

Studies on the Alkali Feldspars from Kii Province, Japan

By

Kunio TSUJIMURA

(Received March 30, 1971)

Abstract

The alkali feldspars which occur as phenocrysts in the granite porphyry of a dike lying from Kurozu to Taiji in the southern part of Kii Prov., Japan were found to be composed of the following phases.

(a) Specimen from Sabe consists of two monoclinic potash-rich and one triclinic soda-rich phases.

(b) Specimen from Oyanagi consists of one monoclinic potash-rich and one triclinic soda-rich phases.

(c) Specimen from Uragami consists of two monoclinic potash-rich phases.

(d) Specimen from Tsukinose is of one monoclinic potash-rich phase.

These phases are all submicroscopic and can only be observed by X-ray diffractions.

Introduction

In the southern part of Kii Prov. there are tertiary formations which are intruded by dikes. These dikes are composed of liparite and granite porphyry, maximum width and length of which being about 1 km and 25 km respectively.

These dikes run eastwards along Koza River from Kurozu to Utsugi, then, changing in direction, run northeastwards and in the vicinity of Uragami sink into the ocean. But the dikes appear again in Taiji (Fig. 1).

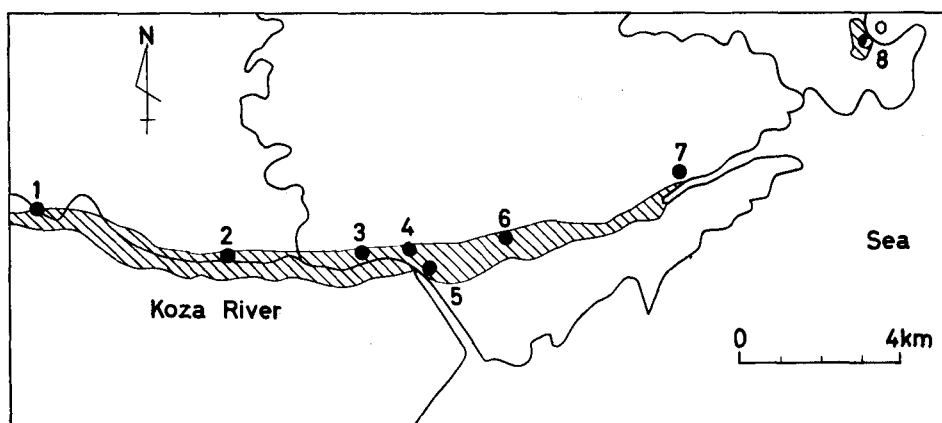


Fig. 1. Showing the localities of the dikes which are composed of liparite and granite porphyry.
1; Kurozu, 2; Oyanagi, 3; Tsukinose, 4; Utsugi, 5; Takaike, 6; Sabe, 7; Uragami, 8; Taiji.

KIMIZUKA (1932) examined feldspar from the dike near Taiji chemically, optically and morphologically and called it *Potash anorthoclase*. He reported that the feldspar varied from $\text{Or}_{66} \text{Ab}_{31} \text{An}_3$ to $\text{Or}_{66} \text{Ab}_{32} \text{An}_2$ and from $17^\circ 39' 44''$ to $18^\circ 15' 00''$ in the optic axial angle, the optic axial plane lying approximately perpendicular to (010), perpendicular to (201). Axial angles which were calculated by using the reflection goniometer were $\alpha = 90^\circ 08' 48''$, $\beta = 116^\circ 06' 36''$ and $\gamma = 90^\circ 13' 14''$.

AOKI (1963) identified the potash feldspar from Taiji as sanidine on the basis of the chemical compositions and optical properties, the molecular percentage being $\text{Or}_{72.5} \text{Ab}_{25.9} \text{An}_{1.6}$, the optic axial angle ranging from 16° to 31° and the optic axial plane lying perpendicular to (010). He plotted these data into the diagram which shows the relationship between the chemical compositions and optical properties. He said that the feldspar belonged to low temperature sanidine-high temperature albite series and that an ordering from sanidine to orthoclase had not taken place at all.

Up to the present time, two opinions have thus proposed. Recently, the author has investigated the alkali feldspars chemically, optically and röntgenographically, which occur as phenocrysts in the granite porphyry of the dike. In the following, details will be given.

Optical and chemical properties

(1) Optics

No perthite structures can be observed in any thin sections of the alkali feldspars from the localities such as Sabe, Oyanagi, Urugami, Utsugi, Tsukinose and Taiji under the microscope.

