Abstract

The Yamato Sanmyaku is a mountain range located about 200 km south of Prins Harald Kyst, East Antarctica. The mountains are composed of charnockitic group and granitic group rocks which were described geologically and petrographically by K. KIZAKI (1965). The present paper deals with the potash feldspars from the charnockitic group and pegmatites. The occurrence of the potash feldspars and their optical characteristics are described first, revealing the mechanism of albitization of potash feldspars which have a wide range in the optical axial angle. Next, the two-feldspar geothermometry method is applied to the potash feldspars from the Yamato Sanmyaku and the results are compared with that of the Norwegian potash feldspars and also with the data of Japanese plutonic rocks. The formation temperatures estimated from the distribution coefficient k, triclinicity and 2Vx value are discussed on the basis of the subsolidus phase relation, the relation between the formation temperature and crystal symmetry, and the relation between the optical axial angle and triclinicity. These relations well support the conclusion held from the geological and petrographical points of view that the charnockitic rocks were originally formed under a granulite facies condition, but their characters were influenced more or less by the subsequent granitization under an amphibolite facies condition.

I. INTRODUCTION

The Yamato Sanmyaku is a mountain range located between 32°25′ E, 71°14′ S and 36°05′ E, 71°45′ S, about 200 km south of Prins Harald Kyst, East Antarctica. The mountains are composed of charnockitic group and granitic group rocks which are distinctly different from each other petrographically, structurally and petrochemically. The geology and petrography of the mountains have been described by K. KIZAKI (1965), one of the authors, in a previous publication of this series.

In the present paper, the problems on the potash feldspar of the region, especially that from the charnockitic group, are dealt with. The potash feldspar, an essential component of charnockitic rocks as well as of granitic rocks, has been studied by many investigators, especially from the petrological point of view by Norwegian school under T. F. W. BARTH who had proposed to estimate the formation temperature by the "two-feldspar geothermometer method", which has been employed in the present work. The microscopical observation of feldspars reveals different phases of metamorphism resulting from albitization of potash feldspar, and other phenomena.

The authors have tried to clarify the transition from granulite facies to amphibolite facies on the basis of the petrography of the feldspars.

II. GEOLOGICAL SETTING

The Yamato Sanmyaku is involved in the basement complex of East Antarctica, and is composed of various gneisses and plutonic rocks probably of lower Paleozoic, the age of which has been determined as 4.57×10^8 years (Sr-Rb method) by E. Picciotto and A. Coppez (1964).

The mountains may be characterized petrographically by the development of migmatitic and syenitic rocks. The rocks exposed in the region are classified as follows:

a) Pyroxene gneisses
b) Pyroxene syenite
c) Migmatitic gneisses and biotite granites
d) Granitic gneisses
e) Microcline granites
f) Metabasites
g) Microcline pegmatites

The rocks are arranged more or less zonally, parallel to the mountain arc.

Pyroxene gneisses and pyroxene syenites occur at the northern and southern ends of the mountain arc, and a small pyroxene syenite mass occurs in the central part of the inner zone of the arc. The small mass of the porphyritic pyroxene syenite is characterized by schiller potash feldspar which will be described later. Along the northern part of the outer zone, there are concordant sheet-like intrusions of biotite granite in the pyroxene gneisses. In the southern part, angular fragments of this gneiss are included in the pyroxene syenite. In the northern part of the mountains, the relation between the pyroxene gneiss and the pyroxene syenite is not clear. The pyroxene gneiss and the pyroxene syenite are referred to the charnockitic group on the basis of their mineralogical features. The porphyritic pyroxene syenite occurs as inclusions in the pink granite relicts, without any distinct boundary.

In the central mountain area, there are migmatitic gneisses, biotite granites and granitic gneisses. The migmatitic gneiss has a nebulitic, agmatitic appearance, with many basic paleosomes. It has been granitized *in situ* to massive biotite granite. These granitic rocks are all characterized by purple-grey quartz grains.

The granitic gneisses occur as banded, augen, and nebulic gneisses, representing a granitization series such as metablastesis and metatexis. The relation between the granitic gneiss and the pyroxene syenite is not clear, but the petrographical and structural investigations suggest that the granitic gneiss was produced by subsequent metamorphism and granitization of the pyroxene syenite.

The sheets of microcline granite, related to the granitization in the granitic gneiss area, occur as small discordant stocks in the pyroxene syenite area. These rocks are associated with pegmatite apophyses, being controlled by the joint pattern and representing post-kinematic granite emplaced in the supracrustal rock, in this case pyroxene syenite.

Metabasites, which occur throughout this mountain area, are of two types; metabasite bands or lenses that are more or less concordant with the country rocks, and are metamorphosed basic dikes.

Microcline pegmatites are also widely distributed and are sometimes related to the microcline granite. In some places, there are pegmatites intruded subsequent to the emplacement of metabasite dikes.

In general, the trend of the foliation of these rocks is parallel to the mountain arc, but their dips are variable. There are some gentle folds in the granitic gneiss area. The pyroxene gneisses and pyroxene syenites are steeply inclined, whereas the inclination of the granitic gneisses and migmatitic gneisses is more gentle. A structural analysis reveals that these two groups may have been involved in earlier and later tectonic events. This has been clarified also from petrographical points of view (KIZAKI, K., 1965).

A thrust fault is associated with a shear zone which strikes N 20° E and dips 50° E. The gneiss, however, is sheared and granulated in places parallel to the fault zone, and the basic inclusions show S-shaped rotation resulting from differential movement along the thrust.

III. DESCRIPTION OF SAMPLES

The petrographic characteristics of the rocks from which the feldspars are obtained, are described here briefly.

A) ***Pyroxene gneisses and metabasites***

Pyroxene-biotite gneiss (*YA 281*): This rock is usually found as basic inclusions in pyroxene gneiss which is agmatitic in appearance. The inclusions are spindle-shaped and dark brown in colour. The gneiss has a fine grained granular texture and shows a preferred orientation of the constituents. Deep brown biotite flakes are especially abundant in the small spindles.

Orthoclase with irregular veinlets of perthites is the essential salic constituent. Polysynthetic twins after albite law are rarely observed in the perthitic plagioclase veinlets (An 20–23). Biotite, monoclinic and rhombic pyroxenes are main mafic constituents in which the rhombic pyroxene is fewer in amount and is usually converted into brown biotite.

Pyroxene amphibolite (*YD 205*): The rock occurs as feldspar porphyroblastic basic layer in granitic gneiss. Mosaic orthoclase is one of the main components and is flame-type perthite, accompanied by small amounts of quartz and plagioclase.

Intergranular albites are often seen at the boundaries between the orthoclase grains (Figs. 1 and 2). Green hornblende, some of which are included in the orthoclase grains, is also an essential constituent.

Pyroxene-bearing granitic gneiss (*YD 225*): The gneiss is characterized by pink potash feldspar augen in a granitic texture. Two kinds of potash feldspars are distinguishable, one is porphyroblastic, large in grain size, and perthitic in texture, sometimes showing partial microcline twinning, and the other is non-perthitic, with mosaic grains of an interstitial amoebean texture. Plagioclase often shows a myrmekitic texture. Quartz is common. Brown biotite, green hornblende and colourless monoclinic pyroxene are the main constituents.

Basic granulite (*YE 52*): Orthoclase is the main salic constituent of the rock. Almost all orthoclase grains are fractured and show intense wavy and/or blocky

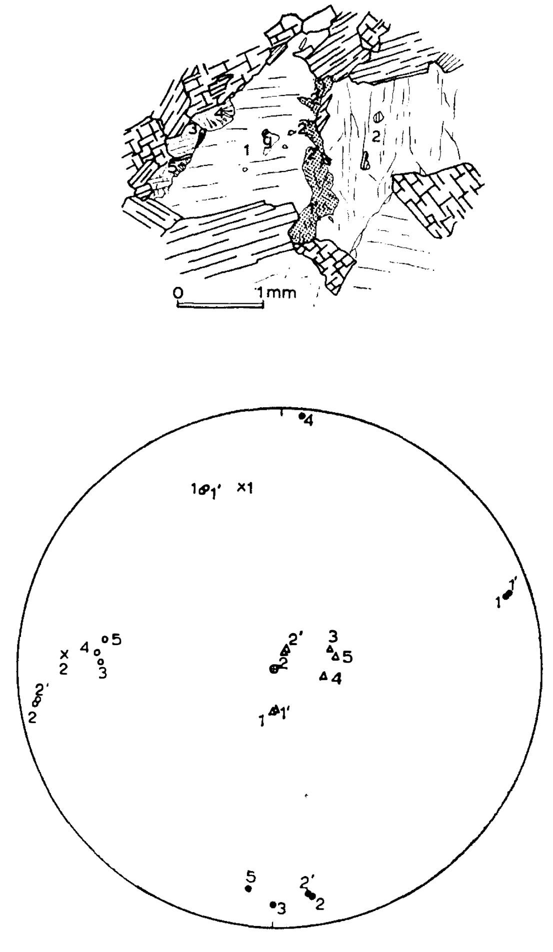

Fig. 1. Intergranular albite.

The small albites have an optical orientation similar to the adjoining potash feldspar, that is, albite grain (1′) has the same optical orientation as potash feldspar (1) and likewise 2′ with 2. The contacts 1/1′ and 2/2′ are always smooth ; in contrast, 1/2′ and 2/1′ are seen to embay into the potash feldspar. Fine streaks in a radial pattern are occasionally visible in the albite grains. The myrmekite grains(3, 4, 5)show a completely different optical orientation, and are dusty with sericite flakes and carbonate grains. These are regarded as the plagioclase remnants by the replacement of potash feldspar. The optical orientation of each grain is plotted on the stereographic net.

○ *Optic elasticity axis X*
● 〃 *Y*
△ 〃 *Z*

The number affixed to each point corresponds to those on the sketch.

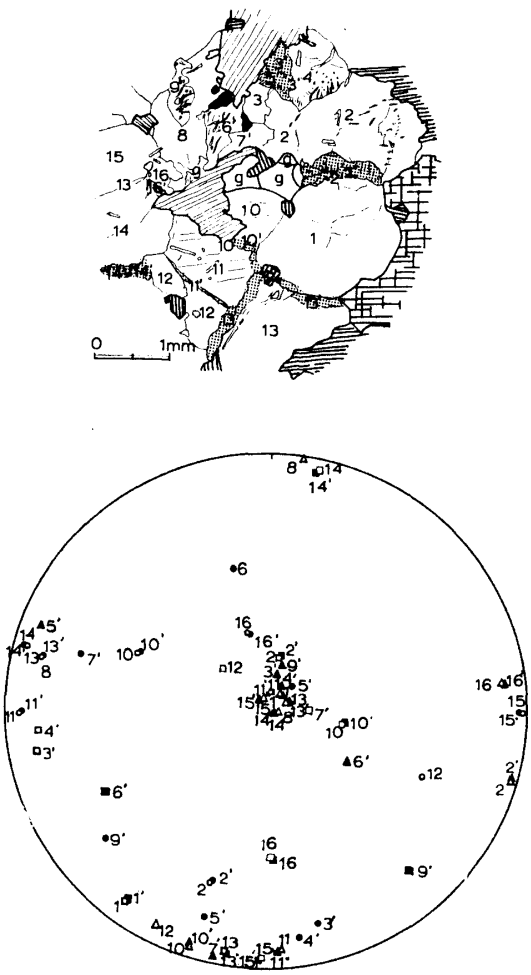

Fig. 2. Orthoclase mosaic with well developed albites.

Along every grain boundary of potash feldspars, narrow veinlets of albite and rows of fine albite blebs are developed. The optical orientations of the same numbered potash feldspar (number without a dash) and albite (number with dash) represent the same relationship as in Fig. 1.

The plagioclase grains, Nos. 3, 4, 5, 6, 7 and 9, represent typical myrmekitic textures and are dusty with fine sericite flakes. They may be relics of older plagioclase now being replaced by potash feldspar. q : shows quartz.

The optical orientation of each grain is shown on the stereographic net.

Legend on the stereographic net :

	Potash feldspar	*Albite*
Optical elasticity axis X	○	●
〃 *Y*	△	▲
〃 *Z*	□	■

The numbers on the points correspond to those on the sketch.

extinction. The mafic constituents are deep-brown biotite and colourless monoclinic pyroxene.

