Bulk Rock Chemistry of the Volcanic Rocks of Goshikidai and Adjacent Areas, Northeast Shikoku, Japan

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Bulk Rock Chemistry of the Volcanic Rocks of Goshikidai and Adjacent Areas, northeast Shikoku, Japan

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Abstract Bulk rock analyses were carried out on 98 volcanic rock samples of Goshikidai and adjacent areas as to major and some trace elements such as Ni, Cr, Sr, Rb, Zr, and Y. It is shown that basalt, high-magnesian andesite, low-magnesian andesite, dacite and rhyolite of the area show compositional gradation. The volcanic rocks possess extreme calc-alkalic features and are characterized by the rapid decrease of iron against increase of SiO_2 content, rather high Mg/Fe, Cr/Mg and Ni/Mg ratios, high Rb/Sr ratio, and low K/Rb ratio compared with the common Quaternary volcanic rocks of island arcs and continental margins.

1. Introduction

The Tertiary volcanic rocks of Goshikidai and adjacent areas in northeast Shikoku consist of basalt, andesite, dacite and rhyolite suite of calc-alkalic rocks. Major element analyses of these volcanic rocks hitherto been published include those of M. Sato (1936a, 1936b, N = 12 : the number of analyses, the same as follows), Yamaguchi (1958, N=9, 1964, N=5), Ujike (1972, N=54), and Henmi et al. (1976, N=22). As to trace elements, Henmi et al. reported the concentration of Ni, Co, Ba and Sr of the volcanic rocks of Goshikidai. In this report, I present 98 bulk rock analyses for major element and some trace elements such as Ni, Cr, Sr, Rb, Y and Zr. The petrogenesis of the volcanic rocks will be discussed in a separate paper.

2. Analytical method

Major element analyses were carried out by either wet chemical method (performed by Mr. H. Haramura), or electronprobe microanalyses of fused glass. The glass beads were prepared according to the procedures of Fukuyama and Sakuyama (1977), or of Nicholls (1974). Some of dacite and rhyolite were analyzed by the method of Mori et al. (1971). Data reduction of the electronprobe microanalyses was after the method of Bence and Albee

(1968) using the correction factors of Albee and Ray (1970). The reliability of the obtained data was checked by the reproducibility of the recommended values of the standard samples as shown in Table 1. It is noted that the reproducibility of the analyzed samples may be better than that of JB-1, because the powder of JB-1 was much coaser grained than other samples, which resulted in the heterogeniety of the glass of JB-1. Analyses of Zr, Ni, Cr, Rb and Sr were performed by X-ray fluorescence equipment using JB-1, JG-1, W-1, PCC-1 and GSP-1 as internal standards after the method of Nakagawa (1980). The reproducibility of the recommended values of these reference standards are as follows: Cr ±6ppm, Ni ±3ppm, Zr ±9ppm, Y±2ppm, Sr ±9ppm and Rb ±3ppm (Nakagawa 1980).

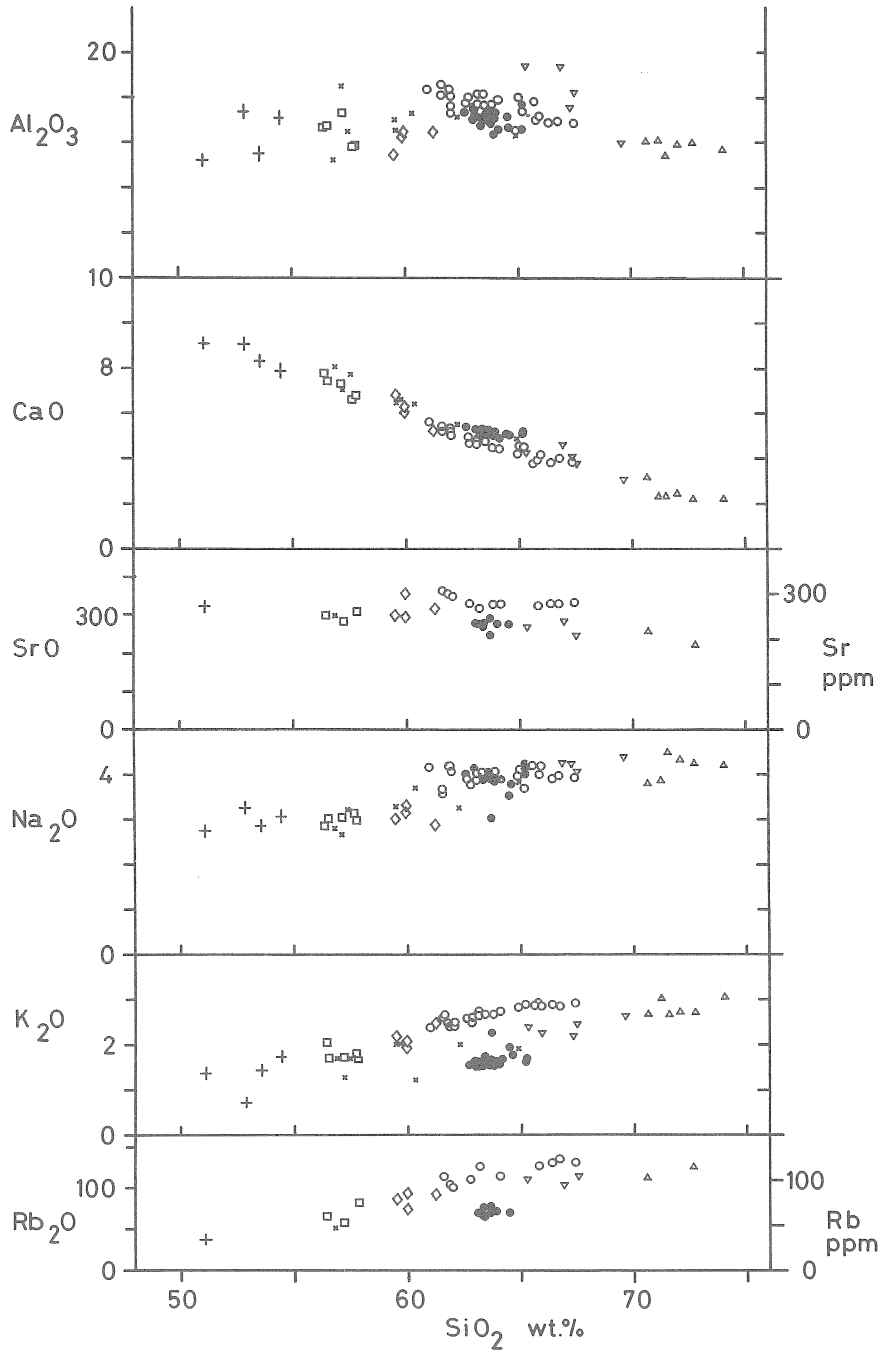
3. Analytical result

Bulk rock chemical composition is shown in Table 2, and plotted in SiO_2 variation diagram (Figure 1). Compositional relations of alkali-iron-magnesium (Figure 2), K_2O-Rb (Figure 3), Rb-Sr (Figure 4), FeO-MgO (Figure 5), Cr_2O_3-MgO (Figure 6), and NiO-MgO (Figure 7) are also illustrated. In the followings, I mention about general compositional characteristics of the rocks of Goshikidai and adjacent areas, and also refer to the compositional relations among volcanic rock types of Goshikidai area.

As a whole, the volcanic rocks conform rather simple compositional variation in the SiO_2 variation diagram (Figure 1). CaO, TiO_2, FeO, MnO, MgO, NiO, and Cr_2O_3 steadily decrease, while Na_2O, K_2O and Rb monotonously increase as SiO_2 content increases. Al_2O_3, Sr, and Zr show concentration maximum in the intermediate SiO_2 content. Peacock's alkali-lime index is ca. 61 for high-K andesites, while it is ca. 63 for low-K andesites. K_{55} and K_{60} of high-K andesites are 1.6 and 2,1, respectively. The volcanic rock suite is also characterized by the absence of iron enrichment. Figure 2 show the Na_2O+K_2O-FeO*-MgO relation. Compared with the compositions of Quaternary volcanic rocks of island arcs and continental margins, the volcanic rocks of Goshikidai and adjacent areas show low FeO concentration. Only the calc-alkalic volcanic rocks of Mt. Shasta have comparably low FeO concentration (Smith and Carmichael 1968). In this respect, the volcanic rock suite of Goshikidai can be regarded as the extremity of calc-alkalic volcanic rock series.

