.43	4.52	7.91	5.29
CaO	4.75	6.53	8.62	10.01	10.75
Na_2O	3.23	2.96	2.67	3.08	3.85
K_2O	1.57	1.63	1.34	.56	.88
P_2O_5	.17	.19	.24	.19	.08
H_2O (+)	1.59	.26	.57	.36	.61
H_2O (−)	1.48	.28	.55	.17	.24
Total	99.60	99.61	99.61	100.34	100.99*
Analyst	MAEDA	MAEDA	KATSUI	KATSUI	KATSUI

* Including 1.01% SO_3, most of which is derived from the groundmass anhydrite (KATSUI, 1958b).

41 Augite-hypersthene-hornblende-andesite, a block of the 4th ejecta bed (Otoe-yama agglomerate) of the Irumukeppu volcano. Loc., western slope of Irumukeppu-yama. (KAWANO, MATSUI & SHIMIZU, 1956).

42 Hornblende-andesite, a block of the 3rd ejecta bed (Irumukeppu agglomerate) of the Irumukeppu volcano. Loc., Irumukeppu. (KAWANO, MATSUI & SHIMIZU, 1956).

43 Hornblende- and quartz-bearing olivine-augite-hypersthene-andesite, a lava of the Shokanbetsu volcano. Loc., summit of Shokanbentsu-dake. (New analysis).

44 Olivine-augite basalt, Oniwaki lava of the Rishiri volcano. Loc., southern shore of Oniwaki. (KATSUI, 1953).

45 Olivine-augite-basalt (with groundmass biotite and anhydrite), a dyke of the Rishiri volcano. Loc., near the top of Rishiri. (KATSUI, 1958b).

TABLE 3. continued

Volcano	Rishiri				
No.	46	47	48	49	50
Type of mineral assemblage	IVb	IVb	IVb	IVb	Vd
SiO_2	49.60	50.69	50.78	53.29	63.48
TiO_2	1.40	1.28	1.09	n.d.	.56
Al_2O_3	16.06	16.59	15.55	18.14	16.89
Fe_2O_3	4.05	4.06	3.90	3.63	2.82
FeO	7.10	5.01	7.02	5.12	2.77
MnO	.21	.10	.12	n.d.	.10
MgO	6.12	7.34	7.06	5.02	2.54
CaO	10.86	10.00	9.82	9.83	6.21
Na_2O	2.76	3.49	3.75	3.48	4.04
K_2O	.86	1.03	.59	1.17	.97
P_2O_5	.17	.14	.07	n.d.	.14
H_2O (+)	.54	.43	.30	n.d.	.20
H_2O (−)	.12	.18	.20	n.d.	.05
Total	99.85	100.34	100.25	99.68	100.77
Analyst	KATSUI	KATSUI	KATSUI	ABE	KATSUI

46 Olivine-augite-basalt (with a few groundmass biotite) Notsuka lava of the Rishiri volcano. Loc., Sainokawara, north of the summit of Rishiri. (KATSUI, 1953).

47 Olivine-augite-basalt, a lava of the 2nd ejecta of the Rishiri volcano. Loc., eastern side of the top of Rishiri. (KATSUI, 1953).

48 Olivine-augite-basalt, Motodomari lava of the Rishiri volcano. Loc., northern coast of Rishiri island. (KATSUI, 1953).

49 Olivine-augite-andesite, Kutsugata lava of the Rishiri volcano. Loc., shore of Kutsugata. (KATSUI, 1953).

50 Augite-hypersthene-andesite, a lava of 1st ejecta of the Rishiri volcano. Loc., eastern ridge of Rishiri. (KATSUI, 1953).

TABLE 3. continued

Volcano	Rishiri	Shikotsu			
No.	51	52	53	54	55
Type of mineral assemblage	Ie	Vd	V	VI	VI
SiO_2	66.41	51.40	64.92	69.05	69.63
TiO_2	.55	.92	.52	.42	.10
Al_2O_3	16.20	19.20	15.08	14.76	14.33
Fe_2O_3	1.98	3.96	1.81	1.87	2.08
FeO	2.93	5.82	2.24	1.27	1.90
MnO	.09	.27	.07	.09	.15
MgO	1.55	3.84	.81	.68	1.12
CaO	3.46	9.94	3.98	3.19	3.20
Na_2O	5.14	2.67	3.40	3.91	3.09
K_2O	1.74	.65	1.71	2.45	1.88
P_2O_5	.17	.20	.10	.11	.19
H_2O (+)	.25	.83	4.20	2.57	2.46
H_2O (−)	.05	.27	.94	.28	
Total	100.52	99.97	99.78	100.65	100.13
Analyst	KATSUI	KATSUI	KATSUI	KATSUI	average of 6

51 Hypersthene-andesite, Ishi-yama dome lava of the Rishiri volcano. Loc., Ishi-yama, west of Oniwaki. (KATSUI, 1953).

52 Olivine-augite-hypersthene-andesite, a scoria of the Shikotsu scoria-fall deposit. Loc., Hayakita. (KATSUI, 1959).

53 Augite-hypersthene-dacite, a pumic from the Shikotsu pumice-fall deposit (Spfa 2). Loc., Hayakita. (KATSUI, 1959).

54 Hornblende-augite-hypersthene-dacite, a pumice from the Shikotsu pumice-flow deposit (Spfl). Loc., Shimamatsu, north of Chitose. (KATSUI, 1959).

55 Hornblende-augite-hypersthene-dacitic welded tuff, welded part of the Shikotsu pumice-flow deposit (Spfl). Average of 6 analyses. (SATO & KAGAWA, 1959).

TABLE 3. continued

Volcano	Shikotsu	Tarumai			
No.	56	57	58	59	60
Type of mineral assemblage	VI	Vd	Vd	V	Vd
SiO_2	72.41	57.40	57.88	58.38	59.17
TiO_2	.31	.53	.49	.62	.48
Al_2O_3	12.83	18.27	19.42	17.84	18.60
Fe_2O_3	1.36	3.50	2.25	3.33	2.78
FeO	1.20	6.01	6.76	5.21	5.84
MnO	.05	.15	.87	.22	1.03
MgO	.45	3.89	3.29	3.42	3.12
CaO	2.04	7.30	6.75	7.38	6.61
Na_2O	3.35	2.12	2.20	2.46	1.88
Ka_2O	3.50	.70	1.00	.72	.98
P_2O_5	.13	n.d.	n.d.	n.d.	.21
H_2O (+)	2.64	} .43	} .02	} .97	} .19
H_2O (−)	.19				
Total	100.46	100.30	100.93	100.55	100.95*
Analyst	KATSUI	NAKAE	Average of 3	Average of 6	Average of 5

* Including 0.06%S as an average value.

56 Augite-hornblende-hypersthene-rhyolite, a pumice from the Shikotsu pumice-fall deposit (Spfa 1). Loc., Bibi, south of Chitose. (KATSUI, 1959).

57 Augite-hypersthene-andesite, central cone lava of the Tarumai volcano. Loc., eastern foot of the lava dome, summit of Tarumai. (SUZUKI, 1935).

58 Augite-hypersthene-andesite (with large anorthite), bread crust bomb and lava block (ejected in 1909) of the Tarumai volcano. Loc., summit of Tarumai. Average of 3 analyses. (ISHIKAWA, 1952).

59 Augite-hypersthene-andesitic welded tuff, welded part of the Tarumai pumice-flow deposit (lavas of Kuchawakkanai, Oppopu, Nishi-yama and Shishamonai according to ISHIKAWA). Average of 6 analyses. (ISHIKAWA, 1952).

60 Augite-hypersthene-andesite (with large anorthite), dome lava (erupted in 1909) of the Tarumai volcano. Loc., summit of Tarumai. Average of 5 analyses. (ISHIKAWA, 1952).

TABLE 3. continued

Volcano	Tarumai	Kuttara	Yôtei		
No.	61	62	63	64	65
Type of mineral assemblage	Vd	V	Vd→c	Vd	Vd
SiO_2	60.80	64.27	57.84	57.89	58.23
TiO_2	.49	.18	.82	.89	1.01
Al_2O_3	17.48	15.78	17.48	18.33	15.98
Fe_2O_3	4.88	3.36	2.72	2.36	3.60
FeO	3.36	2.88	5.74	5.11	5.76
MnO	.11	.36	.12	.10	.14
MgO	2.48	1.64	3.14	2.65	3.32
CaO	6.16	5.62	7.77	7.97	7.65
Na_2O	2.78	3.64	3.13	3.30	2.89
K_2O	.98	1.54	.99	1.07	1.01
P_2O_5	n.d.	.20	.20	.17	.17
H_2O (+)	} .70	} .83	.11	.20	.12
H_2O (−)			.05	.04	.06
Total	100.18*	100.30	100.11	100.08	99.96
Analyst	NAKAE	SATÔ & KAGAWA	KATSUI	KATSUI	KATSUI

* Total=100.22, but remained in original figure.

61 Augite-hypersthene-andesite, Kita-yama lava, north of the Tarumai volcano. Loc., Kita-yama. (SUZUKI, 1935).

62 Augite-hypersthene-andesitic welded tuff, Noboribetsu welded tuff of the Kuttara volcano. Average of 4 analyses. (SATÔ & KAGAWA, 1956).

63 Olivine-bearing augite-hypersthene-andesite, the 2nd stage lava of the Yôtei volcano. Loc., western slope of Yôtei. (KATSUI, 1956).

64 Augite-hypersthene-andesite, the 1st stage lava of the Yôtei volcano. Loc., western foot of Yôtei. (KATSUI, 1956).

65 Olivine-bearing augite-hypersthene-andesite, the 3rd stage lava of the Yôtei volcano. Loc., southern rim of the younger crater, summit of Yôtei. (KATSUI, 1956).

TABLE 3. continued

Volcano	Yôtei	Usu			
No.	66	67	68	69	70
Type of mineral assemblage	Vd	Vc	Ie (~Ve)	Ie	I (~VII)
SiO_2	63.45	53.46	68.26	69.74	70.60
TiO_2	.67	1.06	.36	.45	.36
Al_2O_3	15.97	18.99	15.77	15.59	15.00
Fe_2O_3	2.58	2.75	1.91	1.52	1.37
FeO	4.28	6.74	2.15	2.59	2.49
MnO	.10	.22	.31	.08	.09
MgO	1.95	3.82	.99	.85	.77
CaO	5.08	9.79	4.37	3.63	3.30
Na_2O	3.75	2.47	3.83	3.43	4.42
K_2O	1.34	.48	1.29	1.36	.98
P_2O_5	.18	.32	.18	.22	.21
H_2O (+)	.21	.33	} .51	.67	.69
H_2O (−)	.11	.22		.23	.12
Total	99.67	100.63	99.93	100.36	100.40
Analyst	KATSUI	YAGI	Geol. Surv.	YAGI	YAGI

66 Augite-bearing hypersthene-andesite, a lava of Minamikakô, one of the parasitic cones of the Yôtei volcano. Loc., southwestern foot of Yôtei. (KATSUI, 1956).

67 Olivine-augite-hypersthene-andesite (with large calcic plagioclase), a somma lava of the Usu volcano. Loc., roof mountain of Syôwa-sinzan. (YAGI, 1953).

68 Hypersthene-dacite (with a few phenocrystic augite), the dome lava of Ô-usu, one of the lava domes of the Usu volcano. Loc., summit of the dome. (TANAKADATE, 1930).