The refractive indices were determined by the immersion method using a mixture of cedar oil and cassia oil. Results obtained are given in Table 1.

Table 1. Refractive indices of the alkali feldspars which form the phenocrysts of the granite porphyry.

Locality	Ref. Ind.			
	α	β	γ	$\gamma - \alpha$
Sabe	1.519	1.522	1.528	0.009
Oyanagi	1.520	1.524	1.528	0.008
Utsugi	1.520	1.525	1.527	0.007
Tsukinose	1.520	1.524	1.527	0.007
Taiji	1.521	1.525	1.531	0.010
Urugami	1.520	1.524	1.529	0.009

The results suggest that the alkali feldspars which form the phenocrysts of the granite porphyry vary in chemical compositions. However, when these data were plotted into the diagram devised by TUTTLE (1952, b), any systematic relations could not be observed.

(2) Chemical compositions by X-ray powder method

BOWEN and TUTTLE (1950) showed that chemical compositions of natural alkali feldspars could be estimated by the 201 spacings in X-ray powder patterns. Chemical compositions obtained from the measurements of 201 spacing are given below:

Locality	Chemical composition
Sabe	Or ₇₃ Ab ₂₇
Oyanagi	Or ₇₇ Ab ₂₃
Uragami	Or ₈₃ Ab ₁₇
Utsugi	Or ₈₃ Ab ₁₇
Tsukinose	Or ₆₇ Ab ₃₃
Taiji	Or ₇₇ Ab ₂₃

The X-ray powder patterns were taken by using Norelco diffractometer under the following conditions:

Radiation	CuK α	Filter	Ni
Voltage	30 KVP	Current	10 mA
Chart Speed	5 mm/min.	Scanning Speed. ...	$\frac{1}{4}^{\circ}$ /min.
Scale Factor	4	Multiplier	1
Time Constant	4 sec.		

(3) Chemical analyses

The chemical analyses of the specimens from Taiji and Tsukinose were made by the usual method.

In order to get pure materials for chemical analyses, the specimens were crushed into 150–200 mesh and foreign enclosures, such as biotite and quartz, were picked up under the binocular microscope.

Results of the analyses were given in Table 2. Results of the analyses made by USHIJIMA (1932) and AOKI (1963) were also given in Table 2 for comparison.

Molecular percentages calculated are as follows:

- (1) Or_{72.7} Ab_{24.7} An_{2.6} (2) Or_{67.9} Ab_{29.0} An_{3.1}
 (3) Or_{72.5} Ab_{25.9} An_{1.9} (4) Or_{66.0} Ab_{32.0} An_{2.0}

These experimental results are approximately in agreement with the chemical compositions obtained from the X-ray powder method.

Table 2. Chemical compositions of the alkali feldspars from Tsukinose and Taiji.

	(1)	(2)	(3)	(4)
SiO ₂	64.32%	64.42%	64.59%	64.65%
TiO ₂	0.09	0.18	—	—
Al ₂ O ₃	18.74	18.68	18.99	19.43
Fe ₂ O ₃	0.38	0.49	0.24	0.04
FeO	0.57	0.58	0.21	
MgO	0.27	0.34	—	0.03
CaO	0.54	0.55	0.31	0.38
Na ₂ O	2.71	2.86	2.90	3.71
K ₂ O	12.13	10.17	11.62	10.97
H ₂ O(—)	0.20	0.18	0.10	0.30
H ₂ O(+)	0.81	1.29	0.90	0.50
Total	100.76	99.74	99.86	100.01

1; Alkali feldspar from Tsukinose. (Analyst; K. TSUJIMURA)

2; Alkali feldspar from Taiji. (Analyst; K. TSUJIMURA)

3; Sanidine from Taiji. (Analyst; K. AOKI, 1963)

4; Potash anorthoclase from Taiji. (Analyst; N. USHIJIMA, 1932)

X-ray studies

(1) Experimental observations

The author investigated the alkali feldspars from Sabe, Oyanagi, Uragami, Tsukinose and Taiji using the X-ray single crystal method.

The author took the rotation photographs and equi-inclination Weissenberg photographs of the feldspars about the *a*- and *b*-axes and in some case also about the *c*-axis.

A. The specimen from Sabe

To determine whether the alkali feldspar from Sabe is monoclinic or triclinic, equi-inclination Weissenberg photographs of the 0th, 1st and 2nd levels about the *b*-axis were taken.

