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POTASSIUM FELDSPARS FROM THE TAKAKUMAYAMA GRANITE, KAGOSHIMA PREFECTURE, JAPAN*

By

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Abstract

Potassium feldspars from the Takakumayama granite, Kagoshima Prefecture, Japan, composed of granodiorite and aplitic adamellite, have been studied by chemical and X-ray powder diffraction methods. Although analyzed potassium feldspars range from Or_{74} to Or_{80} in composition and possess monoclinic symmetry in structure, slight differences in composition and structure between potassium feldspars from the granodiorite and those from the aplitic adamellite were observed: the major compositional change from the former to the latter depends upon the $CaAl = (Na, K)Si$ substitution.

Composition of the analyzed potassium feldspars suggests that the crystallization temperature of the granodiorite was slightly higher than that of the aplitic adamellite. Heating experiments on the granite in air indicate that potassium feldspars and plagioclases in both of the granodiorite and of the aplitic adamellite begin to change compositionally and/or structurally at temperatures above 700°C and 800°C, respectively. Hydrothermal experiments on the granite in the presence of excess water suggest that the crystallization of potassium feldspar took place in a earlier stage during the formation of the granite than that of quartz at relatively high temperature and low pressure conditions.

Introduction

The Southwestern Outer Zone-type granitic rocks occur in the southern part of Kyushu, Japan. In the granitic rocks, there are some intrusive bodies characterized by zoned mineralogical and chemical variations. Physical and chemical properties of potassium feldspars from zoned granitic varieties will provide genetical informations during magmatic differentiation of the granitic rocks.

The Takakumayama granite is located in the central part of Osumi Peninsula, Kagoshima Prefecture, Japan (Fig. 1). The geology of the area, in which the granite is exposed, has been reported by OTA (1963) and OTA and KAWACHI (1965). Mineralogical work on the granite has scarcely been carried out, except for a few studies by

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SHIBATA *et al.* (1966) and TSUSUE (1973). Major attention in the present paper will be given to chemical and physical properties and to genetical considerations of potassium feldspars from the granite.

The Takakumayama Granite

The Takakumayama granite (Fig. 1) intrudes the Takakumayama Formation, the Late Mesozoic to Paleogene geosynclinal sedimentary complex. It is lithologically divided into two types of Shinkoji and Sarugajo (ISHIHARA and KAWACHI, 1961; KAWACHI, 1961). Rock of the Shinkoji-type is granodiorite by which the core of the granite body is constituted, and that of the Sarugajo-type is aplitic adamellite by which the margin of the body. The contact between the two types is gradational across a zone several hundred meters wide. The K-Ar age determination on biotite (MILLER *et al.*, 1962) indicates that the granite was emplaced during Late Miocene (16 m.y.). All the contacts between the granite body and the adjacent surrounding metamorphosed sedimentary rocks are extremely sharp.

The granodiorite is a light gray colored and coarse- to medium-grained rock with granular texture. It consists mainly of plagioclase (An_{22}-An_{44}), quartz, potassium feldspar, and biotite. The aplitic adamellite is a light-colored and medium- to fine-grained rock with semiporphyritic texture. It consists of quartz, potassium feldspar, plagioclase (An_{14}-An_{18}), and a small amount of biotite, garnet, muscovite, and tourmaline. Dark-colored small inclusions, which are mainly composed of cordierite, potassium feldspar and quartz, are characteristically found within the aplitic adamellite. Perthite and myrmekite are commonly found throughout the granite body.

Modal analyses (Table 1) of the granite show that plagioclase and biotite decrease in amount from the granodiorite into the aplitic adamellite, whereas potassium feldspar increases. Chemical analyses (Table 1) show that the content of Al_2O_3, Fe_2O_3+FeO, MgO, CaO, and H_2O^+ decreases from the former into the latter, whereas that of SiO_2 and Na_2O+K_2O increases. The differentiation index (D.I.: THORNTON and TUTTLE, 1960), the sum of the normative quartz, orthoclase and albite, increases from the former into the latter.