The K/Rb ratio ranges from 180 to 320, mostly within 180-250, which is among the lowest values of the volcanic rocks of island arc and continental margins. Because Sr content is almost constant, the variation of Rb/Sr ratio reflect the variation of Rb concentration. The Rb/Sr ratio varies from 0.13 to 0.60, mostly concentrating about 0.3, near the average crustal composition. (Figure 4).

Figure 5 through 7 demonstrate that the volcanic rocks of Goshikidai area delineate rather linear variations as to MgO, FeO, NiO and Cr_2O_3 contents, which markedly differs from the non-linear compositional relations of Quaternary volcanic rocks of island-arcs and continental margins (Figure 6 and 7), ocean-floor basalts, and intraplate volcanic rocks.



20
10
8
0
300
0
4
0
2
0
100
0
Al_2O_3
CaO
SrO
Na_2O
K_2O
Rb_2O
300
Sr
ppm
0
100
Rb
ppm
0
50
60
70
SiO_2 wt.%

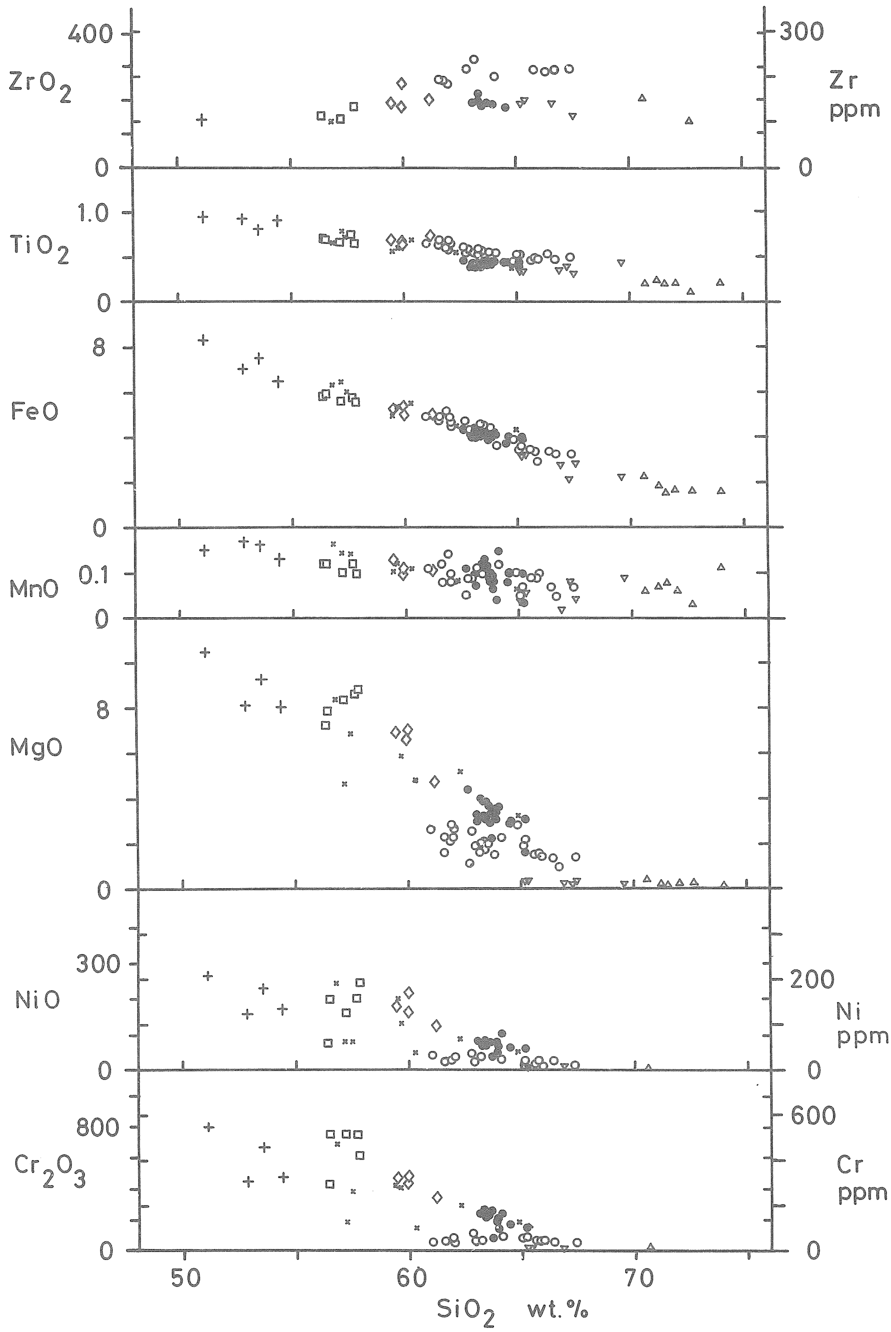


Figure 1 SiO_2 variation diagram. Symbols are common for Figure 1 through 7. Volcanic rocks of Goshikidai mass; square: olivine-phyric andesite, diamond: orthopyroxene-phyric andesite, solid circle: low-K sparsely-phyric andesite, open circle: high-K sparsely-phyric andesite, reverse triangle: dacite, normal triangle: rhyolite. Volcanic rocks of other volcanic mass; normal cross: basalt, oblique cross: andesite.

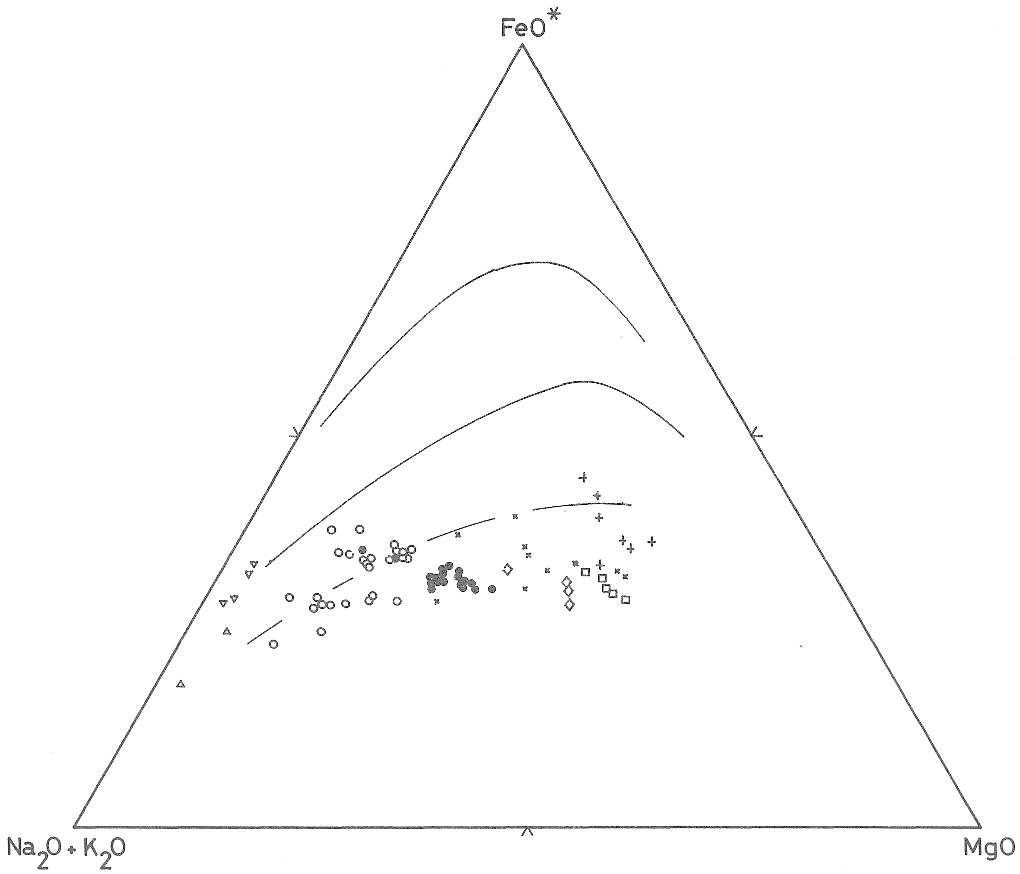


Figure 2 $Na_2O+K_2O-FeO^*-MgO$ diagram. Compositional fields between the upper 2 and the lower 2 curves are those of pigeonitic and hypersthenic rock series of Izu Hakone region (Kuno 1954).