69 Hypersthene-dacite, new dome lava (erupted in 1943-1945) of Syôwa-sinzan, one of the lava domes of the Usu volcano. Loc., Syôwa-sinzan. (YAGI, 1953).

70 Hypersthene-dacite (with a few phenocrystic hornblende), a glassy part of the Ô-usu dome lava. Loc., Ô-usu. (YAGI, 1953).

TABLE 3. continued

Volcano	Usu	Komaga-dake			
No.	71	72	73	74	75
Type of mineral assemblag	Ie (~Ve)	V	V	V	V
SiO_2	71.25	58.03	59.08	59.50	59.86
TiO_2	.43	.61	.57	.29	.75
Al_2O_3	13.21	18.04	17.80	16.46	16.34
Fe_2O_3	3.19	2.63	2.92	3.48	2.73
FeO	1.96	5.36	5.22	5.62	5.33
MnO	.27	.18	.12	tr.	.09
MgO	.84	3.17	3.10	3.16	3.04
CaO	3.10	7.95	7.83	7.52	7.03
Na_2O	4.02	2.99	2.20	2.87	3.67
K_2O	1.15	.65	1.03	.89	.97
P_2O_5	.46	.18	.16	.32	.09
H_2O (+)	.50	.19	.58	.39	.30
H_2O (−)	.25	.04	.06	.06	
Total	100.63	100.02	100.67	100.56	100.20
Analyst	YAGI	TANAKA	SETO	SETO	average of 3

71 Hypersthene-dacite (with a few phenocrystic augite), the dome lava of Ko-usu, one of the lava domes of the Usu volcano. Loc., summit of Ko-usu. (YAGI, 1953).

72 Augite-hypersthene-andesite, a scoria (erupted in 1929) of the Komaga-dake volcano. Loc., southwest slope of Komaga-dake. (TSUYA, 1930).

73 Augite-hypersthene-andesitic welded tuff* (andesite according to SETO), a part of the Kurumisaka agglomeratic lava (named by KATO) of the Komaga-dake volcano. Loc., Shin-ogawa station. (SETO, 1932).

74 Augite-hypersthene-andesitic welded tuff* (andesite according to SETO), a part of the Sahara-dake lava (named by KATO), of the Komaga-dake volcano. Loc., western summit of Sahara-dake. (SETO, 1932).

75 Augite-hypersthene-andesite, lava blocks (erupted in 1929) of the Komaka-dake volcano. Loc., southeastern slope of Komaga-dake and summit of Sumidamori. Average of 3 analyses. (TSUYA, 1930 and SETO & YAGI, 1932).

* The rock names were recently determined by Mr. M. IWANAGA (oral communication).

TABLE 3. continued

Volcano	Komaga-dake		Niseko	Oshima-ôshima	
No.	76	77	78	79	80
Total of mineral assemblage	V	V	VId	IVb	IVb
SiO_2	60.68	60.74	58.29	48.89	49.90
TiO_2	.70	.67	.67	1.02	1.09
Al_2O_3	15.95	15.89	17.72	15.00	16.05
Fe_2O_3	2.65	3.01	4.65	2.92	5.03
FeO	4.86	5.26	2.20	6.41	5.55
MnO	.06	.10	.15	.25	.14
MgO	2.51	2.65	3.94	10.60	7.03
CaO	6.84	6.83	7.09	10.91	10.51
Na_2O	4.28	3.96	2.62	1.95	2.15
K_2O	1.04	.76	1.62	1.13	1.92
P_2O_5	.08	.12	n.d.	.05	.23
H_2O (+)	} .63	} .43	.66	.64	.26
H_2O (−)			.62	.12	.06
Total	100.28	100.59*	100.24**	99.89	99.92
Analyst	average of 3	average of 2	KUSHIDA	KATSUI	KATSUI

* Including 0.17 % S as an average value.

** Total=100.23, but remained in original figure.

76 Augite-hypersthene-andesite, pumice (erupted in 1929) of the Komaga-dake volcano. Loc., Yakeyama slope and Akaigawa. Average of 3 analyses. (TSUYA, 1930; SETO, 1932 and SETO & YAGI, 1932).

77 Augite-hypersthene-andesite, bread crust bombs (erupted in 1929) of Komaga-dake volcano. Loc., near the summit of Komaga-dake. Average of 2 analyses. (TSUYA, 1930 and SETO & YAGI, 1932).

78 Quartz- and hornblende-bearing olvine-augite-hypersthene-andesite, a block of the Naganuma mud-flow from Chisenupuri, one of the lava domes of the Niseko (Iwaonupuri) volcano. Loc., near Naganuma. (HIROKAWA & MURAYAMA, 1955).

79 Augite-olivine-basalt, a lava of the younger somma (Nishi-yama) of the Oshima-ôshima volcano. Loc., Yamasedomari, southern coast of the Oshima-ôshima island. (KATSUI, 1953).

80 Olivine-augite-basalt, a central cone lava of the Oshima-ôshima volcano. Loc., Yakekuzure peninsula, north of the Oshima-ôshima island. (KATSUI, 1953).

TABLE 3. continued

Volcano	Oshima-ôshima		Oshima-Kojima
No.	81	82	83
Type of mineral assemblage	VId	VId	XVId
SiO_2	55.56	61.72	60.46
TiO_2	.61	.37	.57
Al_2O_3	18.28	17.71	16.30
Fe_2O_3	2.46	1.12	3.16
FeO	5.11	4.33	2.83
MnO	.19	.10	.14
MgO	4.05	1.83	3.31
CaO	8.57	5.19	7.11
Na_2O	2.62	3.21	3.04
K_2O	1.80	3.28	1.87
P_2O_5	.22	.20	.22
H_2O (+)	.62	.83	.39
H_2O (−)	.13	.16	.21
Total	100.27	100.05	99.61
Analyst	KATSUI	KATSUI	KATSUI

81 Olivine- and hornblende-bearing augite-hypersthene-andesite, a lava of the younger somma (Nishi-yama) of the Oshima-ôshima volcano. Loc., Aidomari, southern coast of the Oshima-ôshima island. (KATSUI, 1953).

82 Hornblende-augite-hypersthene-andesite, a lava of the older somma (Higashi-yama) of the Oshima-ôshima volcano. Loc., Aidomari, Oshima-ôshima Island. (KATSUI, 1953).

83 Biotite- and quartz-bearing hornblende-hypersthene-augite-andesite, a lava of the Oshima--kojima volcano. Loc., western coast of Oshima-kojima island. (New analyses).

Some of them, however, such as the new Tarumai lava erupted in 1909, are included as an average composition. As to the welded tuff, although there are 21 data at hand, only 3 average composition and 5 original analyses of them are included.

Some calculations of MgO-($FeO+Fe_2O_3$)+(Na_2O+K_2O) ratio, Norm- and Niggli-values for graphical representations, were made by the writer and listed in the following table (Table 4).

TABLE 4. MgO-($FeO+Fe_2O_3$)-(Na_2O+K_2O) ratio and Norm- & Niggli values calculated from Table 3.

No.		1	2	3	4	5	6	7	8	9	10
Wt %	$FeO+Fe_2O_3$	53.7	51.1	64.9	67.8	51.3	28.3	33.5	60.5	66.0	60.5
	MgO	17.3	14.8	22.6	17.6	15.1	9.3	7.5	23.5	18.0	17.0
	Na_2O+K_2O	29.0	34.1	12.5	14.6	33.6	62.4	59.0	16.0	16.0	22.5
	Q	17.8	20.2	6.2	11.9	20.3	32.1	37.2	8.2	13.5	20.2
	Or	8.9	8.3	2.2	2.2	8.3	11.1	9.5	1.7	2.8	2.8
	Ab	29.9	28.9	13.1	19.4	27.3	34.6	30.4	18.9	21.0	22.5
	An	25.3	25.3	48.9	31.4	27.0	15.0	13.6	40.8	30.8	33.1
	C	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Wo	1.2	1.2	5.2	5.1	.6	.0	.0	5.2	5.1	1.9
	En	6.1	5.2	8.7	8.2	5.3	2.2	1.7	9.5	8.0	5.8
	Fs	3.2	3.7	6.2	13.9	2.1	1.1	1.8	10.0	10.2	9.0
	Fo	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Fa	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Mt	5.3	4.6	5.6	4.9	5.1	1.9	1.6	3.7	5.6	3.2
	Il	1.4	1.5	2.3	2.3	2.0	.9	1.1	1.5	2.3	.9
	Hm	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Ap	.3	.3	.0	.3	.3	.3	.3	.7	.7	.7
Wt %	Or	14.0	13.5	3.4	4.2	13.2	18.3	17.8	2.8	5.1	4.8
	Ab	46.5	46.0	20.4	36.6	43.6	57.0	56.8	30.7	38.5	38.6
	An	39.5	40.5	76.2	57.2	43.2	24.7	25.4	66.5	56.4	56.6
Wt %	Wo	11.5	11.0	25.8	18.7	7.5	.0	.0	21.1	21.9	11.4
	En	58.0	52.0	43.3	30.2	66.2	67.0	49.0	38.4	34.4	34.7
	Fs	30.5	37.0	30.9	51.1	26.3	33.0	51.0	40.5	33.7	53.9
color index		17.5	16.5	28.5	35.0	15.5	6.5	6.5	30.5	32.0	21.5
	si	201	212	120	145	208	347	387	135	152	189
	al	32.5	33.2	30.4	24.8	33.9	40.9	40.0	28.5	25.7	31.5
	fm	32.4	30.9	32.7	42.7	30.6	17.5	19.0	35.1	40.3	32.8
	c	20.6	21.4	32.7	25.8	21.7	16.4	16.8	30.4	26.6	26.6
	alk	14.5	14.5	4.2	6.7	13.8	25.2	24.2	6.0	7.4	9.1
	qz	43	54	3	18	53	146	180	11	22	53
	k	.22	.21	.14	.10	.22	.23	.23	.08	.11	.10
	mg	.37	.35	.39	.31	.36	.37	.29	.42	.33	.33
	al-alk	18.0	18.7	26.4	18.1	20.1	15.7	15.8	22.5	18.3	22.4
	c-(al-alk)	2.6	2.7	6.3	7.7	1.6	.7	1.0	7.9	8.3	4.2

Numbers of each column with reference to Table 3.

