THE CHEMICAL CHARACTERISTICS OF THE LAVAS FROM VOLCANO TARUMAI, HOKKAIDÔ, JAPAN

By

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(With 3 tables and 10 figures)

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Contents

Introduction

Volcano Tarumai is an active volcano situated at the south side of Lake Shikotsu in Hokkaidô, Japan, and famous for the typical dome formed on its top part in 1909. The activity was studied by some authorities.[(1)–(4)] Six specimens of the dome lava and the breadcrust bomb erupted on that occasion have been analyzed. KÔZU[(5)] examined carefully the chemical compositions of the above six specimens, and SUZUKI[(6)] wrote on the chemical compositions of the lavas from Volcano Tarumai in 1935, adding newly analyzed data of 9 other main lavas from this volcano and 2 lavas from the Shikotsu volcanic group. The author[(7)] noticed in the course of his geological and petrological studies on this volcano that the lavas from this volcano are comparatively rich in Al_2O_3 or high in *al-alk* of NIGGLI's value, and low in *c-(al-alk)* of NIGGLI's value or low in Wo of norm pyroxene. This chemical characteristic is generally common in the lavas from volcanoes of the Nasu volcanic zone, but different from the chemical aspects of the other volcanic zones in Japan and any volcanic zones or regions in other countries.

Volcano Tarumai is one of the most typical among the Nasu volcanic zone which shows such a chemically characteristic type.

In publishing the present paper, the author wishes to offer his cordial thanks to Dr. J. SUZUKI, Professor of Hokkaidô University, who has given kind advice and encouragement ever since the author has engaged in geological and petrological studies on Volcano Tarumai. He is indebted to Mr. T. NEMOTO, Directer of Hokkaidô Branch of Geological Survey for helpful advice, and acknowledges a grant from the Scientific Research Fund of the Department of Education which was used for this study.

Chemical compositions of the lavas from Volcano Tarumai

Products of Volcano Tarumai are classified from older to younger as follows[8];

I) Products of Kitayama Volcano
  1. Kitayama lava
  2. Kuchawakkanai lava

II) Products of Nishiyama Volcano
  1. Tarumaigawa agglomerate
  2. Nishiyama lower lava
  3. Opoppu lava
  4. Nishiyama upper lava
     a) Tuffaceous lava
     b) Pumiceous lava
     c) Scoriaceous lava

III) Products of Higashiyama Volcano
  1. Fragmental ejecta of the first stage
  2. Tarumai mud flow
  3. Fragmental ejecta of the second stage
     a) Pumice
     b) Scoria
     c) Ash
  4. Shishamonai lava
  5. Central cone lava
  6. Dome lava
  7. Fragmental ejecta in 1909 and thereafter.
     a) Bread-crust bomb
     b) Black compact block

c) Pumice
d) Lapilli
e) Ash

Among the above volcanic products, the analyzed lavas are 11 in sort and 16 in specimen as shown in Table I, and data on only one new specimen (No. 9) was added by KANI[9] after SUZUKI's publication.[6] They are petrographically two pyroxene andesite (augite-hypersthene andesite); the dome lava, breadcrust bomb and black compact block include, in addition, large anorthite crystals of 2 cm in maximum size.[6][7][8]

SiO_2 percent is between 56.50 and 60.80, and amounts of the other main oxides corresponding to SiO_2 in each specimen are shown in Figure I.

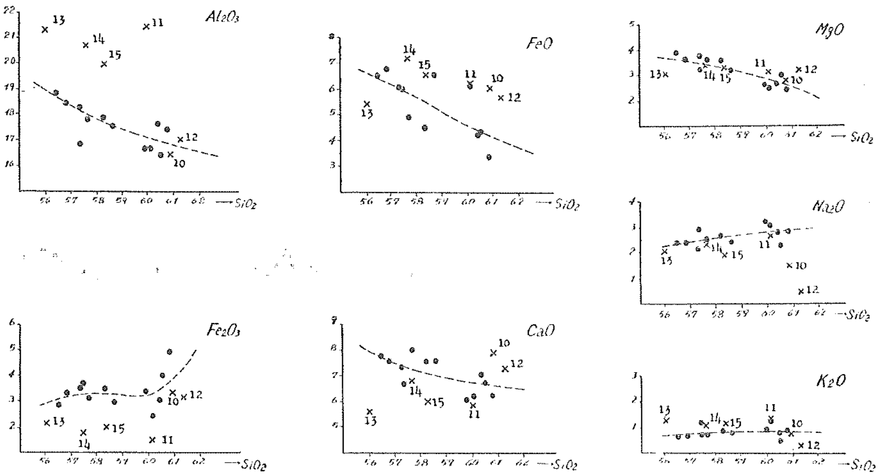


Figure 1. Variation diagrams showing the relation of each oxide to SiO_2 in the lavas from Volcano Tarumai and the Shikotsu volcanic group.

From Figure 1, six specimens of Nos. 10 to 15 are mostly out of the general trend, especially in Al_2O_3, Fe_2O_3, FeO and CaO. They show remarkable irregularity also in norm, NIGGLI's, OSANN's or WOLFF's values calculated from the chemical compositions. Nos. 10 to 13 are the dome lava, and Nos. 14 and 15 are the bread-crust bomb. These were both erupted in 1909, and contain large anorthite crystals in addition to common phenocrystic minerals as above noted. Especially specimens of the former are sometimes heterogeneous in texture, some being vesicular and others compact, and they are often rich in xenoliths. Their abnormal

TABLE I. Chemical compositions and NIGGLI-values of the lavas from Volcano Tarumai and adjacent area.

	1	2	3	4	5	6
SiO_2	60.80	60.52	60.42	56.50	57.68	58.29
TiO_2	0.49	0.63	0.63	0.71	0.63	0.63
Al_2O_3	17.48	16.42	17.60	18.87	17.81	17.92
Fe_2O_3	4.88	4.00	3.05	2.94	3.13	3.50
FeO	3.36	4.31	4.16	6.51	4.89	4.46
MnO	0.11	0.19	0.37	0.15	0.19	0.28
MgO	2.48	3.01	2.71	3.91	3.63	3.59
CaO	6.16	6.64	6.98	7.70	7.93	7.50
Na O	2.78	2.26	2.76	2.34	2.46	2.60
K_2O	0.94	0.50	0.82	0.64	0.76	0.91
H_2O or Ig. Loss	0.70	2.00	1.28	—	1.72	0.80
Total	100.18	100.48	100.78	100.27	100.83	100.48
si	198	197.5	194	158	169	173
al	33.5	32	33	31.5	31.0	31
fm	34	37	32.5	38	35.5	35.5
c	21.5	23	24	23	25.0	24
alk	11	8	10.5	7.5	8.5	9.5
k	0.18	0.12	0.17	0.16	0.17	0.19
mg	0.36	0.40	0.40	0.43	0.45	0.45
al-alk	22.5	24	23.5	24	22.5	21.5
c/fm	0.63	0.62	0.74	0.60	0.68	0.66
c-(al-alk)	− 1	− 1	+ 0.5	− 1	+ 2.5	+ 2.5
alk/al-alk	0.49	0.33	0.45	0.31	0.38	0.44
ti	1.1	1.5	1.5	1.5	1.4	1.4
qz	+54	+65.5	+52	+25	+35	+35

(1) Kitayama lava (Two pyroxene andesite or augite hypersthene andesite) Kitayama, Volcano Tarumai. Anal. E. NAKAE. Lit. J. SUZUKI.[6]

(2) Kuchawakkanai lava (Two pyroxene andesite) Kitayama, Volcano Tarumai. Anal. A. KANNARI. Lit. ibid.

(3) Opoppu lava (Two pyroxene andesite) Nishiyama, Volcano Tarumai. Anal. A. KANNARI. Lit. ibid.

(4) Nishiyama upper lava (a) (Two pyroxene andesite) Nishiyama, Volcano Tarumai. Anal. E. NAKAE. Lit. ibid.

(5) Nishiyama upper lava (b) (Two pyroxene andesite) Nishiyama, Volcano Tarumai. Anal. A. KANNARI. Lit. ibid.

(6) Nishiyama upper lava (c) (Two pyroxene andesite) Nishiyama, Volcano Tarumai. Anal. A. KANNARI. Lit. ibid.