Description of Potassium Feldspars

1. Mode of Occurrence

Modal potassium feldspar of the Takakumayama granite tends to increase from the granodiorite of the Shinkoji-type into the aplitic adamellite of the Sarugajo-type (Table 1). Mode of occurrence of potassium feldspar is generally uniform throughout the specific rock types.

Potassium feldspar occurs in two habits: grains averaging 1 mm in length throughout the granite body, and larger ones averaging 5 mm found characteristically within

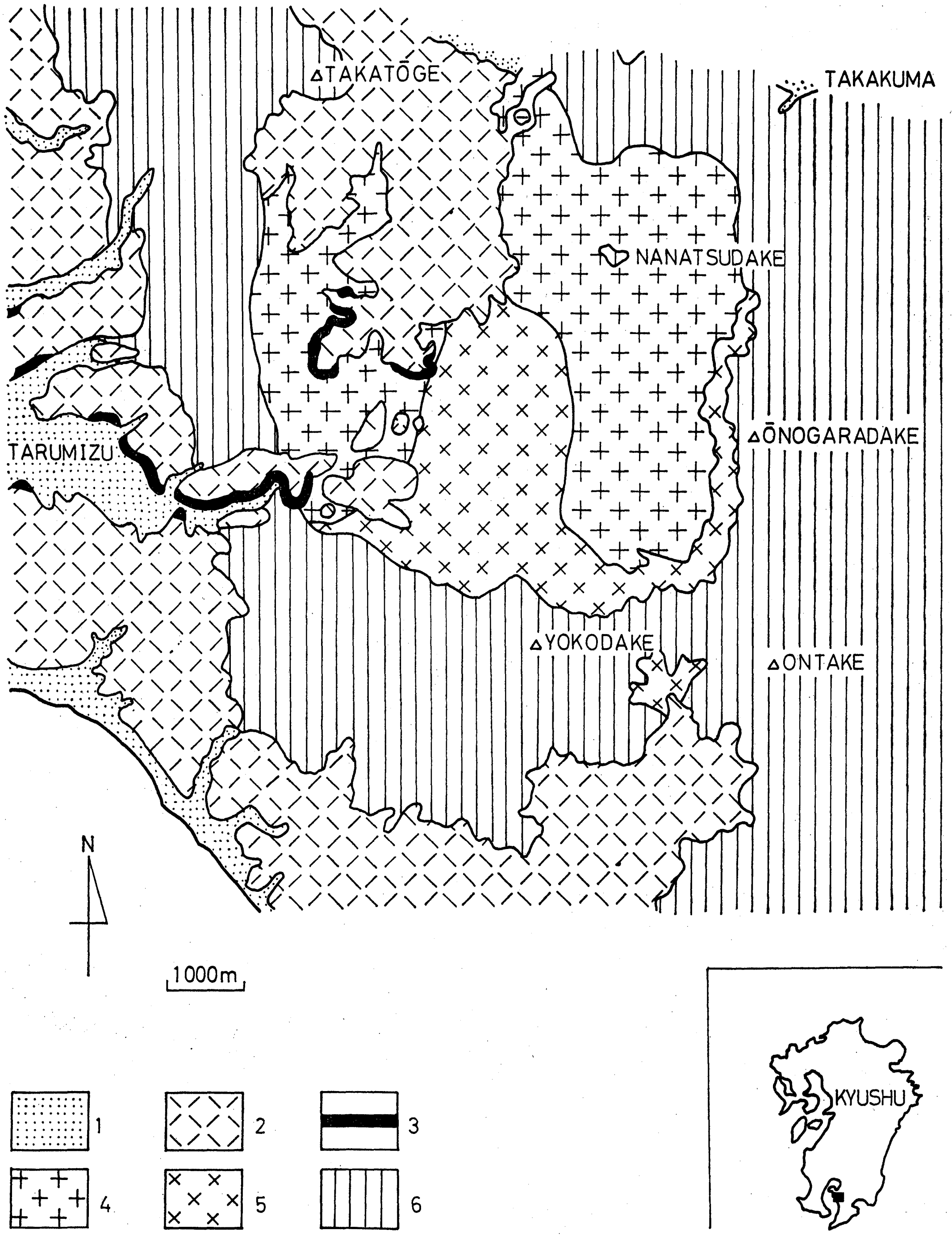

Fig. 1. Index and geologic maps of the Takakumayama granite and surrounding region. Stratigraphic sequence: 1. Alluvial deposits, 2. Pyroclastic flow deposits, 3. Onobaru sandstone and conglomerate and Tarumizu sand and gravel beds, 4 and 5. Takakumayama granite (4. Shinkoji-type, 5. Sarugajo-type), 6. Takakumayama Formation.
The geologic map is compiled from Ota (1963), Ota and Kawachi (1965), Ogura (1970), and Hamada (1970).

Table 1. Composition of the Takakumayama granite

Type	Shinkoji-type		Gradational zone		Sarugajo-type	
No.	TK21	TK01	TK04	TK05	TK07	TK09
Modal analyses						
Quartz	34.6	24.6	33.1	35.5	34.3	34.4
Potassium feldsapr	17.9	27.6	35.0	33.1	36.4	34.2