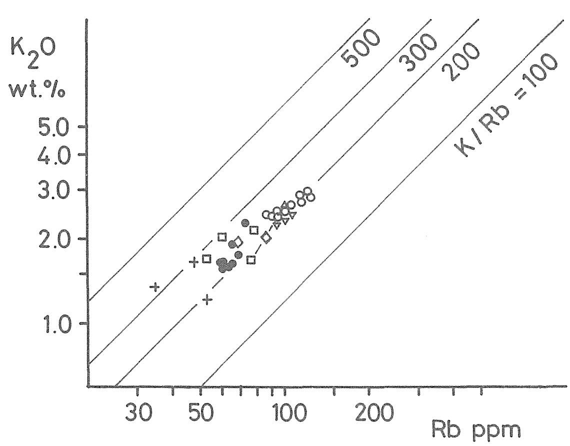


Figure 3 K_2O-Rb relation.

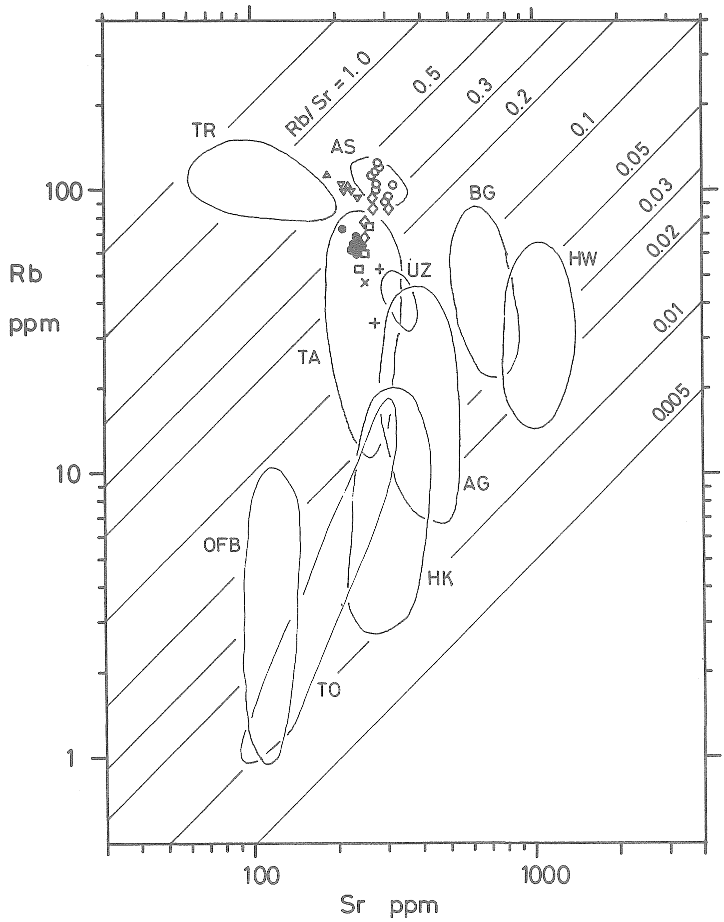


Figure 4 Rb-Sr relation. Letters attached to each compositional field denotes, OFB : ocean floor basalt (Kay et al. 1970), HW : Hawaiian tholeiites, BG : Bougainville islands (Taylor et al. 1968), TO : Tonga islands (Ewart et al. 1973), TA : Taupo andesites, TR : Taupo rhyolites (Ewart and Stipp 1968), HK : Hakone volcano, AG : Amagi volcano, UZ : Unzen volcano, AS : Aso volcano (Kurasawa 1979).

Each symbol in Figures 1 through 7 represents each rock type. The range of SiO_2 concentration of each rock type of Goshikidai is: olivine-phyric andesite 55-58 wt.%, orthopyroxene-phyric andesite 59-62 wt.%, low-K sparsely-phyric andesite 62-66 wt.%, high-K sparsely-phyric andesite 61-68 wt.%, dacite 65-70 wt.%, and rhyolite 70-74 wt.%. It is noted that high-K sparsely-phyric andesite can be further divided into high FeO/MgO and low FeO/MgO subtypes as shown in Figures 2 and 5. SiO_2 content of high and low FeO/MgO subtypes are 61-64 and 64-68 wt.%, respectively.

Among andesites of Goshikidai, olivine-phyric andesite, orthopyroxene-phyric andesite and high-K sparsely-phyric andsite show compositional gradation. These

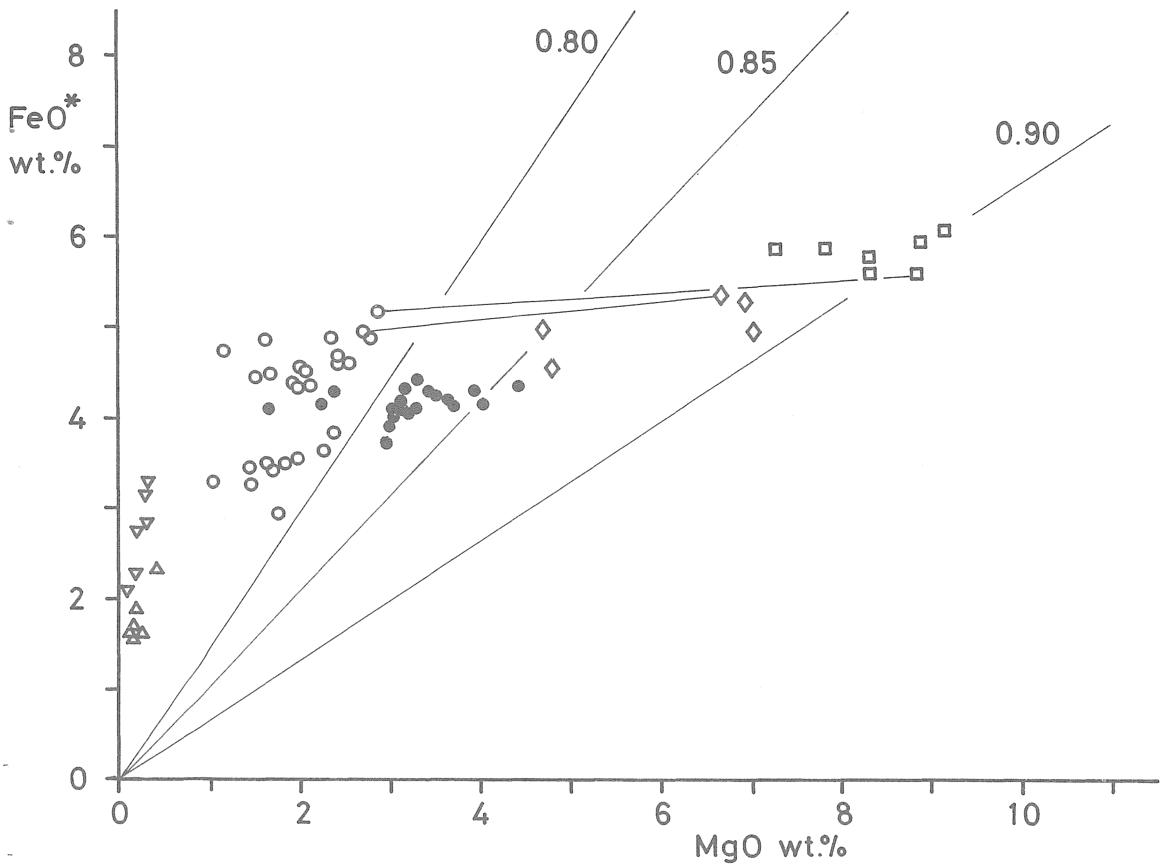


Figure 5 MgO-FeO* diagram. Tie lines show the compositional relations of composite lavas. Straight lines through the origin indicate liquid composition in partition equilibrium with olivine of each Mg/(Mg+Fe) ratio (partition coefficient of 0.3, and oxidiation index of 0.1 of liquid are assumed).

andesites compose the lava flows-II, -III, and IV of Goshikidai. The lava flow- I is composed exclusively of low-K sparsely-phyric andesite. Compared with the high-K sparsely-phyric andesite, the low-K sparsely-phyric andesite have lower Al, Sr, K, Rb, Zr and Ti and higher Ca, Mg, Ni and Cr abundances. Figure 3 shows that both the high-K and low-K sparsely-phyric andesites have virtually the same K/Rb ratio. Dacite and rhyolite show slightly different compositional trend from andesites of Goshikidai, especially recognized in Mg, Ni, Cr, K and Rb versus SiO_2 diagrams (Figure 1).