TABLE I (continued)

	7	8	9	10	11	12
SiO_2	56.84	57.40	57.40	60.93	60.12	61.32
TiO_2	0.49	0.53	0.65	0.42	n.d	0.38
Al_2O_3	18.43	18.27	16.84	16.46	21.40	17.02
Fe_2O_3	3.38	3.50	3.68	3.35	1.50	3.13
FeO	6.73	6.01	5.96	5.94	6.20	5.63
MnO	0.15	0.15	1.08	0.55	1.18	0.33
MgO	3.68	3.89	3.28	2.88	3.13	3.26
CaO	7.52	7.30	6.60	7.84	5.83	7.26
Na_2O	2.32	2.12	2.88	1.44	2.59	0.48
K_2O	0.68	0.70	1.21	0.79	1.32	0.32
P_2O_5	—	—	tr	0.13	—	0.29
H_2O or Ig. Loss	—	0.43	0.36	—	0.06	—
Total	100.22	100.30	99.96*	100.78	103.33**	99.54†
si	159.5	165	168.5	188	176	196
al	30.5	31	29	30	37	32.5
fm	39.0	39.5	40	38	35	40.5
c	23.0	22.5	21	26	18	25
alk	7.5	7	10	6	10	2
k	0.16	0.17	0.22	0.26	0.25	0.27
mg	0.40	0.43	0.36	0.34	0.39	0.40
al-alk	22.5	24	19	24	27	30.5
c/fm	0.59	0.57	0.52	0.67	0.52	0.62
c-(al-alk)	+ 0.5	− 1.5	+ 2	+ 2	− 9	− 4.5
alk/al-alk	0.33	0.29	0.53	0.25	0.37	0.07
ti	1.0	1.2	1.4	0.9	—	—
p	—			0.2	—	—
qz	+29.5	+37	+28.5	+64	+36	+90

* contains S 0.02%   ** contains S 0.05%   † contains S 0.12%

(7) Sishamonai lava (Two pyroxene andesite) Higashiyama, Volcano Tarumai. Anal. E. NAKAE. Lit. ibid.

(8) Central cone lava (Two pyroxene andesite) Higashiyama, Volcano Tarumai. Anal. E. NAKAE. Lit. ibid.

(9) Dome lava (Anorthite bearing augite hypersthene andesite) Higashiyama, Volcano Tarumai. Anal. K. KANI. Lit. K. KANI.[9]

(10) Dome lava (the inner part) Anal. YOSHIOKA. Lit. D. SATÔ.[2]

(11) Dome lava (the inner part) Anal. Sapporo Mining Bureau. Lit. Y. ÔINOUE.[1]

(12) Dome lava (the outer part) Anal. YOSHIOKA. Lit. D. SATÔ.[2]

TABLE I (continued)

	13	14	15	16	17	18
SiO_2	56.09	57.65	58.40	58.64	59.88	60.16
TiO_2	n.d	n.d	n.d	0.49	0.63	0.53
Al_2O_3	21.30	20.69	19.95	17.62	16.65	16.64
Fe_2O_3	2.23	1.74	2.04	2.98	3 40	2.42
FeO	5.47	7.20	6.56	6.51	3.01	6.15
MnO	2.03	1.21	1.25	0.15	0.08	0.11
MgO	3.06	3.40	3.27	3.20	2.64	2.52
CaO	5.54	6.72	6.01	7.52	6.01	6.17
Na_2O	2.01	2.30	1.89	2.42	3.10	3.00
K_2O	1.25	1.09	1.18	0.74	0.93	1.24
H_2O or Ig. loss	0.16	0.02	n.d	—	3.47	1.25
Total	99.14	102.02	100.55	100.27	99.80	100.19
si	166	162	166.5	173	207	194
al	37	34	37	30.5	34	31.5
fm	37	38	37	37.5	31.5	35.0
c	18	20	18.5	24	22.0	21.5
alk	8	8	7.5	8	12.5	12.0
k	0.29	0.25	0.30	0.17	0.17	0.21
mg	0.36	0.38	0.37	0.38	0.44	0.35
al-alk	29	26	29.5	21.5	21.5	19.5
c/fm	0.49	0.53	0.50	0.64	0.70	0.62
c-(al-alk)	−11	− 6	−11	+ 2.5	+ 0.5	+ 2
alk/al-alk	0.28	0.31	0.25	0.37	0.58	0.61
ti	—	—	—	1.1	1.7	1.4
qz	+34	+30	+36.5	+41	+57	+46

(13) Dome lava (the outer part) Anal. Sapporo Mining Bureau. Lit. Y. ŌINOUE[1]

(14) Bread-crust bomb ejected on March 30th, 1909 (Anorthite bearing augite hypersthene andesite) Anal. Sapporo Mining Bureau. Lit. ibid.

(15) Bread-crust bomb ejected on April 2nd, 1909 (Anorthite bearing augite hypersthene andesite) Anal. Sapporo Mining Bureau. Lit. ibid.

(16) Black compact block ejected in 1909 (Anorthite bearing augite hypersthene andesite) Anal. E. NAKAE. Lit. J. SUZUKI.[6]

(17) Kimunmorappu lava (Hypersthene augite dacite) Kimunmorappu belonging to the Shikotsu volcanic group. Anal. A. KANNARI. Lit. ibid.

(18) Monbetsudake lava (Augite dacite) Monbetsu-dake belonging to Shikotsu volcanic group. Anal. E. NAKAE. Lit. ibid.

departure from the general trend of this volcano in chemical composition may be due to the facts as already stated also by SUZUKI,[6] though there may be left something to be desired in the treatment of the analyzed samples. On the other hand, the chemical analyses of the two lavas from Shikotsu volcanic group (Table I, Nos. 17 and 18) forming the base of Volcano Tarumai, show nearly the same characteristics as the lavas from this volcano, though rather more acidic, as they are petrographically pyroxene dacite.

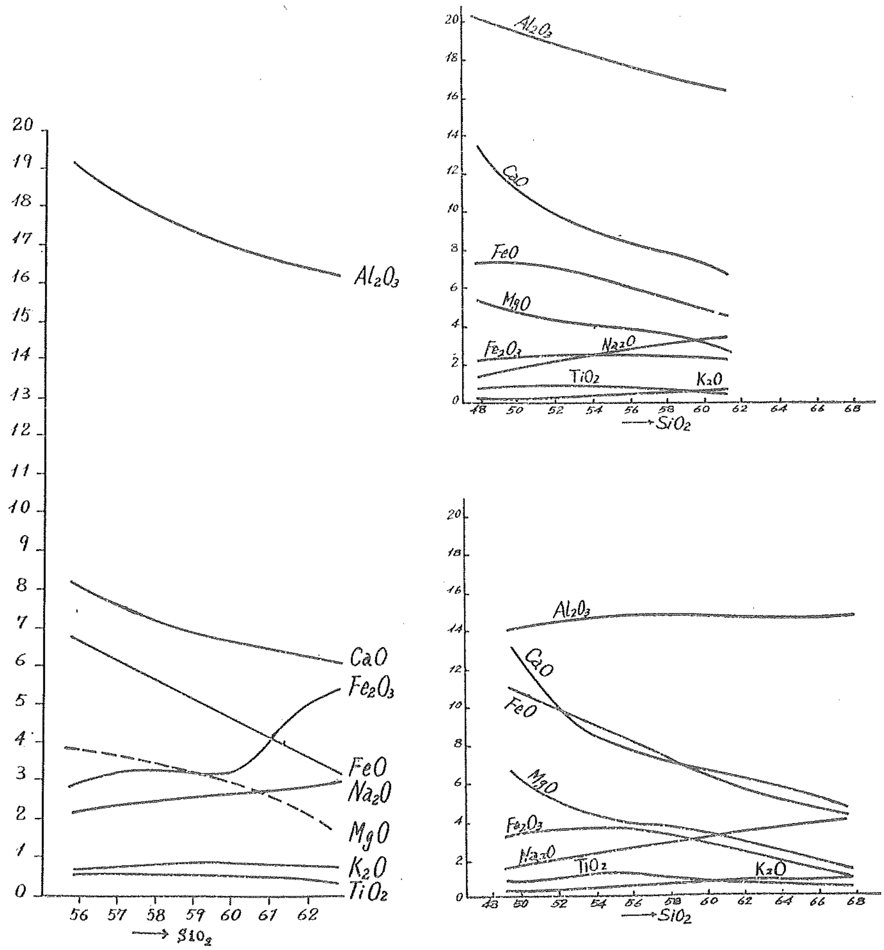


Figure 2. Variation diagrams of the lavas from Volcano Tarumai and its adjacent area (left), porphyritic (right, upper) and non-porphyritic volcanic rocks including the groundmass parts of the porphyritic ones (right, lower) from Idzu and Hakone volcanic district (by KUNO).[10]

Excluding the six analyses of Nos. 10 to 15, the variation diagram showing the general trend of each oxide is shown in Figure 2. In comparison with the variation diagrams drawn by KUNO[10] from chemical compositions of porphyritic and non-porphyritic volcanic rocks or groundmass parts of the former in Idzu and Hakone volcanic district (Figure 2, right), the general trend of specimens from this volcano resembles that of the porphyritic rather than the non-porphyritic volcanic rocks from Idzu-Hakone district. Only Fe_2O_3 is abnormally high and changes rather irregularly.

The average value of 10 analyses excluding Nos. 10 to 15 in Table I is shown in Table II. The averages of andesites in Japan calculated by YAMADA,[11] the lavas from the Central volcanic zone in North Japan (Nasu volcanic zone) and volcanic rocks excluding alkali rocks in Japan both calculated by IWASAKI,[12] andesites and pyroxene andesites in Europe and America shown respectively by DALY[13] and ROSENBUSCH with OSANN[14] are also arranged in the same table for comparison.