Plaigoclase	40.9	40.1	26.8	28.8	27.3	28.6
Biotite	6.0	6.7	4.4	2.5	1.2	1.2
Garnet	—	—	0.4	tr.	0.6	1.3
Muscovite	—	—	tr.	tr.	0.1	tr.
Tourmaline	tr.	tr.	0.2	tr.	tr.	tr.
Chlorite	0.4	0.7	tr.	tr.	tr.	tr.
Opaque minerals	0.1	0.2	tr.	tr.	tr.	0.2
Total	99.9	99.9	99.9	99.9	99.9	99.9
Chemical analyses*						
SiO_2	70.66	71.20	74.80	74.44	76.62	75.82
TiO_2	0.42	0.30	0.18	0.08	0.01	0.09
Al_2O_3	14.84	14.22	14.08	14.25	13.33	13.94
Fe_2O_3	0.24	1.01	0.16	0.66	0.19	0.19
FeO	1.78	1.47	0.65	0.69	0.60	0.48
MnO	tr.	0.07	0.03	0.03	tr.	tr.
MgO	1.00	0.97	0.39	0.31	0.13	0.25
CaO	2.77	2.40	1.34	1.27	0.70	0.74
Na_2O	2.23	2.88	3.54	3.06	3.41	3.30
K_2O	3.20	3.70	4.10	3.72	3.78	4.10
H_2O^+	2.16	1.14	0.62	0.66	0.62	0.32
H_2O^-	0.86	0.26	0.22	0.34	0.40	0.24
P_2O_5	0.09	0.08	0.02	0.03	0.02	0.03
Total	100.25	99.70	100.13	99.54	99.81	99.50
Norms						
Q	36.0	32.0	32.8	37.1	36.2	37.3
Or	20.0	22.5	24.5	22.5	23.5	24.5
Ab	21.0	26.5	32.0	28.5	32.5	30.0
An	13.5	11.5	7.0	6.5	4.0	3.5
C	3.3	1.5	1.5	3.2	2.5	3.2
Hy (En	3.0	2.8	1.2	1.0	0.4	0.6
Fs	2.2	1.4	0.6	0.4	0.8	0.4
Mt	0.3	1.1	0.2	0.8	0.2	0.2
Ol	0.6	0.4	0.2	0.2	tr.	0.2
Ap	0.3	0.3	tr.	tr.	tr.	tr.
D.I.**	77.0	81.0	89.3	88.1	92.2	91.8

* Analyses: TK01 and TK09 by J. Ogura (1970) and others by M. Yamamoto.

