Partition relation of K between magma and plagioclase in a suite of volcanic rocks from northeast Shikoku, Japan

HIROAKI SATO

*Department of Earth Sciences, Faculty of Science, Kanazawa University,
Kanazawa, Ishikawa 920, Japan*

Using available thermodynamic data, a model of K partitioning between magma and plagioclase is constructed. The partition relation is dealt with in terms of the exchange reaction: $(\text{NaAlSi}_3\text{O}_8)_{\text{plag}} + (\text{KAlSi}_3\text{O}_8)_{\text{magma}} = (\text{NaAlSi}_3\text{O}_8)_{\text{magma}} + (\text{KAlSi}_3\text{O}_8)_{\text{plag}}$. The equilibrium condition is expressed as $\ln K = (8630 - 0.7T - 4130 X_{\text{ab, pl}})/RT$, where K, T, R are partition coefficient, absolute temperature, and gas constant, respectively, and $X_{\text{ab, pl}} = \text{Na}/(\text{Na} + \text{Ca})_{\text{plag}}$. This model suggests that the partition coefficient strongly depends on temperature and major element composition of plagioclase crystal. The model was applied to compositional relations of natural plagioclase-groundmass pairs of a suite of calc-alkalic volcanic rocks from northeast Shikoku, and of other volcanic rocks available from literatures. The obtained temperature of crystallization of plagioclase is qualitatively in accord with the liquidus temperature of each rock type, i.e. 700–900°C for rhyolites and 1100–1300°C for andesites.

Introduction

In spite of the importance of K in the petrogenetic discussions of igneous rocks, its behavior in magma-crystal system has only cursory been examined (e.g. Helz, 1979). Sen (1959) noted the temperature dependence of the solubility of K in plagioclase coexisting with K-feldspar in natural rocks, while the experimental work of Seck (1973) also demonstrated the marked temperature effect on the solubility of K in plagioclase. Therefore, the K content of plagioclase crystallizing from a magma may be strongly affected by temperature as well as K content of magma, the composition of plagioclase and magma. In this paper, the author intends to elucidate the factors that affect the partition relation of K between magma and plagioclase. The author first presents a model of partitioning

of K between magma and plagioclase. The model is applied to plagioclase-groundmass relations of a suite of calc-alkalic volcanic rocks from northeast Shikoku, Japan, and of other volcanic rocks from literature. The model is also compared with the experimental data of Drake (1976). The result suggests that the partition relation of K between magma and plagioclase could be used as a thermometer.

Model of partitioning of K between magma and plagioclase

The partition coefficient between magma and crystal, as defined by a simple ratio of the concentration of orthoclase component, should depend on the composition of magma because the constituent oxides of the component do not necessarily form such a molecule (Banno and Matsui, 1973). The author

intends to discuss the partitioning of K between magma and plagioclase using exchange partition coefficient, for which the direct compositional effect of magma is much reduced. Consider the exchange reaction :

and the resulting equilibrium condition :

$$\ln K + r + \ln(\gamma_{\text{ab}}/\gamma_{\text{or}})_{\text{plag}} = \Delta G_0 / RT \quad (2)$$

in which

$$\begin{aligned} K &= (X_{\text{or}}/X_{\text{ab}})_{\text{magma}} / (X_{\text{or}}/X_{\text{ab}})_{\text{plag}} \\ r &= \ln(\gamma_{\text{K}}/\gamma_{\text{Na}})_{\text{magma}} \\ \Delta G_0 &= G_{0(\text{ab, magma})} + G_{0(\text{or, plag})} \\ &\quad - G_{0(\text{ab, plag})} - G_{0(\text{or, magma})} \\ R &= 1.987 \text{ Cal/deg.mol (gas constant)} \\ X &: \text{ mol fraction} \\ \gamma &: \text{ activity coefficient} \\ T &: \text{ absolute temperature} \end{aligned}$$

ΔG_0 , the molar free energy change of the exchange reaction, can be expressed in terms of temperature and pressure using the calorimetric data of Robie and Waldbaum (1968) (this data was preferred because of the consistency compared with those reported by Robie *et al.*, 1978). The obtained equation is :

$$\Delta G_0 = 200 - 0.7T + 0.0053(P - 1) \quad (3)$$

where P is pressure in bars.