TABLE II. Average chemical compositions of volcanic rocks.

	1	2	3	4	5	6
SiO_2	58.25	59.8	61.49	59.84	59.59	59.3
TiO_2	0.58	0.2	0.65	0.74	0.77	0.7
Al_2O_3	17.67	17.6	16.82	16.84	17.31	16.6
Fe_2O_3	3.49	3.7	2.64	2.80	3.33	3.1
FeO	5.27	3.8	4.16	4.55	3.13	3.5
MnO	0.28	0.1	0.18	0.21	0.18	0.1
MgO	3.32	2.7	2.80	2.92	2.75	3.4
CaO	7.15	6.9	6.45	6.54	5.80	6.3
Na_2O	2.48	2.7	2.95	3.00	3.58	3.6
K_2O	0.79	1.4	1.20	1.49	2.04	1.9
P_2O_5	0	0.2	0.13	0.22	0.26	0.2
H_2O	0.72	1.2	0.97	1.28	1.26	1.3
Total	100.00	100.3	100.44	100.53	100.00	100.0

(1) Average of 10 lavas from Volcano Tarumai.
(2) Average of 57 andesites in Japan (YAMADA).[11]
(3) Average of 51 lavas from the Central volcanic zone in North Japan (IWASAKI).[12]
(4) Average of 467 volcanic rocks excluding alkali rocks in Japan (IWASAKI).[12]
(5) Average of 87 andesites in Europe, America etc., (DALY).[13]
(6) Average of 20 pyroxene andesites in Europe, America etc. (ROSENBUSCH and OSANN).[14]

From Table II, the average composition of this volcano is seen to be very low in alkali, especially in K_2O, high in CaO and FeO, and rather high in Al_2O_3. Except the main oxides, MnO is comparatively high and P_2O_5 poor.

Consideration on chemical compositions from NIGGLI's value

NIGGLI's values calculated from the chemical compositions of the lavas from this volcano (see Table I) have already been examined closely by SUZUKI.[(6)] According to him, *si* content is generally higher in the older lava, though there are some exceptions. The value of *alk* increases generally from 7.5 to 12.5 with the rising of *si* from 158 to 207. While the value of *fm* decreases as *si* increases.

The author tried to compare the lavas from this volcano with those from other volcanoes in *al-alk*, *alk/al-alk*, *qz*, *c-(al-alk)* and *k-mg* relation of NIGGLI's value. Selected analyzed data from each volcanic zone in Japan are as follows;

Nasu zone; Tarumai 10, Iwaonupuri 1,[(5)] Komagadake 14,[(15)(5)] Usu 10,[(16)] Bandai 2,[(17)] Iwatesan 2,[(18)] Azumasan 2,[(19)] Zaôsan 2,[(20)(19)] Akagi 5,[(21)] Adatarasan 1,[(19)] Naruko 6,[(22)] Shiranesan 5,[(23)] Asama 16,[(24)] Total 76.

Chishima zone; Taketomi-tô 2,[(25)] Alaid 1,[(26)] Paramushiri 2,[(26)] Harimkotan 1,[(27)] Urup 4,[(28)] Etorofu 1,[(5)] Kunashiri 2,[(5)] Shiretoko-Iwozan 1,[(5)] Meakan 3,[(29)] Total 17.

Fuji zone; Miharayama 11,[(30)] Miyakezima 6,[(31)] Hachijôzima 1,[(32)] Niijima 3,[(33)] Kôzushima 5,[(34)] Mikurashima 1,[(35)] Toshima 1,[(36)] Udoneshima 1,[(36)] Aogashima 1,[(37)] Torishima 1,[(37)] Fujisan 14,[(38)] Idzu-Hakone 15,[(39)] Amagisan 8,[(40)] Usami 8,[(40)] Taga 5,[(40)] Ômuroyama 3,[(40)] Kayagadake 2,[(41)] Kurofuji 1,[(42)] Total 87.

Ryûkyû zone; Aso (Central cone) 7,[(43)] Aso (Somma) 8,[(44)] Sakurajima 16 (averages, from 58 individuals),[(45)] Kuchinoerabu 2,[(46)] Satsunan-Iwôjima 2.[(47)] Total 35.

Daisen zone; Unzendake 11,[(48)] Futagoyama 13,[(49)] Sanpeisan 4,[(50)] Kujûsan 1,[(51)] Total 29.

Sotouchi zone; 10.[(52)]

Iwôjima; 12[(53)]

The other zones such as Chôkai, Norikura and Daisetsu should not be discussed for the reason that there are not sufficent analyzed data to enable the determination of the general characteristics of their own zones. Also some data were excluded on account of uncertainty as to

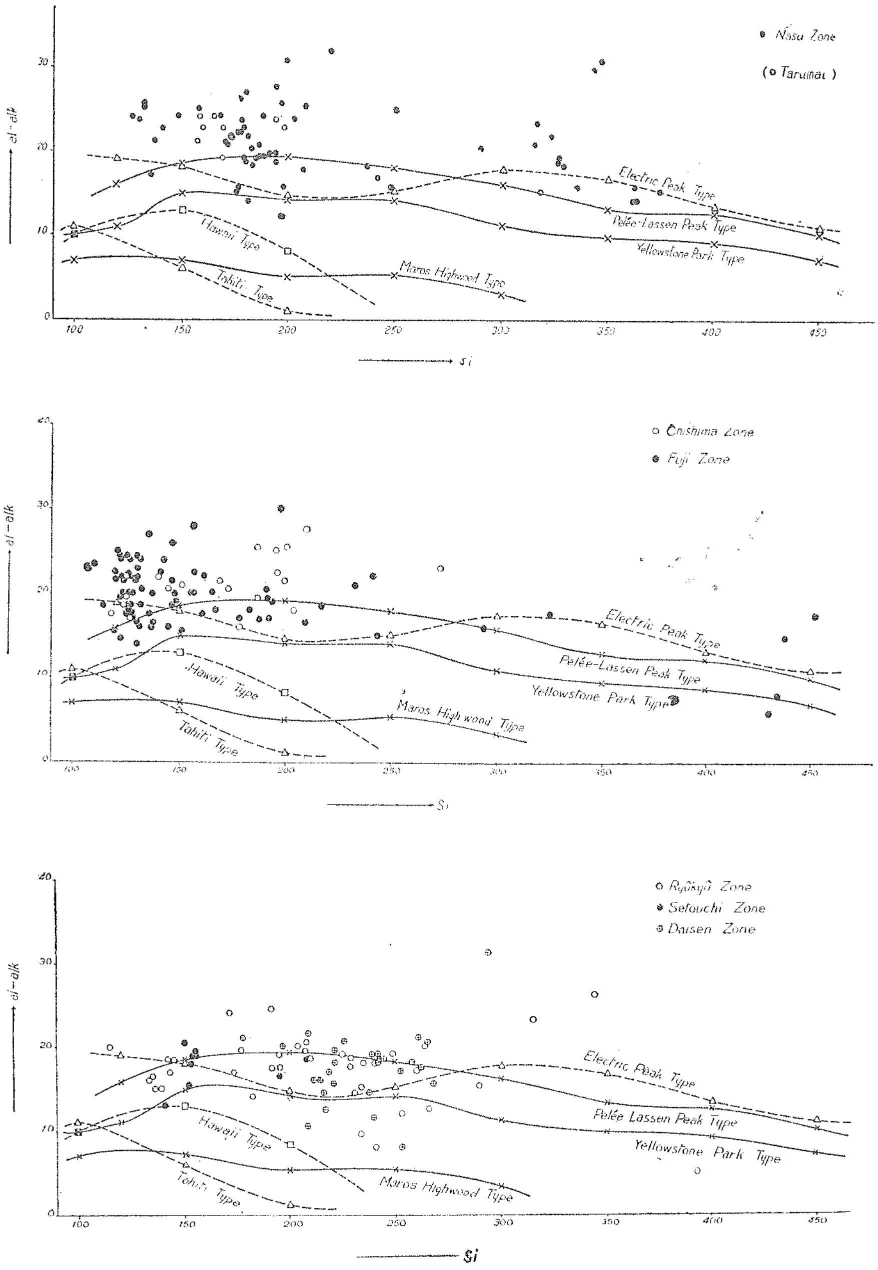


Figure 3. Variation diagrams of *al-alk* values of younger volcanic rocks in Japan.

which zone they may belong to.

To compare with volcanic rocks from other countries, the Pelée-Lassen Peak, Electric Peak and Yellow-stone Park types of the North America Cordillera in calc-alkali rock province, and Hawaii, Tahiti and Maros-Highwood types of alkalic character were selected. Chemical characteristics of the above types were thoroughly studied in NIGGLI's value by BURRI.[51]

al-alk

al-alk values corresponding to *si* are shown in Figure 3. Ten lavas of Volcano Tarumai are all above the curves of the Pelée-Lassen Peak or Electric Peak types drawn respectively from their average values, which show the highest of the North America Cordillera in *al-alk*. Also most lavas from the Nasu volcanic zone are higher than the average values of the Pelée-Lassen Peak and Electric Peak types. The lavas of Tarumai Volcano represent typically the characteristics of the Nasu zone in *al-alk*.