Acknowledgements

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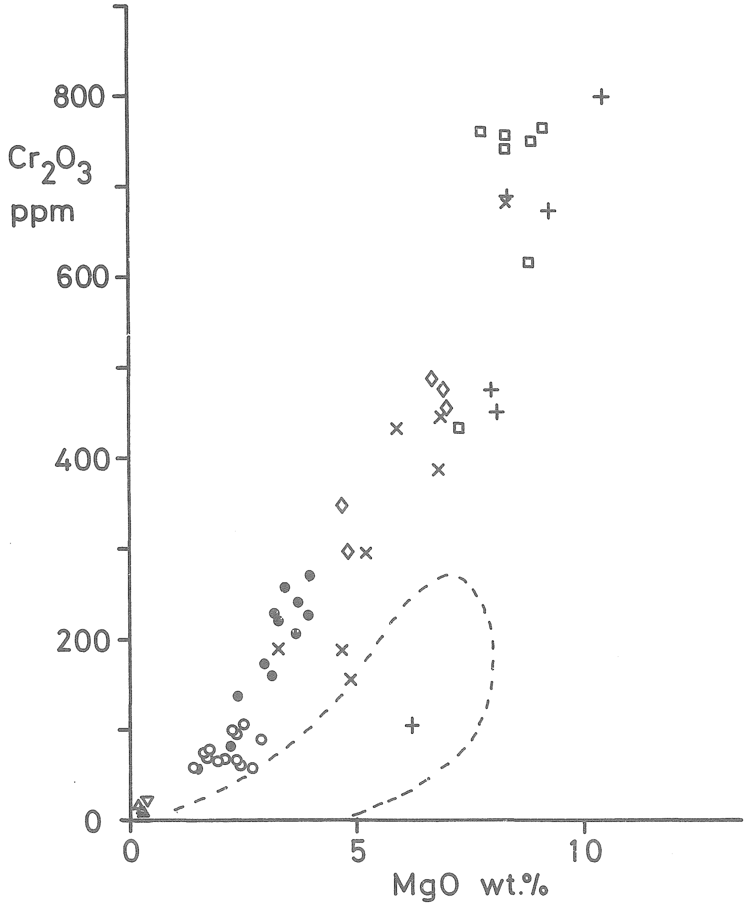

Figure 6 Cr_2O_3-MgO diagram. Dashed line show the compositional field of Quaternay volcanic rocks of island arcs. (Data sources are : Ewart et al. 1968, 1973, Taylor et al. 1968, Kurasawa 1959, Ando 1971, Togashi 1977).

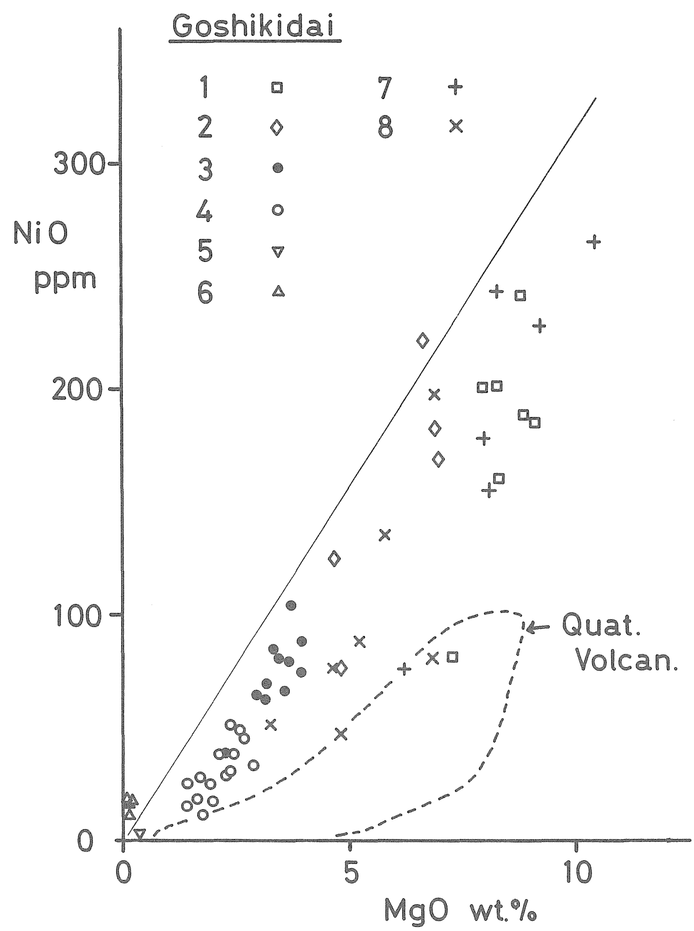

Figure 7 NiO-MgO diagram. Data source is the same as in Figure 6.

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Description of samples

Goshikidai

1. olivine-phyric andesite

#101 lava flow-II, Kamitani (1), 133°55.59′E, 34°19.09′N, 69073122.
#102 lava flow-II, Kamitani (2), 133°55.59′E, 34°19.09′N, 72010705.
#103 lava flow-II, Yamahi lower quarry, 133°55.64′E, 34°18.48′N, 78060107.
#104 lava flow-II, Yamahi middle quarry, 133°55.84′E, 34°18.42′N, 78060109.
#105 lava flow-III, Yamahi upper quarry, 133°55.79′E, 34°18.55′N, 78060112b.

2. orthopyroxene-phyric andesite

#106 lava flow-III, Eboshiyama south quarry, 133°55.42′E, 34°18.40′N, 72010614b.
#107 lava flow-III, Eboshiyama northwest quarry, 133°55.36′E, 34°18.44′N, 78060315a.
#108 lava flow-III, Kuratani-ike S., 133°55.63′E, 34.19.35′N, 80032107.
#109 neck, Peak-176, Higashioku, 133°57.27′E, 34°18.50′N, 80032204.
#110 lava flow-III, Shiramine 290m, Bus stop, 133°55.44′E, 34°19.88′N, 80032103.

3. low-K sparsely-phyric andesite

#111 lava flow-I, Negoroji Route 225m ASL, 133°57.82′E, 34°21.51′N, 69072305.
#112 lava flow-I, Oogoshi Route 206m ASL, 133°55.24′E, 34°21.51′N, 80031801.
#113 lava flow-I, Oogoshi Route 248m ASL, 133°55.37′E, 34°21.51′N, 80031804.
#114 lava flow-I, Oogoshi Route 255m ASL, 133°55.37′E, 34°21.48′N, 80031803.
#115 lava flow-I, Oosakiyama Route 118m ASL, 133°55.85′E, 34°22.77′N, 80031906.
#116 lava flow-I, Oosakiyama Route 130m ASL, 133°55.87′E, 34°22.71′N, 80031907.
#117 lava flow-I, Oosakiyama Route 165m ASL, 133°55.89′E, 34°22.62′N, 80031908.
#118 lava flow-I, Oosakiyama Route 188m ASL, 133°55.91′E, 34°22,54′N, 72010605.
#119 lava flow-I, Oosakiyama Route 213m ASL, 133°55.77′E, 34°22.48′N, 80031911.
#120 lava flow-I, Oosakihana lookout, 133°55.86′E, 34°23.10′N, 80031909.
#121 lava flow-I, Konomine 180m ASL, 133°57.47′E, 34°22.11′N, 80032201.
#122 lava flow-I, Kuromine, 133°56.57′E, 34°21.67′N, 68070914.
#123 lava flow-I, Kamewari-ike 250m ASL, 133°56.49′E, 34°21.17′N, 80031903.
#124 lava flow-I, Kamewari-ike W, 227m ASL, 133°56.54′E, 34°21.19′N, 80031904.
#125 lava flow-I, Negoroji Route 215m ASL, 133°57.83′E, 34°20.75′N, 80032004.
#126 lava flow-I, Negoroji Route 225m ASL, 133°57.82′E, 34°20.67′N, 80032005.
#127 lava flow-I, Negoroji Route 315m ASL, 133°57.95′E, 34°20.47′N, 80032006.
#128 lava flow-I, Negoroji Route 333m ASL, 133°57.88′E, 34°20.54′N, 800322008.
#129 lava flow-I, Oohirayama E, 355m ASL, 133°57.48′E, 34°19.58′N, 78090706.
#130 lava flow-I, Oohirayama E, 362m ASL, 133°57.48′E, 34°19.60′N, 78090705.
#131 lava flow-I, Oohirayama E, 380m ASL, 133°57.48′E, 34°19.63′N, 78090704.
#132 lava flow-I, Oomigawa 275m ASL, 133°56.87′E, 34°19.69′N, 800322003.