In the *b*-axis equi-inclination Weissenberg photographs of the 0th, 1st and 2nd layers, three sets of diffraction spots could be observed. They constitute three kinds of reciprocal lattices respectively. In 0-layer Weissenberg diagram about the *b*-axis, three *a**-axes and two *c**-axes can be drawn (Fig. 5A). In 0-layer Weissenberg diagram about the *a*-axis, two *c**-axes can be drawn. This fact shows that two constituent phases of the three are intergrown in common with the *c**-axis.

In the 1st and 2nd levels equi-inclination Weissenberg photographs about the b -axis, the slanting straight lines on which $h10$, $h20$ and $02l$ reflections of the two constituent phases of the three could be observed. This indicates that the two constituent phases of the three are monoclinic. Here after one will be denoted (1_s) , and the other will be (2_s) . On the other hand, $h10$, $h20$ and $02l$ reflections due to the third phase do not arrange in slanting straight lines. Accordingly the third one is a triclinic phase (denoted (3_s)). These three lattices are C -centered, since hkl reflections appear only when $h+k=2n$.

In the b -axis rotation photograph of the crystal, all the spots to appear arranged perfectly on the layer lines. This fact indicates that the b -axes of the

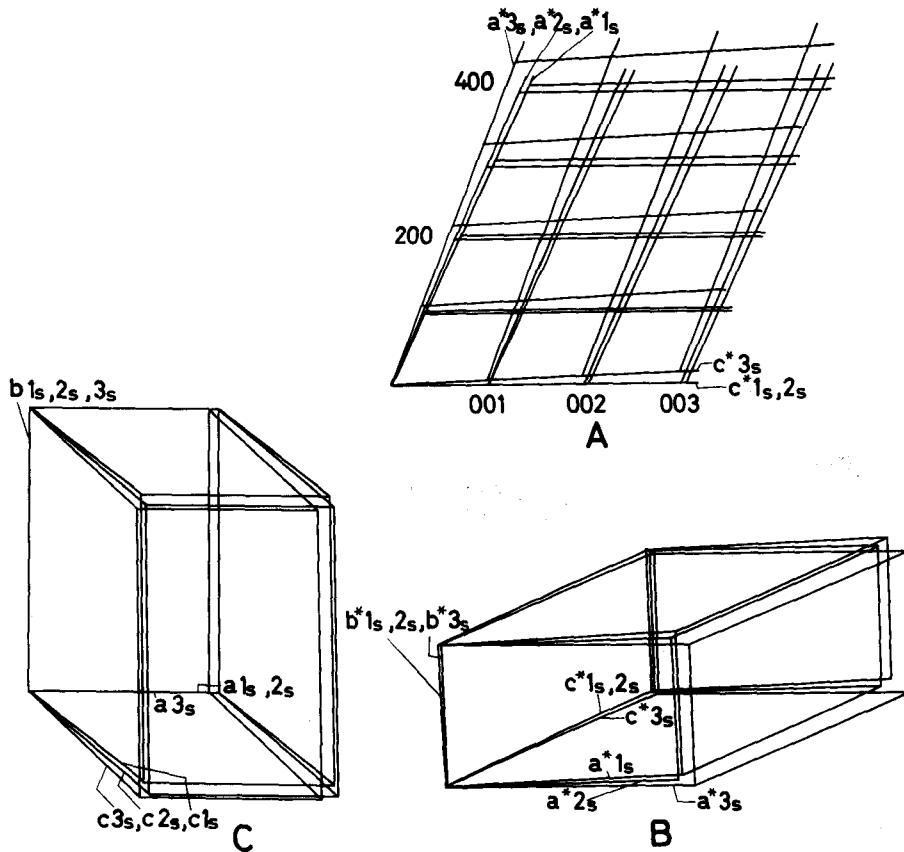


Fig. 2. A; The reconstruction of three constituent reciprocal $h0l$ planes of alkali feldspar from Sabe. B; The reconstruction of three constituent reciprocal lattices (from Sabe). C; The reconstruction of three constituent direct lattices (from Sabe).

three constituent feldspars are equal in length and parallel in direction.