Lavas from two other zones in Japan, the Fuji and Chishima are also higher, while those from the Ryûkyû, Daisen and Setouchi zones are lower in *al-alk* content than the Pelée-Lassen Peak and Electric Peak types in general.

This fact was formerly stated by the present author.[7] *al-alk* value is related to anorthite content of plagioclase in mode in the case of calc-alkali rock. In fact, plagioclase in volcanic rocks from Japan is generally more calcic than those from other countries of the world. Especially plagioclase contained in the lavas from Volcano Tarumai are basic. Large anorthite crystals included often in the lavas from the Nasu, Fuji and Chishima zones are also perhaps related genetically in respect to this chemical characteristic, as already stated by the author.[7] *al-alk* value is low in alkali rocks and high in calc-alkali rock. Consequently volcanic rocks from Japan which show the comparatively higher values[55] of alkali-lime index in the world, are expected to be high also in *al-alk* content.

alk/al-alk

alk/al-alk values corresponding to *si* are shown in Figure 4. Ten lavas from this volcano are all distinctly below the curves of the Pelée-Lassen Peak and Electric Peak types which show the lowest value of the North America Cordillera. Also most lavas of the Nasu zone are

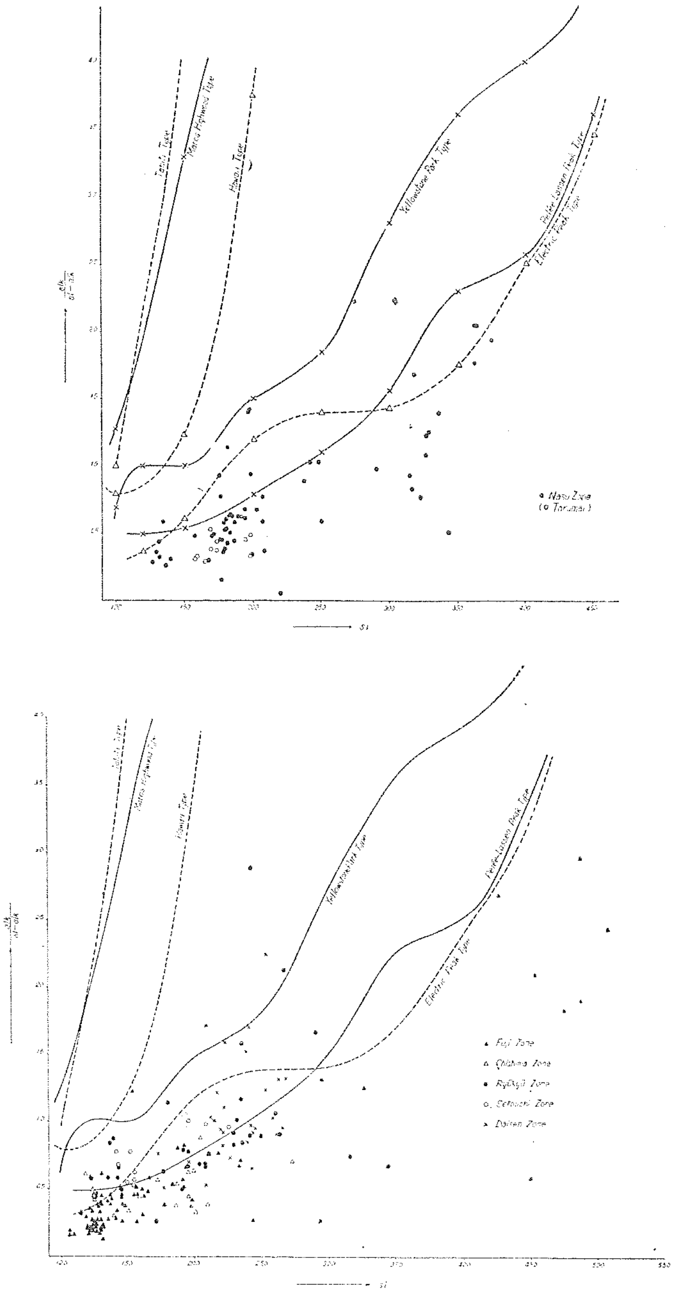


Figure 4. Variation diagrams of *alk*/*al-alk* values of younger volcanic rocks in Japan.

lower than the above stated curves, and the lavas of Volcano Tarumai represent the general type of this zone.

Lavas from the Fuji and Chishima zones are also clearly lower in average than the Pelée-Lassen Peak and Electric Peak types, while most lavas from the Setouchi zone are above the curves in question. *alk/al-alk* points of the Ryûkyû and Daisen zones are scattered considerably on both sides of these curves. The former seems to show the general trend higher in basic part below *si* 150, and lower in acidic part above *si* 200 than the curve of the Pelée-Lassen Peak type. The latter may be a little higher than the former in average.

alk/al-alk value may represent the ratio of albite to anorthite content in plagioclase or ratio of alkali feldspar to lime feldspar in the case of calc-alkali rock. Consequently *alk/al-alk* values show the contrary relation to *al-alk* values, or they are higher in alkali rock and lower in calc-alkali rock. The volcanic zones which represent the higher value of alkali-lime index may be lower in *alk/al-alk*.

qz

qz values corresponding to *si* are shown in Figure 5. The lavas from Tarumai are all distinctly higher than the average curves of the Pelée-Lassen Peak and Electric Peak types. Most lavas of the Nasu zone are also above the curves in question. Volcano Tarumai represents the typical one of the Nasu zone high in *qz*. Most lavas of the Fuji zone are above these curves, though not distinctly high in the very acidic part of *si* 450 and so. The Chishima zone lavas are very high if above *si* 150, though low at values below *si* 150. While most lavas from the Setouchi zone are below the average curve of the Pelée-Lassen peak type, though above that of the Electric Peak type. The Daisen zone lavas show a general trend higher than the Pelée-Lassen Peak type, but lower than the Nasu, Fuji, Chishima and Ryûkyû zones. The Ryûkyû zone lavas show the same inclination in general trend as the Chishima, though rather lower than the latter.

qz value suggests the existence of free silica as quartz, tridymite or cristobalite in mode. In andesites and basalts from Japan, richness in *qz* or norm Q is mostly represented in the form of silica minerals such as tridymite or cristobalite in the groundmass, or as glass containing excess silica. The lavas of Volcano Tarumai mostly contain abundant glass, though a few contain silica minerals in the goundmass. The fact that norm Q or *qz* in the volcanic rocks in Japan is remarkably

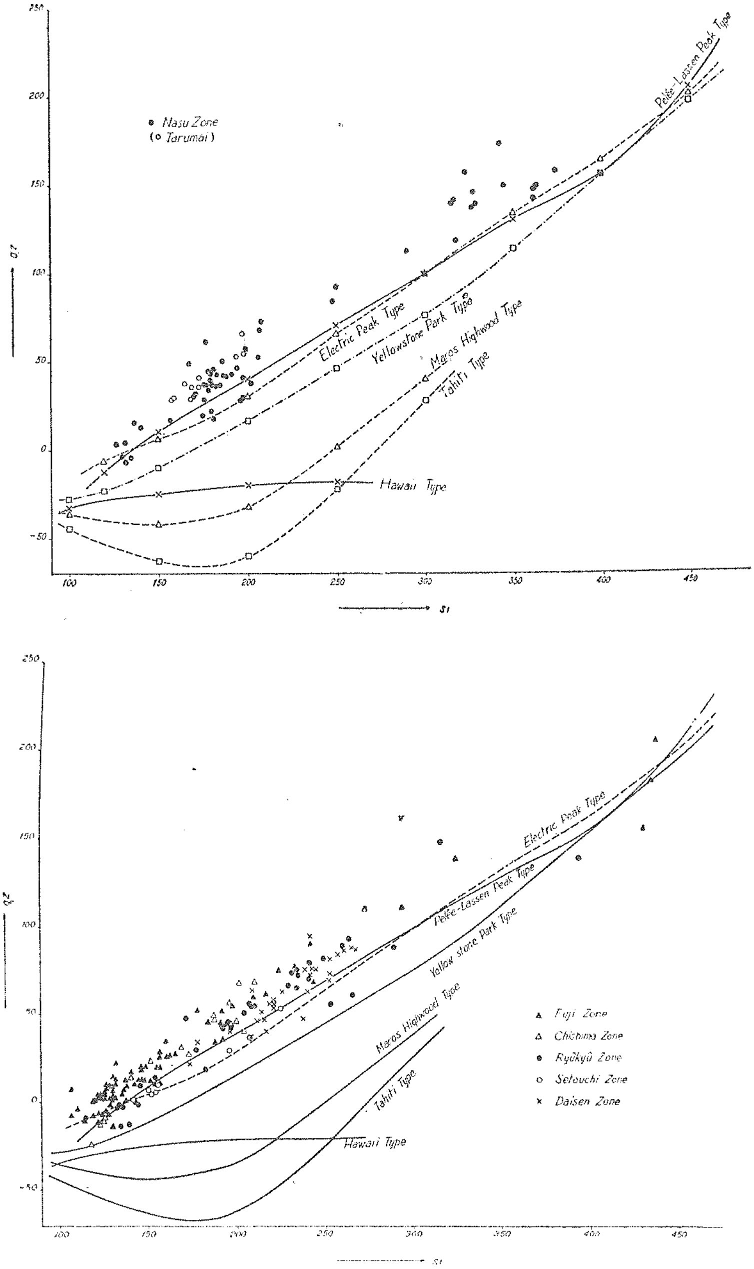


Figure 5. Variation diagrams of qz values of younger volcanic rocks in Japan.