** Differentiation index of Thornton and Tuttle (1960).

the aplitic adamellite. In general, it occurs in anhedral to subhedral, irregularly-shaped grains with commonly Carlsbad or rarely cross-hatch twinning. Minor amounts of plagioclase and ferromagnesian minerals are sometimes found into potassium feldspar grains as inclusions.

2. Chemical Composition

Potassium feldspars were separated from the 60–100 mesh fraction of the crushed and sized rock material by a combination of magnetic separator and heavy liquid techniques. A thallium formate solution diluted with distilled water was used as the heavy liquid. No impurities were detected in X-ray powder diffraction patterns of the final potassium feldspar separate.

Chemical analyses and structural formulae of potassium feldspars from the granite are presented in Table 2. Compositions were determined by a combination of

Table 2. Composition of potassium feldsaprs from the Takakumayama granite

Type	Shinkoji-type		Gradational zone		Sarugajo-type	
No.	TK21	TK01	TK04	TK05	TK07	TK09
			Chemical analyses*			
SiO_2	64.00	64.16	64.20	64.20	64.44	65.12
Al_2O_3	19.14	19.34	18.94	19.05	18.94	18.83
Fe_2O_3	0.16	0.24	0.16	0.16	0.28	0.24
MgO	0.08	0.08	0.08	0.08	0.08	0.08
CaO	0.62	0.71	0.33	0.40	0.31	0.38
Na_2O	2.40	2.20	2.25	2.40	1.98	1.82
K_2O	12.36	12.73	12.94	12.55	12.79	12.16
H_2O^+ H_2O^-	0.96	0.80	0.96	1.08	0.84	1.20
Total	99.72	100.26	99.86	99.92	99.66	99.83
			Structural formulae**			
Si	11.833	11.797	11.875	11.863	11.895	11.978
Al	4.178	4.197	4.136	4.154	4.128	4.088
Fe^{+3}	0.022	0.044	0.022	0.022	0.044	0.044
Z	16.033	16.038	16.033	16.039	16.067	16.110
Mg	0.022	0.022	0.022	0.022	0.022	0.022
Ca	0.122	0.144	0.067	0.078	0.067	0.077
Na	0.867	0.773	0.801	0.866	0.710	0.641
K	2.911	2.982	3.046	2.955	3.018	2.851
X	3.922	3.921	3.936	3.921	3.817	3.591
Or	74.6	76.5	77.8	75.8	79.5	79.9
Ab	22.2	19.8	20.5	22.2	18.7	18.0
An	3.1	3.7	1.7	2.0	1.8	2.2

* Analyst: M. YAMAMOTO.

** Calculated on the basis of 32 oxygens per formula unit.

'standard' and 'ion exchange resin and chelate-titration' (OKI *et al.*, 1962) methods. Structural formulae were calculated on the basis of 32 oxygens per formula unit. The content of orthoclase, albite, and anorthite indicates the normative values recalculated to 100 per cent.