The a -axis rotation photograph of the feldspar was also taken. Two sets of layer lines could be observed. One belongs to $1kl$, $2kl$, $3kl$, reflections of the two monoclinic phases and the other belongs to those of the triclinic phase. This fact can be proved by the existence of the b^* - and c^* -axes of the three phases in 0-level Weissenberg photograph about the a -axis. This indicates that the a -axes of the triclinic phase and the two monoclinic phases are not equal in length, but parallel in direction each other and the a -axes of the two monoclinic phases are equal in length and parallel in direction. With respect to the crystallographic orientations of these constituent phases in the reciprocal space, the c^* -axis of the monoclinic phase (1_s) coincides with that of the other monoclinic phase (2_s) in direction, as said above (Fig. 2A). Accordingly, the b^* -axes of both monoclinic phases, of course, coincide in direction each other (Fig. 2B). In real space, it can be concluded that the triclinic phase (3_s) and the two monoclinic phases (1_s), (2_s) are connected with the common b -axis, and that the a -axes of the three are parallel in direction (Fig. 2C).

According to their lattice constants (Table 3), it was found that the two C -centered monoclinic phases are rich in potash and the C -centered triclinic phase is rich in soda. The triclinic phase may be identified as anorthoclase. The author will discuss once again in detail later on.

B. The specimen from Oyanagi

In the rotation photograph about the b -axis of the specimen from Oyanagi, all the spots to appear arranged perfectly on the layer lines. Though the spots in the rotation photograph about the a -axis of the specimen arranged perfectly on the layer lines, each of them were doubled. One is the reflections from a C -centered monoclinic phase (denoted (1_o), and the other from a C -centered triclinic phase (denoted (2_o)). The determination of the symmetries were done by observing the equi-inclination Weissenberg photographs of the 0th, 1st and 2nd layer lines about the b -axes (see the diagram of the 0th; Fig. 5B).

With respect to their crystallographic orientations, the b -axes of the monoclinic phase and the triclinic phase are equal in length and parallel in direction. The a -axes of the both are coincidental in direction, but not equal in length. In the 0-level Weissenberg photographs about the a - and b -axis, the c^* -axis of the C -centered monoclinic lattice very nearly coincides with that of the C -centered triclinic lattice in direction (Fig. 3A). The reconstruction of the two direct lattices is shown in Fig. 3B.

According to their lattice constants (Table 3), it was shown that the constituent monoclinic phase is rich in potash and the triclinic phase is rich in soda. The

triclinic phase may be identified as anorthoclase. Chemical compositions of the two constituent phases and the identification of the triclinic phase will be referred again later on.

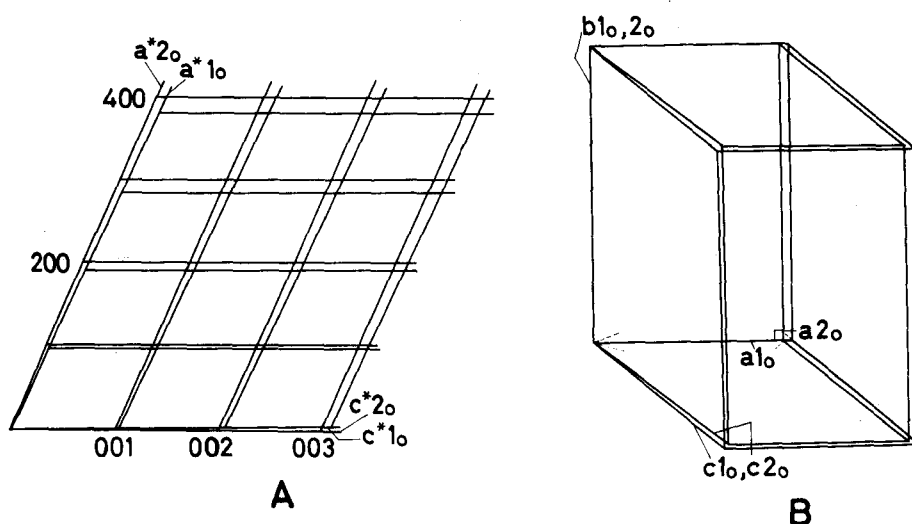


Fig. 3. A; The reconstruction of two constituent reciprocal $h0l$ planes of alkali feldspar from Oyanagi. B; The reconstruction of two constituent direct lattices (from Oyanagi).

C. The specimen from Uragami

In the rotation photographs about the a - and b -axis, all the spots to appear arranged perfectly on the layer lines. The 0-level Weissenberg photograph about the b -axis showed that the reciprocal lattice points could be divided into two groups (see the diagram; Fig. 5C). By higher level equi-inclination Weissenberg photographs, it was indicated that the both phases were monoclinic.