higher than those in other countries has been noticed many years ago.

c-(*al*-*alk*)

Values of *c*-(*al*-*alk*) are shown in Figure 6 in relation to *si*. The lavas from this volcano are all far lower than any of the curves representing each average trend of the six types shown in Figure 6. However other lavas of the Nasu zone are not all much lower, but their average seems to be along the lowest curve of the above six types at values below *si* 250, and runs between the Pelée-Lassen Peak and Electric Peak types above *si* 250. Therefore the lavas of Volcano Tarumai are scattered in the lower part of the distribution area of this zone in *c*-(*al*-*alk*).

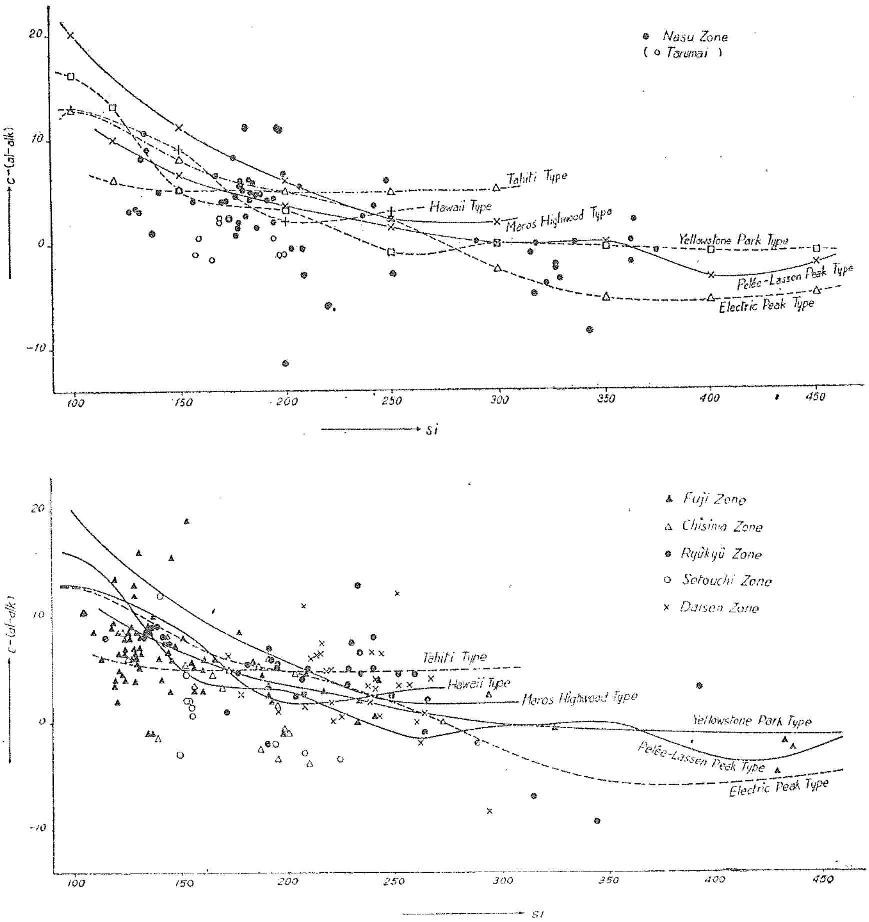


Figure 6. Variation diagrams of *c*-(*al*-*alk*) values of younger volcanic rocks in Japan.

Most lavas from the Setouchi zone are below any curves of the six types shown in Figure 6, and this zone represent the lowest type in Japan in *c*-(*al*-*alk*). The lavas of the Chishima zone are mostly far lower in *c*-(*al*-*alk*) than any curve of six types in the neighbourhood of *si* 200, but not so if below *si* 180. The lavas of the Fuji zone are comparatively high in *c*-(*al*-*alk*), especially at values below *si* 150, and seem to show the average trend higher than the lowest curve of the six types at least. The Daisen and Ryûkyû zones show both the general trends higher than some curves of the six. And the latter seems to be rather higher than the former.

c-(*al*-*alk*) value is related to the lime content in pyroxene in mode. Consequently the low value of *c*-(*al*-*alk*) means richness in rhombic pyroxene. It is interesting that the Setouchi zone lavas characterized by bronzite andesite show the lowest value of *c*-(*al*-*alk*) in Japan. The Nasu zone lavas which are mostly augite-hypersthene andesite comparatively rich in hypersthene, are low in *c*-(*al*-*alk*) next to the Setouchi. Especially the lavas from Volcano Tarumai showing low value of *c*-(*al*-*alk*) are abundant in hypersthene.

But the general trends of volcanic zones in Japan in *c*-(*al*-*alk*) are difficult to be shown in distinct relation to each other, as seen also from the confusion of the curves of the six types in Figure 6.

k-*mg* relation

k-*mg* points which show the mutual relation of *k* and *mg* are plotted in Figure 7. The concentrated area of *k*-*mg* points for younger volcanic rocks of the North America Cordillera is roughly added by the author for comparison.

k-*mg* points of the lavas from this volcano are concentrated from 0.12 to 0.22 in *k* and from 0.36 to 0.45 in *mg*. Those of the Nasu zone are concentrated in an area from 0.1 to 0.3 in *k* and from 0.25 to 0.52 in *mg*, though the separate points are scattered very widely. This area proves to be far lower in *k* than that of the North America Cordillera, but roughly covers the central part of *k*-*mg* area of the Pelée-Lassen Peak type.[51] Volcano Tarumai represents the normal type of the Nasu zone in *k*-*mg* relation.

The Chishima zone resembles the Nasu in *k*-*mg* points area, though *mg* rises with the increase of *k* in general inclination. The Fuji zone shows to be very low in *k* and is, as a whole, out of the concentrated area of the North America Cardillera.

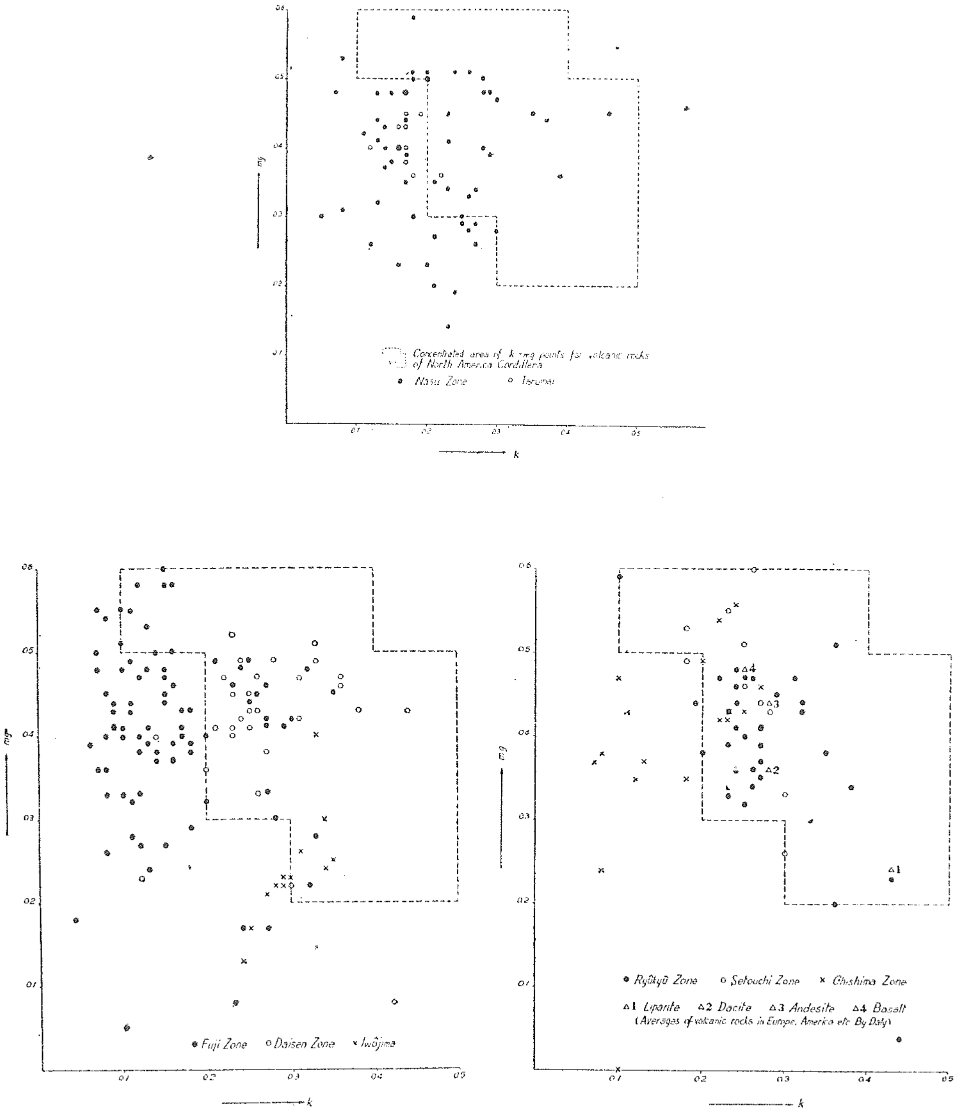


Figure 7. Variation diagrams of k mg points of younger volcanic rocks in Japan.