4. High-K sparsely-phyric andesite

#133 lava flow-III, Mine-ike W, 100m ASL, 133°53.85′E, 34°21.76′N, 80032111.
#134 lava flow-III, Mine-ike W, 173m ASL, 133°53.86′E, 34°21.84′N, 80032109.
#135 lava flow-III, Mine-ike S, 247m ASL, 133°54.00′E, 34°21.78′N, 80032108.
#136 lava flow-III, Kamanoha Pass E, 133°54.88′E, 34°21.36′N, 80031811b.
#137 lava flow-III, Kamanoha Pass E, 133°54.88′E, 34°21.36′N, 80031811a.
#138 lava flow-III, Mayeyama 307m ASL, 133°54.69′E, 34°21.33′N, 80031813.
#139 lava flow-III, Mayeyama 335m ASL, 133°54.59′E, 34°21.35′N, 80031814.

#140 lava flow-III, Kitamine, 133°55.94′E, 34°20.76′N, 80032201.
#141 lava flow-III, Amidagoe E, 133°56.82′E, 34°20.57′N, 72010607.
#142 lava flow-III, Aomine, 410m ASL, 133°57.68′E, 34°20.35′N, 80032009.
#143 lava flow-III, Oohirayama E, 418m ASL, 133°57.38′E, 34°19.54′N, 78090703.
#144 lava flow-III, Ipponmatsu E, 133°57.09′E, 34°19.29′N, 72010611.
#145 lava flow-III, Yamahi upper quarry, 133°55.81′E, 34°18.57′N, 78060112a.
#146 lava flow-III, Eboshiyama south quarry, 133°55.42′E, 34°18.40′N, 72010614a.
#147 lava flow-IV, Renkojiyama, 133°56.09′E, 34°18.23′N, 78053102.
#148 lava flow-IV, Renkojiyama quarry, sanukite, 133°56.29′E, 34°18.10′N, 68032915.
#149 lava flow-III, Shiramine 220m ASL, 133°55.58′E, 34°19.88′N, 80032106.
#150 lava flow-III, Shiramine 285m ASL, 133°55.49′E, 34°19.88′N, 80032104.
#151 lava flow-IV, Shiramine Route 303m ASL, sanukite, 133°55.50′D, 34°19.75′N, 80032102.
#152 lava flow-IV, Shiramine Route 370m ASL, 133°56.02′E, 34°19.54′N, 80032101.
#153 lava flow-IV, Kokubudai S, lava base, 133°56.71′E, 34°18.74′N, 69080138c.
#154 lava flow-IV, Kokubudai S, banded lava, sanukite band, 133°56.64′E, 34°18.76′N, 690729a.
#155 lava flow-IV, Kokubudai S, banded lava, crystalline band, 133°56.64′E, 34°18.76′N, 680131.
#156 lava flow-IV, Kokubudai S, 340m ASL, 133°56.58′E, 34°18.77′N, 80032115.
#157 lava flow-IV, Kokubudai S, 373m ASL, 133°56.56′E, 34°18.78′N, 80032114.
#158 lava flow-IV, Kokubudai top, 133°56.17′E, 34°19.54′N, 68032501.

5. dacite

#159 massive tuff breccia, Higashioku, 133°57.10′E, 34°18.81′N, 72101336.
#160 brecciated lava, Denroku-ike S, 133°56.21′E, 34°20.32′N, 72101204.
#161 massive tuff breccia, Higashioku, 133°57.13′E, 34°18.80′N, 72010801b
#162 massive lava, Nakamura N, 133°55.51′E, 34°20.61′N, 71042809.
#163 massive tuff breccia, Higashioku, 133°57.13′E, 34°18.80′N, 72010801a.
#164 stratified tuff breccia, Higashioku, 133°57.23′E, 34°18.90′N, 68123103b-2.

6. rhyolite

#165 tuff breccia, Negoroji route, 133°57.63′E, 34°21.19′N, 72101410.
#166 tuff breccia, Kamitani S, gray rhyolite fragment, 133°55.20′E, 34°19.15′N, 72010707b.
#167 tuff breccia, Kamitani S, glassy rhyolite, 133°55.20′E, 34°19.15′N, 72010707a.
#168 stratified tuff, Higashioku, glassy rhyolite, 133°57.13′E, 34°18.80′N, 72010801.
#169 tuff breccia, Kamitani N, glassy rhyolite, 133°55.24′E, 34°19.45′N, 68040337.
#170 tuff, Akabana coast, 133°56.48′E, 34°22.49′N.

Other volcanic masses

7. basalt

#171 massive lava, Shirahamayama mass, Kuzurehana quarry, 134°13.72′E, 34°25.35′N, 69080305.
#172 massive lava, Aonoyama summit, 133°49.50′E, 34°10.85′N, 69071907.
#173 massive lava, Sanagishima mass, 133°33.77′E, 34°20.20′N, 78011706.
#174 lava intrusive, Marugame Castle mass, 133°48.13′E, 34°16.92′N.
#175 lava intrusive, Aji Peak-211, 134°09.10′E, 34°22.15′N, 78011506b.
#176 dike, Marugame Castle mass, 133°48.13′E, 34°16.92′N, 69041302.
#177 neck, Yakushiyama mass, 133°59.95′E, 34°20.32′N, 70081903.

8. ,andesite

#178 massive lava flow, Hiyama mass, middle quarry, 134°15.19′E, 34°16.40′N, 78060212.
#179 neck, Iwashiosan mass, 134°02.18′E, 34°20.07′N, 72100903a.

#180 neck, Iinoyama mass, 225m ASL, 133°50.69′E, 34°16.27′N, 78011602.
#181 dike, Marugame Castle mass, 133°48.13′E, 34°16.92′N, 78011601-3.
#182 neck, Kasayama mass, 133°51.80′E, 34°18.39′N, 68080658.
#183 neck (?), Tsukumoyama mass, 133°34.31′E, 34°04.47′N, 70041406.
#184 pyroclastic dike, Nio Pass mass, 133°35.03′E, 34°10.64′N, 75010601a.
#185 massive lava flow, Ootozan mass, lava base, 134°11.34′E, 34°29.62′N, 69112613a.
#186 massive lava flow, Yashima mass, lava base, 134°06.48′E, 34°21.59′N. 69072533
#187 massive lava flow, Amatakiyama mass, 134°14.48′E, 34°16.74′N, 69072604.
#188 massive lava flow, Kiyama mass, 133°53.78′E, 34°17.84′N, 80032202.
#189 neck, Iinoyama mass, 133°50.98′E, 34°16.36′N, 78011609.
#190 massive lava flow, Yokoyama mass, 133°54.23′E, 34°16.17′N, 78011611.
#191 massive lava flow, Shiundesan summit, 133°32.97′E, 34°12.21′N, 70041410.
#192 massive lava flow, Yashima mass, 134°06.40′E, 34°21.35′N, 80060201.
#193 massive lava flow, Hiyama mass, lower quarry, 134°15.13′E, 34°16.40′N, 78060218.
#194 massive lava dome, Hiyama mass, upper quarry, 134°15.17′E, 34°16.45′N, 78060214a.
#195 massive lava flow, Iwashiosan mass, summit, 134°01.55′E, 34°20.10′N, 78060317.

9. dacite

#196 intrusive breccia, Aji Peak-211 mass, 134°09.10′E, 34°22.15′N, 78011506d.
#197 massive lava flow, Washinoyama mass, north quarry, 133°56.98′E, 34°16.60′N, 68080320.
#198 massive lava flow, Yurayama mass, south quarry, 134°05.34′E, 34°16.86′N, 69111307.