With respect to their crystallographic orientations, it was pointed out that the a - and b -axes of the two monoclinic phases (the one denoted as (1_u) the other as (2_u)) are perfectly parallel in direction and equal in length each other. The reconstruction of the two monoclinic lattices are given in Fig. 4A (reciprocal space) and Fig. 4B (real space).

The lattice constants indicate that the monoclinic constituent phases are rich in potash. The author will refer to the chemical compositions later on.

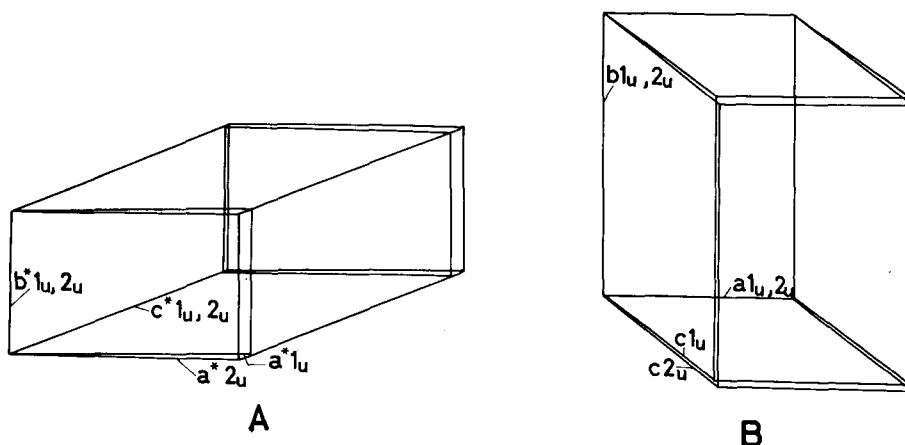


Fig. 4. A; The reconstruction of two constituent reciprocal lattices of alkali feldspar from Uragami. B; The reconstruction of two constituent direct lattices (from Uragami).

D. The specimen from Tsukinose

By the rotation and Weissenberg photographs (0th, 1st and 2nd) about the a -, b - and c -axis, the specimen from Tsukinose was found to be of only one monoclinic phase. The lattice constants indicate that the monoclinic feldspar is rich in potash.

E. The specimen from Taiji

In the rotation photograph about the b -axis, the spots to appear arranged on the layer lines. The 0-level Weissenberg photograph about the b -axis indicated that the three kinds of the reciprocal lattices might exist. In higher level equi-inclination Weissenberg photographs about the b -axis, it was shown that two of them were monoclinic. The lattice constants of these two monoclinic phases (one denoted as (1_t) , the other as (2_t)) indicate to be rich in potash. As to the rest, it is characteristic that diffuse spots can be observed.

The crystallographic orientations between the phase displayed diffuse diffractions (denoted (3_t)) and the two monoclinic phases could not be made clear. The orientation of the two monoclinic potash phases are not simply related to the orientation of the phase displayed diffuse diffractions.

When the feldspar under examination was stained by using cobaltinitrite and barium rhodizonate as reagents, potash-rich part and soda-rich part were distinguished at a glance. As the potash-rich part corresponds to two monoclinic phases, the soda-rich part will correspond to the phase displayed diffuse diffractions. The soda-rich phases are usually triclinic, with the exception of soda-rich monoclinic

