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SPATIAL VARIATION IN CHEMICAL COMPOSITION OF PLIOCENE AND QUATERNARY VOLCANIC ROCKS IN SOUTHWESTERN HOKKAIDO, NORTHEASTERN JAPAN ARC

by

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(with 10 text-figures, 4 tables and 1 appendix)

Abstract

Major element compositions of 192 Pliocene and Quaternary volcanic rocks from 28 volcanic centers in southwestern Hokkaido (SW Hokkaido), which is situated at the northern part of the northeastern Japan arc, are determined. Using this data with previously reported analyses for volcanic rocks from northern Honshu (N-Honshu) and SW-Hokkaido, spatial variations in SiO_2-normalized major element values (SiO_2=60 wt%) at an arc junction are examined. The SiO_2-normalized values for many major elements, TiO_2, Al_2O_3, FeO, CaO, Na_2O, K_2O and P_2O_5, increase or decrease systematically westward. A N-S trending zonation of volcanoes, based on the SiO_2-normalized value of the volcanic rocks, can be recognized from N-Honshu to SW-Hokkaido. The zonation in SW-Hokkaido is not parallel to the present trench axis which bends from a N-S to a NE-SW direction off the coast of SW-Hokkaido. The region comprising Yotei, Konbu and Niseko-Waisuhorun volcanoes displays a local anomaly with respect to TiO_2, Na_2O and P_2O_5 values.

Introduction

Generally, arc volcanic rocks are characterized by systematic across-arc variation in their chemical compositions. In particular, SiO_2-nomalized K_2O values increase away from the trench (eg. Sugimura, 1959; Kuno, 1966; Dickinson, 1968, 1975; Dickinson and Hatherton, 1967). Near arc-arc junctions, such across-arc compositional variations are ambiguous (Katsui and Nakamura, 1979).

The northeastern Japan (NE-Japan) and Kuril arcs join in Hokkaido (Text-fig. 1). Katsui (1961) and Katsui et al. (1978) outlined the geochemical character of Quaternary volcanic rocks from Hokkaido and showed a marked across-arc chemical variations in alkali content exists. Anomalous variations in Hokkaido have been reported by Ui and Aramaki (1978), and Aramaki and Ui (1983). They pointed out that along-arc variation of SiO_2-normalized K values occur central Hokkaido associated with the Kuril arc. Recently, Yamamoto (1988) investigated the compositional zonation of FeO by comparing the volcanic rocks from the front-side and those from the backarc-side in the northern part of NE-Japan including SW-Hokkaido. However, the chemical composition of volcanic rocks from many volcanoes have not yet been determined. Therefore, the spatial variations in chem-

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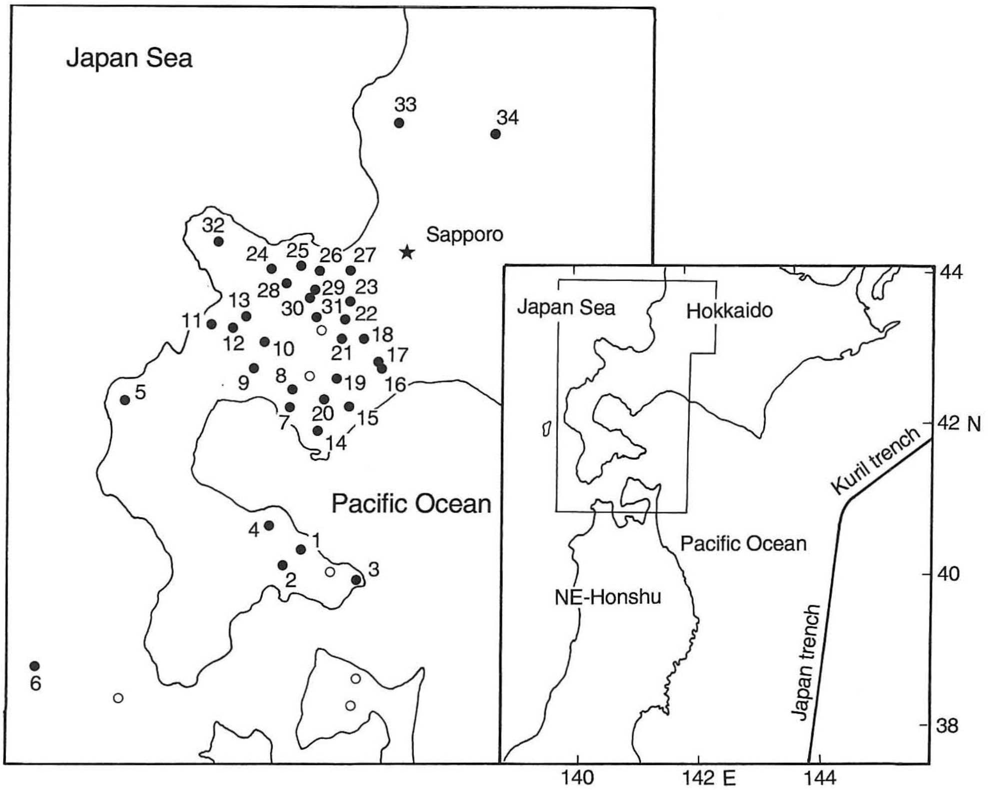


Text-figure 1 Localities of Pliocene and Quaternary volcanic centers in southwestern Hokkaido (SW Hokkaido) in the left. Closed circles are the volcanoes treated in this study and open circles are other volcanoes. Numbers are the same as those in table 1. The caldera volcanoes, Shikotsu, Toya, and Nigorikawa are omitted. Outline of northern Honshu and SW Hokkaido are also shown on the right, including trench axis (Yoshii, 1979).

ical compositions of volcanic rocks in Hokkaido remain uncertain.

In order to reveal the detailed spatial variations in major element composition of volcanic rocks at the arc junction, precise chemical analyses were made for Pliocene and Quaternary volcanic rocks in SW-Hokkaido located at the northern part of the NE-Japan arc. The origin of Pliocene and Quaternary volcanics is regarded to be the same, because chemical characteristics of volcanic rocks in this region have been unchanged since the late Miocene (Okamura, 1987). Text-fig. 1 shows the locality and Table 1 lists the Pliocene and Quaternary volcanic centers in SW Hokkaido. In this study, 192 new data from 28 volcanoes are presented. Combined with previously reported analyses for 6 volcanic centers (Table 1), the detailed spatial variation in chemical compositions of volcanic rocks is discussed.

Tectonic Framework

SW-Hokkaido is located at the northern end of the NE-Japan arc, which adjoins southernmost end of the Kuril arc. Neogene volcanics are widely distributed in SW-Hokkaido. Submarine volcanism during middle Miocene and early Pliocene has been followed by terrestrial activity since middle or late Pliocene (Yamagishi, 1981; Okamura, 1985).

It is well known that a zonal arrangement of subduction related volcanic centers, with a respect to major and trace element chemistry, occurs parallel to the trench axis and the depth contours of deep seismicity (*eg*. Kuno, 1966; Dickinson, 1975). Off the coast of SW-Hokkaido, the Japan and the Kuril trenches join and change orientation from N-S to NE-SW, respectively.

Samples and analytical procedure

Table 1 lists 34 volcanic centers of SW-Hokkaido, which were examined in this study. Shikotsu, Toya and Nigorikawa volcanoes, possessing calderas, are omitted. Major element chemical compositions of 192 rocks from the 28 volcanoes have been determined using a Philips PW1404 XRF following the modified method of Tsuchiya et al. (1989). All new data are listed in Appendix 1. Table 2 shows the precision of this method.

Normalized chemical compositions

Several studies concerning spatial variation in chemical compositions of arc volcanic rocks have investigated the trends using Harker diagrams (*eg*. Kuno, 1966), or normalized values using all data from basalt to dacite (*eg*. Dickinson, 1975; Ui and Aramaki, 1978; Aramaki and Ui, 1983). However, recent detailed petrological studies have revealed that several distinct chemical trends using the silica-oxide variation diagrams are often recognized, even in a single volcano (*eg*. Dupuy et al., 1982; Kay and Kay, 1985; Bullen and Clynne, 1990).