B-I) *Pyroxene syenites*

Porphyritic pyroxene syenite (*YC 226 A*): Porphyritic schiller potash feldspar, the characteristic mineral of this rock, is grey-coloured and characterized by the presence of perthite veinlets. Small magnetite pigments are arranged roughly parallel to the (010) plane (Fig. 3). Plagioclase is common in the sample and shows a myrmekitic texture. Mafic constituents are mainly brown biotite, green hornblende and colourless monoclinic pyroxene. A small pegmatite vein obliquely traverses this specimen (cf. Pegmatite, *YC 226 B*).

Porphyritic pyroxene syenite (*YC 227*): The plane of the foliation is defined by the planner arrangement of brown biotite flakes. The characteristics of the schiller potash feldspar are the same as those in the specimen *YC 226 A*. The fine-grained matrix is composed mainly of mosaic quartz accompanied by a small amount of plagioclase (An 20–27).

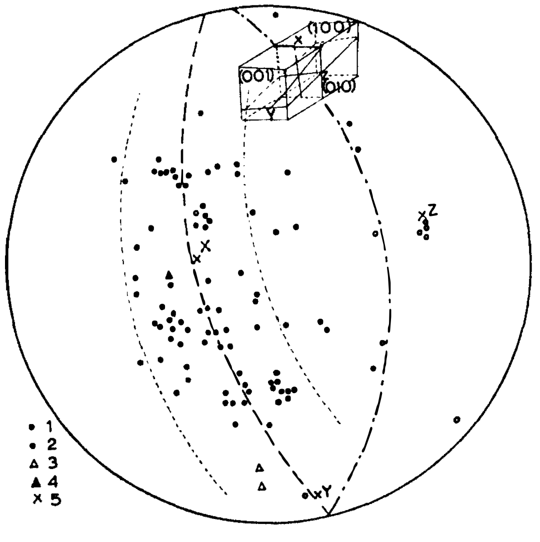

Fig. 3. Orientation of the inclusions in the schiller potash feldspar porphyroblast of the porphyritic pyroxene syenite, plotted on the Schmidt net.

1 : Orientation of the rows, composed of magnetite pigments.
2 : Poles of fine biotite flakes in the potash feldspar.
3 : Poles of distinct cleavage planes (mainly(001) plane).
4 : Pole of average perthite veinlet plane.
5 : Optic elasticity axis.

The dotted rows of magnetite pigments are arranged roughly parallel to the (010) plane, and embryonic biotite flakes mainly have the same orientation in the host potash feldspar.

(The sketchs of the schiller inclusions are in Figs. 6 and 7.)

Porphyritic pyroxene syenite (*YC 228 A*): The mafic and felsic layers are separated in the specimen. The mafic layer is composed mainly of coarse grained khaki-brown biotite and green hornblende, associated with monoclinic and rhombic pyroxenes. The potash feldspar in the layer is represented by large idiomorphic and schillered grains showing strong wavy extinction. The felsic layer is composed essentially of microcline perthite without schillerization. Volumetric ratio of potash feldspar to plagioclase is about 5 : 1.

Porphyritic pyroxene syenite (*YC 231*): This specimen represents an earlier stage of the formation of schiller potash feldspar. It shows a lepidoblastic texture with fine-grained matrix which consists of plagioclase and a small amount of quartz. Most of the potash feldspars are coarse grained, less perthitic in texture, and show distinct microcline twinning, while untwinned smaller grains occur interstitially in the matrix. Monoclinic pyroxene is poikiloblastic in texture, and is usually converted into green hornblende. Biotite is coloured vandyke brown and shows a preferred orientation.

Porphyritic pyroxene syenite (*YC 238*): The rock shows distinct swelled foliation involved in the augen potash feldspar porphyroblasts. The potash feldspars are coarse grained idioblasts with distinct schillerization, and represent a mesoperthitic texture. The albite domains occur irregularly in the host potash feldspar grains. Colourless monoclinic pyroxenes and deep sepia biotite flakes are predominant.

Porphyritic pyroxene syenite (*YE 80*): The rock has a granoblastic texture. Porphyritic schiller potash feldspars show marked heterogeneous extinction. They are rimmed by aggregated grains of pink-coloured potash feldspar which are the same kind as the fine-grained ones in the matrix. Other constituents are reddish-brown biotite, colourless monoclinic pyroxene, pink orthoclase of medium grain size, and small amounts of plagioclase and quartz.

B-II) ***Pyroxene syenites, strongly affected by the pink granites***

Pyroxene syenite (*YA 293*): This rock has a gneissose agmatitic-nebulitic appearance. Orthoclase with irregular perthite veins is the essential constituent associated with small amounts of plagioclase and quartz. The plagioclase often shows a myrmekitic texture. The mafic constituents are sepia-coloured biotite and brownish-green hornblende accompanied by monoclinic pyroxene which is always included in hornblende.

Porphyritic pyroxene syenite (*YE 54*): The rock, occurring as lenticular basic bands in pyroxene syenite, is dark grey and fine-grained with preferred orientation of the constituents. The salic mineral in the rock is exclusively potash feldspar, a large amount of which shows a weakly perthitic texture, whereas the rest has a meso-perthitic one, representing blocky fractures and the most abundant constituents. Monoclinic pyroxene is medium grained, showing mosaic texture with potash feldspar. Some of the pyroxenes are included in the potash feldspar and are converted into biotite.

C) ***Pink granites***

Pink granite (*YE 72*): This is a homogeneous, pink-coloured, aplitic granite, forming the eastern parts of the massif E. Microscopic investigation reveals an extremely complicated intergrowth between potash feldspar and plagioclase, *i. e.*, potash feldspar grains usually show irregular fractures, penetrated by a network of plagioclase (albite-oligoclase). The potash feldspar grains are clouded with numerous fine flakes of sericite and granular carbonate mineral, whereas the plagioclases making the network are always clear. Small amounts of monoclinic pyroxene, green hornblende and deep brown biotite are the accompanying minerals.

Pink granite (*YE 74*): This is a homogeneous granite, consisting of large amounts of quartz and potash feldspar representing a granular texture, large sericite aggregates which are pseudomorphs after scapolite are occasionally observed. This rock seems to have been affected by intense mechanical crushing, because the network impregnation of the plagioclase is seen along the cracks of potash feldspar grains, and strong wavy extinction of quartz is also observed. The plagioclase, which is considered to have been formed earlier than potash feldspar, is clouded with remarkable amounts of sericite dust, and is converted into dusty myrmekitic grains resulting from the reaction with potash feldspar. A few grains of monoclinic pyroxene and small amounts of deep-green hornblende and deep-brown biotite are found as accompanying minerals.

D) ***Pegmatites***

Pink granitic pegmatite (*YE 226B*): This pegmatite, about 15 cm in width, cuts obliquely the porphyritic pyroxene syenite. The plagioclases, An 20–23, show a remarkable myrmekitic texture and are intergrown with potash feldspars in a dendritic pattern. Brown biotite flakes, intensely altered into pale green chlorites, are rarely found.

Pink granitic pegmatite (*YC 235*): This pegmatite also cuts the porphyritic pyroxene syenite obliquely. Large grained smoky quartz is abundant. Plagioclases, which are dusted with fine sericite flakes, form the mosaic textured matrix. The potash feldspar grains show distinct microcline twinning, often overlapping the plagioclase grains and replacing them.

Pink feldspar and epidote pegmatite (*YC 245*): This rock occurs as an irregular-shaped massive pool in the porphyritic pyroxene syenite. A very complicated irregular intergrowth between dusty plagioclase and perthitic potash feldspar is found. Fine-grained epidotes form aggregates which are several millimeters to more than 1 centimeter in size. A small amount of dark brown biotite flakes are present.

Pink, homogeneous, medium-grained pegmatite (*YB 258*): A graphic intergrowth between quartz and potash feldspar, and myrmekitic texture of the plagioclase grains are the most remarkable features of this pegmatite. This rock generally shows a medium grained equigranular texture. Brown biotite flakes are often converted into greenish brown ones, and are accompanied by grains of some opaque minerals surrounded by sphenes.

IV. OPTICAL CHARACTERISTICS OF THE POTASH FELDSPARS

According to the megascopic observation of the hand specimens, three different types of potash feldspars can be distinguished in the rocks treated in this paper. The first type is pale pink or white in colour, and forms the granular matrix of the pyroxene gneisses and metabasites; the second is grey, large, schiller porphyroblasts occurring in the pyroxene syenites; the third is distinctly pink and coarse grained, occuring in the cross-cutting pegmatite veins. These differences are, of course, supported by the optical characteristics of each feldspar under the microscope. The optical natures of the potash feldspar from each specimen are described below (ref. Figs. 4 and 5):

A) ***Potash feldspars from the pyroxene gneisses and metabasites***

YA 281: Two petrographically different kinds of potash feldspars are distinguishable in this specimen, one is granoblastic small mosaic grains, and the other forms large porphyroblasts up to several millimeters in diameter, having a more or less poikiloblastic texture with many fine inclusions of biotite, monoclinic pyroxene and apatite. Regular perthitic texture is developed in both kinds, the former is mainly string type and the latter is mainly veinlet type. The optic axial angles (2V values) of these feldspar grains range from $-40°$ to $-70°$ and the frequency curve of the values (Fig. 4) shows two maxima which, however, do not correspond to the main values of the two petrographically different groups. The 2V values of each kind are dispersed over a wide range so that the two kinds cannot be distinguished from each other by their 2V values. Several grains, whose 2Vx is 40°-60°, represent straight extinction on $\perp(010)$ and are considered to be optically monoclinic in symmetry.

Small and elongated bleb-shaped albites (intergranular albite, Figs. 1 and 2) are often seen along the grain boundaries of coarse grained perthitic potash feldspars. Completely myrmekitized plagioclase grains are rarely included in potash feldspar porphyroblasts, but there are no separate grains of plagioclase in this rock. Potash feldspars of two different colours, clear pink and yellowish-green, were separated by hand-picking from crushed samples of this rock under the

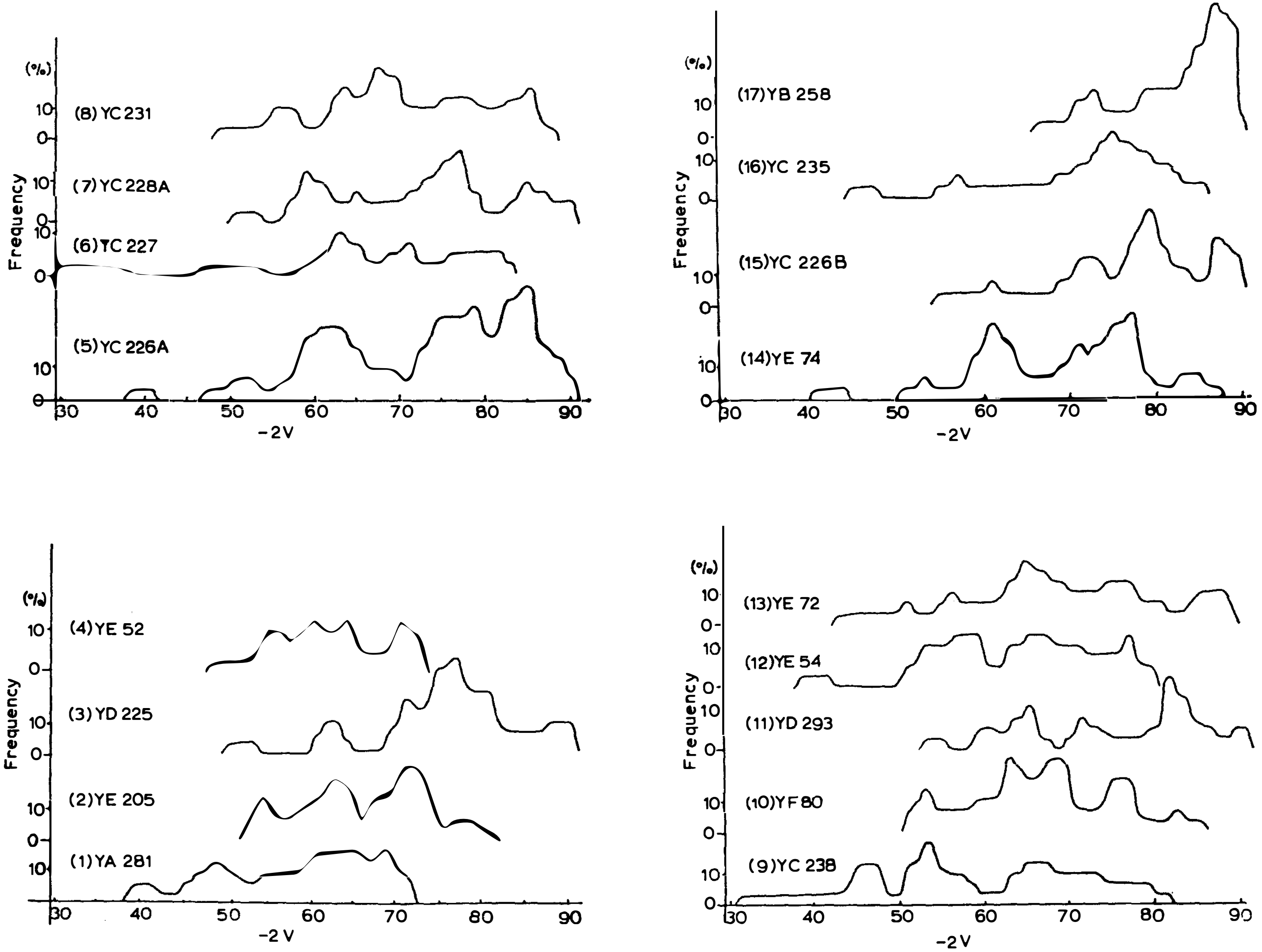

Fig. 4. The frequency curves of the 2Vx values of potash feldspar.