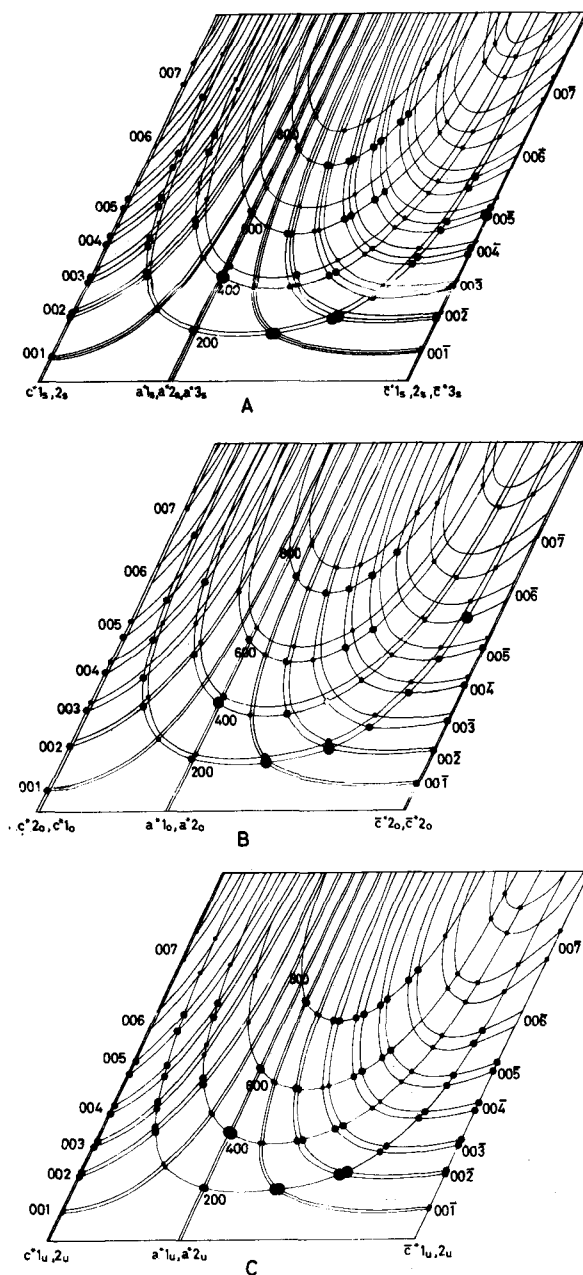


Fig. 5. A; 0-layer Weissenberg diagram about the b -axis of alkali feldspar from Sabe. B; C-layer Weissenberg diagram about the b -axis (from Oyanagi). C; 0-layer Weissenberg diagram about the b -axis (from Uragami).

phase (2) in moonstone studied by Ito (1950). Consequently, the author is of the opinion that the phase displayed diffuse diffractions, may be triclinic and rich in soda. LAVES (1950) thought that the diffuse streaks could be explained by partial transformation from a monoclinic potash feldspar, which is unstable at low temperature, to a triclinic modification, which may be either microcline, triclinic adularia, or both. In such a case, the monoclinic potash feldspar and the transformed triclinic one make no great difference in chemical compositions. Accordingly, the diffuse diffractions which were observed in the present study can not be explained by the transformation.

(2) Determination of lattice constants

The measurements of the lattice constants of the feldspars were made by Weissenberg method. In order to get the accurate values, the *a*- and *b*-axis Weissenberg photographs were taken using $\text{CuK}\alpha$ radiation. The radius of Weissenberg camera (made by Nonius) was corrected by the powder photographs of Si at room temperature. The radius of the camera was 28.2 mm. The direct lattice constants calculated are given in Table 3.

Table 3. Lattice constants of constituent phases of the alkali feldspars from Sabe, Oyanagi, Uragami, Tsukinose and Taiji.

Locality	Constituent phase		<i>a</i> (Å)	<i>b</i> (Å)	<i>c</i> (Å)	α	β	γ
Sabe	Monoclinic (1 _s)		8.56	12.99	7.18	90°00'	116°02'	90°00'
	Monoclinic (2 _s)		8.56	12.99	7.15	90°00'	115°34'	90°00'
	Triclinic (3 _s)		8.14	12.99	7.16	91°37'	116°23'	90°00'
Oyanagi	Monoclinic (1 _o)		8.56	12.99	7.18	90°00'	116°02'	90°00'
	Triclinic (2 _o)		8.14	12.99	7.13	91°15'	115°57'	90°00'
Uragami	Monoclinic (1 _u)		8.56	12.99	7.17	90°00'	115°56'	90°00'
	Monoclinic (2 _u)		8.56	12.99	7.15	90°00'	115°36'	90°00'
Tsukinose	Monoclinic		8.56	12.99	7.18	90°00'	116°02'	90°00'
Taiji	Monoclinic (1 _t)		8.56	12.99	7.18	90°00'	116°02'	90°00'
	Monoclinic (2 _t)		8.56	12.99	7.15	90°00'	115°34'	90°00'
	Triclinic (?) (3 _t)		—	—	—	—	—	—

(3) Chemical compositions and identification of constituent phases

The lattice constants of orthoclase, sanidine and albite have been reported as

follows:

	Orthoclase	Sanidine	Albite
<i>a</i>	8.56(A)	8.56(A)	8.14(A)
<i>b</i>	13.00	13.03	12.79
<i>c</i>	7.19	7.18	7.16
α	90°00'	90°00'	94°20'
β	116°01'	115°59'	116°34'
γ	90°00'	90°00'	87°39'

Comparing the lattice constants of the specimens under examination (Table 3) with the lattice constants above described, it is clarified that the monoclinic constituent phases of the alkali feldspars from Sabe, Oyanagi, Uragami, Tsukinose and Taiji are rich in potash and the triclinic constituent phases of the alkali feldspars from Sabe and Oyanagi are rich in soda.