(to be continued)

TABLE 4. continued

No.		11	12	13	14	15	16	17	18	19	20
Wt %	$FeO+Fe_2O_3$	49.0	42.0	54.1	53.4	41.2	41.3	41.6	38.3	33.4	61.1
	MgO	13.0	10.0	19.0	13.0	12.8	11.7	11.0	9.4	12.0	22.7
	Na_2O+K_2O	38.0	48.0	26.9	33.6	46.0	47.0	47.4	52.3	54.6	16.2
	Q	28.9	39.1	15.2	23.6	29.8	29.4	34.2	33.8	35.5	9.0
	Or	5.0	6.1	6.1	5.0	7.8	7.8	8.3	8.9	9.5	2.8
	Ab	29.9	30.9	24.6	31.4	30.4	30.9	29.9	32.0	34.1	18.9
	An	21.1	14.7	32.0	21.4	20.0	21.1	17.2	14.7	12.5	36.7
	C	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Wo	.0	.0	2.6	2.1	.0	.1	.0	.3	.0	5.8
	En	3.7	2.5	6.9	4.4	3.4	3.1	2.9	2.4	2.9	9.7
	Fs	3.3	1.7	5.5	6.2	1.2	1.8	.8	.8	1.2	9.0
	Fo	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Fa	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Mt	3.7	3.0	4.2	3.3	3.2	2.8	3.5	3.0	2.3	4.4
	Il	.8	.6	1.7	1.7	1.4	1.4	1.1	1.1	1.4	2.0
	Hm	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Ap	.3	.7	.3	.3	.3	.3	.3	.3	.0	.3
Wt %	Or	8.9	11.8	9.7	8.7	13.4	13.0	15.0	16.0	16.9	4.8
	Ab	53.4	59.7	39.2	54.3	52.2	51.7	53.9	57.6	60.8	32.4
	An	37.7	28.5	51.1	37.0	34.4	35.3	31.1	26.4	22.3	62.8
Wt %	Wo	.0	.0	17.3	16.5	.0	2.0	.0	9.0	.0	23.6
	En	53.4	59.5	46.0	34.6	74.0	62.0	78.0	69.0	71.0	39.6
	Fs	37.0	40.5	36.7	48.9	26.0	36.0	22.0	23.0	29.0	36.8
	color index	12.0	8.5	21.5	18.0	10.0	9.5	9.0	8.0	8.0	31.5
	si	272	365	176	234	290	287	323	341	336	137
	al	35.6	36.9	31.6	32.0	37.4	38.0	37.8	38.0	38.4	27.1
	fm	28.5	24.4	32.2	31.5	24.4	23.4	24.2	22.2	23.2	37.5
	c	19.3	17.7	25.6	21.4	19.5	20.4	18.0	17.3	13.6	29.0
	alk	16.6	21.0	10.6	15.1	18.7	18.6	20.0	22.5	24.8	6.4
	qz	105.6	181.0	33.6	73.6	115.2	112.6	147.0	151.0	166.8	11.4
	k	.14	.16	.19	.13	.19	.19	.21	.21	.21	.12
	mg	.32	.31	.39	.31	.36	.34	.33	.32	.38	.41
	al-alk	19.0	15.9	21.0	16.9	18.7	19.6	17.8	15.5	13.6	20.7
	c-(al-alk)	.3	1.8	4.6	4.5	.8	.8	.2	1.8	.0	8.3

TABLE 4. continued

No.		21	22	23	24	25	26	27	28	29	30
Wt %	$FeO+Fe_2O_3$	48.3	52.3	49.4	48.5	50.7	45.7	16.1	53.7	57.6	52.6
	MgO	11.3	22.0	26.4	23.5	22.8	20.7	40.0	24.2	26.5	25.5
	Na_2O+K_2O	40.4	25.7	24.2	28.0	26.5	33.6	43.9	22.1	15.9	21.9
	Q	27.0	14.3	6.8	10.9	13.1	16.4	21.9	9.7	.0	.8
	Or	8.9	6.1	8.3	10.0	8.9	10.8	11.2	7.2	4.4	7.2
	Ab	29.9	22.6	24.1	25.7	23.1	27.8	32.0	22.6	22.5	25.2
	An	19.5	35.0	31.7	27.5	30.6	23.1	21.4	28.9	35.0	31.4
	C	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Wo	1.0	1.4	3.2	2.9	3.9	3.5	.7	5.9	6.8	5.9
	En	3.5	8.0	11.8	9.9	9.0	7.8	5.3	10.7	9.1	12.4
	Fs	3.4	7.4	7.7	5.3	3.7	4.4	1.7	8.3	4.1	11.2
	Fo	.0	.0	.0	.0	.0	.0	.0	.0	3.7	.0
	Fa	.0	.0	.0	.0	.0	.0	.0	.0	2.2	.0
	Mt	3.5	3.0	3.9	4.6	5.3	4.2	3.7	3.9	7.2	3.7
	Il	1.5	1.5	1.7	1.2	1.4	1.1	1.2	2.1	3.0	2.0
	Hm	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Ap	.7	.3	.3	.7	.3	.3	.3	.7	.3	.3
Wt %	Or	15.2	9.6	12.9	15.8	14.2	16.4	17.3	12.3	7.1	11.3
	Ab	51.2	35.5	52.0	40.7	36.9	45.6	49.5	38.5	36.4	39.4
	An	33.6	54.9	33.9	43.5	48.9	38.0	33.2	49.2	56.5	49.3
Wt %	Wo	12.7	8.3	14.1	16.0	23.5	22.3	9.0	23.7	33.1	20.0
	En	44.3	47.6	52.0	54.7	54.2	49.7	69.0	43.0	44.4	42.0
	Fs	43.0	44.1	33.9	29.3	22.3	28.0	22.0	33.3	22.5	38.0
color index		13.5	21.5	29.0	25.0	24.0	21.5	13.0	31.5	37.5	35.5
	si	264	173	147	167	167	196	240	151	107	129
	al	34.4	32.5	28.3	28.8	29.3	30.3	33.5	26.1	24.3	25.9
	fm	27.8	33.4	38.4	36.5	34.4	33.5	27.2	38.4	42.9	40.2
	c	20.3	24.4	23.4	22.9	25.8	22.7	19.2	26.3	25.8	24.8
	alk	17.5	9.7	9.9	11.8	10.5	13.8	18.1	9.2	7.0	9.1
	qz	94.0	34.2	7.4	19.8	25.0	40.8	67.6	14.4	−21.0	−7.0
	k	.22	.20	.25	.27	.27	.25	.25	.23	.16	.21
	mg	.30	.43	.50	.48	.46	.45	.43	.46	.46	.46
	al-alk	16.9	22.8	18.4	17.0	18.8	16.2	17.4	16.9	17.3	16.8
	c-(al-alk)	3.4	1.6	5.0	5.9	7.0	6.5	.8	9.4	8.5	8.0

(to be continued)

TABLE 4. continued

No.		31	32	33	34	35	36	37	38	39	40
Wt %	$FeO+Fe_2O_3$	54.0	45.6	30.0	45.5	44.6	45.1	45.0	43.5	46.3	50.1
	MgO	23.8	15.6	5.7	24.7	25.8	26.2	26.6	25.7	19.4	17.8
	Na_2O+K_2O	22.2	38.8	64.3	29.8	29.6	28.7	28.4	30.8	34.3	32.1
	Q	8.2	16.7	30.9	12.4	12.2	13.2	13.9	12.9	18.5	20.9
	Or	8.3	17.2	20.0	9.4	9.4	8.2	8.9	9.4	8.3	8.9
	Ab	20.4	28.3	33.0	24.1	24.1	24.1	24.1	25.7	26.7	23.6
	An	35.0	18.4	8.1	32.2	32.2	31.4	30.6	30.0	29.7	29.7
	C	.0	.0	.0	.0	.0	.0	.0	.0	.9	.3
	Wo	3.4	3.2	1.2	2.1	1.9	2.1	1.7	1.7	.0	.0
	En	10.3	6.3	1.6	9.1	9.6	9.8	10.2	9.6	6.4	6.0
	Fs	7.1	.0	.0	3.0	3.3	3.2	2.1	2.9	.1	.4
	Fo	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Fa	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Mt	4.4	6.5	1.9	4.4	4.4	4.4	5.1	4.4	5.6	6.0
	Il	2.4	1.5	.6	1.5	1.4	1.5	1.5	1.5	1.2	1.9
	Hm	.0	.3	1.3	.0	.0	.0	.0	.0	.0	.0
	Ap	.3	.3	.0	.3	.3	.3	.3	.3	.3	.3
Wt %	Or	13.1	26.9	32.7	14.3	14.3	13.0	14.0	14.4	12.8	14.3
	Ab	32.1	44.3	54.1	36.7	36.7	37.8	37.9	39.3	41.3	38.0
	An	54.8	28.8	13.2	49.0	49.0	49.2	48.1	43.3	45.9	47.7
Wt %	Wo	16.2	34.0	43.0	14.8	12.8	13.9	12.2	12.0	.0	.0
	En	49.5	66.0	57.0	64.1	64.8	65.0	72.8	67.6	98.5	94.0
	Fs	34.3	.0	.0	21.1	22.4	21.1	15.0	20.4	1.5	6.0
color index		28.0	18.5	7.0	20.5	21.0	21.5	21.5	20.5	14.0	14.5
si		145	204	366	169	168	171	17.2	174	196	202
al		28.9	30.6	39.3	32.0	31.7	31.2	31.0	31.6	32.6	34.9
fm		37.0	32.6	18.4	32.3	33.2	33.8	34.9	33.5	28.8	30.3
c		25.4	19.6	12.0	24.5	28.9	24.0	23.0	23.0	21.9	22.4
alk		8.7	17.2	30.3	12.2	11.2	11.0	11.1	11.9	13.1	12.4
qz		10.2	35.2	145	24.7	23.8	27.0	27.6	26.4	43.6	52.4
k		.28	.37	.36	.27	.27	.25	.26	.26	.23	.26
mg		.45	.39	.27	.50	.51	.47	.53	.51	.44	.40
al-alk		20.2	13.3	9.6	20.8	20.5	20.2	19.9	19.7	23.1	22.5
c-(al-alk)		5.2	6.3	3.0	3.7	3.4	3.8	3.1	3.3	-1.2	-.1

TABLE 4. continued

No.		41	42	43	44	45	46	47	48	49	50
Wt %	$FeO+Fe_2O_3$	48.1	45.0	46.8	45.9	50.4	53.4	43.3	49.0	47.5	42.6
	MgO	18.0	19.0	28.2	37.1	26.2	19.3	35.1	31.6	27.3	19.3
	Na_2O+K_2O	33.9	36.0	25.0	17.0	23.4	17.3	21.6	19.4	25.2	38.1
	Q	21.0	20.0	10.6	.0	.0	.0	.0	.0	1.2	19.8
	Or	9.4	9.4	7.8	3.3	4.9	5.0	5.5	3.3	6.7	5.5
	Ab	27.3	25.2	22.6	25.6	32.5	23.0	29.4	32.0	29.4	34.0
	An	22.8	30.6	31.4	33.0	26.1	29.2	27.0	23.9	30.6	25.3
	C	1.7	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Wo	.0	.3	4.1	6.5	9.6	10.1	9.0	10.0	7.7	2.0
	En	6.4	6.1	11.3	8.0	6.3	15.3	11.0	10.0	12.6	6.4
	Fs	.0	.9	4.1	3.2	2.6	7.8	2.4	4.4	6.3	2.0
	Fo	.0	.0	.0	9.9	4.8	.0	5.1	5.4	.0	.0
	Fa	.0	.0	.0	4.4	2.3	.0	1.1	3.0	.0	.0
	Mt	3.7	4.9	4.9	3.7	6.0	5.8	5.8	5.6	5.3	4.2
	Il	1.2	1.2	1.2	2.3	2.7	2.6	2.4	2.1	.0	1.1
	Hm	2.7	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Ap	.3	.3	.7	.3	.3	.3	.3	.3	.0	.3
Wt %	Or	15.8	14.4	12.6	5.4	7.7	8.8	8.8	5.6	10.0	8.5
	Ab	45.9	38.6	36.6	41.3	51.2	40.2	47.5	54.1	44.0	52.4
	An	38.3	47.0	50.8	53.3	41.1	51.0	43.7	41.3	46.0	39.1
Wt %	Wo	.0	4.4	21.0	36.7	51.9	30.4	40.1	41.0	29.0	19.2
	En	100.0	84.0	58.0	45.2	34.0	46.0	49.2	41.0	47.4	61.6
	Fs	.0	12.0	21.0	18.1	14.1	23.6	10.7	18.0	23.6	19.2
color index		15.0	14.0	26.5	38.0	36.5	42.5	38.0	41.0	32.0	16.0
si		209	204	155	108	119	117	119	118	134	225
al		35.3	35.4	28.5	22.9	23.6	22.4	23.0	21.2	26.7	33.9
fm		32.4	28.0	36.1	46.4	28.6	42.9	42.6	45.2	36.4	28.0
c		17.8	23.5	25.8	23.4	27.6	27.1	25.1	24.3	26.5	22.6
alk		14.5	13.1	9.6	7.3	10.2	7.6	9.3	9.3	10.4	15.5
qz		51.0	51.6	16.6	-21.2	-22.2	-13.3	-18.2	-19.2	-8.1	63.2
k		.25	.26	.24	.11	.13	.17	.15	.10	.17	.13
mg		.42	.44	.52	.62	.49	.50	.61	.54	.52	.46
al-alk		20.8	22.3	18.9	15.6	13.4	14.8	13.7	11.9	16.3	18.4
c-(al-alk)		-3.0	1.2	6.9	7.8	14.2	12.3	11.4	11.4	10.2	4.2