Among the volcanoes associated with the NE-Japan arc, two different rock suites, tholeiite and calc-alkaline, may coexist in a single volcanic center (*eg*. Fujinawa, 1988, 1990; Sakayori et al., 1987). The genetic relationship between the two rock suites has been discussed by many authors (*eg*. Kuno, 1950; Sakuyama, 1981; Takahashi, 1986; Fujinawa, 1988, 1990). Takahashi (1986) and Fujinawa (1988, 1990) suggested both are derived from defferent source materials and argued that one rock suite can not be derived from the other by fractional crystallization and/or internal magma mixing. Strictly speaking, the above two rock suites must be separately investigated to discuss the spatial variation in chemical compositions. In order to avoid averaging the analyses for different rock suites, only rocks with SiO_2 content ranging from 56 to 64% were treated in this study. This method has been adopted in order to investigate about the spatial variation in chemical compo-

Table 1 Summary of the age and the petrography of rocks from Pliocene and Quaternary volcanoes in southwestern Hokkaido

Number	Name	Age	SiO_2	Ph. of and.	Data source
1	Nakitsura	Q	60.4-61.6	OPX CPX (+HB Qz)	this study
2	Yokotsu	Q	56.6-60.9	OPX CPX (+HB QZ OL)	this study
3	Esan	Q*	57.9-62.8	OPX CPX (+HB QZ OL)	Katsui et al. (1983)
4	Komagatake	Q*	58.7-61.9	OPX CPX	Katsui et al. (1989)
5	Kariba	0.7-0.25(1)	53.6-61.4	OPX CPX HB (+BI QZ OL)	this study
6	Oshima-oshima	Q*	48.6-58.3	OPX CPX HB (+BI)	Yamamoto (1984)
7	Usu	Q*	49-53, 68-74	OPX CPX (+HB QZ OL)	Oba (1966)
8	Toya-Nakajima	Q	59.0-65.4	OPX CPX (+HB QZ OL)	Ikeda et al. (1990)
9	Konbu	2.8(4)	56.4-67.6	OPX CPX	this study
10	Yotei	Q	55.3-64.7	OPX CPX (+HB OL)	this study
11	Raiden-Iwanai	1.5-0.8(2)	58.2-60.3	OPX CPX (+HB QZ OL)	this study
12	Niseko	0.8-0(2)	54.5-63.1	OPX CPX (+HB QZ OL)	this study
13	Waisuhorun	1.6-1.3(2)	55.6-61.4	OPX CPX	this study
14	Washibetsu	0.5(4)	53.7-56.8	OPX CPX	this study
15	Kuttara	Q*	47.5-70.7	OPX CPX	Katsui et al. (1988)
16	Tarumai	Q*	56.1-62.0	OPX CPX (+OL)	Nakagawa (in prep.)
17	Fuppushi	Q	59.5-64.2	OPX CPX (+HB QZ OL)	Nakagawa (in prep.)
18	Eniwa	Q*	55.0-64.2	OPX CPX (+OL)	Nakagawa (in prep.)
19	Tokusyunbetsu	0.6(4)	60.7-61.8	OPX CPX	this study
20	Raiba	0.6(4)	59.4-61.7	OPX CPX	this study
21	Izari	2.5(3)	57.5-61.7	OPX CPX (+OL)	this study
22	Soranuma	0.8(3)	60.8-61.3	OPX CPX (+OL)	this study
23	Sapporo	1.6-1.2(3)(5)	52.7-55.7	OPX CPX	this study
24	Akaigawa	2.1(3)	58.5	OPX CPX HB OL	this study
25	Otaru-Maruyama	P	60.1-60.9	OPX CPX OL	this study
26	Kenashi	3.8(3)	57.6-61.7	OPX CPX (+HB)	this study
27	Teine	3.7(3)	55.8-60.7	OPX CPX HB (+OL QZ)	this study
28	Amemasu	3.0(3)	64.1-66.8	OPX CPX (+HB QZ OL)	this study
29	Asari	2.6(5)	52		this study
30	Yoichi	P	66.1	OPX CPX	this study
31	Muine	3.0(3)	62.3-63.6	OPX CPX	this study
32	Shakotan	2.0(3)	59.8-60.4	OPX CPX HB OL QZ (+BI)	this study
33	Shokanbetsu		52.7-64.3	OPX CPX (+HB BI QZ OL)	this study
34	Irumukeppu		55.0-59.2	OPX CPX (+HB BI QZ OL)	this study

Numbers correspond to location in Fig. 1. Ages (Ma) are compiled from the following studies: (1) Kaneoka et al., 1987, (2) NEDO, 1987, (3) Watanabe, 1990; (4) Nakagawa et al., submitted., (5) Nakagawa, 1992., (6) Yagi et al., 1987, (7) Sagawa et al., 1988. Q*: volcaneos with eruption records in historic time. Q and P: Quaternary and Pliocene volcanoes respectively, of which age is estimated by the stratigraphic relationship. Ph. of and.: phenocryst assemblage of andesite, excluding plagioclase and Fe-Ti oxides.
The phenocrystic minerals in ( ) often occur with other phenocrysts.

Table 2 Results of analyses of standards JB-1a, JA-1 and JG-1a by XRF

	JB-1a			JA-1			JG-1a		
	Re. va.	ave.(n=5)	1-sigma	Re. va.	ave.(n=5)	1-sigma	Re. va.	ave.(n=5)	1-sigma
SiO_2	53.36	53.36	0.010	65.08	65.12	0.090	72.97	73.37	0.098
TiO_2	1.33	1.35	0.005	0.89	0.88	0.005	0.25	0.25	0.000
Al_2O_3	14.85	14.80	0.031	15.22	15.27	0.033	14.38	14.19	0.066
FeO*	8.37	8.13	0.060	6.35	6.36	0.058	1.87	1.79	0.017
MnO	0.15	0.16	0.000	0.15	0.15	0.000	0.06	0.06	0.000
MgO	7.93	8.10	0.036	1.63	1.62	0.013	0.70	0.75	0.009
CaO	9.45	9.53	0.039	5.77	5.71	0.028	2.15	2.06	0.007
Na_2O	2.81	2.85	0.033	3.92	3.95	0.027	3.45	3.46	0.045
K_2O	1.49	1.47	0.010	0.84	0.78	0.005	4.09	4.00	0.004
P_2O_5	0.26	0.27	0.005	0.16	0.16	0.000	0.08	0.08	0.004

Re. va.: Recomended value by Ando et al. (1987)
FeO*: total iron as FeO

sitions of calc-alkaline suite, because the tholeiitic suite consists mainly of basalt and basaltic andesite whereas the calc-alkaline suite is dominated by andesite and dacite.

All analyses are normalized to 100% (water free and total iron as FeO). When computing the normalized values, analyses with 56%>SiO_2>64% are excluded. The procedure for calculating the normalized values for major elements in individual volcanoes are as follows:

(1) When more than three analyses (SiO_2=56-64%) are available, the normalized values (SiO_2=60%) are given by a linear regression calculation.

(2) If two analyses or less are available, normalized values can not be calculated (Usu, Washibetsu, Sapporo-dake, Akaigawa. Amemasuyama, Asari-dake and Yoichi-dake volcanoes). However, in case of one analysis within a range of SiO_2=59-61%, the major element contents are used as the normalized value (Toya-Nakajima, Waisuhorun and Soranuma-dake volcanoes).

(3) In the case of Konbu volcano, three analyses of dacite (SiO_2=64.6, 66.0 and 67.6%) in addition to one analysis (SiO_2=56.4%) are used in the normalization calculation, because they are close to andesitic compositions.

Table 3 lists the normalized values (SiO_2=60%) of volcanic rocks from 27 volcanoes in SW Hokkaido. The same calculation were made for volcanic rocks from the Quaternary volcanoes from northern Honshu (Table 4). The volcanoes located at the Sekiryo Mountains of northern Honshu often consist of two different rock suites, tholeiite and calc-alkaline (*e. g.* Fujinawa, 1988). In this study, the rocks of the calc-alkaline suite were used to calculate the normalized values, because the rocks mainly consist of andesite and dacite. in the case of Iwate (Ishikawa et al., 1984), Hachimantai (Yoshida et al., 1983) and Kita-and Minami -Hakkoda volcanoes (Sasaki et al., 1985, 1987), tholeiitic andesites (SiO_2> 54%) were not used in the calculations.