The Ryûkyû, Daisen and Setouchi zones are generally higher than 0.2 in *k* and are included in the concentrated area of the North America Cordillera, though in the *k*-poor part of it. The Ryûkyû zone ranges from 0.2 to 0.3 in *k* and from 0.3 to 0.5 in *mg*. The Daisen zone covers the area from 0.4 to 0.5 in *mg* and from 0.2 to 0.4 in *k*, approaching to the Electric Peak type.[51] The Setouchi type spreads from 0.3 to 0.6 in *mg*, and *mg* falls abruptly with the increase of *k*.

The distribution area of *k*-*mg* points of lavas from the above six volcanic zones in Japan shows them to be *k*-poor in comparison with the concentrated area of the North America Cordillera, and resembles, as a whole, the Pelée-Lassen Peak type.[51] The *k*-*mg* points of the average value of liparite, dacite, andesite and basalt in Europe and America, calculated by DALY,[13] were added in Figure for comparison.

It is interesting that *k*-*mg* points of Iwôzima are rich in *k* and very poor in *mg*, and *mg* increases sensibly with the rising of *k*. The area is far from that of any other volcanic zone in Japan, and rather resembles the Tahiti type.[51]

c-*alk* index

c-*alk* index of the Nasu zone was calculated as 296 by the author, though that of Volcano Tarumai alone was not tried on account of a small quantity of data. The Nasu zone is higher than the Pelée-Lassen Peak type, whose *c*-*alk* index is 246 and the highest among the North America Cordillera.[51]

Consideration on chemical compositions from Norms

Norms calculated from Table I are shown in Table III. Diagrams showing weight perecnt of norm feldspar, norm pyroxene and norm QFM are represented in Figures 8, 9 and 10, excluding Nos. 10 to 15.

Norm feldspar

As seen in Figure 8, the lavas from Volcano Tarumai are concentrated showing a distinct trend. Or percent is lower than 12 and decreases gradually with the increase of An percent. Two points rich in Ab are of the lavas from the Shikotsu volcanic group (No. 17 and 18) which are petrographically pyroxene dacite.

TABLE III. Norms calculated from TABLE I*

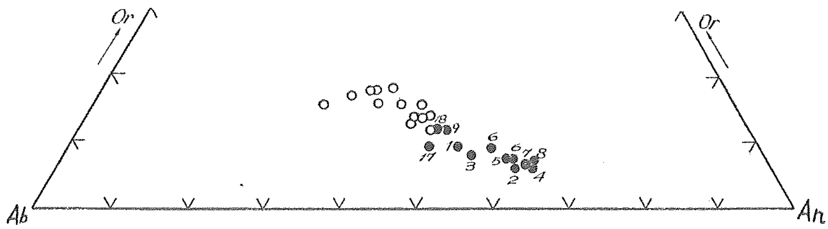
		1	2	3	4	5	6
Norms	Q	23.28	24.96	19.50	13.98	16.68	16.56
	Or	5.56	3.34	4.99	3.89	4.45	5.56
	Ab	23.58	18.86	23.58	19.91	20.44	22.01
	An	30.58	32.80	33.08	38.36	35.31	34.47
	C	0.61	0.10	0	0.20	0	0
	Wo	0	0	0.70	0	1.62	1.16
	En	6.20	7.50	6.80	9.80	9.00	9.00
	Fs	1.72	3.96	4.75	8.58	5.88	4.75
	Mt	6.96	5.80	4.41	4.18	4.41	5.10
	Il	0.91	1.22	1.22	1.37	1.06	1.22
	Wt % Or	9	6	8	6	7	9
	Wt % Ab	40	34	38.5	32	34	35.5
	Wt % An	51	60	53.5	62	59	55.5
	Plagioclase An %	56	64	58	66	63	61
	Wt % Wo	0	0	5.5	0	10	8
	Wt % En	78 (73)	65 (65)	55.5	53 (53)	55	60
	Wt % Fs	22 (20)	35 (34)	39	47 (46)	35	32
	C	(7)	(1)		(1)		
	Wt % Q	23.5	25	20	14	17	17
	Wt % F	60.5	56	92	62	61	62
	Wt % M	16	19	18	24	22	21

		7	8	9	10	11	12
Norms	Q	15.30	17.88	13.86	25.56	17.16	33.06
	Or	3.89	3.89	7.23	4.49	7.78	1.67
	Ab	19.39	17.82	24.10	12.05	22.01	4.19
	An	37.25	36.14	29.19	36.14	18.91	34.47
	C	0.31	0.82	0	0	6.10	2.55
	Wo	0	0	1.51	0.81	0	0
	En	9.20	9.70	8.20	7.20	7.80	8.20
	Fs	8.98	7.39	7.84	8.58	12.41	7.76
	Mt	4.87	5.10	5.34	4.87	2.09	4.64
	Il	0.91	1.06	1.22	0.70	0	0.76
	Ap	0	0	0	0.31	0	0.62

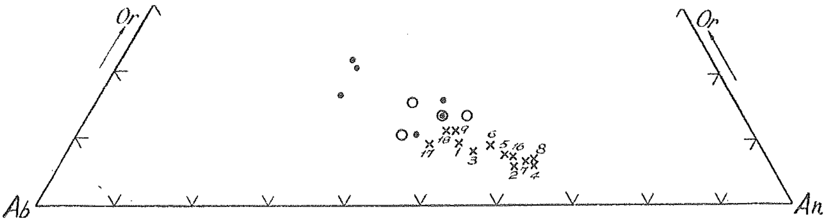
		7	8	9	10	11	12
Norms	Wt % Or	6.5	7	12	8.5	13.5	4
	Wt % Ab	32	31	40	23	37.5	14
	Wt % An	61.5	62	48	68.5	49	82
	Plagioclase An %	66	67	55	75	57	85
	Wt % Wo	0	0	9	5	0	0
	Wt % En	51 (50)	57 (54)	46.5	44	38.5 (29.5)	51.5 (44)
	Wt % Fs	49 (48)	53 (41.5)	44.5	51	61.5 (47.5)	48.5 (42)
	C	(2)	(4.5)			(23)	(14)
	Wt % Q	15.5	18	14	25.5	17.5	34.5
	Wt % F	60.5	58.5	61.5	52.5	60	43.5
	Wt % M	24	23.5	24.5	22	22.5	22

		13	14	15	16	17	18
Norms	Q	17.94	14.16	17.82	17.28	20.88	17.82
	Or	7.23	6.67	7.23	4.45	5.56	7.23
	Ab	16.77	19.39	15.72	20.44	26.20	25.15
	An	27.52	33.36	29.75	35.03	28.63	28.36
	C	6.51	3.47	14.69	0	0	0
	Wo	0	0	0	0.93	0.46	0.93
	En	7.70	8.50	8.20	8.00	6.60	6.30
	Fs	12.01	13.99	12.67	8.34	1.85	5.58
	Mt	3.25	2.55	3.02	4.41	4.87	3.48
	Il	0.76	0	0	0.91	1.22	1.06
	Wt % Or	14	11	13.5	7.5	9	12
	Wt % Ab	32.5	33	30	34	43.5	41.5
	Wt % An	52.5	56	56.5	58.5	47.5	46.5
	Plagioclase An %	62	63	65	63	52	53
	Wt % Wo	0	0	0	5.5	5	6
	Wt % En	39 (29)	38 (33)	39.5 (23)	45	74	40
	Wt % Fs	61 (46)	62 (54)	60.5 (35.5)	49.5	21	54
	C	(25)	(13)	(41.5)			
	Wt % Q	19	14.5	19	17	21.5	18
	Wt % F	56	60	55.5	60	63	61.5
	Wt % M	25	25.5	25.5	23	15.5	20.5

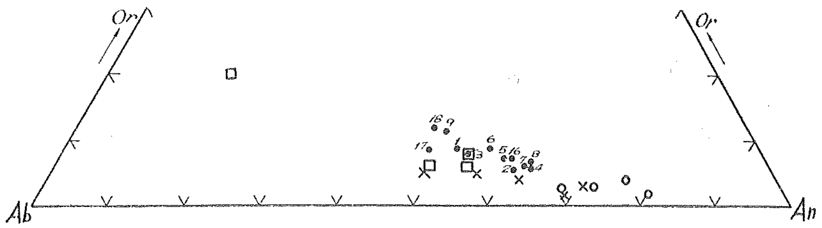
* Numbers are the same as in Table I.