Values of α^* and γ^* of the triclinic phases from Sabe and Oyanagi, measured by the author were plotted into the diagram after MACKENZIE and SMITH (1956) (Fig. 6). The values lie approximately on the line of high temperature alkali feldspars (synthetic anorthoclases). The triclinic phases of the feldspars from Sabe and Oyanagi may be anorthoclase. These chemical compositions determined by the method of the proportional allotments are as follows:

Triclinic phase (3s) (from Sabe); $\text{Or}_{27}\text{Ab}_{73}$

Triclinic phase (2o) (from Oyanagi); $\text{Or}_{30}\text{Ab}_{70}$.

Consideration

LAVES (1950) showed that exsolved soda phases were twinned after either albite law or pericline law and that the soda feldspar was sometimes present in a slightly different form, which afterwards was recognized as that of high temperature albite. The author found the feldspars from Sabe and Oyanagi in which exsolved soda-rich phases present in an untwinned form.

ITO and SADANAGA (1952) showed that soda feldspar twinned after albite law was sole companion of potash feldspar when the latter was more than 70%. If the potash feldspar is less than 70%, soda feldspar twinned after pericline law appears in addition to one twinned after albite law. The ratio of the latter to the former decreases as the potash feldspar becomes less than 50%. When the percentage of potash feldspar becomes as low as 40%, the soda feldspar twinned after albite law disappears entirely leaving soda feldspar twinned after pericline law alone.

The author found a feldspar containing two monoclinic potash phases and one triclinic soda phase (from Sabe) and a feldspar containing one monoclinic potash phase and one triclinic soda phase (from Oyanagi). These exsolved soda phases shows neither albite twinning nor pericline twinning. The results do not agree