Table 3 SiO_2-normarized chemical compositions of andesites (SiO_2=60 wt%) from southwestern Hokkaido

Number	Name	Cal./Tot.	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
1	Nakitsura	4/4	0.70	16.43	8.43	0.18	3.60	6.92	2.76	0.86	0.09
2	Yokotsu	7/7	0.77	16.07	8.08	0.17	3.68	7.03	2.87	1.15	0.12
3	Esan	9/9	0.58	17.61	7.69	0.19	3.15	7.68	2.47	0.56	0.08
4	Komagatake	6/6	0.78	17.04	7.67	0.14	3.08	7.14	3.08	0.92	0.15
5	Kariba	11/16	0.69	17.85	5.80	0.13	3.57	6.10	3.11	2.53	0.22
6	Oshima-oshima	4/33	0.49	17.80	5.95	0.10	2.44	6.33	3.56	3.04	0.30
7	Usu	n. d.									
8	Toya-Nakajima	**2/8	0.70	17.44	6.98	0.15	1.99	7.42	3.90	0.98	0.08
9	Konbu	*1/4	1.09	16.78	7.74	0.20	2.34	6.42	4.11	1.01	0.30
10	Yotei	10/15	0.97	17.23	7.14	0.18	2.34	6.42	4.17	1.25	0.32
11	Raiden-Iwanai	5/5	0.87	17.10	7.70	0.15	2.76	5.94	3.26	2.06	0.21
12	Niseko	9/10	0.81	17.01	7.11	0.16	3.40	6.56	3.14	1.62	0.20
13	Waisuhorun	**3/4	0.89	18.47	5.74	0.16	1.83	6.63	4.14	1.66	0.37
14	Washibetsu	n. d.									
15	Kuttara	4/27	0.68	17.15	7.82	0.14	2.94	7.66	2.87	0.70	0.09
16	Tarumai	9/9	0.68	16.62	7.69	0.15	3.39	7.49	2.87	1.01	0.10
17	Fuppushi	10/11	0.75	17.29	7.54	0.15	2.97	7.18	2.96	1.04	0.11
18	Eniwa	23/27	0.70	16.66	7.33	0.15	3.53	7.40	2.93	1.19	0.11
19	Tokusyunbesu	4/4	0.63	16.22	7.69	0.14	4.08	7.49	2.37	1.31	0.07
20	Raiba	4/4	0.66	16.09	7.83	0.15	4.15	7.41	2.36	1.27	0.08
21	Izari	7/7	0.70	16.57	7.50	0.15	3.76	7.36	2.64	1.20	0.10
22	Soranuma	**3/3	0.66	16.68	6.52	0.31	3.09	7.28	2.93	1.57	0.11
23	Sapporo	n. d.									
24	Akaigawa	n. d.									
25	Otaru-Maruyama	4/4	0.81	16.30	8.17	0.17	3.44	6.83	2.83	1.31	0.13
26	Kenashi	10/10	0.70	16.64	7.25	0.15	3.81	7.08	2.73	1.51	0.13
27	Teine	4/5	0.63	16.90	6.77	0.15	3.90	7.15	2.84	1.54	0.12
28	Amemasu	n. d.									
29	Asari	n. d.									
30	Yoichi	n. d.									
31	Muine	4/6	0.75	16.19	7.92	0.14	3.30	7.66	2.54	1.37	0.11
32	Shakotan	**2/2	0.73	17.02	6.35	0.14	3.51	7.08	3.14	2.01	0.20
33	Shokanbetsu	11/19	0.79	17.52	6.09	0.13	3.61	6.79	3.20	1.68	0.20
34	Irumukeppu	5/8	0.69	17.62	5.89	0.13	3.54	6.69	3.47	1.75	0.21

Cal.: number of andesites with a SiO2 range between 56-64 wt%. (wt%)
Tot.: total number of andesite analyses
n. d.: not determined
**: chemical composition of analyses within 59-61 SiO2 wt% (see text)
*: extraordinary calculation (see text)

Table 4 SiO2-normalized chemical compositons of andesites (SiO_2=60 wt%) from northern Honshu

Number	Volcano	Calc.	TiO_2	Al_2O_3	FeO	MgO	CaO	Na_2O	K_2O	P_2O_5	Data source
1	Osore	11	0.64	17.12	8.00	3.46	7.53	2.41	0.61	0.08	Togashi (1977)
2	Iwaki	20	0.73	17.11	7.25	3.00	6.91	3.57	1.07	0.16	Sasaki (unpublsthed)
3	Kita-Hakkoda	8	0.84	15.98	7.75	3.97	7.18	2.70	1.04	0.10	Sasaki et al. (1985)
4	Minami-Hakkoda	4	0.79	15.81	7.89	3.90	7.11	2.75	1.16	0.09	Sasaki et al. (1987)
5	Akita-komagatake	6	0.81	17.28	8.20	2.81	6.47	3.16	0.97	0.13	Nakagawa et al. (1985)
6	Hachimantai	13	0.76	16.13	8.15	3.74	7.23	2.74	0.99	0.13	Yoshida et al. (1983)
7	Kanpu	7	0.51	17.63	5.53	3.10	6.93	3.97	1.98	0.16	Maruyama et al. (1988)
8	Megata	6	0.79	17.36	5.31	3.82	6.52	3.24	2.54	0.25	Aoki and Fujimaki (1982)
9	Moriyoshi	24	0.88	17.13	7.26	2.82	6.61	3.56	1.40	0.17	Nakagawa et al. (1984)
10	Nanashigure	11	0.63	19.44	6.88	2.98	6.59	2.51	0.67	0.13	Ishikawa et al. (1985)
11	Iwate	5	0.83	16.07	7.69	4.05	7.14	2.86	1.12	0.11	Ishikawa et al. (1984)
12	Aoso	10	0.78	17.71	7.27	3.10	6.96	3.17	0.71	0.15	Shimotori et al. (1983)
13	Gassan	16	0.81	17.89	6.60	2.94	5.99	3.44	1.99	0.20	Koizumi et al. (1984)
14	Minami-Zao	7	0.81	16.05	8.09	3.64	6.99	2.97	1.16	0.16	Sakayori et al. (1984)
15	Chokai	14	0.90	17.93	6.53	2.56	5.62	3.89	2.19	0.21	Hayashi et al. (1984)
16	Funagata	53	0.70	17.20	7.13	3.39	7.57	2.98	0.80	0.07	Yoshida et al. (1987)

Calc: number of andesiteic rocks (SiO2=56-64%) used in the normalized calculation

Results

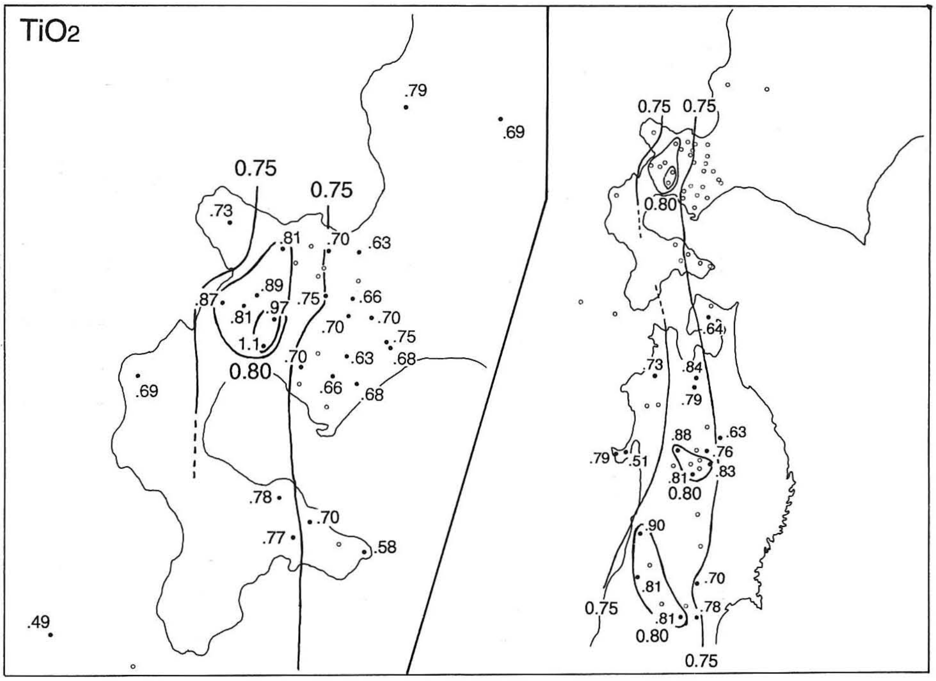
The spatial variation of the SiO_2-nomalized values in NE-Japan arc are shown in Figs. 2-9, in addition to the most plausible contour lines. The normalized values for Shokanbetsu and Irumukeppu volcanoes are also plotted in these figures. However, as it has been considered that these two volcanoes were related to Kuril arc volcanism (Katsui, 1961; Katsui et al., 1978; Ikeda et al., 1987), the contours are not extended to include these volcanoes.

