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Melt contribution to partitioning of trace element between plagioclase and basaltic magma of Fuji volcano, Japan

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Abstract

Ion microprobe analyses of trace elements in plagioclase crystals apply to partitioning between plagioclase phenocrysts and basaltic magma of Fuji volcano. The partitioning of trace elements of plagioclase is governed not only by the site preference of ions in the crystal as it is widely accepted, but also by the components of melt. The observed logarithmic count ratios of the ion microprobe analyses between trace and host elements in plagioclase, is linear with X_{An} (anorthite composition of plagioclase), in the range of X_{An} (0.55–0.85). The observed ratio is proportional with K'-value (apparent exchange partition coefficient) because of nearly constant composition of the basalt. We separate the K'-value into two terms: plagioclase component controlled term and non-plagioclase component controlled term. The second term mainly characterizes the pattern of the Onuma PC-IR-diagram in a magmatic system.

Keywords: Ion microprobe; Partitioning; Plagioclase; Trace element; Magma; Fuji

1. Introduction

Ion microprobe analyses of trace elements in plagioclase crystals apply to partitioning between plagioclase phenocrysts and basaltic magma of Fuji volcano. The partitioning of trace elements of plagioclase is governed not only by the site preference of ions in the crystal as it is widely accepted, but also by the components of melt. We separate the contribution of components of melt from that of plagioclase crystal to explain the observed systematic partitioning in the basaltic magma.

2. Sample and experimental

We selected a representative sample from a well-documented volcano, Fuji, Japan [1]. The rock is a typical arc basalt with zoned plagioclase phenocrysts. The phenocryst assemblage indicates that the crystallization pressure is less than 700 MPa. The crystallization temperature is estimated to be nearly constant (1200 ± 50 °C). Major element compositions of bulk rocks are restricted to basaltic composition, but the core of plagioclase phenocryst has normal zoning from 0.85 to $0.55X_{An}$, where X_{An} is a mole fraction of anorthite in plagioclase phenocryst. The rim of phenocrysts and groundmass were eliminated to avoid the effect of disequilibrated crystallization by rapid cooling [2]. Therefore, only the water pressure of the magma reservoir can cause

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the observed wide change of the anorthite content of plagioclase.

Trace elements (Mg, K, Sc, Ti, V, Mn, Fe, Co, Sr and Ba) and host elements (Ca, Na, Al and Si) were analyzed by an ion microprobe (CAMECA ims1270 instrument at the Geological Survey of Japan). High mass-resolution mode [3,4] is applied to avoid the interference of molecular peaks for zoned plagioclase from Fuji basalts, Japan. Analyses were made by bombardment of the sample with O-ions. Mass-resolution power ranges from 4000 to 4500. Abundance sensitivity is less than 10 ppm for 0.015 mass differences from ^{39}K peak. This condition is sufficient to separate the peak of interest from the tail of the nearest peak of molecular ions. Matrix correction was applied for Na and K by using standards, because matrix effects for Na and K are observed depending on anorthite content of plagioclase.

3. Results

The compositions of averaged plagioclase phenocrysts and bulk rock in single basalt lava from Fuji volcano (E7) are shown in Table 1.

As shown in Fig. 1, the observed logarithmic count ratios of the ion microprobe analyses between trace and host elements in plagioclase is linear with the anorthite composition of plagioclase (X_{An}), in the range of X_{An} (0.55–0.85) for the sample (E7). Then

$$\ln\left(\frac{Y_{Tr}}{Y_h}\right) = A_{Tr}X_{An} + B_{Tr} \tag{1}$$

Table 1
Composition of averaged plagioclase phenocrysts ($X_{An} = 0.65$) and bulk rock in the sample E7 from Fuji volcano[a]

	CaO (%)	K_2O (%)	Na_2O (%)	Ba (ppm)	Sr (ppm)	MnO (%)	Sc (ppm)	Al_2O_3 (%)	Co (ppm)	MgO (%)	FeO (%)	TiO_2 (%)	V (ppm)
Cs	13.3	0.29	3.92	105	662	0.0085	0.2	29.4	0.93	0.11	0.87	0.066	8
S.D.	1	0.05	0.46	18	13	0.0009	0.03	0.97	0.19	0.01	0.04	0.011	1
Cm	10.2	0.69	2.85	248	421	0.17	35	17.3	39	5.3	11.09	1.51	423

[a] Cs: concentration in plagioclase phenocrysts (average), S.D.: standard deviation, Cm: concentration in bulk rock.