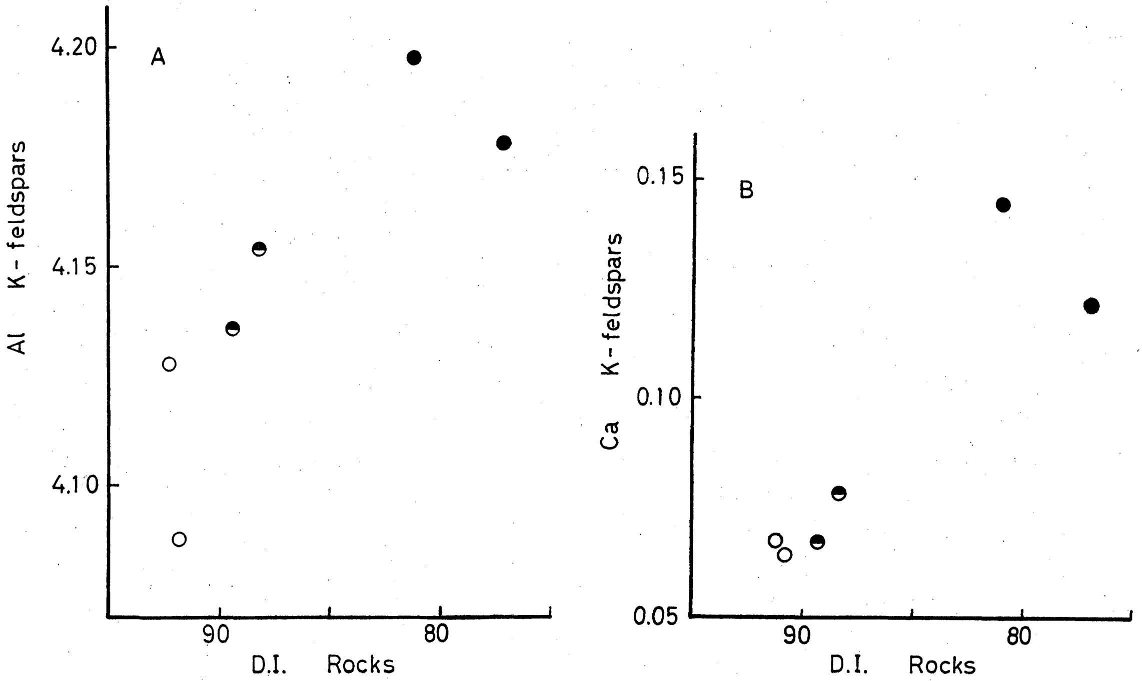

Fig. 2. Chemical variations of aluminum (A) and calcium (B) contents in analyzed potassium feldspars as a function of differentiation index (D.I.) of host rocks. Solid, half-solid, and open circles represent potassium feldspars from rocks in the Shinkoji-type, in the gradational zone, and in the Sarugajo-type, respectively.

Compositional variations of analyzed potassium feldspars are similar to those of host rocks. The Or-content increases slightly from potassium feldspars in the granodiorite into those in the aplitic adamellite, whereas the An-content decreases. Figure 2 shows the content of aluminum and calcium of the analyzed potassium feldspars as a function of differentiation index of the host rocks. In figure 2, solid, half-solid, and open circles represent potassium feldspars from rocks in the Shinkoji-type, in the gradational zone, and in the Sarugajo-type, respectively. It is clearly observed in Fig. 2 that the content of aluminum and calcium decreases from potassium feldspars in the granodiorite into those in the aplitic adamellite.

3. X-ray Powder Diffraction Data

The analyzed potassium feldspars were studied by X-ray powder diffraction techniques. X-ray patterns are similar to those of perthitic orthoclase, sanidine, or homogeneous orthoclase published by WRIGHT and STEWART (1968). 2θ values of $\bar{2}01$, 060, and $\bar{2}04$ reflections of the analyzed potassium feldspars are listed in Table 3. The 2θ values were determined by peaks of CuKα radiation ($\lambda=1.54178$ Å) scanned at a rate

Table 3. 2θ values of $\bar{2}01$, 060, and $\bar{2}04$ reflections of potassium feldsaprs from the Takakumayama granite*

Type	No.	$\bar{2}01$	060	$\bar{2}04$	Comp. **
Shinkoji-type	TK21 TK01	21.06 21.06	41.72 41.67	50.74 50.72	$Or_{86}Ab_{14}$ $Or_{86}Ab_{14}$
Gradational zone	TK04 TK05	21.06 21.02	41.72 41.71	50.74 50.72	$Or_{85}Ab_{15}$ $Or_{89}Ab_{11}$
Sarugajo-type	TK07 TK09	21.03 21.02	41.70 41.70	50.72 50.73	$Or_{88}Ab_{12}$ $Or_{89}Ab_{11}$

* Ni-filtered CuKα radiation (λ=1.54178 Å). Silicon external standard. 1° and 0.3 mm slits. 1/4° 2θ per min. scan speed.