The third term on the left-hand side of the equation (2), the natural logarithm of the ratio of the activity coefficients of plagioclase, may be expressed by a function of temperature, pressure, and composition of plagioclase. The solution model of the ternary feldspar has been given by Saxena (1973) based on the compositional relation of two feldspars at 900°C (Seck, 1971). To extend the solution model for other temperatures, the author adopted ternary regular solution

Table 1. Compositions of the coexisting plagioclase and glass

Run No. B108 (T. Katsura)		
1170°C CO ₂ atmosphere		
	Glass (n=5)	Plagioclase (n=3)
SiO ₂	61.5 (.42)	53.1 (.63)
TiO ₂	0.76 (.03)	n.d.
Al ₂ O ₃	15.4 (.13)	28.1 (.25)
FeO	5.30 (.09)	0.81 (.07)
MnO	0.08 (.03)	n.d.
MgO	4.23 (.06)	0.20 (.00)
CaO	6.30 (.09)	13.51 (.40)
Na ₂ O	3.08 (.12)	3.43 (.13)
K ₂ O	2.92 (.07)	0.39 (.06)
Total	99.6	99.6
Ca/(Ca+Na)	.531	.685

$$\ln K = 2.12$$

$$r = 0.08$$

model (Prigogine and Defay, 1950, Chap. 16). The expression of the model was further simplified by making following assumptions; (1) binary join albite-anorthite is ideal, (2) mole fraction of orthoclase component in plagioclase is negligibly small. Then, the remaining two parameters in the expression of the regular solution model were determined by fitting the Saxena's solution model (Fig. 1). The resulting expression of the third term of the left-hand side of equation (2) is as follows.

$$\ln(\gamma_{\text{ab}}/\gamma_{\text{or}})_{\text{plag}} = (4130X_{\text{ab, pl}} - 8430) / RT \quad (4)$$

The term r, a natural logarithm of the ratio of the activity coefficients of Na and K in magma, was assumed to be zero in the following discussions based on a compositional relation of plagioclase-glass at 1170°C. The fusion experiment was carried out by Prof. T. Katsura, and the experimental procedure followed that of Aramaki and Katsura (1971). As shown in Table 1, compositions

Fig. 1. Graphical illustration of the model of partitioning of K between magma and plagioclase. Solid lines represent the equation (5) in the text. Dashed lines represent a model using Saxena's parameter of the ternary feldspar solid solution at 900 °C.

of the coexisting plagioclase and glass gave a r value of 0.08, which may be neglected when we consider the experimental uncertainty. Activities in the system $\text{NaAlSi}_3\text{O}_8$ - KAlSi_3O_8 obtained by Knudsen cell mass spectrometry (Rammensee and Fraser, 1982) also support the nearly ideal behaviour of albite and orthoclase components in silicate melt.

Substituting equations (3), (4), and the value of r for equation (2), we obtain the following equilibrium condition.

$$\ln K = (8630 - 0.7T + 0.0053P - 4130X_{\text{ab, pl}})/RT \quad (5)$$

The pressure term in equation (5) may be neglected below 10 kilobars. Then, $\ln K$, the natural logarithm of the apparent partition coefficient, varies linearly with albite mole fraction of plagioclase at constant temperature. This linear relation between $\ln K$ and $X_{\text{ab, pl}}$ is illustrated for several temperatures in Fig. 1. Fig. 1 shows the marked effects of temperature and composition of plagioclase on the apparent partition coefficient, which is mainly due to the non-ideal nature of the ternary plagioclase solid solution.