Solid circles indicate Tarumai lavas and open circles Sakurajima lavas.



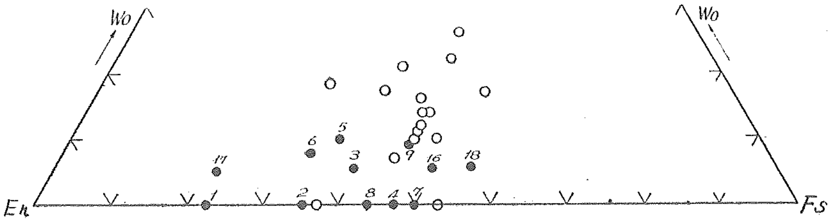
Cross marks indicate Tarumai lavas and circles sanukitic rocks from Takamatsu district. (solid circle—olivine basalt, open circle—sanukite)



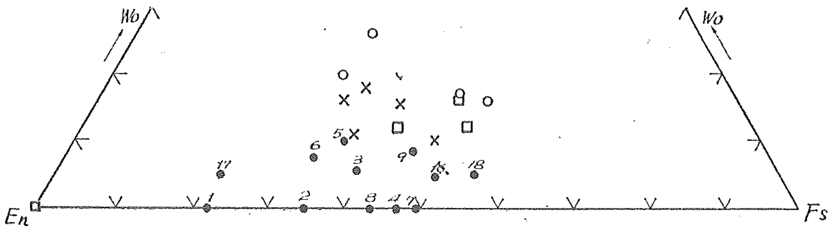
Solid circles indicate Tarumai lavas and others the porphyritic volcanic rocks from Idzu and Hakone district. (open circle—basalt, cross marks—olivine bearing andesite, square—other andesite)

Figure 8. Diagrams showing Norm feldspar.

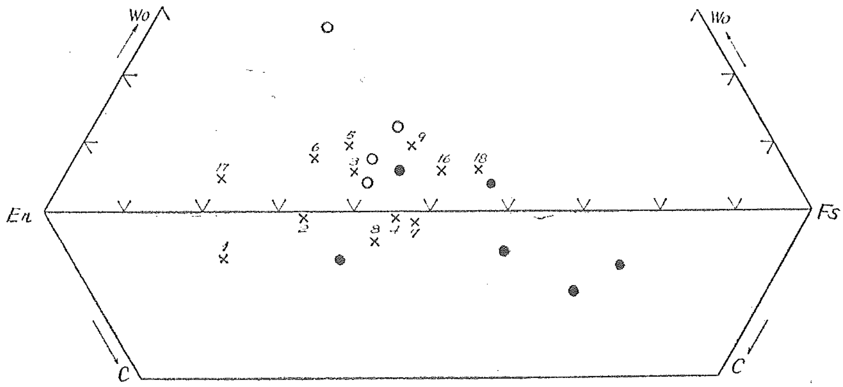
In comparison with the lavas from Volcano Sakurajima belonging to the Ryûkyû zone, whose norm feldspars were calculated by KUNO,[51] Tarumai is distinctly high in An and low in Or and Ab. This result in norms coincides with the fact that *al-alk* is very high, *alk/al-alk* very low and *k* low in NIGGLI's value. Also, when compared with sanukitic rocks in the neighbourhood of Takamatsu, Shikoku district,[52] belonging to the Setouchi volcanic zone, the same relation as the case of Sakurajima was found. It is explained from the fact that the Setouchi zone shows the same characteristics in *al-alk* and *alk/al-alk* of NIGGLI's value as the Ryûkyû. The porphyritic volcanic rocks including basalts and pyroxene andesites in Idzu and Hakone district[10] are lower in Or as a whole, and high in An and low in Ab in the case of basalt, in com-



Solid circles indicate Tarumai lavas and open circles Sakurajima lavas.



Solid circles indicate Tarumai lavas and others the porphyritic volcanic rocks from Idzu-Hakone district. (open circle—basalt, cross mark—olivine bearing andesite, square—other andesite)



Cross marks indicate Tarumai lavas and circles sanukitic rocks from Takamatsu district. (open circle—basalt, solid circle—sanukite)

Figure 9. Diagrams showing Norm pyroxene.

parison with Tarumai. This result is related to the fact that the Fuji zone is very low in *k*, though showing the same inclination in *al-alk* and *alk/al-alk* of NIGGLI's value as the Nasu zone.

Norm Pyroxene

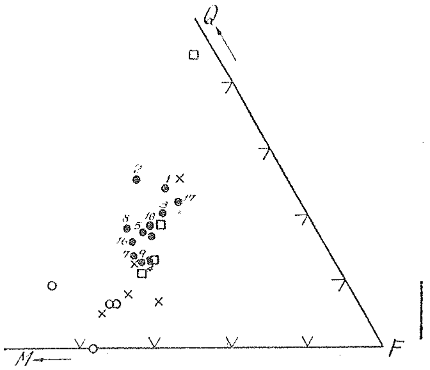
Figure 9 shows that the lavas from Tarumai are very low and all below 10 in Wo. Even norm C values are often calculated, and therefore

En-Fs-C diagram can be figured. This coincides with the fact that *c*-(*al*-*alk*) of NIGGLI's value is remarkably low in this volcano.

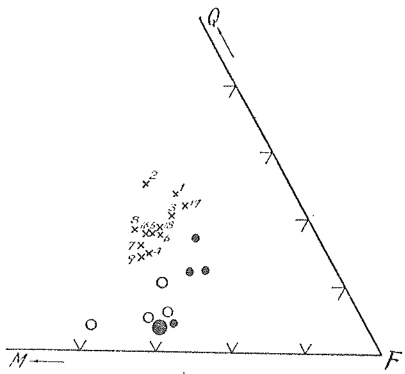
Also the sanukitic rocks from the Setouchi zone whose *c*-(*al*-*alk*) values are mostly very low, are very poor in Wo, though some olivine basalt is rather high. While the lavas from Volcano Sakurajima are higher in Wo and generally lower in En than those of Tarumai. This is proved from the fact that *c*-(*al*-*alk*) values of the lavas from the Ryûkyû zone are genarally high, and that the average of MgO of the lavas from Sakurajima (2.10%) is remarkably lower than that of Tarumai lavas (3.32%). All the porphyritic rocks from Idzu-Hakone district are also higher in Wo than all the lavas from Tarumai. This is suggested from the fact that the lavas from the Fuji zone are generally higher than the latter in *c*-(*al*-*alk*) of NIGGLI's value.

Norm QFM

As shown in Figure 10, the lavas from this volcano are concentrated closely from 14 to 25 in Q and from 56 to 63 in F. The sanukitic rocks from the Setouchi zone are mostly lower than Tarumai lavas in Q. This is expected from the low values of *qz* in the former. In comparison with the porphyritic volcanic rocks from Idzu-Hakone district, Tarumai lavas are generally higher in Q than they are, though both show nearly the same percent in F. This is explained from the fact



Solid circles indicate Tarumai lavas and others the porphyritic volcanic rocks from Idzu-Hakone district. (open circle—basalt, cross mark—olivine bearing andesite, square—other andesite.



Cross marks indicate Tarumai lavas and circles the sanukitic rocks from Takamatsu district. (open circle—olivine basalt, solid circle-sanukite)

Figure 10. Diagrams showing Norm QFM.

that most lavas of Tarumai are distinctly high in *qz*, though also the Fuji zone is not low in *qz*.

In NIGGLI's value, even lavas from one volcanic zone are seen to be rather scattered, although the general trend is shown. Therefore they may not be so closely concentrated also in norm feldspar, norm pyroxene and norm QFM. Nevertheless the lavas from Sakurajima, Takamatsu and Idzu-Hakone districts show the interesting relation to those of Tarumai in norm.

In norms of the plateau basalt or its related non-porphyritic rocks, KUNO[53] ascertained that when Or and An are rich, En is high and if Ab is rich, Fs or Fs and Wo are high. Though this rule may not be always applied to porphyritic volcanic rocks, Tarumai lavas are rich in An and high in En in comparison with Sakurajima lavas and sanukitic rocks. Sakurajima lavas are rich in Ab and Or, and high in Fs. When compared to porphyritic volcanic rocks from Idzu-Hakone district, Tarumai lavas are rich in Or and high in En.