TiO_2 (Text-fig. 2)

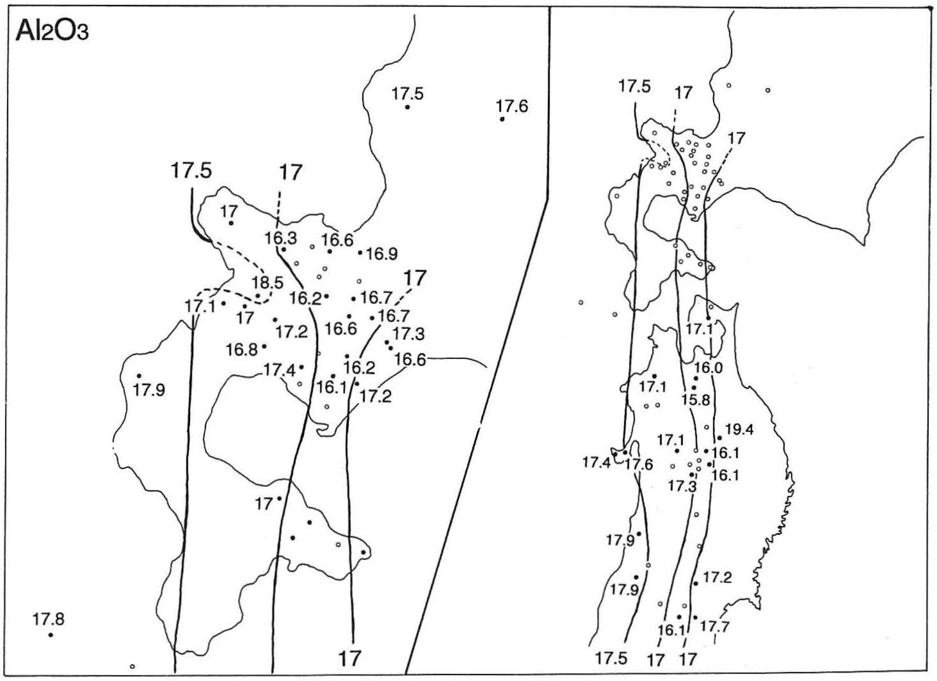
In SW Hokkaido, the region covering Yotei, Niseko, Konbu and Niseko-Waisuhorun volcanoes shows high TiO_2 level and the value reaches to 1.0% (Fig. 2). The normalized TiO_2 values from volcanoes located in the Sekiryo Mountains of northern Honshu and in the region around Yotei volcano in SW Hokkaido are higher than 0.8 wt%. The TiO_2 values decrease slightly from these areas of relatively high TiO_2 values towards both the trench- and backarc-sides.

Al_2O_3 (Text-fig. 3)

Normalized Al_2O_3 values display a minimum (<17%) among the volcanoes in the Sekiryo Mountains of northern Honshu. A high Al_2O_3 region is observed both



Text-figure 2 Spatial variation of normalized TiO_2 values (SiO_2=60%). *Normalized values for each volcanic center and the most plausible contours are shown.



Text-figure 3 Spatial variation of normalized Al_2O_3 values (SiO_2=60%).*

along the volcanic front (*eg*. Esan, Nanashigure and Aoso volcanoes) and along the backarc-side (*eg*. Gassan, Chokai and Megata volcanoes) of northern Honshu. The zonation of normalized Al_2O_3 values in northern Honshu extends to SW Hokkaido. This zonation is different from that previously suggested by Uto (1986), which displayed a simple increase in Al_2O_3 content from the trench- to the backarc-side.

FeO (Text-fig. 4)

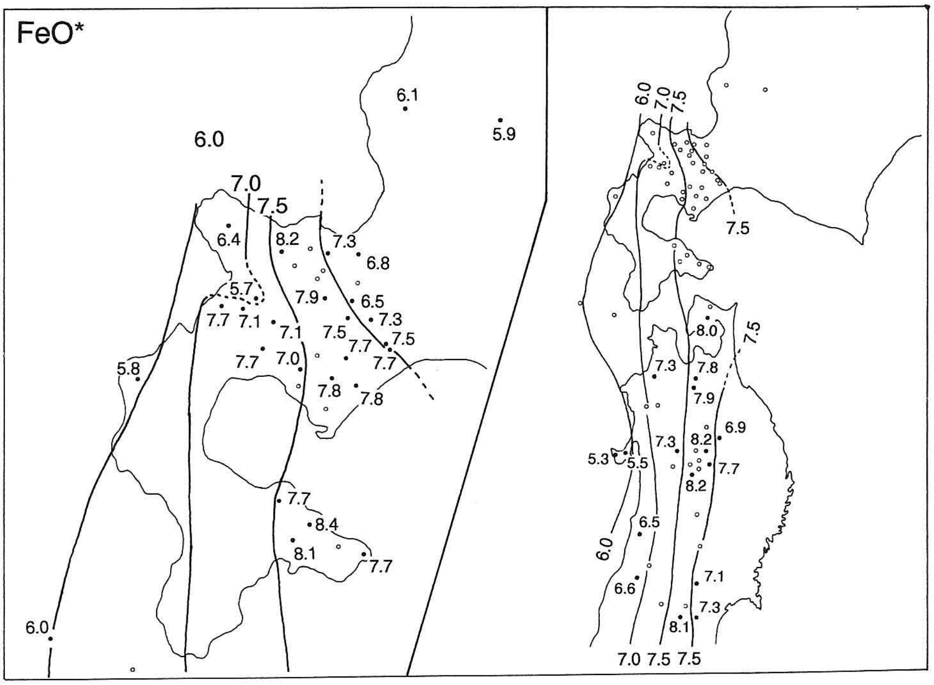
Maximum normalized FeO values occur among the volcanoes located in the Sekiryo Mountains of northern Honshu. The values decresae towards both the trench- and the backarc-side of the Sekiryo Mountains. The obviously N-S trending zonation in normalized FeO values in northern Honshu extends to SW Hokkaido.

MnO and MgO

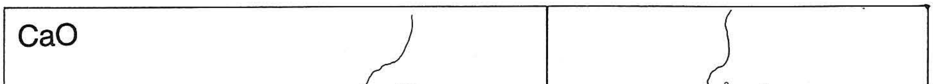
No spatial variation in MnO and MgO contents can be recognized.

CaO (Text-fig. 5)

The normalized CaO values tend to decrease systematically from the trench- to the backarc-side in northern Honshu as mentioned by Takahashi and Fujinawa



Text-figure 4 Spatial variation of normalized FeO values (total iron as FeO)(SiO_2 =60%).*



Text-figure 5 Spatial variation of normalized CaO values (SiO_2=60%).*

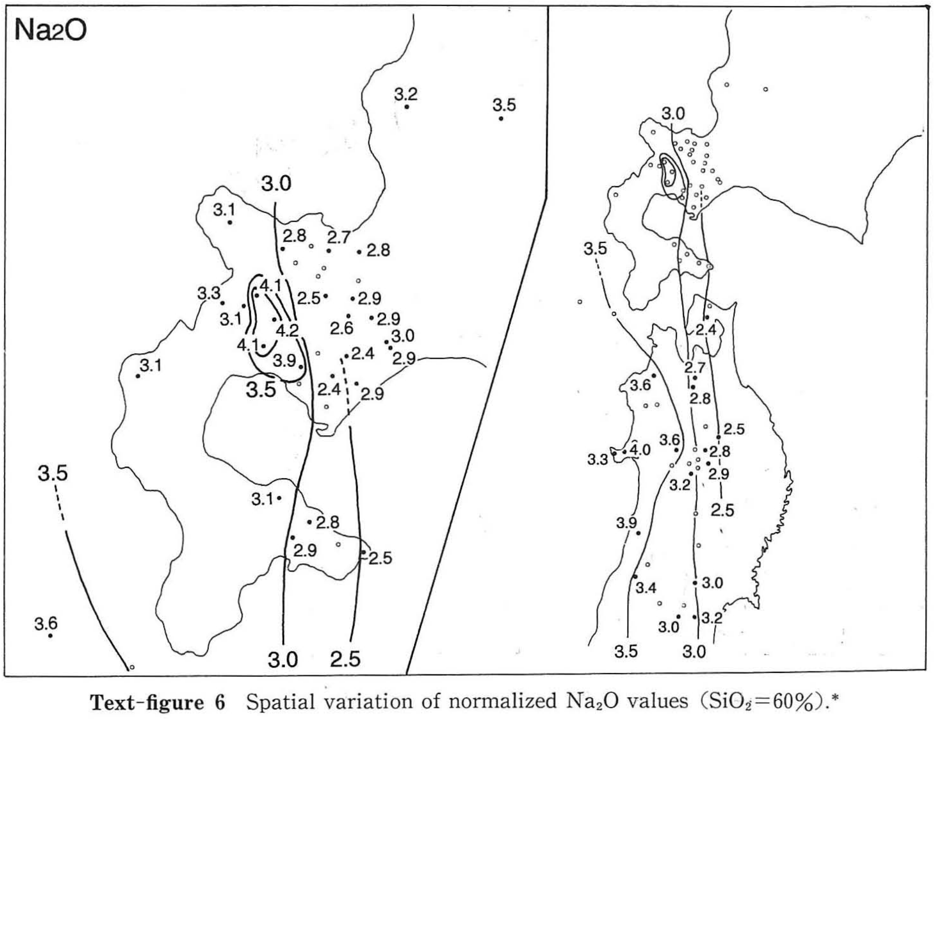
(1983), and Nakagawa ea al. (1986). The N-S trending zonation in northern Honshu continues in SW Hokkaido.