The frequency of the 2V values is illustrated as a histogram for each sample. The number of measurements being 30 from each specimen.

microscope.

YD 205: This rock has a distinct banded structure, consisting of hornblende gneissic layers and pink-coloured granitic layers. There is, however, no difference in the nature of the potash feldspar between layers. All of the potash feldspars are regarded as the flame type vein perthite orthoclase. Their 2V values are scattered in the range of −42°−−80°, with the frequency maxima around −60° and −75°. Mechanically fractured textures, *i. e.*, undulating extinction and cracks which are filled with albite, are seen in some grains. Intergranular albite blebs are often found along the grain boundaries of mosaic orthoclases. The colour of the potash feldspar is pale pink.

YD 225: The potash feldspars of this rock occur as medium granoblastic grains, some of which showing distinct microcline twinning and augen shape. The optic axial angle over X varies from 50° to 90°. Intergranular albite blebs are often developed along the grain boundary of potash feldspars, whose 2V values range from −75° to −80°, with the maximum frequency recorded in the same range. The potash feldspar grains having −70° to −75° 2V values often exhibit a mesoperthitic texture. In some grains the flame type albite domains are developed in nearly the same amount as that of the host potash feldspar, but the crystal always assumes the outline of the latter.

Some dusty potash feldspar grains, having 70° to 88° 2Vx and the "augen" shape, show relic cleavage planes which are represented by the arrangement of dust inclusions. These relic cleavages (which are considered to correspond to the (010) cleavage planes before recrystallization) are crossed obliquely by neo-cleavages which are represented by clear planes. The former shows straight extinction on the $\perp$ (010) plane, whereas the latter has slightly oblique extinction ($Z \wedge \perp (010) = 3^\circ - 7^\circ$). In these grains, microcline twins are locally developed in the narrow area around perthitic patches which are irregular veinlets. Some of the potash feldspars, whose 2Vx are 88°, show distinct microcline twinning throughout the whole grain, and strong wavy extinction. Relic cleavages are also found in these grains. These evidences seem to suggest that the recrystallization involving monoclinic to triclinic inversion has occurred in the potash feldspar grains. The development of microcline twinning is closely related to perthitic unmixing in an early stage of formation. It is assumed that the mechanical strain, which had been concentrated in narrow areas around the perthitic patches, played an important role in the formation of microcline twins in the narrow areas. The same kind of observation has been adopted by several authors (ESKOLA, P., 1952; GOLDSMITH, J. R. and LAVES, F., 1954; and MARFUNIN, A. S., 1961).

YE 52: Medium grained potash feldspar is the only colourless mineral in this rock. The range of the optical axial angles, (2Vx=50°−74°), is the smallest among the specimens which were examined in this paper. The colour of the potash feldspar is dark red. They are dustless and weakly perthitic. Strong wavy and heterogeneous extinctions and blocky fractures are often seen in these grains, which suggest that they were affected by an intense mechanical crushing.

Summary

1. Small dusty grains of plagioclase are rarely found as inclusions in potash feldspar, and they always show remarkable myrmekitic texture. In careful observations, it is evident that the plagioclase grains, which had once been the predominant feldspar, were completely replaced by potash feldspar in these rocks. There was a strong potash metasomatism under the condition of high metamorphic grade (granulite facies).

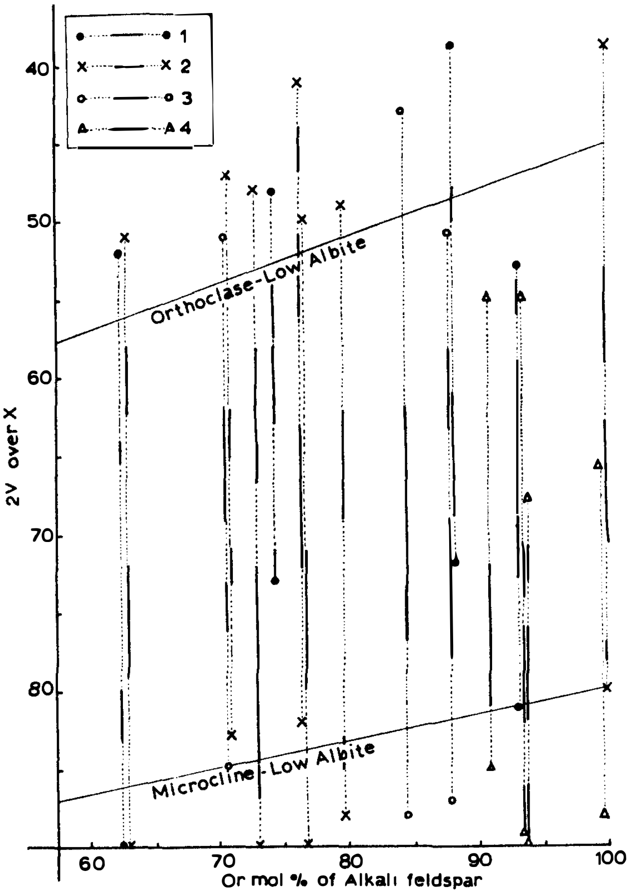

Fig. 5. The relation between 2Vx value and chemical composition of potash feldspars.

Dotted line shows the whole range of the 2V value; solid line shows the range where the frequency of the 2Vx value is more than 10 per cent in Fig. 4.

1 : Pyroxene gneisses and metabasites.

2 : Porphyritic pyroxene syenites (including B-I and B-II in the text.)

3 : Pink granites.

4 : Pegmatites.

Most data indicate an intermediate state, except for several samplse from the pegmatites and the porphyritic pyroxene syenites.

2. The optic axial angles of these potash feldspars spread over a wide range, and the frequency curves of 2V values generally show two maxima, roughly from −60° to −66° and from −71° to −81°.

3. According to the optic axial angle, most of the potash feldspars in these rocks belong to orthoclase and intermediate microcline (Fig. 5). In some rocks, however, there are some indications of mechanical disturbance, as represented by augen structure of the rocks. And it is noticeable that potash feldspars in these rocks generally show microcline twinning and larger 2Vx values.

4. The range of 2V value of the potash feldspars, which are associated with intergranular albite blebs along their grain boundary and have a perthitic texture, is roughly coincident with that of the microcline which is found locally around the perthitic patches. The range of 2V value of these grains may be related to the structual conversion resulting from polymorphic modifications of potash feldspar.

5. The existence of dusty relic cleavage planes, being cross-

ed obliquely by neocleavage in some porphyroblastic potash feldspars, seems to suggest that recrystallization, involving the change of monoclinic to triclinic symmetry, occurred in these potash feldspar grains.

B–I) *Pyroxene syenites and porphyritic pyroxene syenites*

YC 226A: A large number of grey-coloured schiller feldspars, several millimeters to more than 1 cm in size, have 2V values from −62° to −70°. They develop as sub-idiomorphic porphyroblasts, occasionally rimmed by pink coloured potash feldspar. The schillerization of the potash feldspar is due to the large number of the unmixed rows, composed of fine ilmenite pigments, which are arranged roughly parallel to the (010) plane (Fig. 3). The other inclusions, *i. e.*, fine biotite, sericite flakes and small apatite grains, are also quite common in these schiller porphyroblasts. They show irregular-shaped vein type perthitic texture. In some grains, the proportion of albite domains largely exceeds the host potash feldspar (which still keeps its own outline as a whole), and finally they become antiperthite porphyroblasts (An 5–25, determined by the X-ray powder measurement). In the matrix of this rock, medium grained, mosaic potash feldspars with regular vein perthite occur. Their 2Vx values range from 40° to 70°. These grains are often included in the schiller porphyroblasts. These mosaic potash feldspars are evidently formed earlier than the schiller porphyroblasts.

There is another kind of potash feldspar, a pink-coloured one, which occurs as fine to medium grained aggregates and also as rims enclosing the schiller porphyroblasts.

In several cases, where the schiller porphyroblast is surrounded by the pink potash feldspar aggregate, the inner part of the schiller porphyroblast represents distinct microcline twinning and large 2Vx values, whereas in the marginal zone, no "grid" twins of smaller 2Vx values are found. The development of perthitic patches in the schiller porphyroblast results in an antiperthitic texture. Judging from this evidence, it may be reasonably assumed that the older schiller potash feldspars were affected by the new physical conditions which were associated with the introduction of the younger pink-coloured one.

Intergranular albite is found along the grain boundary of medium grained mosaic potash feldspars.

"Grid" twinning is often found in the grains which have not only large 2Vx values, but also intermediate values (65°–75°).

YC 227: The potash feldspar in this sample is mainly the schiller porphyroblast with irregular vein perthite, whereas microcline twins are occasionally observed. The characteristics of the schiller potash feldspar are the same as those of specimen No. *YC 226A*. In the matrix of the rock, fine-grained dusty potash feldspars occur interstitially. Some of them show straight extinction on ⊥ (010) and have 2Vx ranging from 12° to 38°. These grains are considered to be older than the schiller porphyroblasts.

Pink potash feldspars of fine grain size also occur in the matrix. They are amoeba-like in shape, replacing plagioclase grains, and show the 2Vx range from 65° to 75°.

YC 228A : Distinct differences of the characteristics are noticeable between the potash feldspars in the dark biotite rich layers and those in the light coloured pyroxene rich layers about 3–4 cm wide. In the former layer, schillered "grid" twinned and perthitic porphyroblastic potash feldspars having large 2Vx values (74°–90°) are abundant. Some of them show strong heterogeneous extinction. Small amounts of dusty plagioclase grains (An 20–24) are included in these large porphyroblasts. In the pyroxene rich layer, on the other hand, small grains of dusty potash feldspar, with 2Vx values of 50° to 65°, are predominant. They show

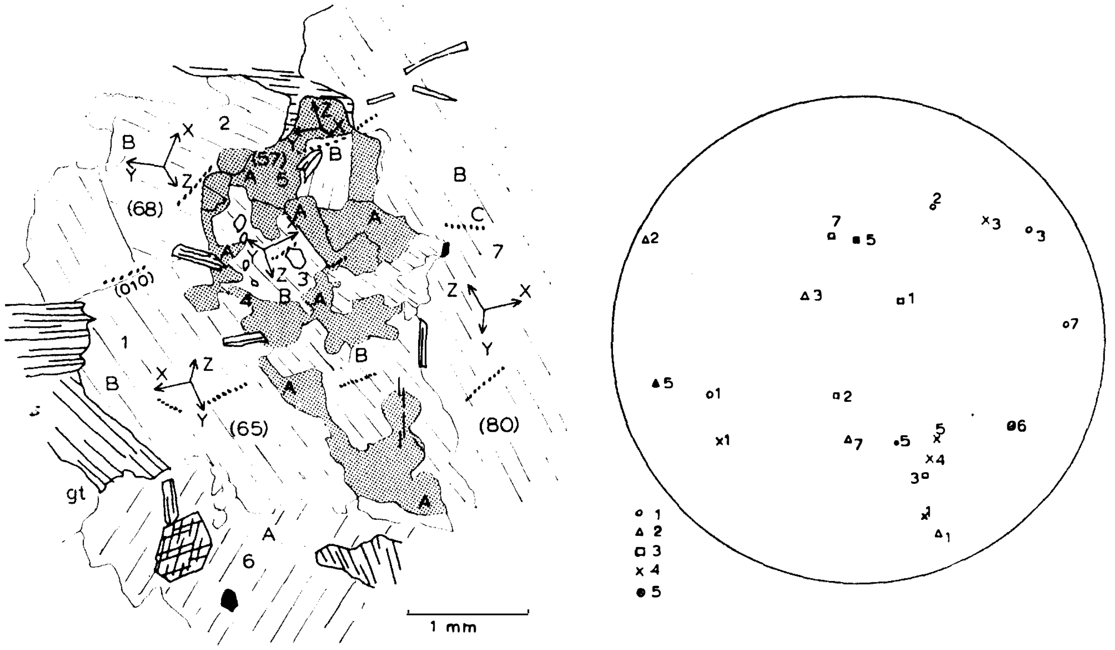

Fig. 6. Albite penetration into the cracks of potash feldspar along grain boundary.
A : Albite.
B : Schiller feldspar and its fragments.
C : Schiller inclusion (some rows of magnetite pigment cross the boundary of potash feldspar and albite).
The number in ( ) shows 2Vx value.