Table 1 Reproducibility of JB-1 analyses

	1	σ*	2	σ*	3	σ*	σ**	recommended*** value
SiO_2	53.98	.65	53.26	.49	53.10	.58	.15	53.26
TiO_2	1.26	.09	1.34	.05	1.35	.04	.02	1.38
Al_2O_3	15.26	.62	14.42	.50	14.56	.75	.07	14.80
FeO	8.06	.19	8.11	.43	7.88	.27	.05	8.26
MnO	0.17	.01	0.23	.07	0.14	.01	.01	0.15
MgO	7.40	.81	8.32	.43	8.04	1.94	.04	7.87
CaO	9.53	.05	9.57	.14	9.68	.16	.04	9.45
Na_2O	2.72	.07	2.72	.08	2.81	.12	.02	2.86
K_2O	1.41	.07	1.44	.07	1.48	.08	.02	1.46
P_2O_5	—	—	—	—	—	—	—	0.27
total	99.8		99.4		99.0			99.99

* Standard deviation for 5 measurements

** Counting statistical error

*** Recalculated volatile-free, Ando et al.(1974).

Table 2 Bulk rock composition

#	101*	102	103	104	105	106	107	108	109	110	111*	112	113
SiO_2	55.37	57.22	57.68	56.44	57.83	59.94	59.93	59.48	61.59	61.25	62.62	63.89	63.95
TiO_2	0.66	0.67	0.75	0.69	0.64	0.65	0.66	0.70	0.74	0.73	0.42	0.45	0.45
Al_2O_3	16.40	16.28	15.78	16.72	15.92	16.42	16.37	15.51	15.91	16.43	17.37	16.38	17.10
Fe_2O_3	2.82										2.33		
FeO	3.25	5.60	5.79	5.88	5.60	5.39	4.98	5.28	4.57	4.98	2.04	4.20	4.32
MnO	0.12	0.10	0.12	0.12	0.10	0.11	0.10	0.13	0.10	0.11	0.10	0.10	0.08
MgO	7.69	8.34	8.33	7.27	8.86	6.67	7.02	6.93	4.81	4.69	4.01	3.67	3.16
CaO	7.30	7.30	6.67	7.78	6.83	6.04	6.11	6.38	6.19	5.65	4.92	5.12	5.14
Na_2O	2.96	3.04	3.16	2.87	2.98	3.13	3.29	3.02	3.26	2.91	3.94	3.95	3.93
K_2O	1.71	1.73	1.79	2.06	1.71	1.95	2.04	2.19	2.53	2.47	1.59	1.63	1.64
P_2O_5	0.00										0.08		
$H_2O(+)$	1.60										0.65		
$H_2O(-)$	0.40										0.45		
Cr	520	516	507	295	421	334	312	325	203	238		140	155
Ni	157	126	158	63	189	174	132	144	60	98		62	54
Zr		106		112	131	133	186	143	114	149			138
Y		18		16	18	14	15	16	20	25			19
Sr		241		252	263	253	303	255	270	270			235
Rb		53		60	76	68	87	78	95	87			66
total	100.28	100.3	100.1	99.8	100.5	100.3	100.5	99.6	99.7	99.2	100.52	99.4	99.8
qz	3.7	4.2	4.9	3.9	5.1	9.7	8.3	8.9	12.4	14.2	15.2	16.8	17.1
or	10.3	10.2	10.6	12.2	10.1	11.5	12.0	13.0	15.0	14.7	9.5	9.7	9.7
ab	25.5	25.6	26.7	24.3	25.1	26.4	27.7	25.6	27.6	24.8	33.6	33.6	33.3
an	26.9	25.6	23.5	26.7	24.9	24.9	23.7	22.4	21.4	24.6	24.1	22.3	24.2
c											0.4		
wo	4.2	4.4	4.0	5.0	3.7	2.1	2.7	3.9	3.9	1.5		1.4	0.6
en	19.5	20.7	20.7	18.1	21.9	16.5	17.4	17.3	12.0	11.8	10.1	9.2	7.9
fs	6.7	6.3	6.4	6.7	6.3	6.0	5.5	5.9	4.9	5.4	4.9	4.9	5.0
il	1.3	1.3	1.4	1.3	1.2	1.2	1.3	1.3	1.5	1.4	0.8	0.9	0.9
mt**	1.9	1.8	1.9	1.9	1.8	1.7	1.6	1.7	1.4	1.6	1.3	1.4	1.4
ap	0.0										0.2		
Mg/(Mg+Fe)**	0.75	0.73	0.72	0.69	0.74	0.69	0.72	0.70	0.65	0.63	0.68	0.61	0.57

* wet chemical analyses by Mr. H.Haramura.
** Fe^{3+}/(total Fe) was assumed 0.1 in calculating C.I.P.W. norm and Mg/(Mg+Fe) ratio.

Table 2 (continued)

#	114	115	116	117	118	119	120	121	122	123	124	125	126
SiO_2	63.69	64.59	63.96	63.73	63.61	63.77	64.51	63.46	62.67	63.81	65.17	63.08	63.37
TiO_2	0.47	0.44	0.48	0.45	0.47	0.49	0.44	0.45	0.45	0.43	0.47	0.43	0.43
Al_2O_3	17.35	16.63	17.24	17.18	16.96	16.79	17.15	17.12	17.35	17.03	16.56	17.23	16.73
FeO	4.31	4.02	4.30	3.92	4.18	4.26	3.72	4.31	4.37	4.06	4.08	4.10	4.19
MnO	0.10	0.10	0.04	0.11	0.12	0.06	0.08	0.13	0.11	0.09	0.10	0.07	0.12
MgO	3.43	3.04	2.36	3.00	3.69	3.52	2.95	3.94	4.43	3.21	3.14	3.02	3.97
CaO	4.55	5.02	5.22	4.98	5.31	5.21	5.07	5.15	5.38	5.05	5.03	5.10	5.15
Na_2O	3.07	3.79	4.00	3.97	4.00	3.94	3.54	3.92	3.94	4.04	4.04	4.11	3.89
K_2O	2.28	1.76	1.60	1.62	1.54	1.57	1.93	1.64	1.54	1.60	1.63	1.64	1.64
Cr	175		193				118	154			109		185
Ni	63		40				50	58			49		69
Zr	142						133	137					144
Y							16	17					19
Sr	208						232	238					227
Rb	73						65	60					62
total	99.3	99.4	99.2	99.0	99.9	99.6	99.4	100.1	100.2	99.3	100.2	98.8	99.5
qz	20.1	18.9	18.1	17.5	15.9	16.8	19.5	15.4	13.7	16.9	18.4	15.9	15.8
or	13.6	10.5	9.5	9.7	9.1	9.3	11.5	9.7	9.1	9.5	9.6	9.8	9.7
ab	26.2	32.2	34.1	33.9	33.9	33.4	30.1	33.1	33.2	34.4	34.1	35.2	33.1
an	22.7	23.3	24.5	24.5	23.8	23.6	25.3	24.2	25.0	23.8	22.2	24.0	23.4
c	1.6						0.0						
wo		0.7	0.7	0.2	1.1	1.0		0.5	0.7	0.6	1.1	0.7	0.9
en	8.6	7.6	5.9	7.5	9.2	8.8	7.4	9.8	11.0	8.0	7.8	7.6	9.9
fs	5.0	4.7	4.8	4.5	4.8	4.8	4.2	5.0	5.1	4.7	4.6	4.7	4.9
il	0.9	0.8	0.9	0.9	0.9	0.9	0.8	0.9	0.9	0.8	0.9	0.8	0.8
mt	1.4	1.3	1.4	1.3	1.4	1.4	1.2	1.4	1.4	1.3	1.3	1.3	1.4
Mg/(Mg+Fe)	0.59	0.57	0.49	0.58	0.61	0.60	0.59	0.62	0.64	0.59	0.58	0.57	0.63

Table 2 (continued)