Na_2O (Text-fig. 6)

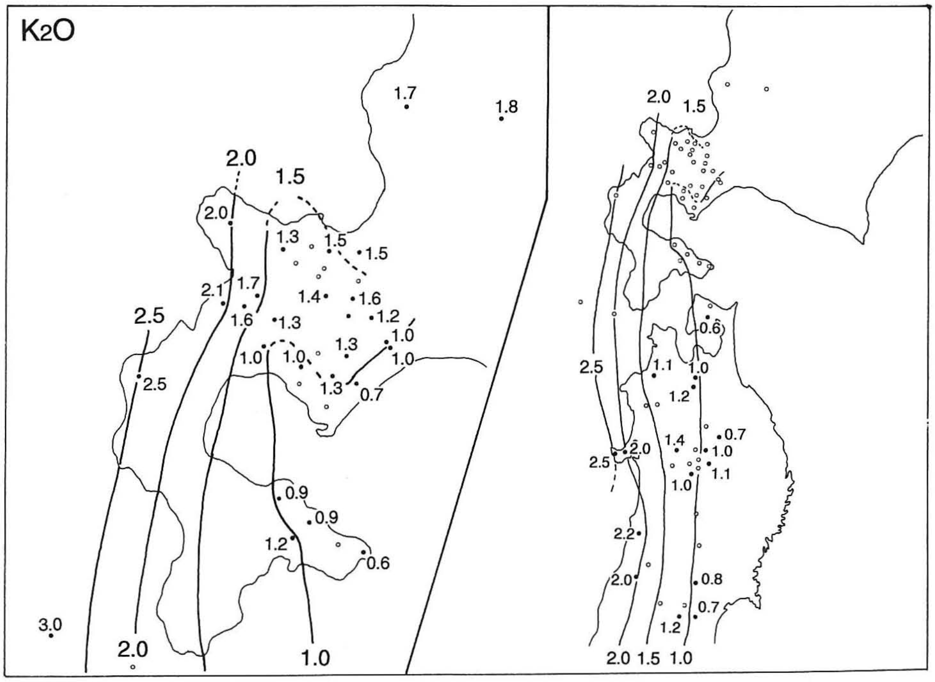
Except for the region around Yotei volcano in SW Hokkaido, the normalized Na_2O values increase westward in northern Honshu and SW Hokkaido. In northern Honshu, the normalized Na_2O values increase from the trench- towards the backarc-side. In SW Hokkaido, the volcanoes with low Na_2O values (<3 wt%) are distributed from the Pacific coast toward the Japan Sea side. Consequently, a N-S trending zonation recognizes in both northern Honshu and SW Hokkaido. However, a regional anomaly around Yotei, Konbu and Niseko-Waisuhorun volcanoes is recognized with normalized Na_2O values reaching a maximum of 4.2 wt%.

K_2O (Text-fig. 7)

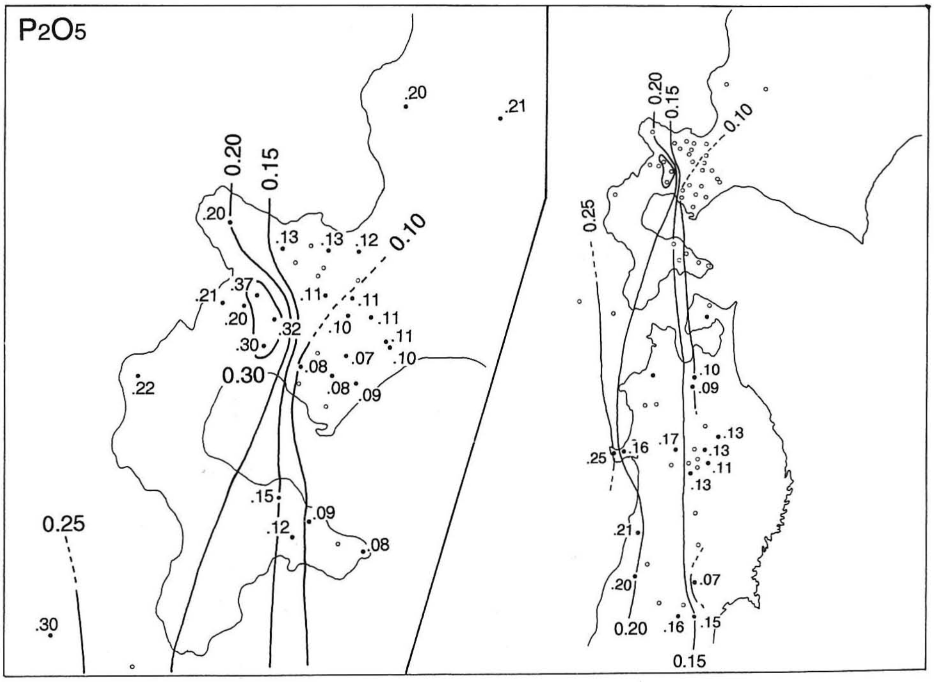
The N-S trending zonation of normalized K_2O values in northern Honshu seems to be ambiguous in SW Hokkaido (Fig. 7). In northern Honshu, the normalized K_2O values systematically increase from the trench- toward the backarc-side as pointed out by previous studies (*e. g.* Takahashi and Fujinawa, 1983; Nakagawa et al., 1986, 1988). However the normalized K_2O values in the eastern region of SW Hokkaido show no clear spatial variation from the Pacific Ocean to the Japan Sea side (Fig 7).



Text-figure 6 Spatial variation of normalized Na_2O values (SiO_2=60%).*



Text-figure 7 Spatial variation of normalized K_2O values ($SiO_2=60\%$).*



Text-figure 8 Spatial variation of normalized P_2O_5 values ($SiO_2=60\%$).*

P_2O_5 (Text-fig. 8)

Weak spatial variation in normalized P_2O_5 values, increasing from the trench-toward the backarc-side, can be recognized in northern Honshu and SW Hokkaido (Fig. 8). However, the normalized P_2O_5 values vary irregularly in SW Hokkaido. The region, including Yotei, Konbu and Niseko-Waisuhorun volcanoes, is characterized by extremely high P_2O_5 values.

Concluding Remarks

The spatial variation of major element values of Pliocene and Quaternary volcanics in the northern region of the NE-Japan arc is summarized as follows.

(1) The N-S trending variation of normalized major element values can be recognized in NE-Honshu and SW-Hokkaido. The zonation in SW-Hokkaido is not parallel to the present trench axis, which bends from a N-S direction (Japan trench) to a NE-SW direction (Kuril trench) (Fig. 1). In order to develop a model for the magmatic and tectonic development in the area of the arc-arc junction, further studies combined with K-Ar age dating for the volcanics, especially in SW-Hokkaido, are needed.

(2) The region, including Yotei, Konbu and Niseko-Waisuhorun volcanoes, displays a local anomaly with respect to several normalized major element values, TiO_2, Na_2O and P_2O_5. However, detailed petrological studies concerning these volcanoes have not been carried out. This preliminary study of major element chemistry of the volcanic rocks from these volcanoes can not provide essential clues for interpreting the nature of the magmatic and tectonic system in the region.