The mode of occurrence of the schiller rows, indicates that the replacement of the potash feldspar by albite took place later than segregation of the magnetite pigments.

Optical orientations of each grain are shown on the stereographic net.
1 : Optic elasticity axis X
2 : Optic elasticity axis Y
3 : Optic elasticity axis Z
(open simboles : potash feldspar
solid " : albite)
4 : Pole of distinct cleavage plane.
5 : Pole of albite twin plane.
The numbers on the net correspond to those of the sketch.

a mosaic texture and have intergranular albite blebs along their grain boundary.

YC 231: Grey schiller potash feldspars have been observed as large porphyroblasts with many inclusions of various kinds of minerals. They show large optic axial angles from 65° to 85°, and also "grid" twinning. These large porphyroblasts, 8–25 mm in diameter, show marked heterogeneous extinction; generally several small domains are definable in a single grain. The optical axial angles, obtained from single porphyroblastic grain, spread from domain to domain over a wide range; for example, −68°, −60°, −72°, −74°, −82°, −74°, −86°. This fact suggests that there is considerable heterogenity in the internal optical characteristics of such large porphyroblasts. In the matrix of this rock, fine-grained mosaic potash feldspars occur with a granoblastic texture, having smaller 2Vx values (50°–73°).

YC 238: The large schillered porphyroblastic potash feldspars in this rock have 2Vx values ranging from 65° to 80° and are extremely perthitic with irregular patches of vein type. Sometimes they are mesoperthitic. The marginal part of these porphyroblastic feldspars exhibits a prominent fractured texture. Albitic feldspars, having rows of magnetite inclusion fill cracks interstitially with convex outline into potash feldspar (Fig. 6). These albites, at least a part of them, were converted from the schillered potash feldspar, because the rows of fine magnetite pigments are also found in these albite grains. In other cases, younger potash feldspars, without schiller inclusions and with irregular patches of perthite, are observed around the schiller porphyroblast. The intergranular albite blebs are found at the boundary between the younger and the schillered potash feldspars (Fig. 7).

Medium grained granular potash feldspars are often seen in the matrix of this rock. They are markedly perthitic in their cores, whereas quite homogeneous in their marginal zones. The former part might have crystallized under the same conditions as that of the rimmed one around the schiller. Interstitial amoeba shaped small potash feldspars without perthitic texture are considered to be the youngest. It is also considered that the marginal parts of the medium grained ones crystallized at this stage.

The magnetite pigment inclusions in the schiller potash fedspar are less abundant in unmixed albite domain than in the host. Some of the rows of the magnetite pigments pass through the bounday plane between the host and the guest domain (Fig. 6). They might have been unmixed later than the albite phase.

YE 80: Large grained schiller porphyroblastic potash feldspars, sometimes with pink feldspar rim, are abundant in this rock. The petrographic characteristics of this feldspar are the same as those in *YC 226A* and *YC 238* already mentioned. Blocky extinction of these feldspars is especially noticeable. They show 2Vx values ranging from 61° to 80°. Pink, nonperthitic potash feldspar grains occur as a medium granoblastic matrix.

Summary

1. There are three kinds of potash fedlspars in the porphyritic pyroxene sye-

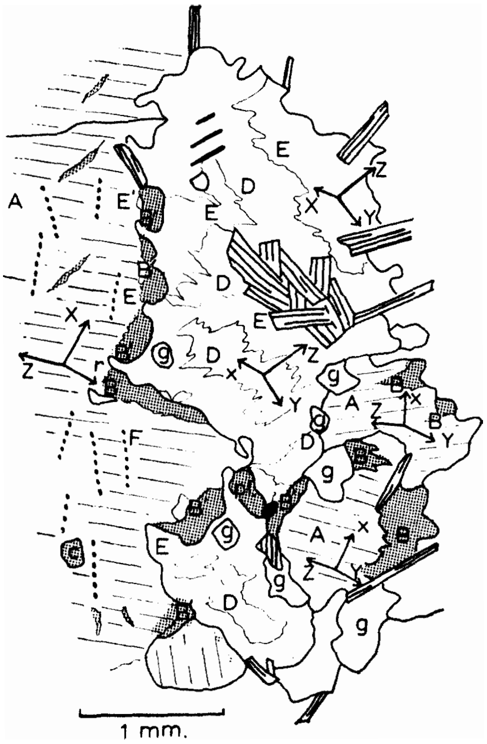

Fig. 7. Younger potash feldspar rims around schiller feldspar.

A : Schiller potash feldspar and its fragments at the margin ($2Vx=63°-80°$).

B : Perthitic patches derived from schiller potash feldspar.

B' : Intergranular albite of the same optic orientation as B.

C : Plagioclase inclusion in the schiller potash feldspar completely albitized by material exsolved from the host.

D : Younger potash feldspar, potash-rich host phase ($2Vx=45°-60°$).

E : Albite-rich phase of the younger feldspar, of the same optic orientation as D. The refractive index of this phase is distinctly lower than B', D' and E never have schiller inclusions.

E' : Intergranular albite of the same optic orientation as E.

F : Schiller inclusions.

G : Quartz.

The margin of the schiller feldspar is fractured and penetrated by younger potash feldspar forming coarse flame like perthite. Intergranular albite forms double rows arranged symmetrically about the grain boundary between A-B and D-E. It suggests that the intergranular albite might be formed after the fracturing of the schiller feldspar. Younger potash feldspars have embayed contacts against the schiller one.

nites; the oldest are dusty mosaic grains, sometimes included in the schiller porphyroblasts, the second are grey schiller potash feldspars, and the youngest are pink ones forming the matrix, sometimes occurring as a rim on the schiller feldspar.

2. The oldest potash feldspars are weakly perthitic in texture and have intermediate 2Vx values. They are predominant in pyroxene rich layers of these rocks. These potash feldspars may be relics from the original charnockitic pyroxene gneisses.

3. The schiller potash feldspars are large porphyroblast with large 2Vx values and often showing microcline twinning. Their texture is intensely perthitic, occasionally large antiperthitic. Heterogeneous extinction and blocky extinction are often observed.

4. The schiller phenomenon is due to fine magnetite pigments arranged roughly parallel to the (010) plane in the host potash feldspar.

5. The youngest, pink potash feldspars occur as a rim of the schillered feldspar, and are abundant also in the granular matrix. They have small optic axial angles over X, and are weakly perthitic, except for the central part of the medium grains and the grains which form the rims of the schiller feldspar.

B-II) *Pyroxene syenites strongly affected by pink granites*

YA 293: It is expected that there were duplications of the crystallization phases of the constituent minerals, because this rock is a basic paleosome in the agmatitic-nebulitic rock. This expectation is supported by a wide range of the optic axial angles of potash feldspar (from −60° to −90°). The potash feldspar grains, with typical intergranular albite blebs developed along their grain boundaries, have intermediate 2Vx values, 60° to 75°. These 2V values mean that they belong to the intermediate structural state between orthoclase and microcline. The date seem to suggest some close relationship between exsolution of perthitic material and the conversion of crystalline states (MARFUNIN, A. S., 1961). Replacement of the plagioclase by porphyroblastic potash feldspar is remarkable. Well developed veinlets of perthitic albites take a form of zonal distribution in some large potash porphyroblasts (Fig. 8). The colour of the feldspars is pale pink.

YE 54: This rock carries not only many potash feldspars but also a considerable amount of plagioclase (An 20–29). There are two groups of potash feldspars. One group is found mainly in the matrix and comprises medium grained mosaic grains with moderate optic axial angle (2Vx=60°−80°). The other is a group of coarse grained and weak perthitic potash feldspars, with relatively small 2V values (2Vx=50°−65°). They always show marked wavy extinction and mechanically crushed features. The cracks are penetrated by albite in irregular network (Fig. 9). In some cases, the potash feldspar grains are broken down into

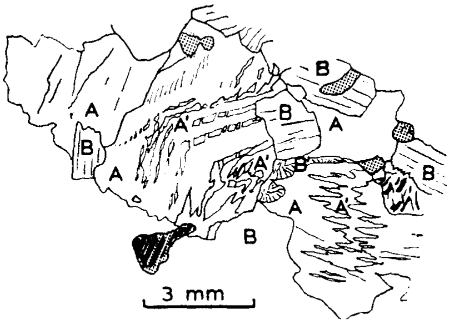

Fig. 8. Zonal perthitic texture in potash feldspar.
A : Perthitic orthoclase.
A′ : Albite patch in orthoclase.
B : Plagioclase, some show myrmekitic texture.
B′ : Intergranular albite with myrmekite like pattern.
shadowed grain : quartz.

All perthitic domains, having a prismatic shape, show the same optical orientation in a single host potash feldspar.

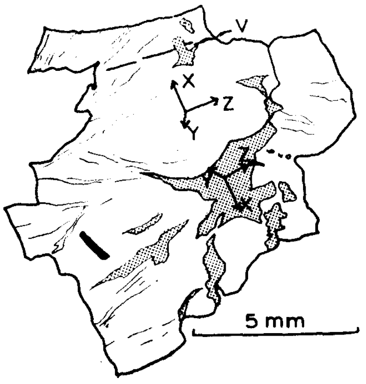

Fig. 9. Replacement of potash feldspar by albite along cracks.

The host potash feldspar shows marked wavy extinction and its cracks are filled with irregular albites. Both feldspars show similar optical orientation. The albite vein cut a veinlet of epidote (V).

fragments, interstitial spaces of which are filled with albitic material. A few albite porphyroblasts are developed as a result of the advanced replacement of potash feldspar. This evidence indicates that there were strong effects of mechanical disturbance followed by the addition of a considerable amount of albitic material, which is evidently later than the potash feldspar consolidation. The origin of this albitic material and its subsequent migration into this rock are important problems. Owing to this strong albite metasomatism, this rock became a two-feldspar granite.

Attention must be paid on the fact that the albite after the replacement of potash feldspars often shows characteristic antiperthitic texture and that unmixed potash feldspar domains are always in a fine square shape elongated parallel to the albite twinning plane. This occurrence is evidently different from the antiperthites of exsolution origin often found in the rocks of granulite facies. (Eskola, P., 1952; Sen, S. K., 1959, p. 993; and Smithson, S. B., 1963, p. 123).

Summary

1. The pyroxene syenites occur as agmatitic blocks and discontinuous bands in the pink granite. Such features are distinctly recognized also under microscope; the porphyroblastic potash feldspar is fractured and is intruded by veins of albitic plagioclase, and sometimes large albite porphyroblasts are developed as a result of the advanced replacement of the potash feldspar.
2. Beside the porphyroblastic fractured potash feldspar, medium grained unfractured ones with pink colour occur in the matrix. These are younger ones with large 2Vx (60°–80°) than the fractured ones (2Vx=50°–60°). The former seems to have been formed under lower metamorphic grade than the latter.
3. Characteristic antiperthite texture is often seen in the albitic plagioclase which is markedly replacing the fractured potash feldspar.
4. Intergranuler albites are developed along the grain boundary of the potash feldspars whose 2Vx values are intermediate (2Vx=60°–75°).