(to be continued)

TABLE 4. continued

No.		51	52	53	54	55	56	57	58	59	60
Wt %	$FeO+Fe_2O_3$	36.8	57.7	41.0	31.0	40.0	25.9	58.6	58.1	56.4	59.0
	MgO	11.6	22.7	8.0	7.0	11.0	4.6	24.0	21.2	22.6	21.4
	Na_2O+K_2O	51.6	19.6	51.0	62.0	49.0	69.5	17.4	20.7	21.0	19.6
	Q	19.0	6.0	28.0	29.4	35.5	34.7	17.8	16.4	17.6	22.4
	Or	10.5	3.9	10.0	14.4	11.1	20.5	3.9	6.1	4.4	5.6
	Ab	43.5	22.5	28.8	33.0	26.2	28.3	17.8	18.9	21.0	15.7
	An	15.8	38.3	18.9	15.0	15.0	9.2	36.2	33.6	35.3	30.8
	C	.0	.0	.7	.2	1.7	.2	.8	2.4	.0	3.2
	Wo	.2	4.3	.0	.0	.0	.0	.0	.0	.6	.0
	En	3.9	9.6	2.0	1.7	2.8	1.1	9.7	8.2	8.6	7.8
	Fs	3.0	6.3	1.8	.3	1.8	.7	7.5	11.3	6.1	9.6
	Fo	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Fa	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Mt	3.0	5.8	2.6	2.8	3.0	2.1	5.1	3.2	4.9	3.9
	Il	1.0	1.8	1.1	.8	.2	.6	1.1	.9	1.2	.9
	Hm	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Ap	.3	.3	.3	.3	.3	.3	.0	.0	.0	.7
Wt %	Or	15.0	6.0	17.3	23.1	21.2	35.4	6.7	10.4	7.3	10.8
	Ab	62.3	34.8	49.9	52.9	50.1	48.7	30.7	32.3	34.6	30.1
	An	22.7	59.2	32.8	24.0	28.7	15.9	62.6	57.3	58.1	59.1
Wt %	Wo	2.8	21.3	.0	.0	.0	.0	.0	.0	3.9	.0
	En	54.9	47.5	53.0	85.0	61.0	61.0	56.4	42.0	56.2	44.8
	Fs	42.3	31.2	47.0	15.0	39.0	39.0	43.6	58.0	39.9	55.2
color index		11.5	28.5	9.0	6.0	10.0	5.0	24.0	26.0	21.5	26.0
si		259	133	296	328	323	402	166	168	174	180
al		37.2	29.1	40.4	41.3	39.2	42.0	31.0	33.1	31.4	33.2
fm		24.5	35.7	20.2	17.1	25.6	15.7	39.3	37.6	36.4	38.0
c		14.6	27.5	19.4	16.3	15.8	12.0	22.6	21.1	23.6	21.5
alk		23.7	7.7	20.0	25.3	19.4	30.3	7.1	8.2	8.6	7.3
qz		64.4	2.0	116.0	127.0	146.0	181.0	37.6	35.0	40.0	51.0
k		.19	.14	.25	.29	.29	.41	.17	.23	.17	.25
mg		.37	.42	.27	.28	.31	.23	.43	.38	.42	.38
al-alk		13.5	21.4	20.4	16.0	19.8	11.7	23.9	24.9	22.8	25.9
c-(al-alk)		1.1	6.1	-1.0	.3	-4.0	.3	-1.3	-3.8	.8	-4.4

TABLE 4. continued

No.		61	62	63	64	65	66	67	68	69	70
Wt %	$FeO+Fe_2O_3$	57.0	47.8	51.5	53.8	56.5	49.3	58.4	39.9	42.1	38.5
	MgO	17.2	12.5	18.3	20.1	20.0	14.1	23.5	9.7	8.7	7.7
	Na_2O+K_2O	25.8	39.7	30.2	26.1	23.5	36.6	18.1	50.4	49.2	53.8
	Q	23.3	22.9	12.8	11.6	15.7	21.2	9.0	29.3	34.9	31.9
	Or	5.6	8.9	6.1	6.1	6.1	7.8	2.8	7.8	8.3	6.1
	Ab	23.6	30.9	27.8	26.8	24.6	32.0	21.0	32.5	28.8	37.2
	An	30.6	22.2	32.2	30.3	27.5	22.8	39.2	20.9	16.4	15.6
	C	.6	.0	.0	.0	.0	.0	.0	.4	2.5	.9
	Wo	.0	2.0	2.7	3.1	4.1	.7	3.3	.0	.0	.0
	En	6.2	4.1	6.6	7.9	8.3	4.9	9.6	2.5	2.1	1.9
	Fs	1.6	2.9	6.1	7.3	6.1	4.8	8.6	2.4	2.9	2.9
	Fo	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Fa	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Mt	7.2	4.9	3.5	3.9	5.3	3.7	4.2	2.8	2.1	2.1
	Il	.9	.3	1.7	1.5	2.0	1.2	2.0	.6	.9	.8
	Hm	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Ap	.0	.3	.3	.3	.3	.3	.7	.3	.7	.3
Wt %	Or	9.4	14.4	9.2	9.6	10.5	12.4	4.4	12.7	15.5	10.4
	Ab	39.4	49.8	42.0	42.4	42.2	51.2	33.4	53.1	53.9	63.2
	An	51.2	35.8	48.8	48.0	47.3	36.4	62.2	34.2	30.6	26.4
Wt %	Wo	.0	22.2	17.5	17.1	22.1	6.7	15.3	.0	.8	.0
	En	78.5	45.5	42.8	43.5	44.9	47.1	44.7	51.0	43.9	40.0
	Fs	21.5	32.3	39.7	40.4	33.0	46.2	40.0	49.0	57.0	60.0
color index		16.5	14.5	21.0	24.0	26.5	16.0	28.5	8.5	9.0	9.0
si		198	234	174	170	172	228	141	291	318	327
al		33.6	33.8	32.5	30.2	27.9	32.9	29.4	39.5	41.8	40.8
fm		34.0	27.9	30.4	34.4	37.5	30.4	35.8	21.2	21.3	20.3
c		21.6	21.8	25.6	24.5	24.3	19.6	27.7	19.9	17.8	16.4
alk		10.8	16.5	11.5	10.0	10.3	16.1	7.1	19.4	19.1	22.5
qz		55.0	68.0	28.0	27.0	31.0	64.1	12.6	113.4	141.6	137.0
k		.18	.21	.17	.18	.19	.19	.11	.18	.27	.12
mg		.36	.32	.39	.41	.39	.35	.42	.31	.21	.21
al-alk		22.8	17.3	21.0	19.3	17.6	17.8	22.3	20.1	22.7	18.3
c-(al-alk)		-1.2	4.5	4.6	5.2	6.7	1.8	5.4	.2	-4.9	-1.9

(to be continued)

TABLE 4. continued

No.		71	72	73	74	75	76	77	78	79	80
Wt %	$FeO+Fe_2O_3$	46.1	54.0	56.3	56.8	51.2	48.9	52.9	45.6	40.5	48.8
	MgO	7.5	21.4	21.4	19.7	19.3	16.4	16.9	26.2	46.0	32.2
	Na_2O+K_2O	46.4	24.6	22.3	23.5	29.5	34.7	30.2	28.2	13.5	19.0
	Q	36.4	14.4	19.0	17.6	14.7	13.8	16.1	16.7	.0	.5
	Or	6.7	3.9	6.1	5.6	5.6	6.1	4.4	9.5	6.7	11.1
	Ab	34.1	25.2	18.6	24.1	30.9	36.2	33.6	22.0	16.8	18.3
	An	12.8	33.9	35.6	29.2	25.3	21.1	23.4	32.0	28.6	28.3
	C	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Wo	.0	2.0	1.0	2.6	3.7	5.0	3.6	1.2	10.3	9.2
	En	2.1	7.9	7.5	7.9	7.6	6.3	6.6	9.9	14.7	17.6
	Fs	.8	7.3	6.6	6.9	6.5	5.7	6.2	.0	4.4	4.5
	Fo	.0	.0	.0	.0	.0	.0	.0	.0	8.5	.0
	Fa	.0	.0	.0	.0	.0	.0	.0	.0	2.9	.0
	Mt	4.6	3.9	4.3	5.1	3.9	3.9	4.4	5.8	4.2	7.2
	Il	.8	1.2	1.1	.6	1.4	1.4	1.2	1.2	2.0	2.1
	Hm	.0	.0	.0	.0	.0	.0	.0	.6	.0	.0
	Ap	1.0	.3	.3	.7	.3	.3	.3	.0	.0	.7
Wt %	Or	12.4	6.2	10.0	9.5	9.1	9.6	7.2	15.0	12.9	19.2
	Ab	63.7	40.0	30.0	40.9	50.0	57.1	54.7	34.6	32.3	31.8
	An	23.9	53.8	60.0	49.6	40.9	33.3	38.1	50.4	54.8	49.0
Wt %	Wo	.0	11.6	6.5	14.9	20.8	29.4	22.0	11.0	35.0	29.4
	En	73.0	45.9	51.0	45.4	42.7	30.0	40.2	89.0	50.0	56.2
	Fs	27.0	42.5	42.5	39.7	36.5	33.6	37.8	.0	15.0	14.4
color index		9.5	22.5	21.0	23.5	23.5	22.5	22.5	19.0	47.5	41.4
si		338	170	179	180	185	193	192	177	105	116
al		36.8	31.3	31.9	29.2	29.6	29.7	29.5	31.5	18.8	22.0
fm		26.0	33.8	34.1	36.4	34.3	31.7	33.7	34.6	50.5	44.1
c		15.5	25.1	25.5	24.3	23.3	23.3	23.1	23.0	25.5	26.2
alk		21.7	9.8	8.5	10.1	12.8	15.3	13.7	10.7	5.7	7.7
qz		151.2	31.0	45.0	40.0	34.0	32.0	37.0	34.2	-18.3	-14.8
k		.28	.13	.23	.17	.15	.14	.11	.29	.27	.36
mg		.16	.41	.41	.39	.41	.38	.37	.54	.66	.55
al-alk		15.1	21.5	23.4	19.1	16.8	14.4	15.8	21.0	13.1	14.3
c-(al-alk)		.4	3.6	2.1	5.2	6.5	8.9	7.3	2.0	11.9	11.9

TABLE 4. continued

No.	81	82	83
Wt % $FeO+Fe_2O_3$	47.0	39.6	42.2
Wt % MgO	25.2	13.3	23.3
Wt % Na_2O+K_2O	27.8	47.1	34.5
Q	8.3	14.1	17.1
Or	10.6	19.5	11.1
Ab	22.5	27.3	26.2
An	32.5	24.2	25.3
C	.0	.0	.0
Wo	3.5	.3	3.5
En	10.1	4.6	8.3
Fs	6.9	5.7	1.9
Fo	.0	.0	.0
Fa	.0	.0	.0
Mt	3.5	1.6	4.6
Il	1.2	.8	1.6
Hm	.0	.0	.0
Ap	.7	.3	.7
Wt % Or	16.2	27.4	17.7
Wt % Ab	34.3	38.4	41.8
Wt % An	49.5	34.2	40.5
Wt % Wo	17.1	2.8	25.5
Wt % En	49.2	43.4	60.6
Wt % Fs	33.7	53.8	13.9
color index	26.0	13.5	20.5
si	155	217	192
al	29.9	36.6	30.8
fm	34.2	25.4	31.5
c	25.5	19.5	24.4
alk	10.4	18.5	13.3
qz	12.6	43.0	39.0
k	.31	.40	.29
mg	.49	.38	.51
al-alk	19.5	18.1	17.5
c-(al-alk)	6.0	1.4	6.9

VI General aspects of the chemical composition

The analysed rocks of Table 3 comprise nearly representative types of the Quaternary volcanic rocks of Hokkaido, varying from 46.79% to 72.62% in silica contents.