** Composition estimated from $2\theta(\bar{2}01)$ data of alkali-exchanged orthoclase of WRIGHT and STEWART (1968) and WRIGHT (1968).

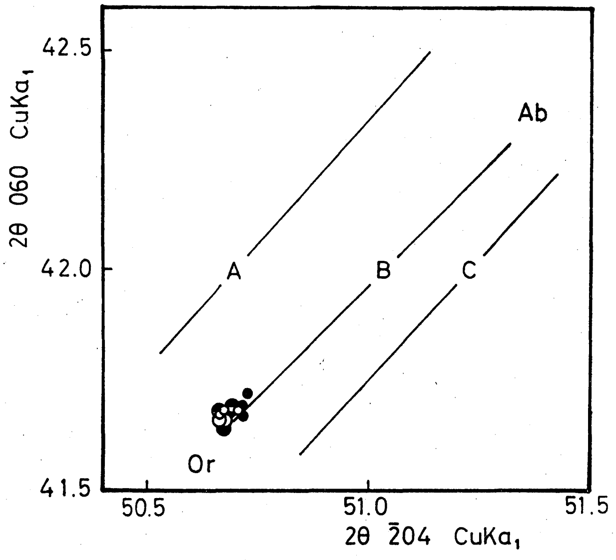

Fig. 3. Analyzed potassium feldspars plotted on the $2\theta(060)$–$2\theta(\bar{2}04)$ diagram simplified from WRIGHT (1968). Large circles correspond to those in Fig. 2. Small solid and open circles represent potassium feldspars after heating of rocks of the Shinkoji-type and the Sarugajo-type, respectively.

Curve A: Maximum microcline-low albite series.
Curve B: Alkali-exchanged orthoclase.
Curve C: High sanidine-high albite series.

of 1/4° 2θ per minute on chart scale of 1/8° 2θ per cm.

Figure 3 shows relation between the 2θ values of 060 and $\bar{2}04$ reflections of the analyzed potassium feldspars recalculated to CuKα_1 radiation (λ=1.54050 Å). In figure 3, large solid, half-solid, and open circles represent potassium feldspars from rocks in the Shinkoji-type, in the gradational zone, and in the Sarugajo-type, respectively. Curves A and C represent 'maximum microcline-low albite' and 'high sanidine-high albite' solid solution series of ORVILLE (1967), respectively. Curve B represents alkali-exchanged orthoclase of WRIGHT and STEWART (1968). Plots of the analyzed potassium feldspars fall within a small area near the orthoclase side of the curve B. On the other hand, 131 and $1\bar{3}1$ reflections are unsolved in all the X-ray powder diffraction patterns. Thus, the analyzed potassium feldspars possess monoclinic symmetry in structure, and are essentially of the orthoclase-low albite variety.

In table 3, the 2θ values of the $\bar{2}01$ reflection decrease slightly from potassium feldspars in the granodiorite into those in the aplitic adamellite. Composition of potassic phase was estimated from 2θ data of $\bar{2}01$ reflection of the alkali-exchanged orthoclase of Wright and Stewart (1968) and Wright (1968). The composition of potassic phase of the analyzed potassium feldspars ranges from Or_{85} to Or_{89}, and is higher as compared to the normative orthoclase content (see Table 2).

Genetical Considerations

The field and petrological observations of the Takakumayama granite show that both of granodiorite of the Shinkoji-type and of aplitic adamellite of the Sarugajo-type were genetically associated, and the crystallization of the granodiorite took place in a earlier stage than that of the aplitic adamellite. Distributions of the aplitic adamellite and the contact aureoles (Ota and Kawachi, 1965; Ogura *et al.*, 1970) and evidence of the sharp contacts with the country rocks suggest that the granite was emplaced at a relatively shallow depth. The amount of hydrous minerals, the content of water, and the textures of the granite suggest that the granodiorite was crystallized at a higher water vapor pressure condition as compared to the aplitic adamellite.