C) Pink granities

YE 72: Medium to large grained potash feldspars having relatively small 2Vx values (50°–75°), present the same features already mentioned in the description of the pyroxene syenite No. *YE 54*. They always show fractured features and are replaced by network of albitic plagioclase. A careful observation reveals that several potash feldspar grains with completely fragmental outline derived from a single original grain, still preserve the same optical orientation, even when they are separated from each other by network of albite veinlets. On the other hand, the network, irregular veinlets and pools of albite show the same extinction position in one set of the potash feldspar fragments derived from a single grain. Judging from this evidence, the replacement of potash feldspar by albitic material is thought to have taken place without any displacement of the original potash feldspar grain. This is one of the characteristic mode of replacement by albitization, often observed in the granitic rocks of this region. The albitization is unquestionably later than the consolidation of the pink potash feldspar, which was formed under a higher metamorphic condition, *i. e.*, granulite facies.

YE 74: Strong effects of mechanical disturbance are indicated by wavy extinction of quartz and fragmental texture of potash feldspar. The younger albite is developed as the product of advanced replacement of potash feldspar and often forms large porphyroblastic grains of amoeba-like shape.

Fine grained microcline mosaics are occasionally found in the matrix of this rock interstitially with, regular string type perthitic texture. The condition of the albitization was lower than that of fractured potash feldspar formation.

Summary

1. Judging from the mineral association, these granites belong to two-feldspar granite containing perthitic potash feldspar and albitic plagioclase. However, these two feldspar did not crystallize simultaneously in equilibrium condition, but the albitic plagioclase has been formed evidently after the consolidation of the potash feldspar, and this later phase was certainly formed under a condition lower than that of the potash feldspar.
2. The albitization of the potash feldspar took place following the mechanical disturbance. All plagioclase grains are the product of advanced albitization. The mechanical disturbance might correspond to some tectonic movement which had once happened to this granite massif, and the albitic material was supplied from outside of the pre-existing pyroxene syenite.
3. A small amount of inerstitial microcline grains occur in the matrix. They are probably the latest potash feldspar in these rocks.

D) *Pegmatites*

YC 226B: Graphic intergrowth between potash feldspar and plagioclase (An 15–22) is well developed in this rock. The potash feldspars, which have 2Vx ranging from 70° to 80°, are always twinned and represent irregular veined perthitic texture. It is noteworthy that the potash feldspars, which have 2Vx from 55° to 70°, usually show distinct "grid" twins. The plagioclases included in potash feldspar have narrow albite rims.

YC 245: A very coarse grained mosaic texture of this rock is composed of microcline-twinned potash feldspar and plagioclase with dusty sericites. Optic axial angles over X of these microclines are 66°, 68°, 72°, 86° and 88° (This data is not exhibited in Fig. 4, because the number of the measurements is not sufficient to make a comparison with the other specimens). Plagioclases are replaced by potash feldspar along their cracks.

YB 258: Graphic intergrowth between potash feldspar and quartz, as well as myrmekitic texture of plagioclase grains are prominent in this rock. Coarse grained and dusty potash feldspars have patches of perthites and have the range of 2Vx from 68° to 89°. Almost all of the potash feldspar show distinct "grid" twinning. Nonperthitic potash feldspars, forming graphic intergrowth, are also found. Plagioclases included in potash feldspars always have wide albitic rims around them.

Summary

1. Graphic intergrowth and myrmekitic texture are characteristics of these rocks.

2. Almost all of potash feldspars show microcline twinning, weak perthitic texture and have large optic axial angles over X. Mechanical effects are occasionally found.

V. X-RAY RESEARCH ON THE POTASH FELDSPARS

During the past ten years, our knowledge on the subsolidus phase related to natural alkali feldspar has rapidly increased. This is due mainly to the contributions by Norwegian petrologists, especially BARTH (1956) with his first proposal concerning the estimation of the formation temperature of alkali feldspar. He and his colleagues have carried out many works on the natural alkali feldspar from Norwegian granites and metamorphic rocks. The method to estimate the temperature of formation of natural alkali feldspar from the viewpoint of the two-feldspar geothermometry has been discussed by many authors, especially in the Feldspar Symposium at Oslo in 1962. In the present paper the authors applied this method to the alkali-feldspars from the Antarctic metamorphic rocks, and the results were compared with those of the Norwegian alkali feldspars and also with the data of Japanese plutonic rocks, which have been obtained mainly by the senior author himself and recalculated from data of MURAKAMI and his colleagues (MURAKAMI et al., 1963 and 1964).

A) *Preparation of the samples and X-ray measurement*

The samples were crushed into 100–150 mesh in size. The procedure of the separation is as follows:

(1) Separation of colourless minerals by the Franz Isodynamic Separator.

(2) Floatation of alkali feldspar grains in heavy liquid (thulet solution) to separate the quartz and feldspar mixture.

(3) Finally, hand-picking under binocular microscope had to be carried out for some samples which still contained a small amount of foreign material.

In the cases where different coloured potash feldspar grains occurred in one sample, they were separated by their colour (*i. e.*, pink, white and grey groups) by hand-picking.

By the above procedures, the prepared alkali feldspars are considered to have been purified to more than 98% of potash feldspar.

For X-ray treatment, the "NORELCO" X-ray diffractometer was used with a Ni-filtered Cu-target, 35 Kv, 17 mA and at the scanning speed of 1°/min. The Or-content of the potash feldspar was determined from the interval of the 2θ

Table 1. Feldspars from the charnockitic group and pegmatite in the Yamato Sanmyaku, Antarctica.

Sample No.	Rocks	Potash feldspar			Plagioclase Ab cont. (mol. %)	$K=\frac{\text{Ab in K.f.}}{\text{Ab in Pl.}}$	Estimated formation temperature (°C)
		Ab cont. (mol. %)	2Vx (cfr. Fig. 4)	Triclinicity			
YA 281(1)	Px-bi gneiss	21.9	69, 63, 49	0	77	0.28	560
YA 281(2)	〃	11.8	49, 63, 69	0	77	0.15	420
YD 205	Px amphibolite	6.7	54, 63, 71	0	78	0.08	343
YC 225	Px granitic gneiss	37.3	62, 76	(RO) 0.06	78	0.48	750
YE 52	Basic granulite	25.6	61, 71	0	80	0.32	595
YC 226A	Porph-px syenite	26.8	62, 79, 85	(RO) 0 ?	77	0.35	625
YC 227	〃	28.9	63, 71	(RO) 0 ?	80	0.36	635
YC 228	〃	37.3	59, 77, 85	(RO) 0.09	80	0.47	743
YC 231(1)	〃	23.2	63, 67	0.06-0.25	78	0.30	577
YC 231(2)	〃	38.8	67, 85	(RO) 0.38	78	0.50	770
YC 231(3)	〃	20.2	63, 67, 85	(RO) 0.63	78	0.26	538
YC 238(1)	〃	25.4	47, 53, 66	0	79	0.32	595
YC 238(2)	〃	18.2	47, 53, 66	(RO) 0.18	79	0.23	510
YC 238(3)	〃	23.8	47, 53, 66	(RO) 0.71	79	0.30	577
YF 80	Porph-px syenite	28.9	53, 65, 76	0	80	0.36	635
YA 293	Px syenite	23.2	64, 71, 81	(RO) 0	77	0.30	577
YE 54	Porph-px syenite	0.0	58, 66, 77	0.15	76	—	—
YE 72	Pink granite	15.3	65, 76	0	79	0.19	468
YE 74	〃	11.8	61, 77	0.09	80	0.15	420
YC 226B	Pegmatite	6.3	79, 88	(RO) 0.40	80	0.08	343
YC 235	〃	8.7	74	(RO) 0.30	78	0.11	373
YC 245(1)	〃	0.0	66, 88	(RO) 0.11	76	—	—
YC 245(2)	〃	0.0	66, 88	(RO) 0.31	76	—	—
YB 258	〃	6.3	88	0.90	79	0.08	343

(Ro): randomly ordered (CHRISTIE, O. H. J., 1962)

$(\bar{2}01)$ feld.-(010)$KBrO_3$ of $CuK\alpha$, according to the diagram proposed by ORVILLE (1963, Fig. 1), after the completion of the inversion of the feldspar into monoclinic structure by heat treatment was verified.* The refraction peaks (131) and $(1\bar{3}1)$ of the potash feldspar completely became a single peak in heat treatment at 1100°±50° for 10 hours.

The An-content of the plagioclase co-existing with potash feldspar was determined by the optical method. The anorthite content of potash feldspar was neglected in the determination.

To estimate the temperatures of formation, the "two-feldspar geothermometer method" suggested by BARTH (1956) was used. The distribution constants $\left(K=\frac{\text{mole fraction of Ab. in potash feld.}}{\text{mole fraction of Ab. in plagioclase}}\right)$ were calculated from the data obtained by the above mentioned procedures. The natural empirical curve proposed by BARTH (1956, Fig. 9, p. 15) was utilized as the standard for estimation.

B) *Results and discussion*

The data obtained from the X-ray powder diffraction are shown in Table 1, with the optic axial angles. In analyzing the data, special attention must be paid to the situation that the data have resulted from different procedures; the optical data were obtained from each potash feldspar grain, while the X-ray and chemical data from a mixture of a large number of grains each of which may have different optical characteristics.

For this reason, there is no strictly one-to-one correspondence between the optical data and the X-ray data. Mineralogically, this data must not be treated in the same way as that for single crystals of potash feldspar. In this chapter the difference in mineralogical characteristics of potash feldspar as an indication of petrogenetic processes are mainly considered from the petrographical view points.

(1) Subsolidus phase relation of alkali feldspar

In Fig. 10, the data of the rocks of the Yamato Sanmyaku are plotted on the diagram showing the relationship between the estimated temperature of formation of potash feldspar and the Or-content. The plots of the porphyritic pyroxene syenites occupy the areas of comparatively high temperatures and high Ab-contents. This means that the syenites, although they are weakly affected by the retrogressive influence of the later pegmatitic material, retain a higher metamorphic condition. The potash feldspars of these rocks often show a marked mesoperthitic texture with irregular, vein shaped large patches, which sometimes

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* According to a personal communication from Mrs. NILSSEN of the Mineralogical Museum of Oslo, the use of this method proposed by ORVILLE (1963) is very dangerous to determine the Or-content of potash feldspar, because heat treatment of potash feldspar for a long time would give rise to a higher value of Or-content than the true value (CHRISTIE, O.H.J. and NILSSEN, B., 1964).

occupy more than half of a grain of the feldspar, so that the texture becomes antiperthitic. According to this petrographic evidence, prominant albitization might have occured later than the formation of potash feldspar. But, the potash feldspar still retains its high temperature characteristics.

The plots of the pyroxene gneisses and metabasites are scattered over a wide range in the diagram. This result is natural because these rocks are the older member of the metamorphic region and are affected by various changes due to the succeeding events.

The potash feldspars from the pink granites show a high temperature character. This is harmonious with the co-existence of rhombic pyroxene. The plots of the pegmatites take the lowest position on the diagram. These pegmatites are closely related to pink microcline granite which has not been treated in this paper.

The general trend of the above mentioned plots roughly coincides with the curve "A" which was proposed by BARTH (1962) using the data of natural feldspars from the rocks of southern Norway, although our values are somewhat higher than BARTH's curve "A".

The diagrams, showing the same relations in the rocks of several localities in Japan and Norway, are illustrated in Figs. 11 to 20. All Or-contents of the potash feldspars in these diagrams were determined by chemical analysis, not by the X-ray powder method. Figs. 11 to 13, showing results on the metamorphic and granitic rocks in Japan, have a tendency of being a little higher than the curve "A". The Funatsu granites and accompanying metamorphic rocks of the Hida metamorphic terrain are mainly derived from hornblende gabbros and hornblende dioritic gneisses belonging to the amphibolite facies, and were formed by strong mechanical crushing followed by intense potash feldspar metasomatism. This metasomatic process is considered to have proceeded under high vapor pressure conditions, so that the complete alteration of green hornblende into epidote, chlorite, sphene, and the strong sericitization of granulated plagioclase are always observed in the whole rocks. The potash feldspars in these rocks appear as large porphyroblasts with strong idiomorphism, with a large number of inclusions, and also as amoebae-shaped interstitial grains, both showing distinct microcline twinning.

The rocks from the Yanai, Yamaguchi Prefecture, belong to the typical Ryoke metamorphic belt. The gneisses were derived mainly from pelitic sediments, *i. e.*, banded

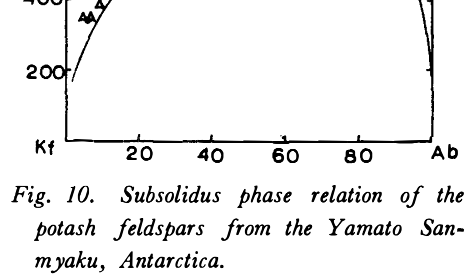

Fig. 10. Subsolidus phase relation of the potash feldspars from the Yamato Sanmyaku, Antarctica.