An analysis of the existing petrochemical data shows a characteristic frequency distribution for the silica contents. (See Fig. 2). Rocks of

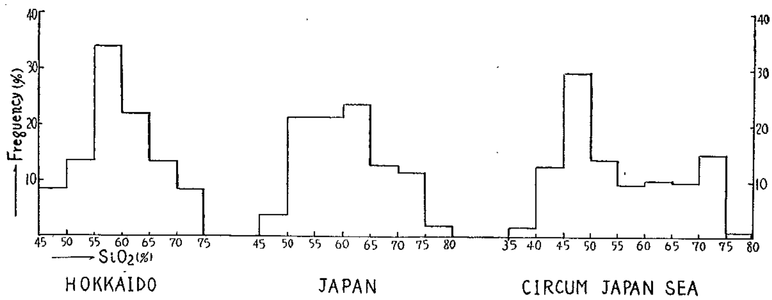


Fig. 2. Frequency distribution of analysed rocks for the silica contents. Number of data: Hokkaido 83, Japan 334 (TANEDA, 1952) and Circum Japan Sea 220 (YAGI, 1959),

SiO_2 55~60% are most dominant, those of SiO_2 55~65% exceed more than one half of the total, and the remainder decrease synmetrically toward the higher or lower end of the silica contents, respectively. Similar distribution is also seen in the younger volcanic rocks throughout the Japanese Islands. Possibly, such distribution is a result of the fact that mafic to intermediate rocks were apt to originate through sialic contamination of basaltic magma under an active orogenic condition which scarcely favoured eruption of primary basaltic magma nor generation of its crystal differentiated derivatives. In this connection, it is genetically significant that in the Cenozoic Circum-Japan Sea petrographic province, a non-orogenic area, the frequency distribution shows two maxima, namely, one is olivine-basalt and trachy-basalt and the other is alkali-rhyolite respectively.

Alumina contents of the rocks in the present area are so high as a whole, namely in the front zone, that it arouses interest. Perhaps it may also be stated that such active zones as the present area between continental block and oceanic shield are characterized by volcanic rocks high in alumina, as has been noticed by many authors.

The degree of silica saturation is well represented by NIGGLI's *qz* value (NIGGLI, 1920). Diagram of the variation of *qz* against *si* shown

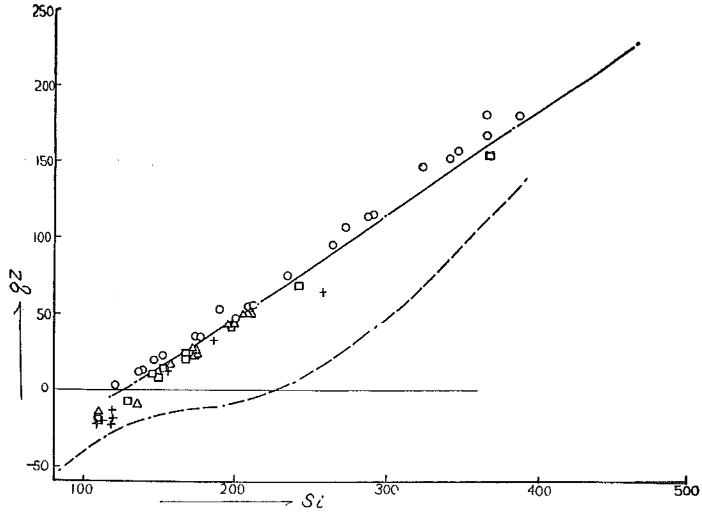


Fig. 3. Variation diagram of qz values for the rocks of the Kuril arc. Open circles: Shiretoko-Akan chain, squares: Daisetsu-Tokachi chain, triangles: Irumukeppu and Shokanbetsu, crosses: Rishiri, full line: average of Japanese volcancic rocks (TANEDA, 1952), broken line: average of the Circum Japan Sea alkali rocks (TOMITA, 1935).

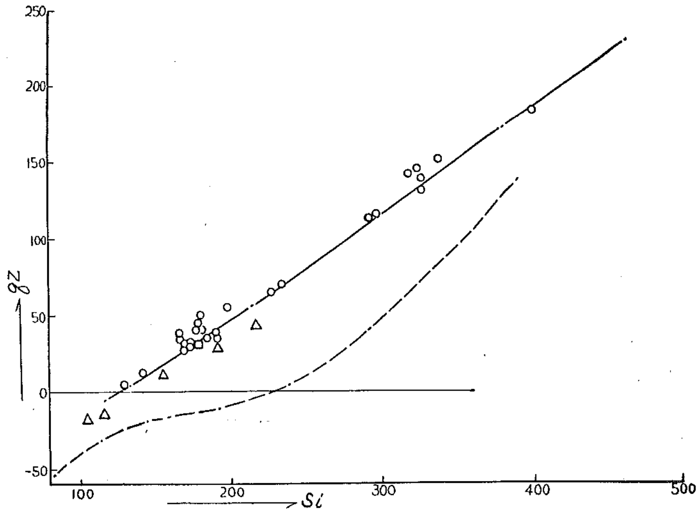


Fig. 4. Variation diagram of qz values for the rocks of the northern Honshu arc. Open circles: Nasu zone, square: Niseko, triangles: Chôkai zone. Full and broken lines same as in Fig. 3.

in Figures 3 and 4. The most outstanding aspect in these diagrams is expressed as follows: the rocks of the front zone are always oversaturated, as is expected from the fair amount of interstitial silica minerals; on the other hand, those of the inner zone are rather poor in *qz*, namely most mafic rocks are characterized by dificient *qz* which depends on paucity of silica minerals as well as carrying a fair amount of olivine. This relation, needless to say, is also applicable to normative Q value (Table 4).

NIGGLI's *k-mg* relation shows the relative proportions of potash to total alkalies and of magnesia to mafic oxides in a single variation diagram. As seen in Figures 5 and 6, all rocks of the front zone are

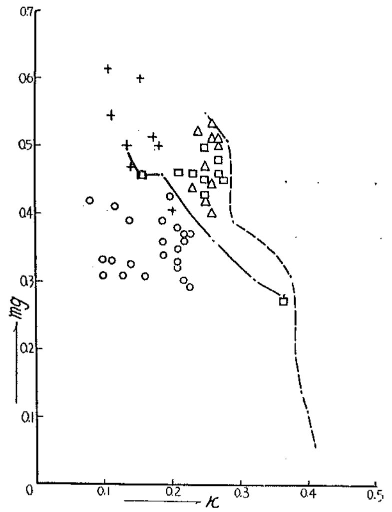


Fig. 5. Variation diagram of *k-mg* relation for the rocks of the Kuril arc. Symbols same as in Fig. 3.

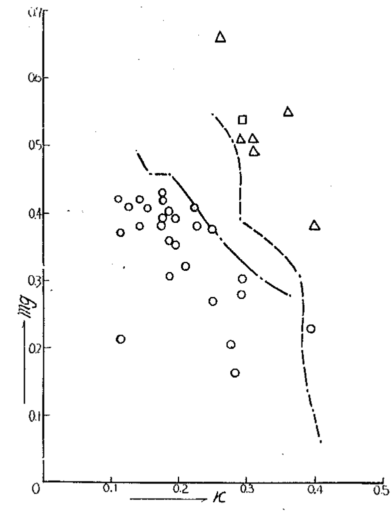


Fig. 6. Variation diagram of *k-mg* relation for the rocks of the northern Honshu arc. Symbols same as in Fig. 4.

lower in both *k* and *mg* values than those of the inner zone. In fact, a distinct boundary curve between them can be drawn according to the average value of the young volcanic rocks in Japan.

Besides the general characters above mentioned, analysis by NIGGLI's *al-alk* value of the rocks of the present area, also results in the finding a similar relation that values for rocks of the front zone are higher than those of the inner zone. Other features seen in NIGGLI's value agree with the results announced by ISHIKAWA (1952) and ISHIKAWA and KATSUI (1959).

The well known alkali-lime index proposed by PEACOCK (1931) is

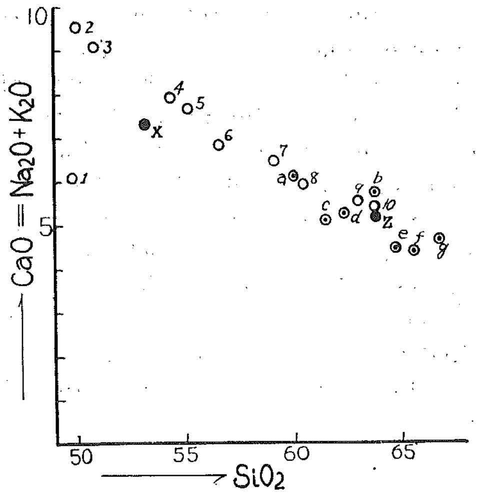


Fig. 7. Alkali-lime index. (*cfr.* Table 5).

TABLE 5. Alkali-lime Index

	Province	Alkali-lime index	$CaO=Na_2O+K_2O$	Index of quotient*
a	Chôkai zone	60.0	6.0	10.0
b	Rishiri	64.0	5.6	11.4
c	Irumukeppu & Shokanbetsu	61.3	4.9	12.5
d	Daisetsu-Tokachi chain	62.0	5.3	11.7
e	Nasu zone (Shikotsu)	64.5	4.4	14.7
f	Nasu zone (Usu)	55.5	4.4	14.9
g	Shiretoko-Akan chain	65.7	4.7	14.0
x	Circum Japan Sea (Tomita, 1935)	53.1	7.2	7.4
z	Japan (Taneda, 1952)	63.7	5.1	12.5
1	Midland Valley	49.5	6.0	8.3
2	Highwood	50.0	9.5	5.3
3	Crazy Mtn.	51.5	9.3	5.5
4	Little Belt	54.5	7.6	7.2
5	Absaroka	55.0	7.5	7.3
6	Crandall	56.6	6.5	8.7
7	San Juan	59.4	6.5	9.1
8	Yellowstone	60.3	5.7	10.6
9	Gardiner River	63.0	5.6	11.2
10	Katmai (1-10, Barth, 1952)	63.5	5.6	11.3

* Index of quotient is a value of PEACOCK'S alkali-lime index divided by CaO ($=Na_2O+K_2O$)

represented by the SiO_2 value for the intersection of the CaO and Na_2O+K_2O curves of a variation diagram. This index is also represented by the quotient of alkali-lime index divided by CaO value ($=Na_2O+K_2O$) which is more useful in the comparing rock suites than the original index.