Of the excluded six lavas from Tarumai, Nos. 10 and 12 are the highest in An, and No. 11, 13, 14 and 15 are all high in Or among the lavas of Tarumai. Especially norm C is calculated from the above six in the value of 3.47 to 14.69. In NIGGLI's values they are higher in *al-alk* and mostly far lower in *c-(al-alk)* than other lavas.

Except the above six, the lavas belonging to Kitayama, Nishiyama and Higashiyama respectively in Volcano Tarumai show the more distinct trend in norm feldspar. In Higashiyama lavas, Wo is high in the lava rich in Ab and Or, and En is high in the lava rich in An. In Nishiyama lavas, En is high in the lava rich in Or. And Higashiyama lavas are high in M of norm QFM and in Fs of norm pyroxene. This coincides with the fact that Higashiyama lavas are generally abundant in pyroxene and especially the dome lava contains hypersthene high in Fs percent (En_{50} Fs_{50}).

An percent of norm plagioclase is generally high, showing 52 to 67 except Nos. 10 to 15. Shikotsu lavas which are pyroxene dacite show the lowest An percent among them. Composition of phenocrystic plagioclase in Tarumai lavas ranges from An 60 to An 90, An 70 to An 75 in average, though showing An 40 to An 60 at the margin of phenocrystic plagioclase or in the groundmass plagioclase. Phenocrystic plagioclase in Shikotsu lavas shows An 65 or so. Nos. 10 and 12 are abnormally high in An percent of norm plagioclase, showing 75 and 85 respectively. The dome lava from which No. 10 and No. 12 were analyzed includes large anorthite crystals and often heterogenious in texture.

As known from the above, An percent of norm plagioclase is lower than that of modal plagioclase in this volcano. TSUBOI and KUNO[57] stated already that norm plagioclase of pyroxene andesites in Japan is, as a rule, more basic than An_{50}, but more acidic than modal plagioclase. This is interpreted[57] to be related with glass solidified before crystallizing out as more acidic plagioclase. BOWEN[58] considered that An percent of norm plagioclase is more basic than that of modal plagioclase, because Al_2O_3 content of modal pyroxene adds to plagioclase in calculation of norm. But BOWEN's theory can not be applied to pyroxene andesites in Japan.

Though diagram figures were excluded from this paper, the result found from calculation according to OSANN's and WOLFF's systems are added briefly.

In A–C–F, Al–S–F and C–Al–Alk relations of OSANN's system, the lavas from this volcano are closely concentrated respectively, except Nos. 10 to 15. In A–C–F relation nearly all the lavas are plotted in the neighbourhood of gabbro, though Shikotsu lavas approach to quartz diorite. And Higashiyama lavas are high in F, suggesting that they are rich in coloured minerals in mode. While in Al–S–F relation, most lavas are scattered around diorite, showing the general distinct trend ranging from quartz diorite (Shikotsu lava) to gabbro. In C–Al–Alk relation, Shikotsu lavas are rather high in Alk. Nos. 11 to 15 are out of the igneous field of C–Al–Alk diagram.

Also in WOLFF's diagram, all the lavas, except Nos. 10 to 15, are closely concentrated in the area of andesite. But Kitayama lavas approach to dacite, and Shikotsu lavas are situated near the boundary among dacite, trachyte and andesite. Higashiyama lavas are the richest in M, showing them to be rich in coloured minerals.

Conclusion

From the above discussion, it is concluded that the lavas from Volcano Tarumai are related closely to each other and derived from the same magma, because they are concentrated with the general trend in chemical compositions and in any system after C. I. P. W., NIGGLI, OSANN and WOLFF. The lavas of this volcano are high in *al-alk* and *qz*, very low in *alk/al-alk* and *c-(al-alk)*, and low in *k* of NIGGLI's value, in comparison with the Pelée-Lassen Peak and Electric Peak types. In norm, An percent is comparatively rich and Or low in norm feldspar, Wo is very low and En often high in norm pyroxene, and Q is rich in norm QFM.

These chemical characteristics are related to the facts that plagioclase is more basic and rhombic pyroxene is more predminant in the lavas from Volcano Tarumai than the normal andesite, and most lavas from Tarumai generally contain abundant glass which is rich in excess silica, though a few contain tridymite in the groundmass.

From comparison chiefly in NIGGLI's value calculated from chemical compositions, the main volcanic zones in Japan, excluding the Chôkai, Norikura and Daisetsu on account of their poor data, may be roughly characterized chemically as follows;

The Nasu zone is high in *al-alk* and *qz*, low in *alk/al-alk*, rather low in *c-(al-alk)* below *si* 250 and somewhat high in *c-(al-alk)* above *si* 250 in comparison with the Pelée-Lassen Peak or Electric Peak types. *k* is 0.1 to 0.3 and *mg* is 0.25 to 0.52, or *k* is comparatively low, when compared with the North America Cordillera.

The Fuji zone is high in *al-alk* and *qz*, low in *alk/al-alk* and generally high in *c-(al-alk)*, especially below *si* 150. But *qz* is not high above *si* 450. *k* is low, mostly being below 0.2. In the Idzu-Hakone volcanic rocks belonging to this zone, Or is generally poor and An rich in basic rocks in norm feldspar, Wo is rich in norm pyroxene and Q is generally low in norm QFM when compared with Tarumai lavas.

The Chishima zone is high in *al-alk* and *qz*, low in *alk/al-alk* and low in *c-(al-alk)* above *si* 180. But *qz* is low below *si* 150 and *c-(al-alk)* is rather high below *si* 180. *k-mg* points are included in the area of the Nasu zone, showing the general trend of increase in *mg* with the increase of *k*.

The Daisen zone is low in *al-alk*, high in *alk/al-alk*, *qz* and *c-(al-alk)* especially between *si* 200 and 250. But *qz* is lower than the Nasu, Fuji, Chishima and Ryûkyû zones. *k* is mostly from 0.2 to 0.4 and *mg* from 0.4 to 0.5. Consequently *k-mg* points are included in the concentrated area of the North America Cordillera, approaching the Electric Peak type rather than the Pelée-Lassen Peak.[51]

The Ryûkyû zone is low in *al-alk* and high in *alk/al-alk*, *qz* and *c-(al-alk)* especially between *si* 200 and 250. But *alk/al-alk* is slightly low above *si* 200, *qz* is a little lower than the Chishima and *c-(al-alk)* is higher than the Daisen. *k* is from 0.2 to 0.3 and *mg* 0.3 to 0.5, and *k-mg* points are included in the concentrated area of the North America Cordillera. Sakurajima lavas belonging to this zone is rich in Or, poor in An and rich in Wo in comparison with Tarumai lavas.

The Setouchi zone is low in *al alk*, *qz* and *c-(al-alk)* and very high in *alk/al-alk*. But *qz* is higher than the Electric Peak type, while *c-(al-alk)* is, as a whole, the lowest in Japan. *k* is higher than 0.2, and *mg* is from 0.3 to 0.6, showing the general tend of rapid decrease in *mg* with the increase of *k*. In sanukitic rocks belonging to this zone, Or is rich, An poor, and Q poor in comparison with Tarumai lavas. Wo shows mostly the same low value as Tarumai lavas.

Alkalic types such as the Maros-Highwood, Tahiti and Hawaii are low in *al-alk* and *qz*, and high in *alk/al-alk*. The more calcic type seems to be the richer in *al-alk* and *qz*, and the poorer in *alk/al-alk*. Consequently the Pelée-Lassen Peak and Electric Peak types are the most calcic among young volcanic rocks from the North America Cordillera. The Nasu, Fuji and Chishima zones may be more calcic than the above two types, while the Ryûkyû, Daisen and Setouchi zone lavas are more alkalic than the above three. In *k-mg* relation, the latter three zones are high in *k*. TANEDA[59] stated already that the Ryûkyû, Daisen, Chôkai and Setouchi zones are more alkalic than other volcanic rocks from Japan. It is interesting that the Setouchi zone is very low in *c-(al-alk)*, far from the other two. It has been already suggested by SUGI[52] and TOMITA[60] that sanukitic rocks from the Setouchi zone have peculiar characteristics.

Also the Nasu zone is comparatively low in *c-(al-alk)* as is also the Chishima, far from the Fuji. The Nasu zone is considered to be one of the extreme types among calc-alkalic series. Volcano Tarumai belongs to the representative type of the Nasu zone in chemical characteristics. TOMITA[60] stated that there are some types among volcanic rocks of Japan type which can not be explained only by crystallization differentiation. The author[7] considers that the lavas from Volcano Tarumai may be presumed to have been formed by the aid of magmatic assimilation of sedimentary rocks rich in Al_2O_3.

Also the formation of large anorthite crystals included in the Dome lava, bread-crust bomb and black compact block may be due to the abnormal addition of Al_2O_3 to magma.[7] The area where large anorthite crystals included in volcanic rocks can be found may be the petro-province (proposed by TOMITA[60]) where contamination between magma and Al_2O_3-rich rocks has taken place.[7]

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