Table 2. Rock composition

Sample No.	(1) #177		(2) #101		(3) #111		(4) #158		(5) #197		(6) #169	
	bulk	gm.	bulk	gm.	bulk	gm.	bulk	gm.	bulk	gm.	bulk	gm.
SiO ₂	53.80	56.1	55.37	57.7	62.62	65.64	68.07	71.8	72.68			
TiO ₂	0.89	1.0	0.66	0.8	0.42	0.47	0.31	0.1	0.12			
Al ₂ O ₃	16.83	19.1	16.40	19.0	17.37	17.82	16.46	15.7	16.01			
Fe ₂ O ₃	2.54	2.9	2.82	3.3	2.33	1.28	1.74	2.0	0.49			
FeO	4.12	3.2	3.25	2.3	2.04	2.35	1.16	0.5	1.17			
MnO	0.13	0.1	0.12	0.1	0.10	0.09	0.06	0.06	0.03			
MgO	7.94	4.0	7.69	3.5	4.01	1.61	1.28	0.7	0.25			
CaO	7.74	8.2	7.30	7.8	4.92	3.83	3.10	2.1	2.16			
Na ₂ O	3.07	3.50	2.96	3.44	3.94	4.18	3.82	3.85	4.24			
K ₂ O	1.72	1.97	1.71	1.99	1.59	2.90	2.72	3.19	2.73			
H ₂ O(-)	0.20		0.40		0.65	0.13	1.16		0.00			
H ₂ O(+)	1.22		1.60		0.45	0.05	0.50		0.70			
P ₂ O ₅	0.04	0.04	0.00	0.0	0.08	0.16	0.17	0.17	0.00			
Total	100.24	(100)	100.28	(100)	100.52	100.51	100.55	(100)	100.58			
qz	1.5	6.0	5.5	9.7	16.8	18.8	27.5	31.8	31.9			
or	10.3	11.6	10.3	11.8	9.5	17.1	16.3	18.9	16.2			
ab	26.3	29.6	25.5	29.1	33.5	35.3	32.7	32.6	35.9			
an	27.4	30.6	26.9	30.6	24.0	17.9	14.4	10.2	10.7			
c	-	-	-	-	0.4	1.2	2.0	2.2	2.2			
wo	4.7	4.1	4.2	3.5	-	-	-	-	-			
en	20.0	10.0	19.5	8.8	10.1	4.0	3.2	1.8	0.6			
fs	4.3	2.0	2.8	0.4	1.3	2.6	0.3	-	1.6			
mt	3.7	4.2	4.2	4.8	3.4	1.9	2.6	1.6	0.7			
il	1.7	1.9	1.3	1.4	0.8	0.9	0.6	0.1	0.2			
hm	-	-	-	-	-	-	-	0.9	-			
ap	0.1	0.1	0.0	0.0	0.2	0.4	0.4	0.4	0.0			

(Analyst: H. Haramura)

Table 3. Representative plagioclase analyses

Sample No.	(1) #177			(2) #101			(3) #111			(4) #158			
Point	4-1	1-2	4-3	1-4	2-1	2-3	2-1	3-1	3-2	1-2	1-12	6-1	
	core	core	rim	rim	core	rim	core	core	rim	p.c.	p.r.	mph. c.	
SiO ₂	47.6	50.0	51.8	56.0	51.6	56.3	52.4	53.1	55.6	47.6	51.0	56.9	
Al ₂ O ₃	33.1	31.5	30.3	25.4	29.9	26.2	29.9	29.4	27.4	33.7	30.8	27.4	
FeO*	0.62	0.67	0.73	1.02	0.60	0.86	0.52	0.53	0.51	0.24	0.27	0.38	
MgO	0.10	0.10	0.11	0.58	0.11	0.13	0.06	0.05	0.03	0.07	0.01	0.01	
CaO	17.12	15.79	13.79	10.60	14.23	10.56	13.16	11.95	10.18	16.8	13.68	9.42	
Na ₂ O	1.78	2.65	3.60	5.00	3.28	5.42	3.82	4.16	5.14	1.85	3.38	5.77	
K ₂ O	0.07	0.18	0.24	0.63	0.22	0.38	0.21	0.23	0.36	0.12	0.22	0.47	
Total	100.4	100.9	100.6	99.2	99.9	99.9	100.1	99.4	99.3	100.4	99.3	100.3	
Si	2.182	2.273	2.349	2.558	2.354	2.549	2.379	2.418	2.524	2.176	2.335	2.549	
Al	1.789	1.687	1.621	1.365	1.609	1.399	1.603	1.578	1.467	1.816	1.660	1.446	
Fe	0.024	0.025	0.028	0.039	0.023	0.033	0.020	0.020	0.019	0.009	0.010	0.014	
Mg	0.007	0.006	0.007	0.039	0.008	0.009	0.004	0.003	0.002	0.005	0.001	0.001	
Ca	0.840	0.769	0.670	0.519	0.696	0.513	0.641	0.583	0.495	0.825	0.672	0.452	
Na	0.158	0.234	0.317	0.443	0.290	0.476	0.336	0.367	0.452	0.164	0.300	0.502	
K	0.004	0.010	0.014	0.037	0.013	0.022	0.012	0.014	0.021	0.007	0.013	0.027	
Total	5.004	5.005	5.006	5.000	4.993	5.000	4.994	4.983	4.979	5.002	4.991	4.992	
Ca/(Ca+Na)	.841	.767	.679	.539	.706	.518	.656	.614	.522	.835	.691	.474	
ln K	2.65	2.12	2.12	1.49	2.15	2.10	2.01	1.97	1.77	2.35	2.35	2.14	