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Appendix. Major element compositions by XRF

Region	Nakitsura				Yokotsu							Kariba			
sample	891024-1	891024-2	891024-3	891024-4	91023-10	91023-11	891024-5	891024-6	90505-2	90505-3	90505-4	89704-10	89704-11	89704-12	89705-1
SiO2	60.87	60.21	59.48	59.90	59.92	58.36	59.99	59.78	60.83	60.59	56.64	57.43	55.44	57.33	55.84
TiO2	0.60	0.62	0.67	0.64	0.75	0.79	0.70	0.69	0.77	0.77	0.91	0.68	0.86	0.75	0.74
Al2O3	16.18	16.22	16.12	16.61	15.80	16.24	15.97	15.97	15.65	15.90	16.75	17.97	18.29	17.60	17.07
FE2O3	8.02	8.19	8.96	8.07	8.96	8.94	8.32	8.38	8.72	8.77	10.78	6.31	7.04	6.67	6.84
MnO	0.14	0.15	0.17	0.17	0.15	0.18	0.16	0.16	0.16	0.16	0.19	0.14	0.14	0.13	0.13
MgO	3.34	3.45	3.52	3.01	3.26	3.65	3.74	4.10	3.49	3.51	3.93	4.09	5.23	5.06	4.68
CaO	6.79	6.78	6.82	6.53	6.20	6.89	6.93	6.68	7.04	7.18	8.30	6.50	6.79	6.93	7.24
Na2O	2.71	2.57	2.71	2.89	2.96	2.90	2.73	2.70	2.89	2.88	2.91	3.01	2.63	2.87	2.88
K2O	0.97	0.91	0.89	0.79	1.11	1.13	1.36	1.35	1.15	1.11	0.63	2.10	2.07	2.15	2.23
P2O5	0.08	0.08	0.09	0.09	0.12	0.13	0.10	0.10	0.13	0.13	0.14	0.21	0.28	0.24	0.19
sum	99.70	99.18	99.43	98.70	99.23	99.21	100.00	99.91	100.83	101.00	101.18	98.44	98.77	99.73	97.84

Region	Kariba												Konbu		
sample	89705-2	TOP-COG	89705-5	89705-6	89705-7	89705-8	89705-4	90803-1	90803-2	90803-3	90803-5	90803-6	891022-2	891022-3	891022-4
SiO2	59.00	53.38	56.80	60.30	56.82	57.68	56.43	52.56	54.72	53.49	54.28	56.51	55.36	63.63	66.38
TiO2	0.64	0.93	0.76	0.68	0.76	0.79	0.76	0.83	0.84	0.84	0.84	0.72	1.21	0.88	0.85
Al2O3	17.24	18.70	17.52	17.58	17.59	18.05	17.87	17.64	18.03	17.76	18.07	17.28	16.95	15.74	14.73
FE2O3	6.45	8.75	6.86	6.05	6.86	6.68	6.96	7.94	7.60	7.84	7.73	6.75	9.97	6.56	5.89
MnO	0.14	0.16	0.14	0.13	0.14	0.13	0.14	0.15	0.15	0.15	0.16	0.14	0.22	0.16	0.16
MgO	3.61	6.03	4.40	2.74	4.41	4.24	4.83	6.27	6.30	6.42	6.23	5.51	2.84	1.70	1.05
CaO	5.98	8.30	7.27	5.12	7.45	6.87	7.40	8.46	8.43	8.44	8.48	7.32	7.61	4.73	3.47
Na2O	2.98	2.51	2.99	3.14	2.93	2.97	2.78	2.93	2.96	2.89	2.99	3.06	3.86	4.38	4.08
K2O	2.42	1.49	2.14	2.86	2.06	2.12	1.97	1.66	1.70	1.68	1.65	2.05	0.77	1.19	1.95
P2O5	0.21	0.21	0.23	0.24	0.22	0.23	0.23	0.30	0.31	0.32	0.31	0.25	0.32	0.26	0.23
sum	98.67	100.46	99.11	98.84	99.24	99.76	99.37	98.74	101.04	99.83	100.74	99.59	99.11	99.23	98.79

Major element compositions by XRF (continued)

Region	Konbu	Yotei													
sample	891024-7	90526-1	90526-2	90526-3	90526-10	90526-17	90526-11	90526-15	90526-14	90526-12	90526-4	90526-8	90526-18	90526-5	90526-19
SiO2	64.92	59.91	59.73	61.42	56.47	64.60	53.98	57.89	62.58	58.58	54.64	55.31	60.18	62.80	57.71
TiO2	0.84	1.04	1.03	0.87	1.15	0.86	1.15	1.01	0.85	1.12	1.11	1.13	0.83	0.85	1.01
Al2O3	16.23	16.85	17.03	17.63	17.66	16.19	17.09	16.84	15.29	16.71	17.42	17.34	16.63	15.92	18.07
FE2O3	5.51	8.44	8.28	6.60	9.67	6.24	10.30	9.23	6.19	9.40	9.91	9.96	6.38	6.46	8.29
MnO	0.16	0.17	0.18	0.17	0.18	0.17	0.18	0.17	0.18	0.18	0.18	0.18	0.17	0.17	0.19
MgO	1.30	2.66	2.62	1.97	3.35	1.49	3.44	2.98	1.31	3.13	3.35	3.41	1.63	1.48	2.27
CaO	4.01	6.57	6.59	6.25	7.53	4.33	7.55	6.85	4.14	6.92	7.57	7.56	5.58	4.34	7.25
Na2O	4.36	3.76	3.86	4.22	3.72	4.90	3.72	3.64	5.02	3.81	3.76	3.80	4.52	5.04	4.12
K2O	1.35	1.28	1.20	1.27	0.93	1.56	0.96	1.15	1.60	1.17	0.95	0.96	1.42	1.59	0.90
P2O5	0.26	0.28	0.32	0.34	0.35	0.29	0.35	0.26	0.24	0.30	0.35	0.36	0.32	0.29	0.38
sum	98.94	100.96	100.84	100.74	101.01	100.63	98.72	100.02	97.40	101.32	99.24	100.01	97.66	98.94	100.19

Region	Yotei	Niseko													
sample	90526-6	89706-1	89706-3	89706-4	89706-2	89704-1	89704-5	89704-2	89704-3	89704-4	N-2	N-7	N-9	N-14	N-16
SiO2	54.21	60.38	54.81	59.27	58.53	58.08	57.63	59.10	60.18	58.85	59.15	63.01	58.69	59.61	54.11
TiO2	0.89	0.81	0.89	0.88	0.87	0.91	0.91	0.88	0.86	0.80	0.81	0.76	0.82	0.77	0.84
Al2O3	18.61	17.53	20.21	18.21	19.05	16.84	16.80	17.22	16.69	17.27	16.87	16.52	17.15	16.61	17.20
FE2O3	8.17	6.94	7.56	6.29	6.73	8.45	8.99	8.91	8.19	8.31	7.59	6.85	8.41	7.95	9.43
MnO	0.16	0.17	0.15	0.16	0.14	0.18	0.17	0.01	0.15	0.15	0.16	0.14	0.15	0.17	0.19
MgO	2.23	2.31	2.31	1.80	1.84	3.18	3.27	2.58	2.70	3.26	4.05	2.70	3.35	3.93	5.91
CaO	8.07	5.60	8.77	6.54	7.48	6.63	6.79	5.20	6.22	6.87	7.11	5.37	6.90	6.98	9.00
Na2O	3.69	3.42	3.26	4.08	3.79	3.31	3.13	3.06	3.35	3.25	3.03	3.37	3.16	3.05	2.26
K2O	1.02	1.58	1.15	1.64	1.30	1.93	1.97	2.11	2.06	1.87	1.63	1.66	1.84	1.50	1.08
P2O5	0.28	0.23	0.25	0.36	0.29	0.20	0.19	0.21	0.21	0.20	0.23	0.15	0.20	0.21	0.18
sum	97.33	98.97	99.36	99.23	100.02	99.71	99.85	99.28	100.61	100.83	100.63	100.53	100.67	100.78	100.20

Major element compositions by XRF (continued)