1 : Pyroxene gneisses and metabasites.

2 : Porphyritic pyroxene syenites (including (B-I) and (B-II) in the text.)

3 : Pink granites.

4 : Pegmatites.

A-curve : The solvus proposed by ***BARTH*** *(1962, p. 35, Fig. 2), based on the data from natural feldspars.*

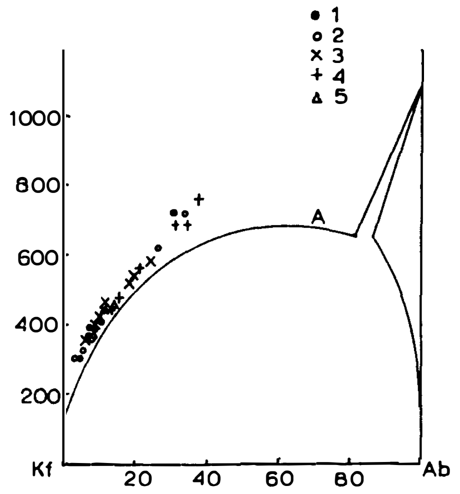

Fig. 11. Phase diagram of the potash feldspars from the Funatsu granites and metamorphic rocks of the north-eastern part of the Hida metamorphic terrain.

1 : Hornblende granodiorites.

2 : Potash feldspar porphyritic granites.

3 : Augen gneisses.

4 : Aplites of replacement origin.

5 : Cross-cutting aplites.

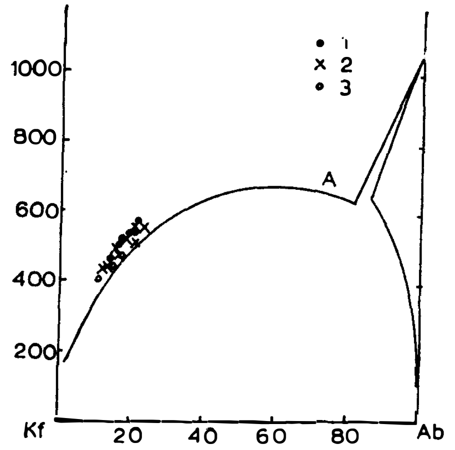

Fig. 12. Phase diagram of the potash feldspars from the Ryoke metamorphics, syn- and late-kinematic granites, Yanai area, Yamaguchi Prefecture (recalculated from the data of MURAKAMI *et al. (1963) p. 472, Table 4).*

1 : Ryoke metamorphics (banded gneisses, biotite gneisses).

2 : Synkinematic granite (Ohbatake granodiorite).

3 : Late kinematic granite (Gamano granodiorite).

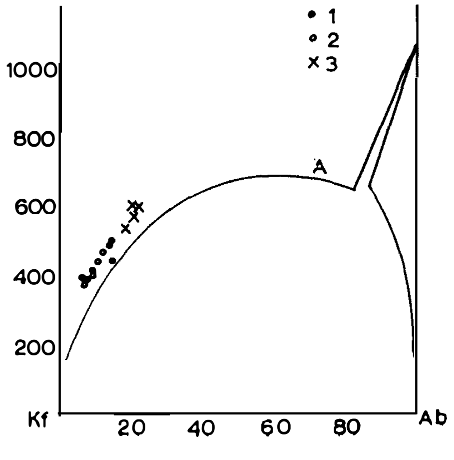

Fig. 13. Phase diagram of the potash feldspars from the post kinematic granite of Kibe area, Yamaguchi Prefecture, (recalculated from the data of MURAKAMI *et al. (1963), p. 473, Table 5; p. 470, Table 1).*

1 : Hyperite.

2 : Granodiorite.

3 : Aplite and pegmatites.

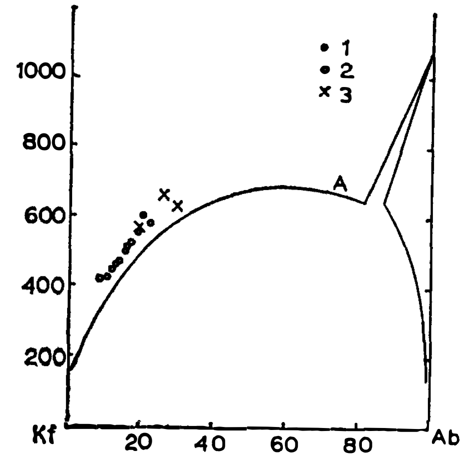

Fig. 14. Phase diagram of the potash feldspars from the Cretaceous granites of the Misasa area, Tottori Prefecture (recalculated from Murakami *et al. (1964), p. 145, Table 1).*

1 : Hornblende bearing biotite granites.

2 : Biotite granites.

3 : Aplites and pegmatites.

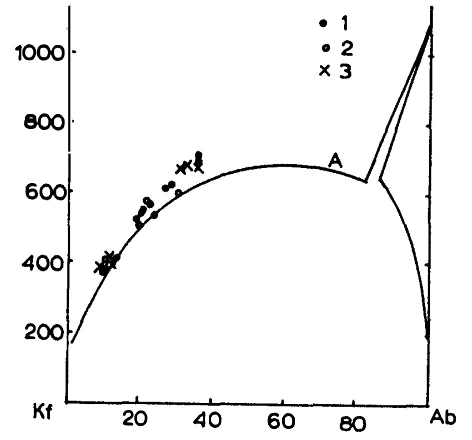

Fig. 15. Phase diagram of the potash feldspars from the Cretaceous granites of the western part of the Sanin district (recalculated from Murakami *et al. (1964), p. 146, Table 2).*

1 : Biotite granites.

2 : Granite porphyries.

3 : Aplites and pegmatites.

biotite gneisses, the autochthonous granite (Ohbatake granodiorite) with migmatitic characteristics, and the paraautochthonous granite (Gamano granodiorite) which intruded into the former two. The Kibe granite is regarded as a post-kinematic granite of the Ryoke metamorphism and is monzonitic biotite granite, accompanied by aplite and pegmatites (Okamura, Y., 1960; Nureki, T., 1960).

The data of the Hida (Fig. 11) and the Yamato Sanmyaku (Fig. 10) are scattered over a range wider than that of the Yanai (Fig. 12) and Kibe areas (Fig. 13). This difference is considered to reflect the degree of complexity of each metamorphic history.

Figs. 14 to 19 illustrate the phase diagrams obtained from the true intrusive granites of the Chugoku District, SW Japan (recalculated from the data of Murakami et al., 1964). The data of these areas are distributed very closely (see Figs. 14, 16, 18 and 19) or separated into several groups (see Figs. 15 and 17) on the phase diagrams. All of them, especially the potash feldspars from aplites and pegmatites, coincide well with the curve "A". These granites are considered to have been intruded as a melt in the late Cretaceous time at a shallow level of the crust. They show fine to medium grained, homogeneous texture, often with mi-

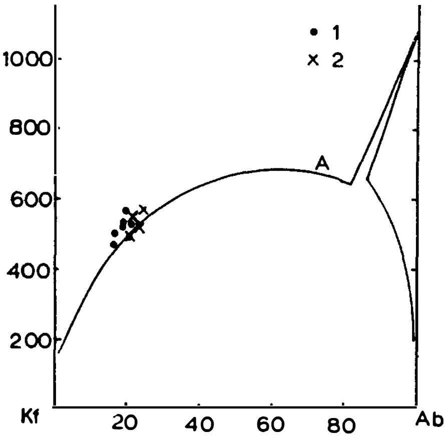

Fig. 16. Phase diagram of the potash feldspars from the Cretaceous granites of the Ikeda area, Shodo Island, Kagawa Prefecture (recalculated from MURAKAMI *et al. (1964), p. 147, Table 3).*

1 : Biotite granites.

2 : Aplites and pegmatites.

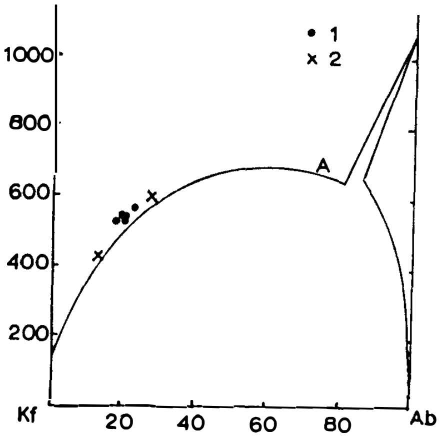

Fig. 17. Phase diagram of the porash feldspars from the Cretaceous granites of the Kure area, Hiroshima Prefecture (recalculated from MURAKAMI *et al. (1964) p. 147, Table 4).*

1 : Btotite granites.

2 : Aplites.

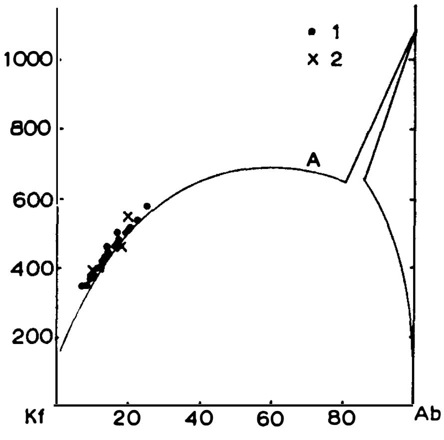

Fig. 18. Phase diagram of the potash feldspars from the Cretareous granites of the Kuga area, Yamaguchi Prefecture (recalculated from MURAKAMI *(1964), p. 148, Table 5).*

1 : Biotite granites.

2 : Aplite and pegmatites.

arolitic cavities.

The characteristics of the phase diagrams of the Japanese Cretaceous granites are distinctly different from those of the metamorphic rocks mentioned above. This difference reflects that the exsolution of the potash feldspar in the metamorphic rocks, syn- and late-kinemtatic granites advanced more than that in the magmatic granites, which intruded into shallow levels as a melt. The phase diagram obtained from the southern Norwegian metamorphics (Barth, T.F.W., 1962, Fig. 20 of this paper) also differs from that of the Japanese Cretaceous granites.

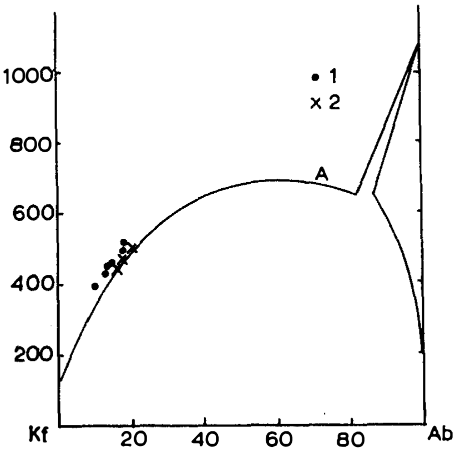

Fig. 19. Phase diagram of the potash feldspars from the Cretaceous granites of the Shiratori-honmachi area, Kagawa Prefecture (recalculated from Murakami et al. (1964) p. 152, Table 6).

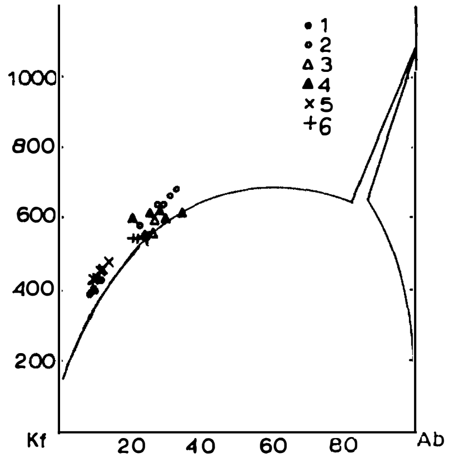

Fig. 20. Phase diagram of the potash feldspar from the southern Norway (Barth (1956), p. 18, Table 1; p. 27, Table 4).

1 : Granite gneisses.
2 : Augen gneisses.
3 : Small pegmatites.
4 : Large pegmatites.
5 : Anatectic granites.
6 : Diapir granites.

(2) Relationship between formation temperature and crystal symmetry

The symmetry change of potash feldspar is a function of formation temperature, vapor pressure and cooling rate. The relationship between the formation temperature and the symmetry of the potash feldspar from different localities is shown in Figs. 21 to 25.