The alkali-lime index of PEACOCK and the index of the quotient for the rocks of the present area are listed in Table 5 and graphed in Figure 7, together with similar indexes for various provinces in the world. After PEACOCK's four fold classification, the rocks of the present area are comprised in calcic or calc-alkalic rock series.

Similar relation between the inner zone and the front zone as above noted is also exhibited by the alkali-lime index; the index for the inner zone is rather low, while that for the front zone is extremely calcic throughout the world.

VII Rock types and their consanguinity —Rock series—

Study on the genetic relations of assemblages within the basalt-andesite-dacite-rhyolite range of the volcanic suites of the orogens is one of the most important problems of volcanic petrogenesis. Under this heading, consanguinity of rock types will be considered on the basis of the descriptions in preceding chapters.

Most of the rocks in the present area are comprised in the category of "calc-alkali rock series*," which is characteristically accompanied by orogenic belts, obviously from their mineral and chemical characters. These rocks frequently have some indications of contamination of magma, and are usually characterized by presence of rhombic pyroxene in groundmass (types d and e). For these rocks it was named "hypersthenic rock series" by KUNO (1950) who considered that the very rock series represents calc-alkali rock series.

A question, however, arises as to why marked difference is generated between the rocks of the separate volcanic fields as shown above. To this question a solution may be given by considering the intensity of

* Unfortunately, confusion is apt to arise here concerning definition of "calc-alkali rock series." For instance, as concerning their alkali-lime indices, even basalt-andesite suites of pure fractionation product of the tholeiite magma may be comprised in calc-alkali rock series. Peacock's index con only distinguish alkli rock series from calc-alkali rock series, but not clarify a relation between the latter and tholeiite rock series. The term "calc-alkali rock series" for such tholeiite rock seems now undesirable.

contamination of the same magma, as has been postulated by KUNO (1952). It is true that this answer may explain such a difference as the increase in value of K_2O/Na_2O ratio resulting from the contamination of magma by granitic materials, as shown by YAMASAKI (1956).

For all that, there is no reason to believe that as a result of contamination of magma the unique characters of each volcanic field or zone were formed, because the effect of contamination of magma resulted in only a limited increasing of the K_2O/Na_2O ratio. That is also self-evident from data presented by YAMASAKI. For instance, a basalt of high K_2O/Na_2O value is not always a product of intense contamination of magma.

On the other hand, the writer has been of the opinion that the nature of basaltic magmas would decide the character of their contaminated derivatives as well as crystal differentiated ones (KATSUI, 1956).

TILLEY (1950) has pointed out that even in orogenic belts there are exceptionally andesites which should claim direct parentage from an iron-enriched tholeiite magma, such as the andesites of the southern part of the Fuji volcanic zone. These andesites are extremely poor in alkalies; they are comprised in KUNO's "pigionitic rock series" characterized by the type b→c or c in groundmass mineral assemblage (KUNO, 1950). Occurrence of andesite as well as basalt belonging to this series (types IVc, Vc *etc.*) is also known in the front zone of Hokkaido, accompanied by andesite and dacite (types Vd, Ie *etc.*). All of them are characterized by low contents of alkalies, especially K_2O, and high of excess silica as shown above.

On the contrary, olivine-basalt (type IVb), slightly alkalic and undersaturated in silica, actually erupted in the Japan Sea area, namely at Oshima-ôshima and Rishiri, together with andesite and dacite characterized by hornblende- and/or biotite-bearing rocks (types VId, XVId *etc.*). In this connection it is interesting that similar alkali olivine-basalts occur in the base of the volcanoes Irumukkepu and Shokanbetsu. All of them have a higher content of alkalies than basalts of the other volcanic fields. It is evident that the olivine-basalt of Oshima-ôshima has a similar composition to that of the olivine-basalt of Dôgo which is regarded by TOMITA (1951) to represent the parental olivine-basalt magma

In central Hokkaido, there is little known basalt which has not suffered from contamination. Olivine-basalt (type IVb→c) of Furano-dake of the Daisetsu-Tokachi chain is an exclusive example. This rock is essentially to be included in the tholeiite rock series, but it has slightly more abundant alkali contents than that of the front zone. All of the rocks of the Daisetsu-Tokachi chain have also slightly abundant alkalies, and hornblende- and/or biotite-bearing rocks are common.

Recent studies of Mr. ÔBA on the rocks of the Niseko volcano showed them to be very close in nature to those of the Daisetsu-Tokachi chain. According to him, mafic andesites (type Vc) weakly alkalic were erupted in early stage, they were followed by intermediate andesites (types Vd and VId) frequently including xenocrysts and cognate xenoliths. These rocks are also slightly high in alkalies, as shown in Table 3 (column 78).*

From what has been stated above, there is no escape from the conclusion that the unique character of calc-alkali rocks in each volcanic field owed its origin to the difference in characters of their parental basaltic magmas, i.e., alkali-poor and -rich tholeiite magmas and alkali olivine basalt magma, respectively.

In the light of above discussion, consanguinity of various rock types in the present area are shown in Table 6.

TABLE 6. Rock types and their consanguinity of the Quaternary volcanic rocks of Hakkaido

(Zone) (Basalt) (Andesite) (Dacite) (Rhyolite)

Front zone (Shiretoko-Akan chain & Nasu zone)

IVc ——→ Vc, Vd→c, Ic, c
Tholeiite rock series (alkali-poor)
↘ Vd ------→ Ve, Ie ------→ VI
Calc-alkali rock series (alkali-poor)

Inner zone (I) (Daisetsu Tokachi chain & Niseko)

IVb→c ——→ Vc
Tholeiite rock series (weak alkalic)
↘ Vc→d, Vd, VId, XVId, XVII ------→ XVI ------→ XVI
Calc-alkali rock series (weak alkalic)

Inner zone (II) (Rishiri, Shokanbetsu, Irumukeppu & Chôkai zone)

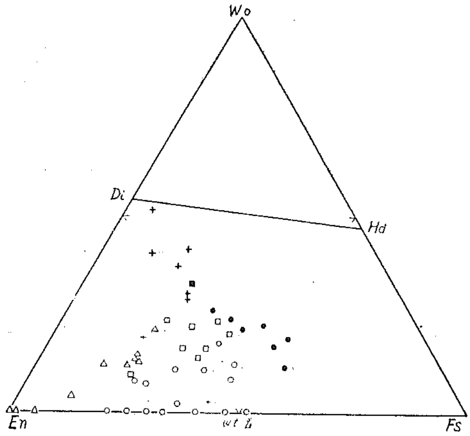
↗ IVd, Vd, VId, VII, IX, Ve, Ie, XVI, XVIII, XIX
Calc-alkali rock series (weak alkalic)
IVb→IVc
Alkali rock series

——→ fractional crystallization
------→ contamination

* Oral communication from Mr. OBA to whom the writer's thanks are due.

VIII Nature of the rock series

All available data on the chemical composition of the rocks in the present area are plotted in the triangular diagrams of Norm pyroxene and MgO-(FeO+Fe_2O_3)-(Na_2O+K_2O) ratio. (Figs. 8~11). Reference to these diagrams, will clarify the behavior in chemical composition of each rock series defined above (Figs. 14 & 15). The groupings seen in Figures 14 and 15, are too regular to be fortuitous and must indicate the existence of some fundamental chemical relationships.



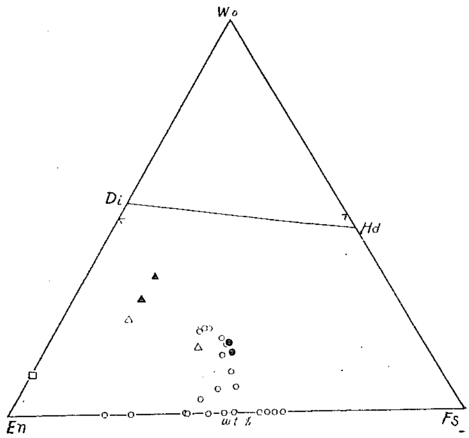


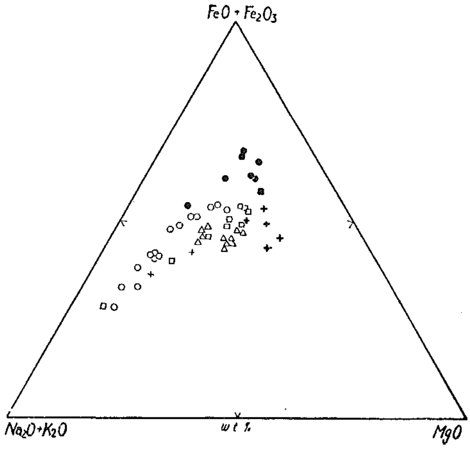
Fig. 8. Norm-pyroxene diagram for the rocks of the Kuril arc. (left)

solid circles:	tholeiite series (alkali-poor)	Shiretoko-Akan chain
open circles:	calc-alkali series (alkali-poor)	
solid square:	tholeiite series (weak alkalic)	Daisetsu-Tokachi chain
open squares:	calc-alkali series (weak alkalic)	
open triangles:	calc-alkali series (weak alkalic)	Irumukeppu & Shokanbetsu
heavy crosses:	alkali series	Rishiri
thin crosses:	calc-alkali series (weak alkalic)	

Fig. 9. Norm-pyroxene diagram for the rocks of the northern Honshu arc. (right)

solid circles:	tholeiite series (alkali-poor)	Nasu zone
open circles:	calc-alkali series (alkali-poor)	
open square:	calc-alkali series (weak alkalic)	Niseko
solid triangles:	alkali series	Chôkai zone
open triangles:	calc-alkali series (weak alkalic)	

1) *Tholeiite rock series* (*alkali-poor*). The rocks of this series are represented by the members which are most enriched in iron and poor in alkalies, throughout the present area. The course of fractional crystallization of tholeiite magma is usually characterized by increasing of iron,



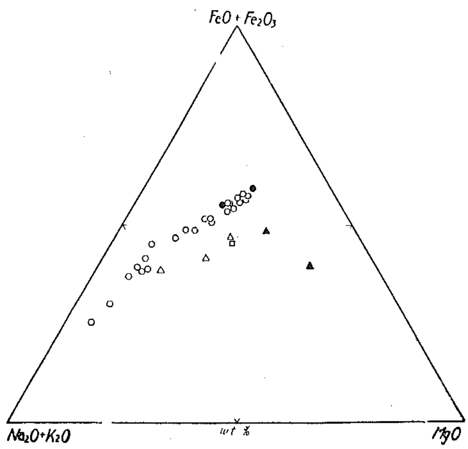


Fig. 10. MgO-($FeO+Fe_2O_3$)-(Na_2O+K_2O) diagram for the rocks of the Kuril arc. (left) Symbols same as Fig. 8.

Fig. 11. MgO-($FeO+Fe_2O_3$)-(Na_2O+K_2O) diagram for the rocks of the northern Honshu arc. (right) Symbols same as Fig. 9.

with its final product of granophyre (FENNER, 1929; WAGER and DEER, 1939; TILLEY, 1950). Absence of rocks corresponding to the final products shows that fractional crystallization does not easily occur in such an active orogenic belt as the present area.