It is clearly observed in Fig. 2 that the content of aluminum and calcium decreases from potassium feldspars in the granodiorite into those in the aplitic adamellite. In general, the aluminum content of feldspars is changeable in substitution of potassium or sodium for calcium, although it is unchangeable in the substitution of potassium for sodium. It is considered, therefore, that the compositional change of the analyzed potassium feldspars depends upon the CaAl=(Na, K)Si substitution.

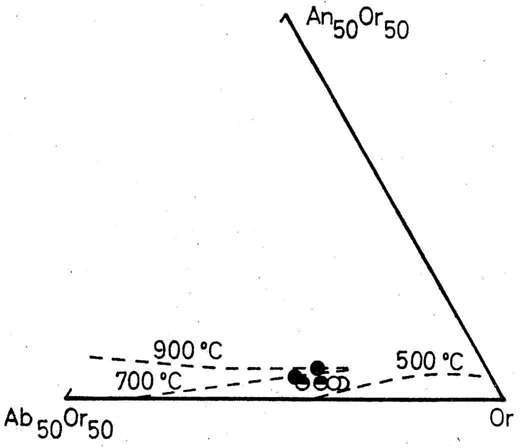

Fig. 4. Plots of analyzed potassium feldspars on the anorthite-albite-orthoclase ternary diagram. Dashed lines represent subsolidi of alkali feldspars at indicated temperatures by Barth (1962). The symbols same as Fig. 2.

Figure 4 shows composition of the analyzed potassium feldspars in the ternary diagram of anorthite-albite-orthoclase. In figure 4, solid, half-solid, and open circles represent potassium feldspars from rocks in the Shinkoji-type, in the gradational zone, and in the Sarugajo-type, respectively. Dashed lines represent subsolidi of alkali feldspars at temperatures of 900°C, 700°C, and 500°C determined by BARTH (1962). The subsolidi show that An-rich potassium feldspar crystallizes in higher temperatures compared to An-poor one. Therefore, the compositional change of the analyzed potassium feldspars suggests that the crystallization temperature of the granodiorite was slightly higher than that of the aplitic adamellite.

Table 4. 2θ values of $\bar{2}01$, 060, and $\bar{2}04$ reflections of potassium feldsaprs after heating of the Takakumayama granite in air

Type (No.)	Temp.	$\bar{2}01$	060	$\bar{2}04$	Comp.*
Shinkoji-type (TK01)	Unheated	21.06	41.67	50.72	$Or_{86}Ab_{14}$
	800°C	21.11	41.70	50.76	$Or_{82}Ab_{18}$
	900	21.20	41.73	50.76	$Or_{73}Ab_{27}$
	1000	21.23	41.75	50.78	$Or_{71}Ab_{29}$
Sarugajo-type (TK09)	Unheated	21.02	41.70	50.73	$Or_{89}Ab_{11}$
	800°C	21.10	41.71	50.72	$Or_{82}Ab_{18}$
	900	21.21	41.71	50.73	$Or_{73}Ab_{27}$
	1000	21.33	41.72	50.75	$Or_{62}Ab_{38}$

* See footnote, table 3.

Heating experiments on the granite were carried out by the ordinary quenching method from 800°C up to 1000°C in air. 2θ values (CuKα radiation) of $\bar{2}01$, 060, and $\bar{2}04$ reflections of potassium feldspars after heating of the granite are listed in Table 4. The 2θ values of 060 and $\bar{2}04$ reflections of heated potassium feldspars recalculated to CuKα_1 radiation were plotted in Fig. 3. In figure 3, small solid and open circles represent heated potassium feldspars from the granodiorite and the aplitic adamellite,