* Total Fe as FeO

Table 3. (continued)

Sample No.	(4) #158				(5) #197				(6) #169			
Point	6-2	9-1	3-2	3-3	3-4	3-5	2-1	2-2	2-4	3-1	3-2	
	mph.r.	mph.c.	core	core	core	rim	core	core	rim	core	core	
SiO ₂	52.8	53.9	57.1	51.7	54.7	58.5	47.4	56.9	57.2	58.3	61.3	
Al ₂ O ₃	29.4	28.9	27.3	30.7	28.6	26.0	34.2	27.6	27.3	26.0	24.5	
FeO*	0.42	0.44	0.25	0.25	0.27	0.23	0.12	0.10	0.11	0.10	0.02	
MgO	0.06	0.00	0.02	0.02	0.01	0.02	0.04	0.01	0.00	0.00	0.00	
CaO	12.79	11.47	10.00	13.81	11.16	8.99	16.92	9.85	8.76	8.25	5.85	
Na ₂ O	3.95	4.61	5.57	3.29	4.51	6.06	1.93	5.75	6.15	6.43	7.92	
K ₂ O	0.34	0.36	0.30	0.16	0.21	0.43	0.05	0.21	0.26	0.29	0.43	
Total	99.7	99.7	100.5	99.9	100.1	100.1	100.6	100.5	99.8	99.4	100.0	
Si	2.403	2.446	2.551	2.350	2.467	2.618	2.162	2.542	2.567	2.621	2.722	
Al	1.577	1.547	1.439	1.645	1.522	1.368	1.836	1.455	1.442	1.377	1.282	
Fe	0.016	0.017	0.009	0.010	0.010	0.009	0.005	0.004	0.004	0.004	0.001	
Mg	0.004	0.000	0.001	0.001	0.001	0.001	0.003	0.001	0.000	0.000	0.000	
Ca	0.624	0.558	0.479	0.672	0.568	0.426	0.827	0.472	0.422	0.397	0.278	
Na	0.348	0.406	0.483	0.290	0.394	0.526	0.170	0.499	0.536	0.561	0.682	
K	0.019	0.021	0.017	0.009	0.012	0.025	0.003	0.012	0.015	0.017	0.024	
Total	4.992	4.994	4.979	4.977	4.975	4.973	5.006	4.985	4.986	4.977	4.989	
Ca/(Ca+Na)	.642	.579	.498	.699	.591	.448	.829	.486	.440	.415	.290	
ln K	2.10	2.10	2.74	2.84	2.90	2.45	3.11	2.80	2.66	2.57	2.40	

Application to natural rock systems

The foregoing partition model is applied to natural coexisting plagioclase-groundmass pairs. The author analyzed plagioclase and rocks of a suite of calc-alkalic volcanic rocks from northeast Shikoku. Chemical compositions of the bulk rock and groundmass are shown in Table 2. The SiO_2

content of the groundmass of the analyzed samples ranges from 54.6 to 71.5 wt.%. K_2O content is a little less than 2 wt.% for basaltic andesite and andesites, and about 3 wt.% for sanukite and rhyolites. Quantitative analyses of plagioclase were made on representative crystals of each samples after semiquantitative scanning analyses of many plagioclase phenocrysts. The selected analytical

Fig. 2. Composition of plagioclase in a suite of volcanic rocks from northeast Shikoku region. Petrographic description of the sample is given in the appendix. Data plotted as microphenocryst of (2), (3), and (4) may be regarded as coarse groundmass (see appendix).

Fig. 3. Comparison of K_2O versus $Ca/(Na+Ca)$ ratio of the analyzed plagioclase.

result appears in Table 3. Petrographic description of each sample can be found in the appendix.