Compared with the world-wide tholetiitic basalts, the rocks of the present area are characterized by high content of alumina that is also seen in the tholeiitic basalts of the southern subzone of the Fuji volcanic zone. GREEN and PODERVAART (1955) pointed out that active margins of oceanic shields are characterized by basalts high in alumina as much as they seem to be marked by andesite (also high in alumina). In fact, large anorthite (or calcic bytownite) phenocrysts are occasionally included in some tholeiitic rocks as well as in calc-alkali pyroxene-andesites in the Kuril, Nasu and Fuji volcanic zones, all of which are comprised in the front zone. ISHIKAWA (1951) inferred that such anorthite crystallized out very rapidly in parts rich in alumina owing to contamination of the magma by country rocks. Separation of calcic plagioclase may be facilitated by reaction of magma with aluminous sediments, simultaneously with the decreasing of lime-pyroxene molecule (READ, 1923; BOWEN, 1928). So far as the rocks of tholeiite series carrying such anorthite crystals in the present area are concerned, decreasing of their Wo value is not very great. Possibly, these rocks might have formed mainly through fractional crystallization from the theoleiite magma high in alumina which may be peculier to orogenic belts.

2) *Tholeiite rocks series* (*weak alkalic*). As well exhibited in Figures 14 and 15, the rocks of this series show transitional characters between those of the extremely alkali-poor tholeiite series and alkali series. Yet, owing to scantiness of the data, the over-all character of this series is not sufficiently clarified. It is, however, worth while to note that calc-alkali series originated from this series is characterized by high content of alkalies and hornblende-bearing rocks, in contrast to those from alkali-poor tholeiite series.

3) *Alkali rock series.* The rocks of this series are characterized by high values of Wo and En as well as alkalies. Such chemical character is closely related to modal mineral composition; *e.g.*, in alkali olivine-basalt, interstitial alkali-feldspar is always observed instead of silica mineral while the groundmass pyroxene is mostly augite and in some cases titan-augite; orthopyroxene can be observed in neither phenocrysts nor groundmass. The final and mid products resulting from fractional crystallization are also lacking in this area. It is evident that iron enrichment is not so great as in the case of the tholeiite series. Increasing of the alkali content outpaces and overshadows the simultaneous rise of the $FeO+Fe_2O_3/MgO$ ratio.

4) *Calc-alkali rock series* (*alkali-poor*). This series comprises so-called pyroxene-andesite and -dacite and a very little of hornblende-bearing pyroxene-rhyolite, all of which originated through sialic contamination of alkali-poor tholeiite magma.

Even from the viewpoint of chemical composition, the rocks of this series show intimate relation to those of the parent series. The trend of differentiation is usually from the composition of the parent series toward an increase in alkali and silica, never toward iron enrichment. The most outstanding character of this series is represented in the tendency of decreasing Wo value which implies contamination of magma by wall rock, namely aluminous sediments as above noted. A reverse tendency of evolution compared to that of tholeiite series, is shown by increasing of En value in the calc-alkali series. This unusual direction might have resulted from oxidation of ferrous to ferric iron due also to sialic contamination of magma. The increasing En value is the most characteristic feature throughout the calc-alkali series; it will be discussed below.

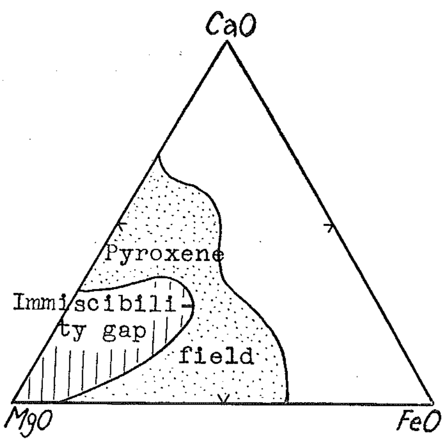
These aspects are well exhibited in the calderas (Kurakatoan type) of Kutcharo, Mashû and Atosanupuri (KATSUI, 1955 and 1958a). Somma lavas of these calderas were mostly made up from the rocks of alkali-poor tholeiite series; whereas the following pumiceous deposits erupted just before caldera depression, were comprised of calc-alkali series material which is characterized by extremely low Wo value (nearly zero) and rather high En value. Numerous lava-domes and steap-sided cones erupted in the last stage are composed of felsic andesite—dacite of the same character. Similar succession is also traceable in the Usu volcano (YAGI, 1953).

5) *Calc-alkali rock series* (*weak alkalic*). The rocks of this series show close relation to those of the alkali series and weak alkali tholeiite series, not only in their occurrence but also in chemical character (Figs. 14 and 15).

The rocks belonging to this series are characterized by common bearing of hornblende (and/or biotite). Occasionally, even in a so-called "pyroxene-andesite" of this series, completely resorpted hornblende can be observed. Hornblende always occurs as only phenocrysts in the present area; while in the groundmass crystallization stage, phenocrystic hornblende was apt to suffer from magmatic resorption due to releasing of vapor pressure. Accordingly, it goes without saying that hornblende crystallized out under the available pressure sufficient to retain the volatile components. But, presence of the vapor pressure alone could not have controlled the nature of the ferromagnesian crystallization.

W. Q. KENNEDY (1935) showed that points of the MgO-CaO-FeO ratios of igneous hornblendes, together with the basic metasilicate proportions of hornblende-bearing rocks free from pyroxene and biotite, fall within the area representing the immiscibility gap in ASKLUND's diagram for the pyroxene system (Figs. 12 and 13). A similar fundamental chemical relationship also exists among the rocks of the present area. As has been considered by W. Q. KENNEDY, the ratios of the oxides in the magma must constitute the determining factor in the separation of pyroxene or hornblende.

It is very interesting that the hornblende-field occupies the $MgSiO_3$ corner of the ternary system. G. C. KENNEDY (1948) considered an intimate relation between the partial pressure of water in a melt and the ratio of ferric to ferrous iron, and arrived at the conclusion that magmas which for other reasons are deduced to be dry have a high FeO/Fe_2O_3 ratio, and magmas which are deduced to be wet have a low FeO/Fe_2O_3 ratio. Enrichment of $MgSiO_3$ in hornblende-bearing rocks must have resulted from the separation of a ferric iron compound (magnetite) in magma due to enrichment of Fe_2O_3 caused by increasing of vapor



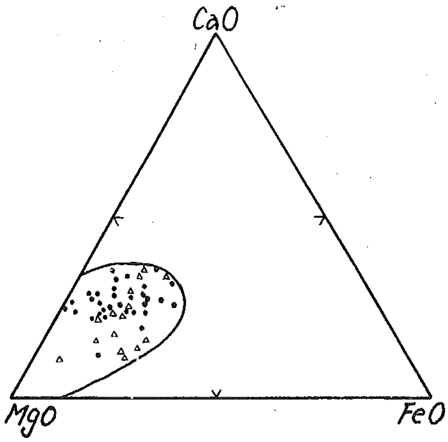
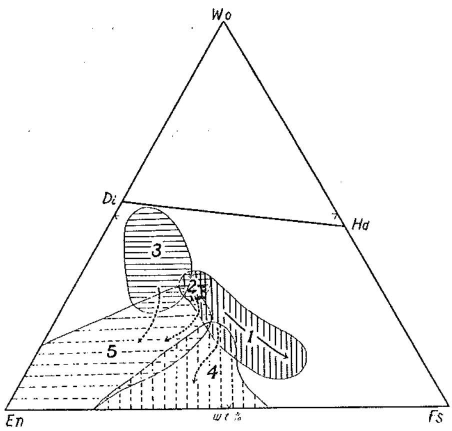


Fig. 2. Diagram showing the MgO-CaO-FeO ratios of the pyroxenes and metasilicate proportions of pyroxene-bearing rocks. (after B. ASKLUND, 1925). (left)

Fig. 13. Diagram showing the MgO-CaO-FeO ratios of igneous hornblende (triangles) and metasilicate proportions of rocks containing hornblende as the sole ferro-magnesian constituent (dots). (after W. Q. KENNEDY, 1935). (right)



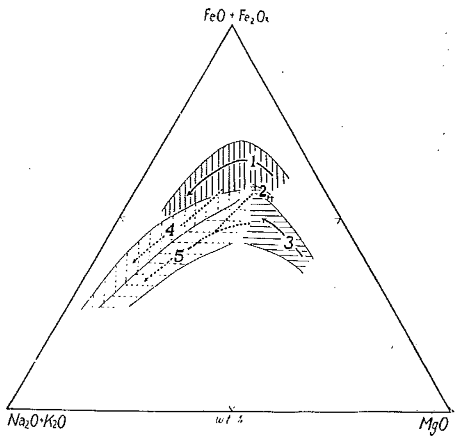


Fig. 14. Norm-pyroxene diagram showing genetic relation of each rock series. (left)

1. tholeiite series (alkali-poor)
2. tholeiite series (weak-alkalic)
3. alkali series (mostly alkali olivine basalt)
4. calc-alkali series (alkali-poor, pyroxene-andesite~dacite suites)
5. calc-alkali series (weak alkalic, hornblende-and/or biotite bearing andesite~rhyolite suites)

Full-line arrows represent avolution mainly due to fractional crystallization.
Broken-line arrows indicate evolution mainly due to contamination.

Fig. 15. MgO-($FeO+Fe_2O_3$)-(Na_2O+K_2O) diagram showing genetic relation of each rock series. (right)

Numbers of each field and arrows same as in Fig. 14.

pressure. For this reason, it can be also explained that the course events in the formation of this rock series was directed toward increasing alkalies in the MgO-($FeO+Fe_2O_3$)-(Na_2O+K_2O) ratio as seen in Figure 15.

In this connection, it is very signinficant that hornblende-bearing rocks usually occur in the inner zone, except for the most felsic pumice of the Shikotsu volcano. As has been discussed above, most hornblende-bearing rocks were derived through sialic contamination of alkali olivine basalt magma or alkali rich tholeiite magma, which possibly originally contained volatiles in much larger quantity than those of alkali-poor tholeiite magma. High vapor pressure which favoured separation of hornblende would be attributed to sialic contamination as well as fractional crystallization of these alkali-rich magmas.

IX Concluding remarks
—Petrographic provinces and their origin—

It has long been accepted by many petrologists that the two types of basaltic magmas posturated by W. Q. KENNEDY (1933), tholeiite and olivine basalt magmas, are ultimately parent for all world-wide igneous rocks. With regard to the relation of the two types of basaltic magmas, W. Q. KENNEDY noted that "it is a remarkable fact that whereas the olivine basalt magma occurs both in the continental crust and in the ocean basins, the tholeiite magma is always absent from the latter areas, and seems to be connected in some manner with presence of the granitic crust." A similar conclusion was reached by TOMITA (1935).*

However, TILLEY (1950) considered the rocks of the Hawaiian archipelago which is characterized by the absence of sialic underlayer, and arrived at the conclusion that primitive olivine-basalt of this archipelago is of tholeiitic type, and that tholeiite magma represents the parental type for the ocean basins as well as for continental regions. Differentiation courses of the Hawaiian magmas traced by KUNO *et al.* (1957) accord with the conclusions reached by TILLEY.

* In this connection, it can be pointed out that quartz-basalt of the Sanin district, southwestern Japan, which was formerly regarded as of tholeiitic type by TOMITA (1935), originated surely through contamination of olivine basalt magma (SUGI, 1942). Nevertheless, this quartz-basalt and andesite of the Daisen volcanic zone are identified as calc-alkali series similar to that series of the Chôkai zone both in modal aspect and in chemical composition. (KATSUI, 1956).