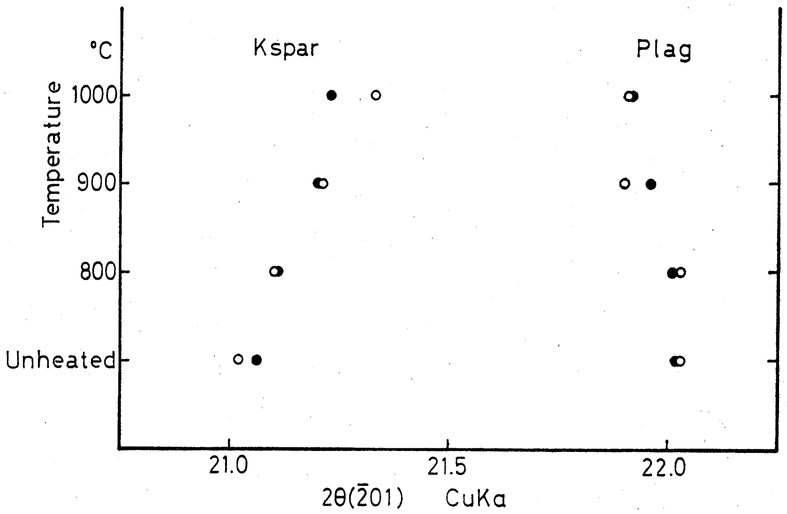

Fig. 5. 2θ values of $\bar{2}01$ reflections of coexisting potassium feldspars and plagioclases after heating of the Takakumayama granite as a function of temperature. Solid and open circles represent coexisting potassium feldspars and plagioclases from rocks in the Shinkoji-type and in the Sarugajo-type, respectively.
Kspar: Potassium feldspars, Plag: Plagioclases.

respectively. The 2θ values of heated potassium feldspars don't change largely in temperatures below 1000°C as compared to those of the unheated ones. WRIGHT (1968) has demonstrated that the *b* and *c* cell dimensions are related to the 2θ values of the 060 and $\bar{2}04$ reflections, respectively. Thus, the structural state and the *b* and *c* cell dimensions of the analyzed potassium feldspars were unchangeable during the heating experiments.

On the other hand, the 2θ values of $\bar{2}01$ reflection of the heated potassium feldspars begin to shift to higher angle at temperature above 700°C as compared to those of the unheated ones (Fig. 5). According to the experimental studies on the albite-orthoclase solid solution series by BOWEN and TUTTLE (1950) and on the natural granite system by ROBERTSON and WYLLIE (1971), crystallization temperature of potassium feldspar indicates the maximum temperature in dry conditions. It is suggested, therefore, that the analyzed potassium feldspars may have been formed in temperatures below 800°C during the formation of the granite.

Table 5. 2θ values of $\bar{2}01$ reflection of plagioclases after heating of the Takakumayama granite in air

Type (No.)	Temp.	$\bar{2}01$
Shinkoji-type (TK01)	Unheated	22.02
	800°C	22.01
	900	21.96
	1000	21.92
Sarugajo-type (TK09)	Unheated	22.03
	800°C	22.03
	900	21.90
	1000	21.91

Similarly, 2θ values of $\bar{2}01$ reflection of plagioclases after the heating of the granite are listed in Table 5. The 2θ values of heated plagioclases begin to shift to lower angle at temperature above 800°C as compared to those of the unheated ones. It is also suggested that plagioclases may have been crystallized in temperatures below 900°C during the formation of the granite.

Finally, hydrothermal experiments on the granite were carried out in the presence of excess water at 750°C in temperature and 1000 bars in total pressure. Mineral assemblages in both runs of the granodiorite and the aplitic adamellite are plagioclase-potassium feldspar-biotite. This fact suggests that the crystallization of potassium feldspar took place in a earlier stage than that of coexisting quartz at relatively high temperature and low pressure conditions.

The above-mentioned genetical considerations of potassium feldspars don't contradict with the field observations, the petrography and the petrochemistry of the Takakumayama granite.

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