Region						Washibetu		Tarumai							
sample	N-5	N-6	N-8	N-12	N-17	89601-1	89601-2	90527-1	90527-4	90527-2	90527-3	KA-1	KA-2	KA-3	KA-4
SiO2	57.46	62.17	57.47	62.54	58.68	52.88	55.97	60.50	60.42	58.56	59.59	56.55	58.55	54.92	60.40
TiO2	0.96	0.69	0.88	0.81	0.76	0.76	0.64	0.70	0.70	0.68	0.71	0.70	0.66	0.75	0.65
Al2O3	17.03	16.48	17.49	17.51	17.40	17.54	19.79	16.65	16.78	16.60	16.60	17.26	16.53	16.54	16.16
FE2O3	9.47	6.62	9.18	6.93	8.43	11.15	7.69	8.53	8.49	8.67	8.84	9.89	8.75	10.42	7.99
MnO	0.17	0.14	0.16	0.14	0.17	0.19	0.14	0.16	0.15	0.15	0.16	0.17	0.16	0.18	0.15
MgO	3.74	3.07	3.57	2.15	4.23	4.67	2.22	3.45	3.41	3.30	3.46	3.94	3.48	4.38	3.17
CaO	7.17	5.94	7.26	5.33	7.23	9.70	9.55	7.53	7.58	7.62	7.70	8.59	7.74	8.38	6.92
Na2O	3.07	3.31	2.86	3.52	2.76	2.19	2.74	2.80	2.85	2.87	2.89	2.53	2.82	2.60	2.88
K2O	1.35	1.90	1.68	1.61	1.36	0.40	0.54	0.95	0.95	0.96	0.98	0.68	0.94	0.73	1.17
P2O5	0.18	0.18	0.20	0.24	0.20	0.08	0.11	0.10	0.10	0.10	0.10	0.09	0.10	0.10	0.09
sum	100.60	100.50	100.75	100.78	101.22	99.56	99.39	101.37	101.43	99.51	101.03	100.40	99.73	99.00	99.58

Region	Tarumai		Fuppushi											Eniwa	
sample	KA-5		F10-6-R	F-13	181-R	184	185	187	183	F13-4	F5-2	F12-1	186	En-a-1	En-a-2
SiO2	61.56	0.00	61.04	58.30	63.05	62.69	59.41	60.39	62.01	60.34	60.76	59.83	60.87	62.71	63.16
TiO2	0.63	0.67	0.64	0.74	0.62	0.58	0.68	0.74	0.57	0.68	0.63	0.71	0.70	0.61	0.58
Al2O3	16.21	15.76	16.67	17.10	16.01	15.79	16.87	16.29	15.71	16.35	16.34	16.54	16.47	15.80	16.08
FE2O3	7.45	8.64	7.21	8.26	6.41	6.64	7.76	8.22	6.61	7.56	7.25	7.92	7.79	6.32	6.48
MnO	0.14	0.15	0.14	0.15	0.13	0.14	0.14	0.16	0.13	0.14	0.14	0.16	0.15	0.13	0.13
MgO	2.96	4.16	2.54	2.97	2.18	2.36	2.77	2.92	2.26	2.69	2.48	2.71	2.67	2.15	2.22
CaO	6.68	7.74	6.59	7.27	5.90	5.93	6.93	6.19	5.93	6.70	6.50	6.63	6.19	5.89	5.91
Na2O	3.03	2.42	3.01	3.02	3.15	3.12	3.06	2.57	3.11	2.95	3.09	2.95	2.57	3.25	3.02
K2O	1.23	1.18	1.28	0.93	1.39	1.47	1.13	1.28	1.47	1.25	1.29	1.12	1.13	1.48	1.40
P2O5	0.10	0.08	0.09	0.12	0.09	0.09	0.10	0.08	0.09	0.10	0.10	0.11	0.11	0.10	0.09
sum	99.99	40.80	99.21	98.86	98.93	98.81	98.85	98.84	97.89	98.76	98.58	98.68	98.65	98.44	99.07

Major element compositions by XRF (continued)

Region	Eniwa														
sample	5201	5202	814	821	824	8171	8172	971	972	9292	9302	101	125	126	161
SiO2	58.00	61.76	61.35	55.24	58.98	60.99	61.06	52.27	58.34	60.59	57.39	56.68	58.70	61.20	56.49
TiO2	0.71	0.64	0.62	0.80	0.67	0.66	0.65	0.82	0.64	0.64	0.73	0.72	0.67	0.66	0.76
Al2O3	16.74	15.88	16.17	16.80	16.75	15.73	16.05	16.99	16.53	16.14	16.43	16.69	16.22	16.05	16.66
FE2O3	8.04	6.90	6.88	9.50	7.55	7.61	7.31	9.25	7.56	7.32	8.46	8.16	8.14	7.58	8.33
MnO	0.15	0.14	0.13	0.17	0.14	0.15	0.15	0.16	0.14	0.14	0.16	0.15	0.15	0.14	0.15
MgO	3.27	2.31	2.32	4.17	3.38	2.70	2.57	5.57	3.33	2.76	4.31	3.82	3.53	2.57	3.79
CaO	7.60	6.13	6.30	8.85	7.33	6.34	6.36	9.76	7.30	6.62	7.56	8.03	7.33	6.24	8.03
Na2O	2.70	3.18	3.18	2.66	2.72	3.10	3.11	2.64	2.98	3.04	2.73	2.84	2.86	3.00	2.64
K2O	1.23	1.40	1.38	0.82	1.23	1.28	1.30	0.84	1.19	1.27	1.07	1.12	1.16	1.29	1.13
P2O5	0.11	0.10	0.09	0.10	0.12	0.10	0.10	0.13	0.11	0.10	0.12	0.11	0.11	0.09	0.11
sum	98.55	98.44	98.42	99.11	98.87	98.66	98.66	98.43	98.12	98.62	98.96	98.32	98.87	98.82	98.09

Region	Eniwa										Tokusyunbetsu				Raiba
sample	163	241	248	252	257	272	273	277	302	304	89525-1	890525-2	890525-3	So	890525-4
SiO2	57.19	56.19	57.08	61.01	60.81	60.98	61.16	61.26	56.24	53.85	60.71	59.84	60.87	60.08	59.72
TiO2	0.75	0.73	0.71	0.66	0.68	0.65	0.64	0.65	0.64	0.75	0.62	0.62	0.61	0.62	0.63
Al2O3	16.62	16.43	16.38	16.07	16.07	16.31	16.06	16.04	15.51	17.53	15.41	15.74	15.51	15.78	15.69
FE2O3	8.07	8.90	8.72	7.54	7.62	7.44	7.37	7.56	8.63	8.91	7.73	8.17	7.67	7.93	8.52
MnO	0.15	0.16	0.16	0.15	0.15	0.14	0.15	0.14	0.17	0.16	0.14	0.14	0.13	0.14	0.15
MgO	3.62	4.70	4.53	2.62	2.69	2.55	2.63	2.66	5.83	4.99	3.60	3.98	3.58	3.48	4.10
CaO	7.89	7.98	7.79	6.35	6.45	6.44	6.37	6.29	8.21	9.11	6.92	7.18	6.90	7.14	6.86
Na2O	2.74	2.69	2.68	3.05	3.07	3.06	3.01	2.97	2.57	2.58	2.49	2.36	2.53	2.55	2.26
K2O	1.21	0.97	0.97	1.26	1.24	1.29	1.31	1.30	0.92	0.87	1.36	1.34	1.40	1.31	1.33
P2O5	0.11	0.13	0.11	0.10	0.11	0.09	0.10	0.10	0.10	0.13	0.08	0.07	0.07	0.08	0.07
sum	98.35	98.88	99.13	98.81	98.89	98.95	98.80	98.97	98.82	98.88	99.06	99.44	99.27	99.11	99.33

Major element compositions by XRF (continued)

Region	Raiba			Ko-Izari							Sapporo			Soranuma	
sample	890525-5	89601-3	890525-7	891110-1	891110-2	891110-3	891110-4	891110-5	891110-6	891110-7	891110-8	891110-9	91110-10	S-1	s-3
SiO2	60.64	58.72	58.46	56.72	57.58	57.24	62.10	61.27	61.17	60.60	53.32	55.78	52.60	59.39	60.03
TiO2	0.65	0.65	0.67	0.69	0.70	0.87	0.66	0.66	0.67	0.69	1.06	0.71	0.96	0.73	0.67
Al2O3	16.02	15.94	15.76	16.61	16.42	16.99	16.27	16.21	16.75	16.77	17.94	18.59	20.08	16.34	16.25
FE2O3	8.14	8.63	8.64	9.03	9.34	8.99	7.75	7.89	7.97	8.33	11.45	8.87	9.77	7.85	7.70
MnO	0.14	0.14	0.15	0.15	0.16	0.17	0.14	0.14	0.14	0.14	0.18	0.16	0.18	0.14	0.14
MgO	3.79	4.09	4.16	4.73	4.38	3.76	3.59	3.71	3.25	3.42	4.65	4.18	3.85	2.93	3.01
CaO	5.93	7.53	7.74	8.16	7.95	7.38	6.82	7.09	7.25	7.38	8.75	9.73	10.42	6.02	6.65
Na2O	2.32	2.27	2.42	2.45	2.46	2.62	2.70	2.64	2.73	2.75	2.58	2.22	2.39	2.75	2.91
K2O	1.38	1.24	1.18	1.00	1.00	1.47	1.32	1.25	1.15	1.10	0.67	0.71	0.44	1.49	1.49
P2O5	0.08	0.07	0.08	0.09	0.09	0.13	0.10	0.10	0.09	0.09	0.16	0.11	0.17	0.12	0.11
sum	99.09	99.28	99.26	99.63	100.08	99.62	101.45	100.96	101.17	101.27	100.76	101.06	100.86	97.76	98.96