Fig. 21 shows the data of the Yamato Sanmyaku. The plotted values of various kinds of rocks show different distributions on the diagram. The values of

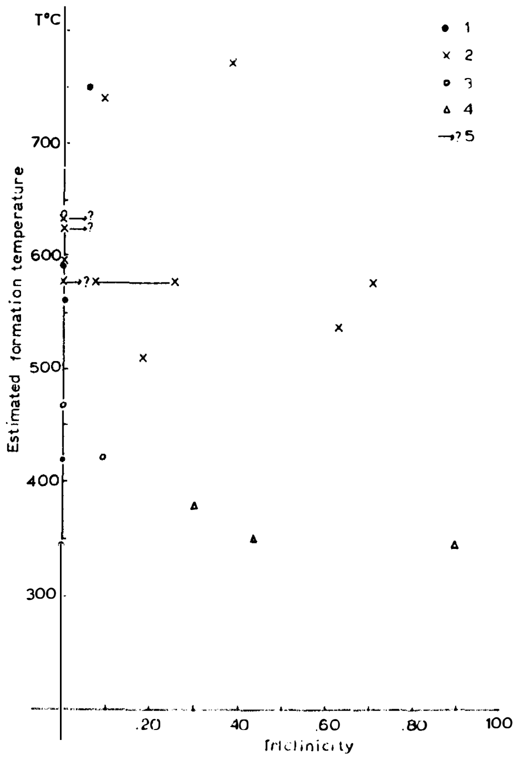

Fig. 21. Symmetry-formation temperature diagram of the potash feldspars from the metamorphic and granitic rocks of the Yamato Sanmyaku, Antarctica.
1 : Pyroxene gneisses and metabasites.
2 : Porphyritic pyroxene syenites(including (B-I) and (B-II) in the text).
3 : Pink granites.
4 : Pegmatite.
5: (131), ($1\bar{3}1$) peaks are diffused.

the pyroxene gneisses and metabasites occupy an area of low triclinicity, while those of the porphyritic pyroxene syenites and cross-cutting pegmatites deviate toward a high triclinicity area in the diagram, the former with relatively high temperature of formation and the latter with lower one.

According to the field and microscopical evidences, the pink granites (*YE 72* and *74*) are considered to have been granitized from the pyroxene syenite and some samples (*YA 293* and *YE 54*) show a transitional relation of these two. The pyroxene syenites treated in the present paper are strongly permeated by pink feldspathic material of the pink granite and often show an agmatitic structure. On the other hand, the porphyritic pyroxene syenite still retain their metablastic characteristics with strongly undulated mafic-rich layers. The, pegmatites, which are related to the younger microcline granites, cut the country rock obliquely and are often accompanied by epidote and chlorite. The field occurrences and petrographic characteristics of each rock group already mentioned is well explained as a whole by the interpretation which is deduced from the temperature-symmetry diagram of the feldspars, that is, the low triclinicity of the pyroxene gneisses and the pink granites are explained as a consequence of their low vapor pressure and granitization under the granulite facies. The deviation of triclinicity of the schiller feldspar bearing pyroxene syenites shows prolonged growth of the porphyroblasts under relatively high metamorphic condition and strongly affected by the

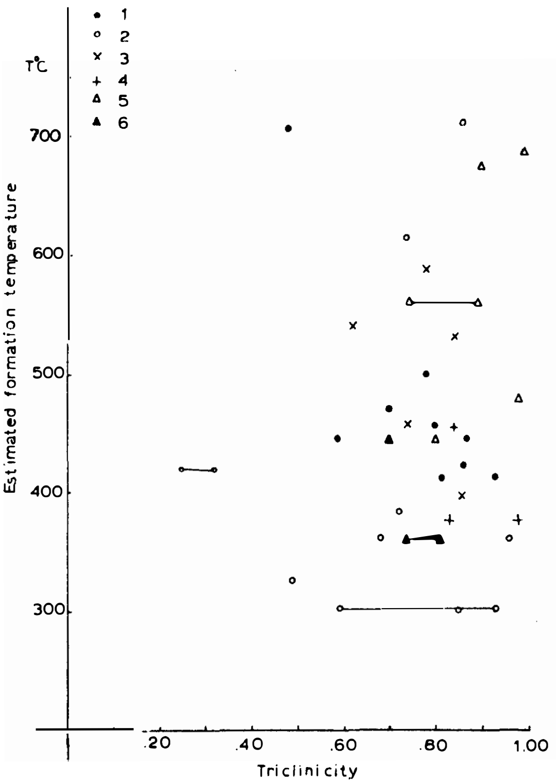

Fig. 22. Symmetry-formation temperature diagram of the potash feldspars from the Funatsu granites and metamorphic rocks, Hida.

1 : Hornblende or biotite granodiorites.
2 : Potash feldspar porphyritic granites.
3 : Augen gneisses.
4 : Aplites of replacement origin.
5 : Cross cutting aplites.
6 : Intrusive homogeneous granites.

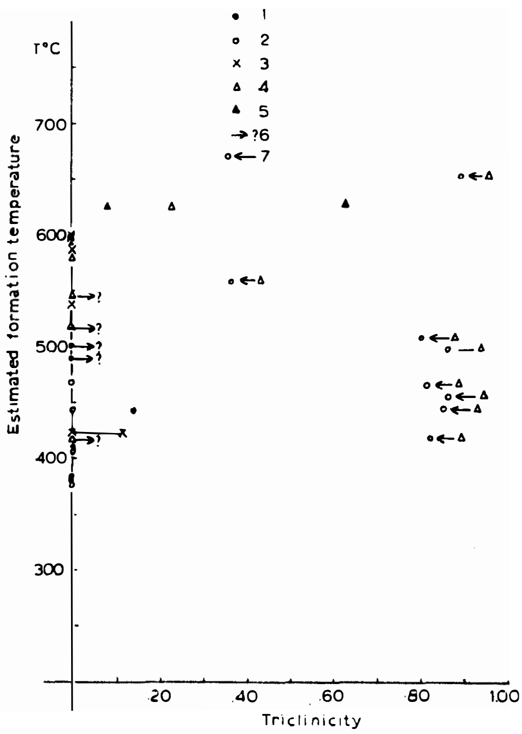

Fig. 23. Symmetry-formation temperature diagram of the potash feldspars from the Ryoke metamorphic rocks and granites of Yamaguchi Prefecture.

1 : Banded biotite gneisses.
2 : Syn-kinematic granites (Ohbatake granodiorites).
3 : Late-kinematic granites (Gamano granodiorites).
4 : Post-kinematic granite (Kibe granites).
5 : Hyperite accompanied with Kibe granites.
6 : (131), $(1\bar{3}1)$ *are diffused from O.*
7 : (181), $(1\bar{3}1)$ *are diffused until O.*

granitization of the pink granite. The pegmatites might have crystallized under low temperature and high vapor pressure, probably lower than amphibolite facies.

The diagrams showing the relationship between the formation temperature and the symmetry of feldspar from various localities are also illustrated in Figs. 22, 23, 24 and 25.

The data obtained from the Funatsu granites and related metamorphic rocks are shown in Fig. 22. Almost all of them are plotted in the area of intermediate to maximum microcline even in the higher temperature area. Judging from the field and petrographic observations, these rocks were strongly affected retrogres-

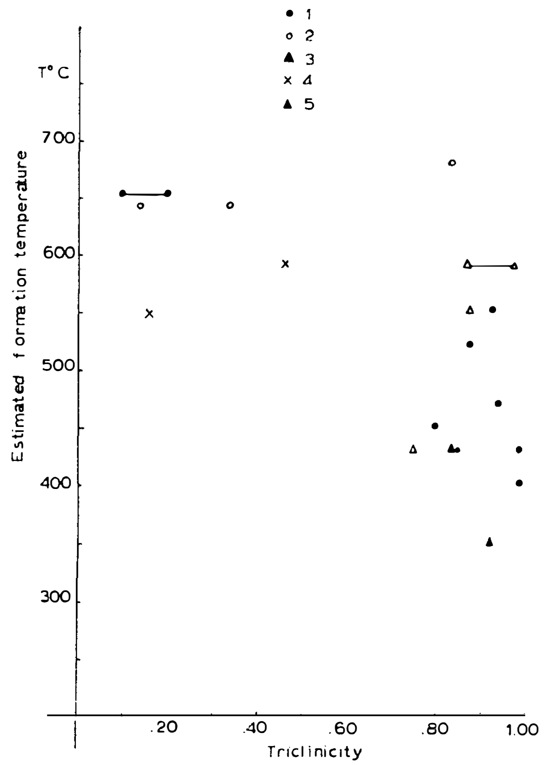

Fig. 24. Symmetry-formation temperature diagram of the potash feldspars from the gneiss area of South Norway (after HEIER *(1957), p. 478, Fig. 4).*
1 : Granites and granodiorites.
2 : Augen gneisses.
3 : Gneisses and schists.
4 : Aplite and pegmatite.

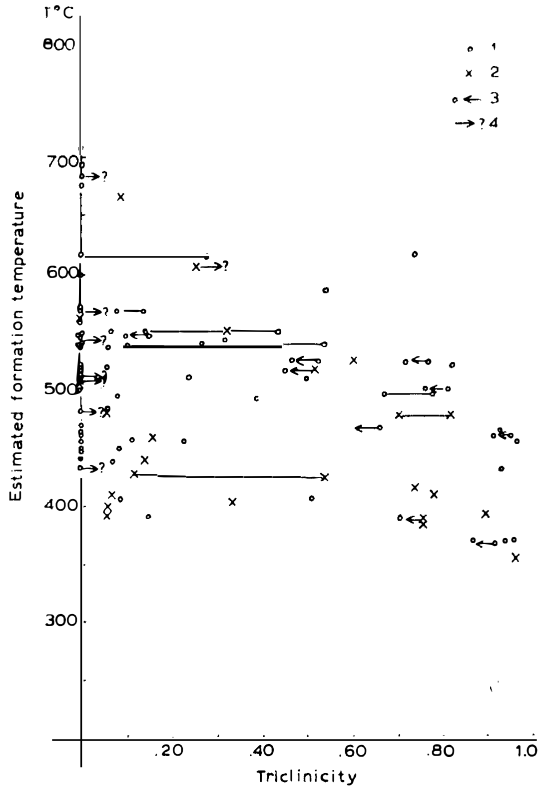

Fig. 25. Symmetry-formation temperature diagram of the potash feldspars from the Cretaceous granites of SW Japan.
1 : Granites.
2 : Aplites and pegmatites.
3 : (131), $(\bar{1}31)$ are diffuse until 0.
4 : (131), $(\bar{1}31)$ are diffuse from ●.

sively by mechanical granulation and hydrothermal alteration. The high triclinicity of these minerals are reasonably explained by their field occurrences.

The data of the Ryōke metamorphics and accompanying syn- and late-kinematic granites (Fig. 23) occupy a small triclinicity area in the diagram, as do the banded biotite gneisses belonging to amphibolite facies. The triclinicity values of the post-kinematic granites (Fig. 23), on the contrary, deviate widely up to almost maximum triclinicity, often retaining monoclinic symmetry. This may reflect the difference in physical condition and the process of cooling of each granite emplaced.

The monoclinic symmetry of the patash feldspar from these metamorphic rocks and migmatitic granites seems to be anomalous. The same anomalous phenomena were already mentioned by BARTH (1956, p. 20) in the common biotite gneisses from southern Norway, and he explained it as a recrystallization effect under lower temperature, corresponding to that of Alpine veins. The same anomaly is observed in the pyroxene gneisses and pink granites of the Yamato Sanmyaku. It seems that the intrusive movement from the deeper tectonic level to the upper levels along tectonic fractures, such as the thrust along the main trend of the orogenic zone, strongly influenced the characteristics of potash feldspar by re-heating and rapid cooling during granite emplacement under low vapor pressure. The same anomalous trend is already reported by MARFUNIN (1962, p. 313, Fig. 4) from the Precambrian shield of Ukraina. The geological details, however, were not described by him.

The data from southern Norway published by HEIER (1957, p. 478, Figs. 4 and 24 in this paper) shows a trend quite different from Figs. 21 and 22. In the case of southern Norway, the Precambrian metamorphic rocks suffered the later retrogressive metamorphism, whereas in the Ryoke area the regionally metamorphosed rocks were affected only by late-kinematic granites which might have been under a higher temperature than that when the metamorphic rocks were formed.