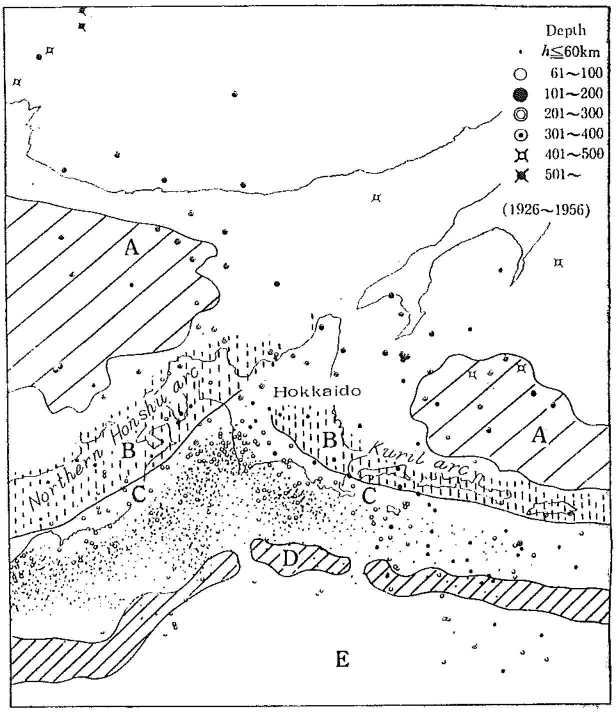


Fig. 16. Geotectonic map of Hokkaido and surrounding areas.
A: basins (>-3,000 m), B: inner arc or green-tuff region with volcanic velts, C: outer arc, D: Japan trench (>-6,000 m), E: oceanic shield (after MINOTO, *et al*, 1956). Distribution of epicenters of earthquakes, occurred 1926–1956, are indicated by different marks in every depth of the foci. (after "Catalogue of major earthquakes which occurred in and near Japan" 1958).

Moreover, it is true that there are no distinct types of basaltic magma, but rather a continuous series from silica satuated (tholeiitic) to silica undersaturated (olivine basaltic) rocks. (GREEN and POLDERVART, 1955).

In view of the above results and discussions the present writer finds it difficult to avoid the conclusion that the calc-alkali rock series which is most predominant member throughout the present area, should claim parentage from three representative magmas, viz., alkali-poor tholeiite magma, weak alkali tholeiite magma and alkali olivine basalt magma respectively. Furthermore, it is worthy of notice that the rocks comprised in calc-alkali series which derived from alkali-poor tholeiite magma

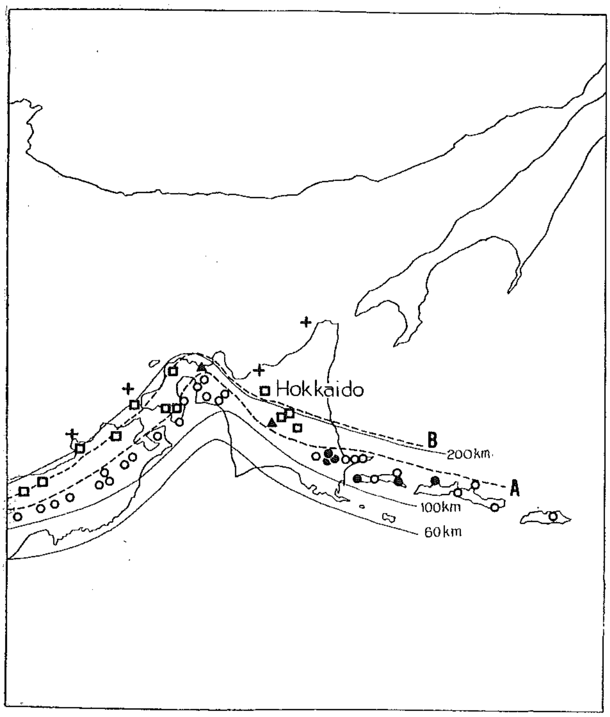


Fig. 17. Distribution of rock series of the Quaternary volcanic rocks in Hokkaido and surrounding areas.

Solid circles: tholeiite series (alkali-poor) and associated calc-alkali series (alkali-poor), open circles: calc-alkali series (alkali-poor), solid triangles: tholeiite series (weak alkalic) and associated calc-alkali series (weak alkalic), squares: calc-alkali series (weak alkalic), crosses: alkali series and associted calc-alkali series (weak alkalic). Broken lines A and B indicate boundary curve among the distribution of every parental rock series. Full lines of 60, 100 and 200 km show the contour of depth of the foci, which are drawn from Fig. 16.

are also poor in alkalies and characterized by pyroxene-andesite and dacite; on the other hand, those from weak alkali tholeiite magma or alkali olivine basalt magma are rich in alkalies and characterized by association of hornblende- (and/or biotite-) bearing andesite-dacite-rhyolite. In view of these considerations, the Quaternary petrogaphic provinces of Hokkaido and surrounding areas as shown in Figure 17, may be drawn.

Zonal arrangements along the Kuril and the northern Honshu arcs which are represented by a magmatic character of increasing alkalies from the front zone toward the inner zone, arouse the writer's special interest. This rule is well kept both in extensions toward the Kuril Islands and Kamchatka (TOMKEIEFF, 1949; SAWAMURA, 1956 and KATSUI, 1958c) and in northern Honshu (KATSUI, 1954), and also throughout the

TABLE 7. Chemical compositons of tholeiitic basalts and mafic andesites in the Kuril Islands* and North Honshu

No.	1	2	3	4	5
Type	IVb→c	Vc	Vc	Vc	Vc
SiO_2	50.45	51.90	50.79	51.31	53.71
TiO_2	1.64	1.08	.78	.69	.63
Al_2O_3	17.99	17.51	17.74	20.60	17.63
Fe_2O_3	3.08	3.91	3.67	2.62	2.05
FeO	8.87	7.62	7.06	6.78	7.97
MnO	.17	.18	.14	.10	.19
MgO	4.02	4.57	5.38	4.86	6.45
CaO	10.59	9.50	10.52	10.05	7.97
Na_2O	2.97	2.26	2.29	2.33	2.12
K_2O	.58	.25	.28	.26	.27
P_2O_5	.16	.15	.09	.08	.09
H_2O (+)	.07	.50	.73	} .72	} 1.31
H_2O (−)	.08	.33	.60		
Total	100.67	99.76	100.07	100.40	100.39
Analyst	KATSUI	KAWANO	KAWANO	Geol. Surv.	Geol. Surv.

1 Augite- olivine-basalt, a central cone lava of the Atsanupuri volcano, Iturup Island, Kuril Islands. (New analysis)**.

2 Olivine-augite-hypersthene-basalt, an older somma lava of the Towada volcano, North Honshu. (KAWANO, 1939).

3 Olivine-augite-hypersthene-basalt, a younger somma lava of the Towada volcano. (KAWANO, 1939).

4 Olivine-augite-hypersthene-andesite, Yakushi lava of the Iwate volcano, North Honshu. (YAMANE, 1915).

5 Augite-hypersthene-andesite, Yakehashiri lava (erupted in 1719) of the Iwate volcano. (YAMANE, 1915).

* Besides them, in the front volcanic zone of the Kuril Islands, not a few basalts and mafic andesites which should claim direct parentage from tholeiitic magma, are known from their chemical compositions, viz. somma lava of the Krenitzyn peak volcano (Onnekotan Island), lavas and bombs of the volcanoes of Mendeleev, Tiatia, Golovin (Kunashir Island); though we have as yet very little information as to their modal composition. (BLODABETS, GORSHKOV and PIIP, 1957; GORSHKOV, 1958a).

** The rock was collected by Prof. T. ISHIKAWA to whom the present writer's grateful thanks are due for kindly supplying material.

TABLE 8. Chemical compositions of alkali olivine basalts in the Kuril Islands and North Honshu

No.	1	2	3	4
Type	IIIb	IIIb	IIIb	?
SiO_2	50.83	50.35	50.29	52.42
TiO_2	.35	1.28	1.28	.61
Al_2O_3	21.48	19.29	18.96	16.76
Fe_2O_3	3.70	4.07	3.44	3.59
FeO	5.89	5.81	6.75	4.42
MnO	.18	.45	.33	.17
MgO	3.03	4.11	4.14	6.42
CaO	10.64	10.22	10.25	8.18
Na_2O	3.11	2.69	2.85	2.27
K_2O	1.06	1.35	1.25	1.40
P_2O_5	.08	.39	.40	.21
H_2O (+)	—	.13	.20	2.54
H_2O (−)	—	.09	.09	1.02
S	—	.01	.02	—
Total	100.35	100.24	100.25	100.01
Analyst	KANNARI	Geol. Surv.	Geol. Surv.	KATSURA

1 Olivine-basalt, a somma lava of the Alaid volcano, Kuril Islands, (SUZUKI and SASA, 1932).
2 Olivine-basalt, a scoria (erupted in 1933) of Taketomi Island, a parasitic cone of the Alaid volcano. (KUNO 1935).
3 Olivine-basalt, a lava (erupted in 1933) of Taketomi Island. (KUNO, 1935).
4 Olivine-basalt, an ejecta of the Ichinomegata maar, North Honshu. The rock contains abundant xenocrysts derived from granite. (KUNO, 1959).

Japanese Islands (ISHIKAWA and KATSUI, 1959 and KUNO, 1959). (See Tables 7 and 8).

It may be remarked here that such zonal arrangements are ultimately based also upon the zonal arrangement of a continuous series from alkali-poor tholeiite magma in the oceanic side to alkali olivine basalt magma in the continental side. Thus, there is no reason to support TOMKEIEFF's opinion on the origin of a similar zonal arrangement in Kamchatka, that both calcic and alkali rocks formed through magmatic fractionation from the hypothetic common parent represented by an average chemical composition calculated from all analysed lavas. (TOMKEIEFF, 1949). It seems more desirable to consider "how are zonal arrangements of parent magmas related with geotectonic movements of the Kuril and the northern Honshu arcs?"

It is known with certainly that the depth of foci of earthquakes descends gradually from the oceanic side toward the continent, and that under the active volcanic zones it reaches about 100-200 km. (WADATI, 1935; WILLIAMS, 1954 and TOKAREV; 1958). There is an important relation between the zonal arrangement of the parental magmas and the contour of depth of foci, as seen in Figure 17. In fact, alkali-poor tholeiite magma is generated in a narrow zone of 100-150 km of depth of foci, weak alkali tholeiite magma in that of 150-200 km and alkali olivine basalt magma in an area deeper than 200 km respectively.

Recently, KUNO (1959) also noticed that the boundary line between provinces of tholeiite and alkali olivine basalt magmas corresponds to the 200 km contour, and inferred that tholeiite magma is produced at depths shallower than 200 km, whilst the alkali olivine basalt magma is at deeper levels. A similar conception was held by GORAI (1958).

Even in the case of central eruptions, the depth of the magmatic reservoir is determined to lie at an interval between 50-70 km, i.e. virtually on the boundary between the earth's crust and the mantle. (GORSHKOV, 1958). Generation of basaltic magmas may take place at this or more probably deeper levels as shown above. The occurrence of earthquakes at depths of 100-200 km under the active volcanoes suggests a common cause, but hardly a direct relation of cause and effect. The investigation of the above possibility must be the subject of future research.

(Dec. 20, 1959, at Sapporo)

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