Fig. 2 shows the K_2O wt.% versus $Ca/(Ca+Na)$ ratio of the analyzed plagioclase for six samples. Plagioclase phenocryst generally shows marked compositional zoning as to $Ca/(Ca+Na)$. Fig. 2 illustrates that the K_2O content of plagioclase in each specimen tends to increase monotonously as plagioclase becomes more sodic. This tendency holds even for reversely zoned plagioclase phenocryst. In respect of the standard counting errors of the plagioclase analyses, K_2O versus $Ca/(Ca+Na)$ relation in a sample can be represented by a smooth curve. In Fig. 3, these curves are presented together. The composition of plagioclase exhibits semi-parallel curves, always showing positive correlation between K_2O and albite contents. The K_2O content level of these curves differ each other, which implies that simple fractional crystallization of phenocryst cannot explain the generation of the rock suite. The K_2O content level of the curves in Fig. 3 tends to be higher for rocks with less

silicic groundmass, and does not correspond to the K_2O concentration of the groundmass. This apparent discrepancy of the partition relation of K between magma and plagioclase is explained by the preceding model.

In Fig. 4, natural logarithm of the apparent partition coefficient, calculated from the groundmass and plagioclase compositions, was plotted against $Ca/(Ca+Na)$ ratio of the plagioclase. It is noted that the choice of the magma composition, either bulk rock composition or groundmass composition, does not affect the apparent partition coefficient more than 10%. For each specimen, the apparent partition coefficient tends to be larger for more calcic plagioclase, and lies approximately on the isothermal line of the model. The apparent partition coefficient is smaller for the more basic rocks, and the order of temperatures derived from the model is qualitatively in accord with the known liquidus temperatures of rock types. Therefore, the higher K trend of plagioclase in basaltic andesite and andesites rather than that in rhyolites is mainly due to its higher crystallization temperature.

Fig. 4. Logarithm of the partition coefficient versus $\text{Ca}/(\text{Na} + \text{Ca})$ ratio for a suite of volcanic rocks from northeast Shikoku. Numbers (1) through (6) corresponds to those found in Figures 2 and 3.

In Fig. 5, the partition coefficient of natural rock systems obtained from literature are shown for comparison. In this case, partition coefficient also tends to be smaller for more basic rock systems, support-

ing its strong temperature dependence. For Taupo rhyolite, Ewart *et al.* (1973) obtained equilibration temperature of 700–760°C by magnetite-ilmenite thermometer, which is in accord with the temperature obtained by the

Fig. 5. Logarithm of the partition coefficient versus $\text{Ca}/(\text{Na}+\text{Ca})$ ratio for volcanic rocks from literatures. a, Hawaii tholeiitic basalts (Keil *et al.* 1972); b, Hawaii, alkalic basalts (*ibid*); c, southern Cascade, basaltic andesite and andesite (Smith and Carmichael 1973); d, Tonga andesite (Ewart *et al.* 1973); e, Tonga rhyodacite (*ibid*); f, Taupo, rhyodacite (Ewart *et al.* 1968, 1969).

present model.

Figs. 4 and 5 show that for some of the basalts and andesites the obtained equilibration temperature exceeds 1300°C and is slightly higher than the liquidus temperatures of these rocks. This discrepancy of temperature may be ascribed mainly to the uncertainties of the plagioclase solid solution parameters at high temperatures as well as of the activity coefficients of magmatic melts.

Comparison of the model with the experimental data of Drake

Drake (1976) presented experimental data on the element partitioning between plagioclase and magmatic liquids. His experiments were carried out in the temperature range of $1297\text{--}1090^{\circ}\text{C}$. The partition coefficient of Na-K between plagioclase and glass was calculated and plotted in Fig. 6. The data are divided into three groups according to the equilibration temperature. In Fig. 6, we can see the general tendency

Fig. 6. Logarithm of the partition coefficient versus Ca/(Na + Ca) ratio for experimental systems of Drake (1976).

that the partition coefficient for higher equilibration temperature is smaller, which is in accord with the model. The scatter of the data points may partly be due to the analytical errors (average K_2O content of the analyzed plagioclase is 0.145 wt.%).