#	127	128	129	130	131	132	133	134	135	136	137	138	139
SiO_2	65.18	64.13	63.07	63.49	63.41	63.69	61.99	61.62	62.89	63.09	63.82	63.20	63.21
TiO_2	0.45	0.48	0.50	0.45	0.42	0.46	0.68	0.68	0.58	0.55	0.56	0.51	0.52
Al_2O_3	17.59	16.49	17.15	17.28	17.05	17.67	17.59	18.10	17.84	17.51	17.64	18.14	17.57
FeO	4.10	4.14	4.43	4.19	4.11	4.16	4.90	4.89	4.39	4.34	4.45	4.49	4.37
MnO	0.03	0.15	0.09	0.10	0.11	0.09	0.10	0.12	0.09	0.08	0.09	0.11	0.11
MgO	1.63	3.71	3.30	3.12	3.28	2.24	2.78	2.34	1.93	1.97	1.51	1.67	2.11
CaO	5.12	4.92	5.25	5.17	5.04	5.21	5.38	5.42	4.70	4.64	4.54	4.69	4.71
Na_2O	4.20	3.89	3.96	3.97	3.91	4.13	4.00	3.61	3.94	3.87	4.01	4.00	3.94
K_2O	1.67	1.67	1.59	1.51	1.75	1.59	2.47	2.66	2.62	2.63	2.69	2.66	2.73
Cr		165	166		150	56		44	44				46
Ni		82	66		56	30		21	20				30
Zr			140		163	136		192					238
Y			19		15	19		25					28
Sr			235		235	248		309					268
Rb			63		69	64		105					116
total	100.0	99.6	99.3	99.3	99.1	99.2	99.9	99.4	99.0	98.7	99.3	99.5	99.3
qz	19.1	17.3	16.0	17.0	16.5	17.2	12.0	13.3	14.9	15.7	16.1	14.9	14.7
or	9.9	9.9	9.5	9.0	10.4	9.5	14.6	15.8	15.6	15.7	16.0	15.8	16.2
ab	35.5	33.0	33.7	33.8	33.4	35.2	33.9	30.7	33.7	33.2	34.1	34.0	33.6
an	24.2	22.7	24.5	25.0	24.0	25.2	22.8	25.4	23.5	22.9	22.3	23.4	22.3
c												0.2	
wo	0.5	0.8	0.7	0.3	0.5	0.4	1.7	0.7	0.0	0.2	0.1		0.5
en	4.1	9.3	8.3	7.8	8.2	5.6	6.9	5.9	4.9	5.0	3.8	4.2	5.3
fs	4.6	4.8	5.1	4.9	4.8	4.8	5.4	5.4	4.9	4.9	5.0	5.2	5.0
il	0.9	0.9	1.0	0.9	0.8	0.9	1.3	1.3	1.1	1.1	1.1	1.0	1.0
mt	1.3	1.3	1.4	1.4	1.3	1.4	1.6	1.6	1.4	1.4	1.4	1.5	1.4
Mg/(Mg+Fe)	0.41	0.62	0.57	0.57	0.59	0.54	0.50	0.46	0.44	0.45	0.38	0.40	0.46

Table 2 (continued)

#	140	141	142	143	144	145	146	147	148*	149	150	151	152
SiO_2	63.47	63.37	62.69	62.78	62.01	61.86	61.02	64.85	64.07	61.98	61.63	65.82	66.65
TiO_2	0.58	0.59	0.62	0.58	0.59	0.61	0.65	0.46	0.56	0.65	0.67	0.50	0.47
Al_2O_3	17.65	18.11	17.75	16.97	18.09	18.36	18.37	16.50	17.89	17.32	18.65	16.98	16.89
Fe_2O_3									1.68				
FeO	4.53	4.61	4.74	4.62	4.70	5.18	4.97	3.97	2.34	4.63	4.88	3.42	3.29
MnO	0.10	0.10	0.05	0.09	0.08	0.14	0.11	0.10	0.12	0.09	0.08	0.09	0.05
MgO	2.06	2.02	1.15	2.54	2.42	2.87	2.68	2.91	2.35	2.42	1.61	1.69	1.01
CaO	4.74	4.82	5.09	4.98	5.06	5.50	5.63	4.23	4.43	5.28	5.34	3.95	3.99
Na_2O	3.92	4.06	3.91	3.80	4.11	4.16	4.15	3.96	4.01	4.06	3.63	4.02	3.96
K_2O	2.67	2.63	2.61	2.51	2.40	2.41	2.37	2.85	2.74	2.44	2.66	2.89	2.86
P_2O_5									0.03				
$H_2O(+)$									0.25				
$H_2O(-)$									0.00				
Cr				78		60	39		64	41		47	
Ni				38		26	35		24	30		22	
Zr				215		190			199	186		214	216
Y				24		21			14	22		21	22
Sr				277		302			277	297		275	280
Rb				101		95			104	92		117	124
total	99.7	100.3	98.6	98.9	99.0	101.1	99.9	99.8	100.47	98.9	99.2	99.4	99.2
qz	15.1	14.1	15.6	15.0	14.5	10.2	10.0	15.9	15.4	12.9	14.2	18.8	21.2
or	15.8	15.5	15.6	15.0	14.3	14.1	14.0	16.9	16.2	14.6	15.8	17.2	17.0
ab	33.2	34.2	33.5	32.5	31.7	34.8	35.1	33.5	33.9	34.7	31.0	34.2	33.8
an	22.7	23.3	23.5	22.1	25.3	24.0	24.5	18.8	21.8	22.1	26.7	19.7	20.0
c					0.2						0.1	0.1	0.0
wo	0.4	0.2	0.9	1.2		1.2	1.4	0.9	0.3	1.9			
en	5.1	5.0	2.9	6.4	6.1	7.1	6.7	7.3	5.9	6.1	4.0	4.2	2.5
fs	5.1	5.1	5.2	5.2	5.3	5.8	5.5	4.5	4.2	5.1	5.4	3.8	3.6
il	1.1	1.1	1.2	1.1	1.1	1.1	1.2	0.9	1.1	1.3	1.3	1.0	0.9
mt	1.5	1.5	1.6	1.5	1.5	1.7	1.6	1.3	1.2	1.5	1.6	1.1	1.1
ap									0.1				
Mg/(Mg+Fe)	0.45	0.44	0.30	0.50	0.48	0.50	0.49	0.57	0.52	0.48	0.37	0.47	0.35

Table 2 (continued)

#	153	154	155	156	157	158*	159	160	161	162	163	164	165
SiO_2	65.17	65.91	65.05	66.41	67.44	65.64	65.25	65.31	66.91	67.3	67.54	69.6	70.59
TiO_2	0.54	0.49	0.54	0.53	0.50	0.47	0.40	0.36	0.36	0.40	0.31	0.44	0.19
Al_2O_3	17.39	17.12	17.93	16.83	16.83	17.82	20.34	19.36	19.35	17.60	18.15	16.01	16.08
Fe_2O_3						1.28							
FeO	3.64	2.94	3.56	3.45	3.26	2.35	3.17	3.32	2.77	2.10	2.86	2.28	2.33
MnO	0.07	0.09	0.05	0.07	0.07	0.09	0.04	0.06	0.02	0.08	0.04	0.09	0.06
MgO	2.25	1.75	1.97	1.43	1.44	1.61	0.28	0.31	0.21	0.08	0.30	0.18	0.42
CaO	4.52	4.12	4.55	3.80	3.87	3.83	3.70	4.37	4.65	4.04	3.85	3.02	3.22
Na_2O	3.68	4.20	4.10	3.93	3.93	4.18	3.65	4.10	4.31	4.26	4.07	4.40	3.79
K_2O	2.90	2.89	2.78	2.90	2.94	2.90	2.28	2.43	2.31	2.23	2.50	2.69	2.70
P_2O_5						0.16							
$H_2O(+)$						0.13							
$H_2O(-)$						0.05							
Cr	67	52		39	39	50	8	6	11				15
Ni	23	9	13	20	12	14	13	14	9				2
Zr				210	215		138	140	141		112		151
Y				23	18		11	15	14		13		9
Sr				281	281		215	228	239		209		217
Rb				121	121		101	101	95		106		103
total	100.2	99.5	100.5	99.4	100.3	100.51	99.1	99.6	100.9	98.1	99.6	98.7	99.4
qz	17.8	17.9	16.1	20.6	21.2	18.3	25.6	20.7	21.2	24.7	24.2	26.2	29.6
or	17.1	17.2	16.3	17.2	17.3	17.1	13.6	14.4	13.5	13.4	14.8	16.1	16.1
ab	31.1	35.7	34.5	33.5	33.1	35.3	31.1	34.8	36.1	36.7	34.6	37.7	32.3
an	22.3	19.4	22.2	19.0	19.1	17.9	18.5	21.8	22.9	20.4	19.2	15.2	16.1
c				0.3	0.1	1.2	5.2	2.0	1.3	0.9	1.8	0.4	1.1
wo	0.0	0.5	0.1										
en	5.6	4.4	4.9	3.6	3.6	4.0	0.7	0.8	0.5	0.2	0.8	0.5	1.1
fs	3.9	3.2	3.8	3.7	3.5	3.9	3.5	3.8	3.0	2.2	3.3	2.4	2.8
il	1.0	0.9	1.0	1.0	1.0	0.9	0.8	0.7	0.7	0.8	0.6	0.9	0.4
mt	1.2	1.0	1.1	1.1	1.1	1.1	1.0	1.1	0.9	0.7	0.9	0.7	0.8
ap						0.4							
Mg/(Mg+Fe)	0.52	0.51	0.50	0.42	0.44	0.45	0.14	0.14	0.12	0.08	0.16	0.15	0.24