HEIER (1960 and 1961) also studied the amphibolite-granulite facies transition reflected in the structural state of potash feldspar in the progressive metamorphic rocks of Langøy, northern Norway, and reached the conclusion that, 1) the transition of the monoclinic-triclinic phase of potash feldspar occurred at the boundary between granulite facies and amphibolite facies, and the temperature of this transition was roughly 500°C, and 2) the change of the optical axial angle of potash feldspar is more sensitive than that of the triclinicity against the change of the metamorphic conditions. This conclusion is easily accepted from his diagram (HEIER, K. S. 1961, p. 139, Figs. 3a, 3b), and is well summarized in the diagram by DIETRICH (1962, p. 711, Fig. 5). Potash-feldspar from the Abukuma Plateau in Japan had also studied by F. SHIDO (1958) related to the symmetry change of potash feldspar in her upper part of B zone in Nakoso area, Fukushima Prefecture.

The data of several metamorphic and granitic rocks of Japan show that they belong to the amphibolite facies or possibly lower ones. In the Yamato Sanmyaku, the metamorphism had once belonged to granulitic facies, later changed to amphibolite facies, and the granitic rocks of the amphibolite facies do not completely agree with HEIER's conclusion. The potash feldspars often show monoclinic symmetry even in the rocks of amphibolite facies and have rather higher formation temperatures.

A contrast is found between the Ryoke metamorphics-granites (Fig. 23) and the Funatsu complex (Fig. 22); the former is the typical pelitic regional metamorphic rocks of the amphibolite facies, whereas the latter is a metasomatic product of pre-existing hornblende gneisses formed under conditions of epidote amphibolite facies with high water vapor pressure and strong mechanical disturbance. The causes of the contrast depend not only on the temperature of formation and metamorphic grade, but also to a large extent on the water vapor pressure and on the mechanism of the emplacement of each rock, such as the intrusion movement, the rate of cooling, and the role of shearing stress.

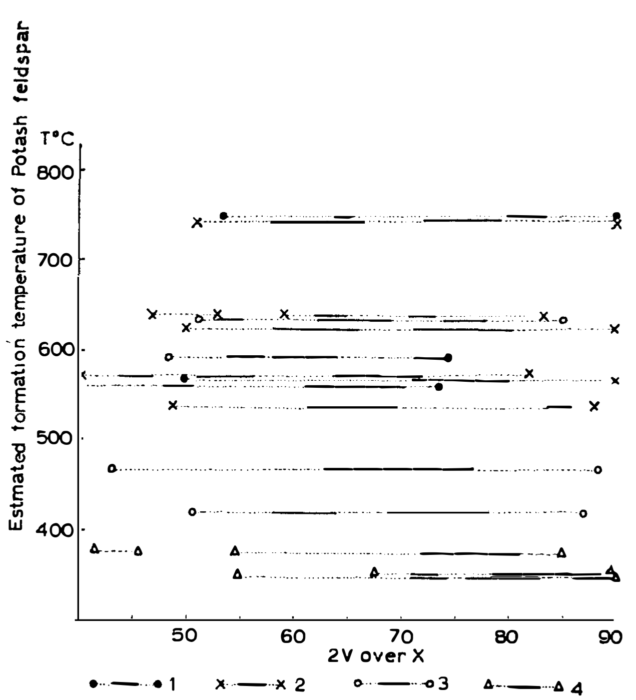

Fig. 26. The relationship between 2 Vx and the formation temperature of the potash feldspars from the Yamato Sanmyaku.

1 : Pyroxene gneisses and metabasites.

2 : Porphyritic pyroxene syenites (including (B-I) and (B-II) in the text.)

3 : Pink granites.

4 : Pegmatites.

The dotted line shows the whole range of 2Vx from one sample, and the solid line shows the 2Vx range of higher frequency (more than 10%) (cf. Fig.4).

The upper-most two are No.(YC226) and (YC 228), see the text.

The second point of Heier's conclusion is well supported by the present data, by comparison of Fig. 21 with Fig. 26. In Fig. 26 several samples show rather anomalous trends (*i. e.*, *YC 225* and *YC 228*, refer to Table 1). They might have been affected intensely by the later intrusion of the microcline granites and the associated cross-cutting pegmatites.

The conclusion by Heier (1961, p. 478) is not contradictory to that by the present authors, that is, "A feldspar formed at a higher (lower) temperature may, during a later metamorphism of a lower (higher) temperature, change its symmetry quite easily, whereas a redistribution of sodium between potash feldspar and plagioclase may not be possible".

The Cretaceous granites from southwestern Japan (Fig. 25) present a different trend, *i. e.*, a continuous change of triclinicity from monoclinic to almost maximum triclinic symmetry, and this trend resembles that of the post-kinematic granites of the Ryoke metamorphic area (Fig. 23).

(3) Relationship between optic axial angle and triclinicity

The relationship between optic axial angle and triclinictiy is illustrated in Fig. 27, and shematically summarized in Fig. 28. The relation between these two parameters of potash feldspar was studied mineralogically by Marfunin (1961) in detail. He divided the data of X-ray analyses and optical parameter of potash feldspar into two groups.

1) Optical orientation, degree of triclinicity and lattice angle depend on both the degree of order-disorder and sub-microscopic twinning.

2) Optical axial angle : this parameter has no analogue among X-ray con-

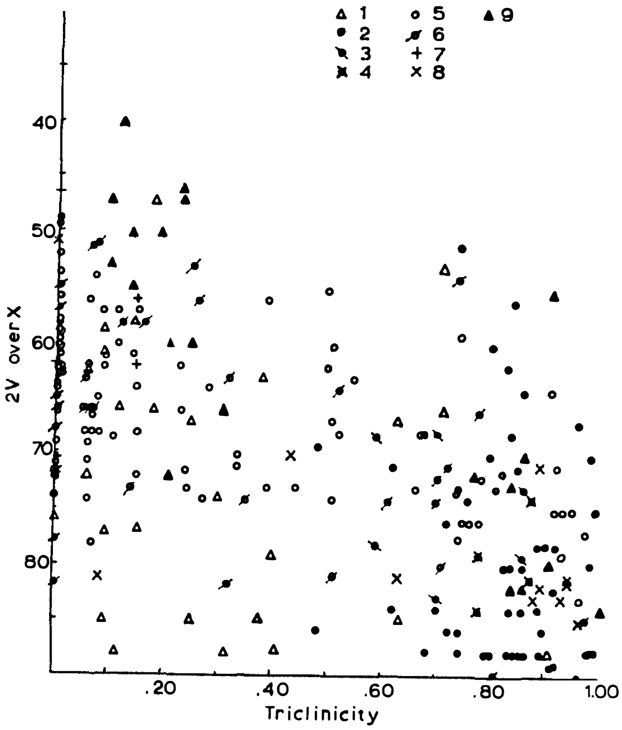

Fig. 27. The relationship between 2Vx and triclinicity of potash feldspar from several localities.
1 : The metamorphic and granitic rocks from the Yamato Sanmyaku, Antarctica.
2 : Funatsu granites, Hida area.
3 : Augen gneisses of the Funatsu metamorphic terrain.
4 : Aplites of the Funatsu granites.
5 : Ryoke metamorphic rocks, syn- and late-kinematic granites (MURAKAMI et al., 1963).
6 : Post-kinematic Ryoke granites (MURAKAMI et al., 1963).
7 : Cretaceous granites from SW Japan (MURAKAMI et al., 1963).
8 : Aplites and pegmatites of the Cretaceous granite (MURAKAMI et al., 1964).
9 : The metamorphic rocks from Langφy, North Norway (HEIER, 1961).
50 points of the monoclinic (triclinicity =0), potash feldspars (10 from Yamato Sanmyaku, 22 from the Cretaceous granites, 11 from the Ryoke metamorphics, syn-and late-kinematic granites, and 7 from the post-kinematic Ryoke granite) are omitted to avoid the confusion on the diagram.

stants, and depends only on the degree of order-disorder.

MARFUNIN proposed a classification of potash feldspar on the diagram showing the relationship 2V and triclinicity or ⊥ (010) ^Ng.

Fig. 28 is based on MARFUNIN's diagram. However, the data used in the present paper were obtained from the aggregates of many grains in one hand specimen, not from individual potash feldspar grain. Consequently, any interpretation for this diagram cannot be given from mineralogical points of view.

The distribution trends of the data from various localities on this diagram are generally those from small 2Vx-low triclinicity to large 2Vx-high triclinicity.

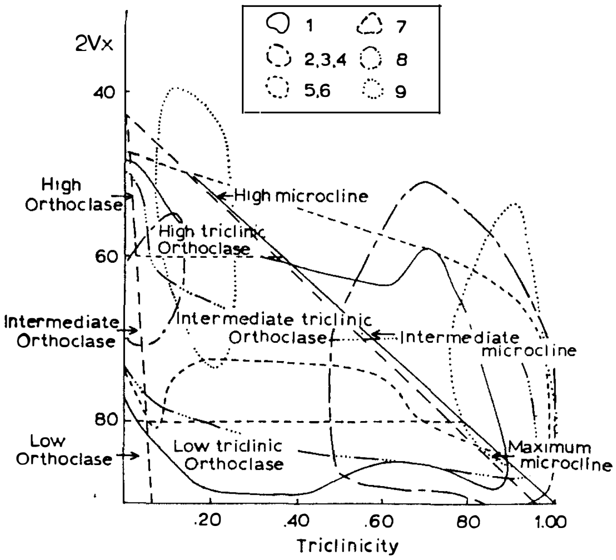

Fig. 28. Schematic illustration of the relationships between 2Vx and triclinicity. Legend as in Fig. 27.

However, the data of several metamorphic rocks, namely, the Ryoke metamorphics, syn-and late-kinematic granites, the Funatsu metamorphics, the metamorphic rocks from Langøy, North Norway, and the pyroxene gneisses and the metabasites from the Yamato Sanmyaku, Antarctica,* are not scattered along the general trend, but concentrated on both ends of the diagram. The data of the Ryoke metamorphics (mostly belonging to higher parts of amphibolite facies), the charnockites from the Yamato Sanmyaku and the Langøy metamorphics (belonging to granulite facies) show low triclinicity and comparatively smaller 2Vx, whereas the Funatsu metamorphic and the Langøy metamorphics (belonging to amphibolite facies) show high tricilinicity and relatively large 2Vx. These differences, though they may be essentially due to insensibility of triclinicity against the change of the structural state of the potash feldspar, may also indicate the difference in the mode of crystallization, re-crystallization, cooling history, effects of tectonic disturbance and other factors which occured during the formation and/or emplacement of each rock massif. These mineralogical characteristics of potash feldspars may offer useful information about the plutonic and metamorphic history experienced by the rocks.

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* The data, not illustrated separately in Figs. 27 and 28, occupy the area closest to the left hand side of these diagrams and have 2Vx values ranging from 48° to 77°.

VI. CONCLUDING REMARKS

The potash feldspars treated in the present paper are limited to those in the charnockitic group and pegmatite, and those in the granitic group are ommited, though the granitic gneiss and granitic rocks occupy a large part of the region. Therefore, the investigation on the potash feldspar from the mountains is not complete yet. It has been confirmed, however, that the mineralogical and petrographical studies of the potash feldspar is valid to the analysis of the metamorphic and plutonic condition of the region.

In the megascopic observation of hand specimens, three different types of potash feldspas can be distinguished; pale pink or white potash feldspar forming granular matrix in pyroxene gneiss and metabasite, grey large schiller porphyroblast in porphyritic pyroxene syenite and pink large one in pegmatite. The classification is supported by the optical characteristics of each feldspar under microscorpe. The microscopic obsevation reveals that the potash feldspar of the pyroxene gneiss was formed by metasomatism under granulite facies condition, and then in the pyroxenes syenite and the pink granite, albitization along fractures as well as grain boundaries of potash feldspar occured sometimes to form large albite porphyroblast as a result of the advanced replacement of the potash feldspar under the lower condition than the former. The graphic intergrowth and myrmekitic texture are the characteristics of the potash feldspar in pegmatite.

The relationship between the formation temperature estimated by the "two-feldspar geothermometer method" and triclinicity and 2Vx value of the potash feldspars indicates that the charnockitic rocks were originally formed under the granulite facies condition and change more or less their characters owing to the subsequent granitization under the amphibolite facies condition. The result coincides well with the conclusion of the geological and petrographical studies by Kizaki (1965). The deviation of the formation temperature, triclinity and 2Vx value reflects generally the transition from the granulite facies to the amphibolite facies, and further, the duplication of both facies may be divided by the optical measurement of potash feldspar. It is enough to say that the two-feldspar geothermometer method is not perfect yet but is valid for determination of the petrographic characteristics of potash feldspar.

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