Region	Soranuma	Akaigawa	Otaru-Maruyama			Teine						Kenashi			
sample	s-4	89706-10	89722-1	89722-2	01	89722-5	89722-6	89722-7	9722-7cg	T5	H2	891028-1	891028-3	891028-4	K1
SiO2	59.46	57.04	59.20	59.99	58.93	58.19	57.60	60.22	54.64	58.23	58.06	61.57	60.81	60.59	58.27
TiO2	0.65	0.81	0.86	0.78	0.74	0.62	0.68	0.63	0.72	0.58	0.69	0.70	0.66	0.66	0.65
Al2O3	16.50	17.82	15.39	15.39	15.55	16.06	17.10	16.82	17.72	16.48	16.37	15.57	15.92	16.43	16.52
FE2O3	7.09	8.49	9.29	8.74	9.08	8.38	7.59	6.98	8.19	7.99	8.07	8.14	7.64	7.82	7.84
MnO	0.13	0.17	0.17	0.16	0.16	0.16	0.15	0.14	0.14	0.15	0.15	0.15	0.15	0.15	0.16
MgO	3.02	3.50	3.48	3.38	3.15	4.39	3.82	3.76	5.40	3.76	3.67	3.34	3.59	3.72	3.65
CaO	7.12	6.42	6.88	6.67	6.81	7.52	6.84	6.78	8.12	7.70	7.26	6.65	6.58	6.99	7.07
Na2O	2.86	2.91	2.70	2.78	2.73	2.41	2.92	2.96	2.29	2.54	2.62	2.66	2.78	2.61	2.60
K2O	1.53	0.96	1.36	1.45	1.33	1.46	1.48	1.55	1.33	1.51	1.41	1.69	1.62	1.50	1.44
P2O5	0.11	0.18	0.11	0.11	0.11	0.10	0.14	0.13	0.13	0.10	0.12	0.10	0.12	0.14	0.13
sum	98.47	98.30	99.44	99.45	98.59	99.29	98.32	99.97	98.68	99.04	98.42	100.57	99.87	100.61	98.33

Major element compositions by XRF (continued)

Region	Kenashi		Byoubu			Amemasu					Asari			Yoichi	Muine
sample	K5	K6	B1	B3	B5	891028-8	891028-9	91028-10	91028-11	91028-12	Am1	891028-5	891028-7	Y1	M1
SiO2	59.48	59.47	55.20	56.45	57.18	63.84	66.89	65.81	66.47	67.33	64.04	51.85	56.61	63.58	61.23
TiO2	0.64	0.62	0.79	0.79	0.69	0.63	0.54	0.56	0.57	0.57	0.54	0.72	0.63	0.60	0.67
Al2O3	16.34	16.40	16.50	16.46	16.92	15.57	15.48	15.51	15.65	15.85	15.05	19.03	16.30	14.98	15.29
FE2O3	7.63	7.50	8.26	8.22	8.14	6.92	5.88	6.33	6.36	6.27	6.07	9.90	8.67	6.58	7.70
MnO	0.15	0.15	0.15	0.15	0.15	0.12	0.10	0.11	0.11	0.10	0.12	0.18	0.16	0.13	0.11
MgO	3.22	3.23	4.71	4.65	3.93	3.08	2.07	2.22	1.87	1.96	1.97	5.48	5.88	2.08	2.72
CaO	6.27	6.47	6.98	7.86	7.62	5.29	4.87	4.67	4.05	4.19	4.46	11.01	9.44	3.69	5.85
Na2O	2.69	2.73	2.50	2.72	2.90	2.86	3.16	3.07	3.04	3.02	3.04	2.14	2.12	2.85	2.68
K2O	1.58	1.52	1.26	1.32	1.35	1.94	2.04	2.03	2.10	2.08	2.11	0.27	0.86	2.32	1.94
P2O5	0.13	0.13	0.15	0.14	0.14	0.12	0.10	0.10	0.10	0.10	0.10	0.10	0.08	0.11	0.10
sum	98.13	98.22	96.50	98.76	99.02	100.37	101.13	100.41	100.32	101.47	97.50	100.68	100.75	96.92	98.29

Region	Muine			Syakotan		Shokanbetsu									
sample	91028-13	91028-14	91028-15	89624-1	89624-4	ovd	s2	e2	m4	s1	ev-a	e1	ev-b	e3	m2
SiO2	63.72	62.81	62.51	58.70	59.32	62.66	61.82	52.20	58.47	59.10	57.21	54.95	57.20	53.25	54.20
TiO2	0.66	0.70	0.68	0.72	0.68	0.73	0.66	0.96	0.94	0.86	0.87	0.92	0.86	0.96	0.91
Al2O3	15.19	15.63	15.46	16.71	17.83	17.69	17.05	16.24	17.52	17.79	17.53	16.58	17.60	17.27	16.14
FE2O3	7.48	7.68	8.09	6.93	6.79	5.71	6.00	8.80	7.15	7.23	7.97	7.95	7.94	8.77	8.30
MnO	0.12	0.13	0.13	0.14	0.14	0.11	0.13	0.15	0.13	0.15	0.14	0.22	0.15	0.15	0.15
MgO	2.96	3.09	3.13	3.45	3.55	3.08	2.94	8.18	3.54	3.05	5.21	5.46	5.12	7.20	7.34
CaO	5.90	6.67	6.45	6.95	5.71	5.60	6.24	8.90	7.72	6.93	7.53	9.34	7.76	8.58	8.59
Na2O	2.75	2.63	2.72	3.08	2.91	3.26	3.38	2.86	3.28	3.17	2.82	3.00	2.80	2.85	2.81
K2O	2.04	1.79	1.82	1.97	1.76	1.68	2.05	1.38	1.72	1.91	1.41	1.71	1.38	1.34	1.63
P2O5	0.09	0.10	0.09	0.20	0.17	0.20	0.19	0.20	0.21	0.22	0.21	0.23	0.20	0.24	0.20
sum	100.91	101.23	101.08	98.85	98.86	100.72	100.46	99.87	100.68	100.41	100.90	100.36	101.01	100.61	100.27

Major element compositions by XRF (continued)

Region	Shokanbetsu							Irumukeppu				
sample	e4	e-b-2	eve	ev-c	m1	sd	m3	89602-1	89602-2	89602-3	89602-4	89602-5
SiO2	53.51	58.46	57.66	56.81	59.91	64.26	57.32	57.27	58.34	57.55	54.09	55.36
TiO2	0.98	0.76	0.84	0.86	0.81	0.61	0.85	0.81	0.73	0.74	0.95	0.90
Al2O3	16.94	17.59	17.23	17.20	17.49	16.80	18.28	16.96	17.62	17.70	17.84	18.08
FE2O3	8.50	7.39	7.54	8.09	7.25	6.03	6.80	7.27	6.82	6.99	8.46	8.02
MnO	0.15	0.14	0.15	0.15	0.12	0.12	0.13	0.14	0.13	0.14	0.16	0.15
MgO	6.97	3.87	5.39	5.39	3.44	2.25	4.60	4.63	3.37	3.84	4.74	4.22
CaO	9.16	7.51	7.84	7.87	6.81	4.67	7.94	7.31	6.92	6.78	8.03	7.37
Na2O	2.76	3.01	2.95	2.80	3.31	3.11	3.32	3.30	3.40	3.29	3.13	3.17
K2O	1.53	1.58	1.48	1.33	1.56	2.59	1.04	1.78	1.71	1.59	1.55	1.67
P2O5	0.23	0.21	0.19	0.19	0.21	0.12	0.19	0.20	0.21	0.20	0.19	0.18
sum	100.73	100.52	101.27	100.69	100.91	100.56	100.47	99.67	99.25	98.82	99.14	99.12

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