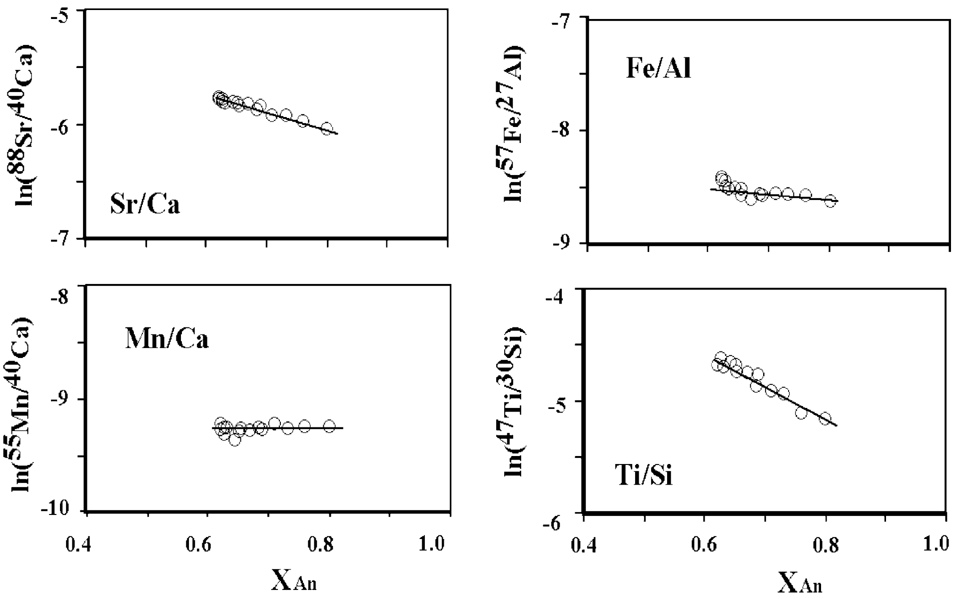

Fig. 1. Count ratios of ion microprobe analyses between trace and host elements in plagioclase.

where (Y_{Tr}/Y_h) is a count ratio of ion microprobe analyses between trace element (Tr) and host element (h) in plagioclase phenocryst, and A_{Tr} and B_{Tr} are the constants for the trace element Tr [4,5].

4. Discussion and conclusions

The concentrations of trace elements in host melt should be estimated from those in plagioclase by using partition coefficients. Our results require the partition coefficients to be evaluated by the dependence of both anorthite contents of the plagioclase and the bulk major composition of the melt [4,5]. The anorthite content varies not only with melt composition but also with P_{H_2O} for these basalts.

The partitioning pattern for trace elements of plagioclase in the Onuma PC-IR-diagram ([6], Fig. 2a) is governed not only by the site preference of ions in the crystal, but also by the components of melt. The K'-value (apparent exchange partitioning of trace and host elements between plagioclase phenocryst and melt, Fig. 2b) can be calculated from the PC-IR-diagram (Table 2). Fig. 2a and b are very similar.

It is noted that the variation of Y_{Tr}/Y_h in Fig. 1 and Eq. (1) means the variation of the K'-value due to compositional dependence on X_{An}, where the bulk composition of the melt of the sample (E7) is nearly constant during the variation. We separate the K'-value into two terms: plagioclase component controlled term ($A_{Tr}X_{An}$, Fig. 2c) and non-plagioclase component