Acknowledgements: Prof. T. Katsura kindly carried out the fusion experiments. Discussions with Dr. M. Toriumi and Prof. S. Banno were of much help. Prof. M. Yamasaki encouraged me during the study. Mr. H. Haramura made bulk rock chemical analyses. Messrs. K. Nakamura and S. Kasajima helped me to prepare illustrations and polish-

ed thin sections, respectively. The author would like to express his sincere thanks to these people. This study was partly defrayed by the Scientific Grant of the Ministry of Education, Science and Culture of Japan (No. 5754074).

References

- Aramaki, S. and Katsura, T. (1973), Petrology and liquidus temperature of the 1970 eruption of Akita-Komagatake Volcano, north-eastern Japan. *J. Japan. Assoc. Min. Petr. Econ. Geol.*, **68**, 101-124.
- Banno, S. and Matsui, Y. (1973), On the formulation of partition coefficients for trace element distribution between minerals and

- magma. *Chem. Geol.*, **11**, 1-15.
- Drake, M.J. (1976), Plagioclase-melt equilibria. *Geochim. Cosmochim. Acta*, **40**, 457-465.
- Ewart, A., Taylor, S.R. (1969), Trace element geochemistry of the rhyolitic volcanic rocks, central North Island, New Zealand, Phenocryst data. *Contrib. Mineral. Petrol.*, **22**, 127-146.
- Ewart, A., Bryan, W.B. and Gill, J.B. (1973), Mineralogy and geochemistry of the younger volcanic islands of Tonga, S.W. Pacific. *J. Petrology*, **14**, 429-465.
- Ewart, A., Taylor, S.R. and Capp, A.C. (1968), Trace and minor element geochemistry of the rhyolitic volcanic rocks, central North Island, New Zealand: total rock and residual liquid data. *Contrib. Mineral. Petrol.*, **18**, 76-104.
- Helz, R.T. (1979), Alkali exchange between hornblende and melt: a temperature-sensitive reaction. *Amer. Mineral.*, **64**, 953-965.
- Keil, K., Fodor, R.V. and Bunch, T.E. (1972), Contribution to the mineral chemistry of Hawaiian Rocks, II. Feldspars and interstitial material in rocks from Haleakala and West Maui Volcanoes, Maui, Hawaii. *Contrib. Mineral. Petrol.*, **37**, 253-276.
- Prigogine, I. and Defay, R. (1950), Chemical Thermodynamics (I) Japanese Translation by Senoo, M. (1966), Misuzu-Shobou, p. 261.
- Rammensee, W. and Fraser, D.G. (1982), Determination of activities in silicate melts by Knudsen cell mass spectrometry-I. The system $\text{NaAlSi}_3\text{O}_8$ - KAlSi_3O_8 . *Geochim. Cosmochim. Acta*, **46**, 2269-2278.
- Robie, R.A. and Waldbaum, D.R. (1968), Thermodynamic properties of minerals and related substances at 298.15°K and one atmosphere pressure and at high temperatures. *Geol. Surv. Amer. Bull.*, 1251.
- Robie, R.A., Hemingway, B.S. and Fisher, J.R. (1978), Thermodynamic properties of minerals and related substances at 298.15°K and 1 bar (10^5 pascals) pressure and at higher temperatures. *U.S. Geol. Surv. Bull.*, 1452.
- Saxena, S.K. (1973), Thermodynamics of Rock Forming Crystalline Solutions, Springer Verlag, 188 p.
- Seck, H.A. (1971), Koexistierende Alkalifeldspate und Plagioklase in System $\text{NaAlSi}_3\text{O}_8$ - KAlSi_3O_8 - $\text{CaAl}_2\text{Si}_2\text{O}_8$ - H_2O bei Temperaturen von 650°C bis 900°C. *N. Jb. Mineral. Abh.*, **115**, 315-345.
- Sen, S.K. (1959), Potassium content of natural plagioclases and the origin of antiperthites. *J. Geol.*, **67**, 479-495.
- Smith, A.L. and Carmichael, I.S.E. (1968), Quaternary lavas from the southern Cascades, Western U.S.A., *Contrib. Mineral. Petrol.*, **19**, 212-238.

APPENDIX: Description of samples

(1) augite-olivine basaltic andesite (# 177), Yakushiyama mass

Phenocryst: olivine (8.7 vol. %, the same as follows), augite (2.7%), pigeonite, microphenocryst: plagioclase (1%), groundmass: augite, pigeonite, orthopyroxene, titanomagnetite, plagioclase (ca. 50 %), and mesostasis. Microphenocryst plagioclase is tabular (100 by 400 microns), while groundmass plagioclase is thin tabular (10-20 by 100-200 microns). Microphenocryst plagioclase shows abrupt normal zoning at the rim. Groundmass plagioclase shows gradual normal zoning at the rim.