Table 2 (continued)

#	166	167	168	169*	170	171	172*	173	174	175	176	177*	178
SiO_2	71.2	71.5	72.0	72.68	74.0	51.11	51.52	52.88	53.47	53.56	53.77	53.80	56.83
TiO_2	0.25	0.20	0.21	0.12	0.21	0.95	0.94	0.93	1.35	0.81	0.89	0.89	0.64
Al_2O_3	16.08	15.44	15.93	16.01	15.64	15.21	18.60	17.35	14.97	15.54	17.18	16.83	15.23
Fe_2O_3				0.49			1.96					2.54	
FeO	1.88	1.57	1.69	1.17	1.63	8.35	6.44	7.03	7.84	7.56	7.92	4.12	6.28
MnO	0.07	0.08	0.06	0.03	0.11	0.15	0.16	0.17	0.15	0.16	0.14	0.13	0.16
MgO	0.20	0.21	0.18	0.25	0.16	10.48	6.22	8.12	7.58	9.27	6.80	7.94	8.33
CaO	2.30	2.32	2.43	2.16	2.28	9.10	9.31	9.04	9.46	8.34	9.51	7.74	8.01
Na_2O	3.88	4.51	4.32	4.24	4.22	2.76	2.64	3.25	2.88	2.84	2.60	3.07	2.77
K_2O	3.05	2.68	2.76	2.73	3.06	1.36	1.22	0.73	1.47	1.43	1.28	1.72	1.68
P_2O_5				0.00			0.10					0.04	
$H_2O(+)$				0.70			0.75					1.22	
$H_2O(-)$				0.00			0.15					0.20	
Cr						547	72	308		460		324	417
Ni						208	60	122		179		132	191
Zr				98		102	147						99
Y				7		20	21						20
Sr				186		273	289						251
Rb				114		35	53						48
total	98.9	98.5	99.6	100.58	101.3	99.5	100.01	99.5	99.2	99.5	100.1	100.24	99.9
qz	31.1	29.3	30.1	31.7	31.3		0.5		0.9		2.5	0.3	4.7
or	18.2	16.1	16.4	16.2	17.8	8.1	7.3	4.3	8.7	8.5	7.5	10.3	9.9
ab	33.2	38.7	36.7	35.9	35.2	23.4	22.5	27.6	24.5	24.1	21.9	26.3	23.4
an	11.5	11.7	12.1	10.7	11.2	25.2	35.6	30.7	23.7	25.5	31.3	27.4	24.1
c													
wo	2.2	0.9	1.4	2.2	1.2	8.4	4.3	6.0	9.8	6.7	6.6	4.7	6.5
en	0.5	0.5	0.5	0.6	0.4	12.4	15.6	18.3	19.0	21.5	16.9	20.0	20.7
fs	2.2	1.9	1.9	1.9	1.9	4.5	9.4	7.1	8.2	8.1	9.0	7.1	7.3
fo						9.7		1.4		1.2			
fa						3.9		0.6		0.5			
il	0.6	0.5	0.6	0.5	0.5	1.8	1.8	1.8	2.6	1.5	1.7	1.7	1.2
mt	0.5	0.4	0.4	0.2	0.4	2.7	2.7	2.3	2.5	2.4	2.5	2.1	2.0
ap				0.0			0.2					0.1	
Mg/(Mg+Fe)	0.19	0.23	0.19	0.26	0.18	0.69	0.57	0.67	0.63	0.69	0.60	0.69	0.70

Table 2 (continued)

#	179	180	181	182*	183	184	185	186*	187	188	189	190	191
SiO_2	57.18	57.53	58.18	58.63	58.86	59.35	59.47	59.57	60.75	61.33	61.72	62.32	63.11
TiO_2	0.78	0.72	0.75	0.59	0.88	0.54	0.56	0.66	0.60	0.72	0.69	0.54	0.47
Al_2O_3	18.42	16.43	18.16	16.27	17.64	15.00	16.96	17.08	18.54	17.34	16.49	17.12	17.64
Fe_2O_3				1.23				3.47					
FeO	6.40	5.98	5.72	4.20	6.14	5.96	5.26	2.31	5.08	5.17	5.36	4.55	4.30
MnO	0.14	0.14	0.14	0.12	0.11	0.11	0.10	0.11	0.10	0.11	0.09	0.08	0.08
MgO	4.64	6.85	4.22	5.80	4.84	8.32	6.90	4.85	2.93	3.30	5.09	5.21	3.13
CaO	7.14	7.71	7.15	6.45	6.84	6.41	6.79	6.31	6.00	6.26	5.74	5.54	5.21
Na_2O	3.66	3.16	3.05	3.03	3.28	2.83	3.28	3.63	3.50	3.97	3.17	3.26	4.03
K_2O	1.31	1.78	1.81	2.02	1.49	1.44	2.04	1.23	2.12	1.40	1.82	2.01	1.68
P_2O_5				0.00				0.10					
$H_2O(+)$				1.42				0.80					
$H_2O(-)$				0.10				0.32					
Cr	128	265		295		468	304	106				202	
Ni	59	63		106		157	155	37				69	
total	99.7	100.3	99.2	99.86	100.1	100.0	101.4	100.44	99.6	99.6	100.2	100.6	99.6
qz	6.6	5.3	10.1	9.8	10.2	9.7	6.7	11.5	12.7	13.2	14.4	13.9	15.4
or	7.8	10.5	10.8	12.1	8.8	8.5	11.9	7.3	12.6	8.3	10.7	11.8	10.0
ab	31.0	26.6	26.0	26.1	27.7	23.9	27.4	31.0	29.7	33.7	26.8	27.4	34.2
an	30.0	25.3	30.7	25.3	29.0	24.0	25.2	26.9	28.7	25.4	25.3	26.0	25.1
c													
wo	2.3	5.4	2.1	3.1	2.1	3.3	3.4	1.7	0.5	2.4	1.3	0.6	0.3
en	11.6	17.0	10.6	14.7	12.0	20.7	16.9	12.2	7.3	8.2	12.6	12.9	7.8
fs	7.2	6.7	6.4	6.2	6.6	7.0	5.9	6.2	5.7	5.7	5.9	5.1	4.9
il	1.5	1.4	1.4	1.1	1.7	1.2	1.1	1.3	1.1	1.7	1.3	1.0	0.9
mt	2.1	1.9	1.9	1.7	2.0	1.9	1.7	1.8	1.6	1.4	1.7	1.5	1.4
ap				0.0				0.2					
Mg/(Mg+Fe)	0.56	0.67	0.57	0.66	0.58	0.71	0.70	0.61	0.51	0.53	0.63	0.67	0.56

Table 2 (continued)

#	192	193	194	195	196	197*	198
SiO_2	63.81	64.16	64.17	64.91	67.98	68.07	68.27
TiO_2	0.60	0.41	0.48	0.42	0.32	0.31	0.31
Al_2O_3	17.28	16.14	18.33	16.39	17.16	16.46	16.63
Fe_2O_3						1.74	
FeO	4.02	3.46	3.74	4.29	2.70	1.16	3.53
MnO	0.10	0.07	0.04	0.06	0.08	0.06	0.05
MgO	3.54	4.04	2.37	3.28	0.91	1.28	1.51
CaO	4.82	4.63	5.20	4.81	3.54	3.10	2.96
Na_2O	3.77	4.07	3.83	3.92	3.92	3.82	3.84
K_2O	2.58	2.29	2.54	1.96	2.78	2.72	3.75
P_2O_5						0.17	
$H_2O(+)$						0.50	
$H_2O(-)$						1.16	
Cr				129			
Ni				40			
total	100.5	99.3	100.7	100.0	99.4	100.55	100.8
qz	14.6	15.0	15.6	17.7	24.3	26.3	20.9
or	15.2	13.6	14.9	11.6	16.5	16.3	22.0
ab	31.7	34.7	32.2	33.1	33.4	32.7	32.2
an	22.5	19.1	25.1	21.3	17.7	14.5	14.6
c					1.3	2.0	0.9
wo	0.5	1.7	0.2	1.1			
en	8.8	10.1	5.9	8.2	2.3	3.2	3.7
fs	4.3	3.9	4.1	4.9	3.1	3.1	4.1
il	1.1	0.8	0.9	0.8	0.6	0.6	0.6
mt	1.3	1.1	1.2	1.4	0.9	0.9	1.1
ap						0.4	
Mg/(Mg+Fe)	0.61	0.68	0.53	0.58	0.38	0.46	0.43