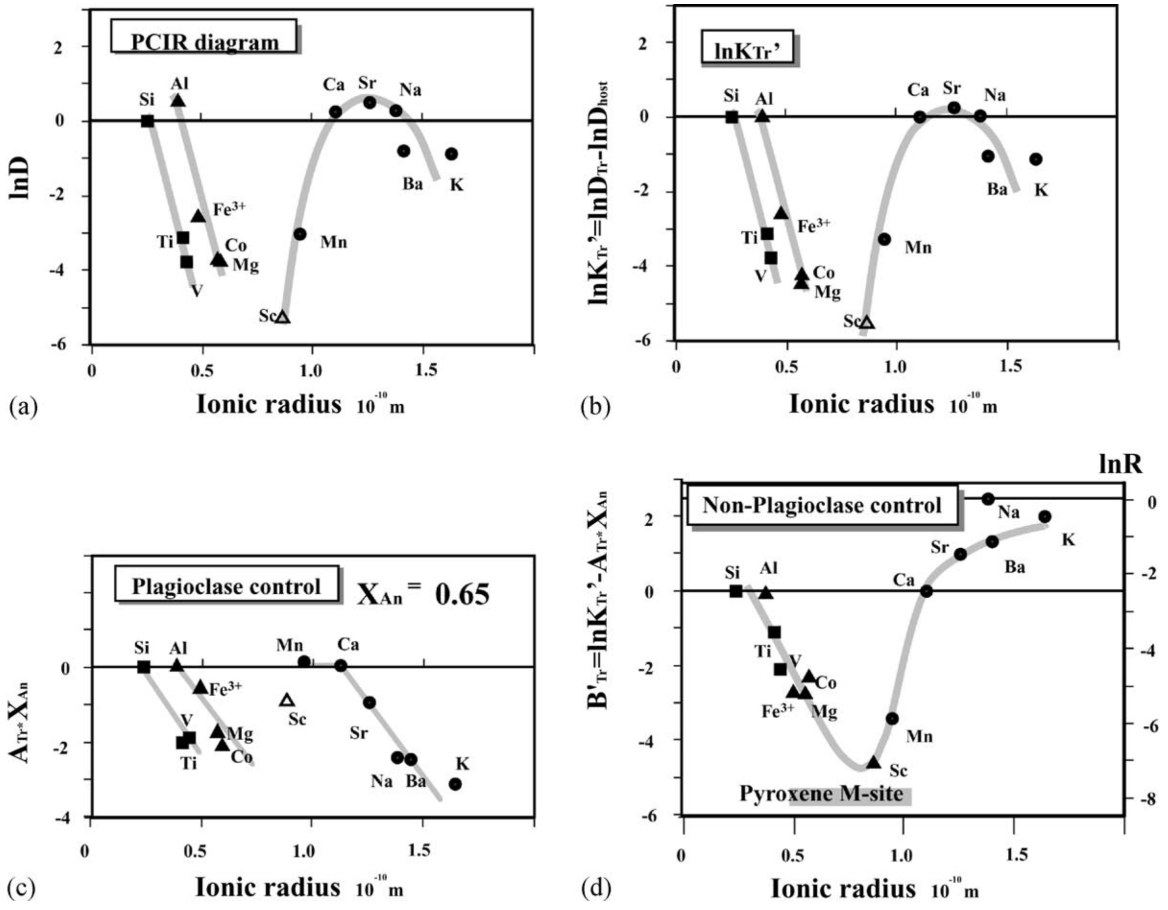

Fig. 2. Variations of the parameters against ionic radii.

Table 2
Calculated parameters from Table 1 and Fig. 1[a]

	Ca	K	Na	Ba	Sr	Mn	Sc	Al	Co	Mg	Fe	Si	Ti	V
Valence	2+	+	+	2+	2+	2+	3+	3+	2+	2+	3+	4+	4+	4+
Coordination	VIII	XII	XII	VIII	VIII	VIII	VIII	IV	IV	IV	IV	IV	IV	IV
Ionic radius	1.12	1.64	1.39	1.42	1.26	0.96	0.87	0.39	0.58	0.57	0.49	0.26	0.42	0.44
$D = \mathrm{Cs/Cm}$	1.3	0.42	1.38	0.42	1.57	0.05	0.006	1.7	0.02	0.02	0.078	1	0.044	0.02
$\ln D$	0.27	−0.87	0.32	−0.9	0.45	−3	−5.15	0.53	−3.73	−3.87	−2.55	0	−3.13	−3.97
Host element		Ca	Ca	Ca	Ca	Ca	Ca		Al	Al	Al		Si	Si
$\ln K'_{\mathrm{Tr}}$	0	−1.14	0.05	−1.1	0.18	−3.27	−5.42	0	−4.26	−4.4	−3.08	0	−3.13	−3.97
A_{Tr}		−4.8	−3.76	−3.7	−1.4	0.21	−1.42		−3.22	−2.72	−0.86		−3	−2.88
$A_{\mathrm{Tr}}X_{\mathrm{An}}$ ($X_{\mathrm{An}} = 0.65$)		−3.1	−2.44	−2.4	−0.9	0.14	−0.92		−2.09	−1.77	−0.56		−1.95	−1.87
B'_{Tr}		1.97	2.49	1.26	1.08	−3.41	−4.5		−2.17	−2.63	−2.52		−1.18	−2.1

[a] D: apparent distribution coefficient, A_{Tr}: averaged slope value in Eq. (1) from Fig. 1, K'_{Tr}: apparent exchange partition coefficient, $\ln K'_{\mathrm{Tr}} = \ln D_{\mathrm{Tr}} - \ln D_{\mathrm{h}}$, $B'_{\mathrm{Tr}} = \ln K'_{\mathrm{Tr}} - A_{\mathrm{Tr}}X_{\mathrm{An}}$.

controlled term (B'_{Tr}, Fig. 2d, Table 2)

$$\ln K'_{\mathrm{Tr}} = A_{\mathrm{Tr}}X_{\mathrm{An}} + B'_{\mathrm{Tr}} \tag{2}$$

The variation of the first term ($A_{\mathrm{Tr}}X_{\mathrm{An}}$) is limited but systematic with ionic radii [5]. On the other hand, the second term (B'_{Tr}) widely varies with the melt composition and characterizes the pattern of the K'-value diagram for the small ions relative to Ca.

We propose the R-value that shows the partitioning of trace elements in plagioclase components in melt against total melt including non-plagioclase components (Fig. 2d right axis). The R-value is estimated from B'_{Tr} value assuming that all of Na in plagioclase component

$$\ln R = B'_{\mathrm{Tr}} - B'_{\mathrm{Na}} = B'_{\mathrm{Tr}} - 2.5 \tag{3}$$

The R-value is independent of X_{An}, and characterizes the pattern in the PC-IR-diagram for the small ions relative to Ca. The ionic radii at the minimum R-value approximately correspond to the size of the M-site of pyroxenes (Fig. 2d). We think that the R-value thermodynamically relates to the activity of the element in the melt.

In conclusion, we separate the contribution of non-plagioclase components in melt from that of plagioclase component to explain the observed systematic partitioning in the basaltic magma.

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