(2) orthopyroxene-augite-olivine andesite (# 101), Goshikidai mass.

Phenocryst: olivine (6.2%), augite (2.6%), orthopyroxene (1.8%), Xenocryst: rare quartz and plagioclase, groundmass: orthopyroxene, augite, plagioclase, opaque oxides and mesostasis with crystallites. Plagioclase shows long tabular form and its size is 5-100 by 30-300 microns. Coarse groundmass plagioclase (more than 30 microns thick) exhibits abrupt normal zoning at the rim. Because the volume of the core of coarse plagioclase is about 20% in this rock, the rim plagioclase might have crystallized from a little more differentiated magmas than the core plagioclase.

(3) Orthopyroxene andesite (# 111), Goshikidai mass

Phenocryst: orthopyroxene (1.5%), groundmass: orthopyroxene, opaque oxides, plagioclase, mesostasis. Groundmass plagioclase can be divided into coarse-grained (20-100 by 100-300 microns, ca. 20 vol. %) and fine-grained (5-10 by 20-50 microns, ca. 40%). The former displays step-like normal zoning at the rim.

(4) Hornblende-orthopyroxene-olivine sanukite (# 158), Goshikidai mass

Phenocryst: trace amounts of hornblende, orthopyroxene, olivine and plagioclase, groundmass: minute crystals of orthopyroxene, opaque oxide, plagioclase, and glass. The size of plagioclase phenocryst attains up to 5 mm with stout tabular form. The analyzed plagioclase phenocryst shows gradual reverse zoning in the core, and abrupt normal zoning at the rim. Plagioclase microphenocryst shows

step-like reverse zoning at the rim, where K_2O content of plagioclase decreases from the core to the rim.

(5) Garnet-biotite-hornblende-hypersthene rhyolite (# 197), Washinoyama mass

Phenocryst: garnet (0.0%), biotite (0.0%), hornblende (1.1%), hypersthene (1.7%), ilmenite (0.3%), plagioclase (7.9%), groundmass: orthopyroxene, opaque oxides, plagioclase, quartz, alkali-feldspar. Both normal and reverse zonings were observed within the core of plagioclase phenocryst. K_2O content of plagioclase correlates with albite content regardless of the type of zoning.

(6) Garnet-biotite rhyolite (# 168), Goshikidai mass

Phenocryst: trace amounts of garnet, biotite, ilmenite, plagioclase, microphenocryst: plagioclase, groundmass: plagioclase, glass with crystallites. Some of the phenocryst and microphenocryst plagioclase show abrupt reverse zoning at the rim, while others show abrupt normal zoning at the rim. The $Ca/(Na+Ca)$ ratio of the rim of these crystals are the same at about 0.44. The most calcic composition ($Ca/(Na+Ca)=0.83$) of the analyzed plagioclase represents the rounded core of plagioclase phenocryst bounded by the step-like normal zoning to the outer core ($Ca/(Na+Ca)=0.50$).

マグマ-斜長石間のカリウムの分配

佐藤 博 明

マグマ-斜長石間のカリウムの分配関係を次の反応式により検討した: $(NaAlSi_3O_8)_{plag} + (KAlSi_3O_8)_{magma} = (NaAlSi_3O_8)_{magma} + (KAlSi_3O_8)_{plag}$ この反応式の平衡条件は $\ln K = (8630 - 0.7T - 4130 X_{ab, pl}) / RT$ で表わせる。ここで, K, T, R は各々, 見かけの分配係数, 絶対温度, 気体定数であり, 又, $X_{ab, pl} = Na/(Na+Ca)_{plagioclase}$ である。この式は, 見かけの分配係数が, 温度と斜長石組成に強く依存することを示しているが, それらの効果は主に斜長石の $KAlSi_3O_8$ 溶解度に関する非理想性に由来する。上の式を用いて天然の火山岩の石基-斜長石の平衡温度を求めると, 流紋岩で 700-900°C, 安山岩類で 1100-1300°C と略各岩石の液相温度と調和的な値が求められた。