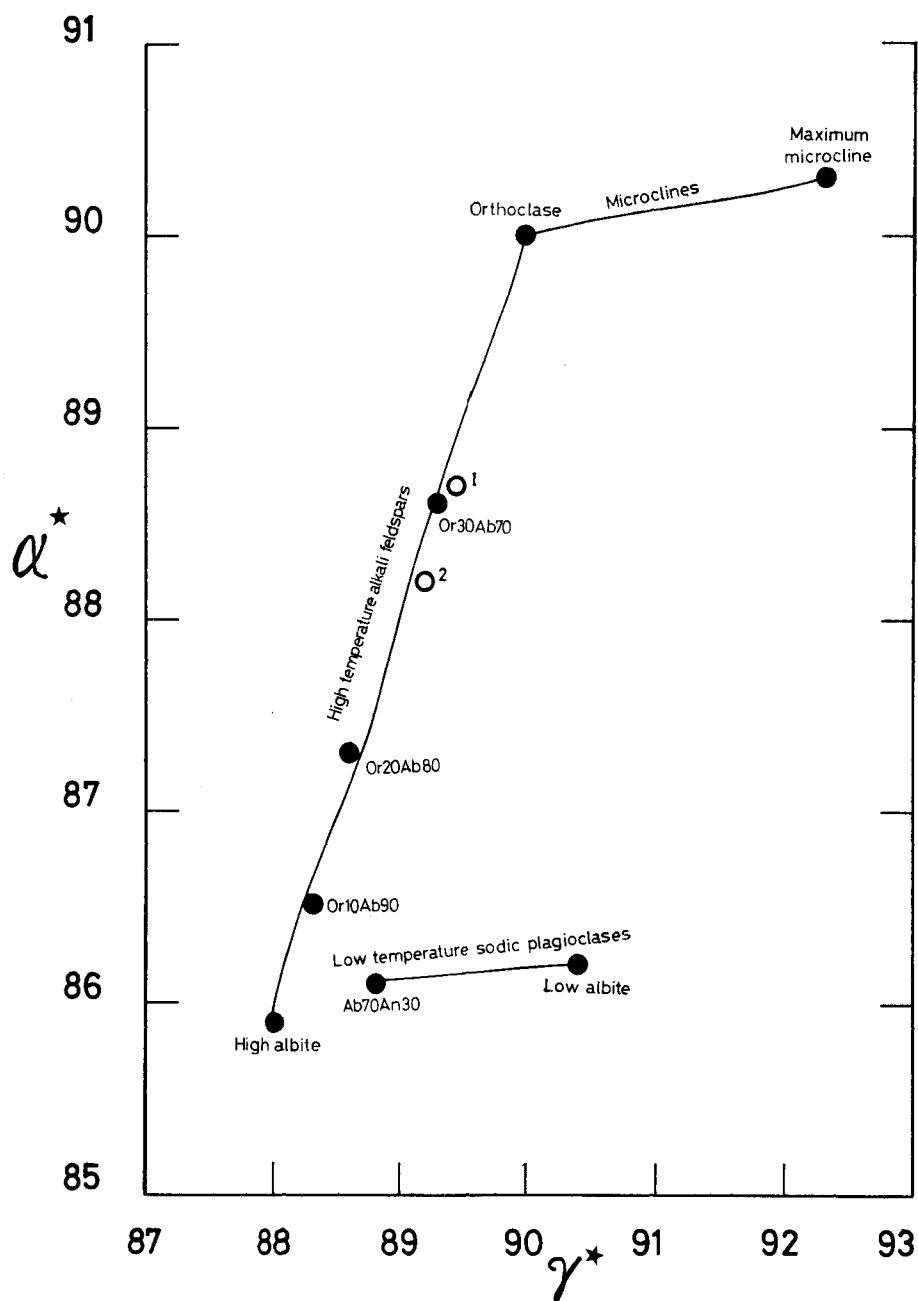


Fig. 6. Showing the relationship between the values of α^* and γ^* and the chemical compositions represented as Or-Ab or Ab-An of the feldspar (MACKENZIE & SMITH, 1956).
 1; Triclinic phase (2_o) (from Oyanagi) 2; Triclinic phase (3_s) (from Sabe)

with those reported by ITO and SADANAGA. Accordingly, it might be indicated that there is no causality between the twinning and the bulk chemical composition.

LAVES (1950) showed that exsolved feldspar is sometimes present in one form identical with low temperature albite. The author found the exsolved soda feldspar having one form, however, not identical with low temperature albite but maybe identical with anorthoclase.

Conclusion

The alkali feldspars which occur as phenocrysts in the granite porphyry of a dike lying from Kurozu to Taiji in the southern part of Kii Prov., Japan were found to be the associations of the following phases:

- (a) Two monoclinic potash-rich and one triclinic soda-rich phases (specimen from Sabe),
 - (b) One monoclinic potash-rich and one triclinic soda-rich phases (specimen from Oyanagi),
 - (c) Two monoclinic potash-rich phases (specimen from Uragami),
 - (d) One monoclinic potash-rich phase (specimen from Tsukinose),
 - (e) Two monoclinic potash-rich phases and one phase (possibly, triclinic and soda-rich) displayed diffuse diffractions by an X-ray (specimen from Taiji).
- These constituent phases are all submicroscopic and only be observed by X-ray diffractions.

Acknowledgment

The author wishes to express his sincere thanks to Dr. T. UEDA who gave him useful advice throughout this work and to his critical reading of the manuscript. The author is also indebted to Prof. I. HAYASE who kindly gave him a specimen from Taiji used in the present study.

References

- AOKI, K. (1963): The chemical compositions and optical properties of sanidine from Kii Province, Japan. *Jour. Jap. Assoc. Min. Petr. Econ. Geol.*, **50**, pp. 132-133. (in Japanese).
- BAILEY, E.H. and R.H. STEVENS (1960): Selective staining of K-feldspar and plagioclase on rock slabs and thin section. *Amer. Min.*, **45**, pp. 1020-1025.
- BOWEN, N.L. and O.F. TUTTLE (1950): The system $\text{NaAlSi}_3\text{O}_8$ - KAlSi_3O_8 . *Jour. Geol.*, **58**, pp. 489-511.
- ITO, T. (1950): *X-Ray studies on polymorphism*. Maruzen.
- ITO, T. and R. SADANAGA (1952): The lamellar structure of certain microcline and anorthoclase. *Acta Cryst.*, **5**, pp. 441-449.
- KIMIZUKA, K. (1932): A study of potash anorthoclase from Taiji, Kii Province, Japan. *Jap.*

Jour. Geol. Geogr., **9**, pp. 213-242.

LAVES, F. (1950): The lattice and twinning of microcline and other potash feldspars. *Jour. Geol.*, **58**, pp. 548-569.

MACKENZIE, W.S. and J.V. SMITH (1955): The alkali feldspars. *Amer. Min.*, **4**, pp. 707-732.