

THE ALKALI FELDSPARS V. THE NATURE OF ORTHOCLASE
AND MICROCLINE PERTHITES AND OBSERVATIONS
CONCERNING THE POLYMORPHISM OF POTASSIUM
FELDSPAR*

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ABSTRACT

The observations recorded in paper 1 of this series have been extended to cover 37 specimens of orthoclase and microcline perthites. The exsolved sodium phase of the perthitic specimens is usually a low temperature albite or oligoclase, although some specimens falling near the composition $Or_{30}(Ab+An)_{20}$ and with $2V$ between 50° and 70° contain an anorthoclase instead. The anorthoclase occurs as a pericline twin-type superstructure. Most of the albite-oligoclases are dominantly albite twinned: four specimens show both pericline and albite twinning, while seven specimens with compositions $\sim Or_{70}$ and $2V_\alpha$ between 60° and 80° show mainly albite twin-type superstructure.

The potassium phase is monoclinic in 14 specimens, triclinic in 4 and partly each in 15 specimens. The triclinic components give reflections that vary from sharp to diffuse, with lattice angles α^* , γ^* varying from 90° , 90° to about $90^\circ 24'$, $92^\circ 20'$. All the triclinic components are composed of two or more units whose angular relations vary between the extremes of albite and pericline twinning, with the "diagonal" association fairly common.

The optic axial angles fall either in or close to a triangle formed by the three extreme varieties: low albite, Or_0 $2V_\alpha$ 100° ; orthoclase, Or_{100} $2V_\alpha$ 35° ; and maximum microcline, Or_{100} $2V_\alpha$ 80° . There is a moderate, but not good, correlation between the position of the specimens in this triangle and the nature of the potassium-rich component. Specimens which either contain anorthoclase or consist predominantly of the albite twin-type superstructure of low albite-oligoclase fall into two small areas in the $2V$ versus composition diagram. The preferential occurrence of the superstructure in the more potassium-rich compositions supports the hypothesis that strain favors its existence in orthoclase and microcline perthites. The anorthoclase is thought to occur because the containing specimens have compositions that lie close to a phase boundary, a condition known to favor metastability.

INTRODUCTION

In paper 1 of this series (MacKenzie and Smith, 1955), the results of a mineralogical study of some orthoclase perthites were presented. Since then, data on additional orthoclase perthites and on some microcline perthites have been obtained and form the basis of this paper. To conserve space, familiarity with the literature reviews contained in the earlier papers of this series will be assumed. No papers that bear solely

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on the relations between the perthitic components have appeared since these reviews, but a considerable number have appeared that are concerned with the polymorphism of potassium feldspar (Bailey and Taylor (1955), Goldsmith and Laves (1954a,b), Hafner and Laves (1957), Heier (1957), Ferguson, Traill and Taylor (1958)). A detailed review will be given in a later paper of this series which is to be devoted to the polymorphism of potassium feldspar, and it is sufficient for the present purpose to record that Hafner and Laves state that there is a continuous series of structural states between high-sanidine and maximum microcline, that the conversion of a fully disordered to a fully ordered potassium feldspar may occur in innumerable ways by variation of the distribution of Al ions between the four possible sites, and that the distribution of Al in the intermediate states depends on the previous temperature-time relations.

DESCRIPTION OF THE SPECIMENS

The origin, bulk chemical composition and optic axial angles of the 37 specimens studied by single crystal *x*-ray methods are recorded in Table 1, together with the lattice angles α^* and γ^* of the triclinic phases, where these have been measured. (All compositions are expressed as weight per cent Or, Ab, An.) Most of the specimens are derived from pegmatites, five are from charnockitic rocks and one each from a quartz monzonite, a porphyroblastic orthoclase gneiss, a granite and from a vein in a low-grade schist. The specimens were originally called orthoclase- or microcline-perthites on the basis of the observed optical symmetry. Fig. 1 shows the relationship between the optic axial angle and bulk chemical composition, where it may be seen that almost all specimens fall in the triangular area formed from the apices low-albite, orthoclase and maximum microcline.

Except for a few which are either very potassium-rich or sodium-rich, the feldspars are perthitic, containing either two or three different phases. These can be most certainly characterized by their α^* , γ^* angles as shown in Fig. 2. The measurements fall into three groups. The first group composed of potassium-rich components, falls on an essentially continuous series (the microcline series), with monoclinic orthoclase at one end. The position of the other end is subject to some uncertainty because one specimen, N, lies off the common trend: neglecting it the other specimens show that the microcline series extends at least as far as $\alpha^* 90^\circ 24'$, $\gamma^* 92^\circ 20'$ —the *maximum microcline* defined by MacKenzie (1954). The triclinic potassium phase of N occurs in an uncommon orientation (Smith and MacKenzie, 1954) which could not be interpreted in terms of the known twin laws, and while the angles may indicate a

TABLE 1. PROPERTIES OF THE SPECIMENS

Specimen Number	Chemical composition				2V α	Potassium phase		Sodium phase	
	Or	Ab	An	Cs		α^*	γ^*	α^*	γ^*
A	96.1	3.9	0.0	—	34.8°	—	—	—	—
B	91.2	7.9	0.6	0.3	68.4°	—	—	—	—
C	90.8	6.7	2.5	—	43.6°	—	—	—	—
U	85.9	12.7	1.4	—	76.2°	90°05'	90°46'M	—	—
3705	84.9	13.1	2.0	—	83-86°	—	—	—	—
D	84.5	13.8	1.7	—	46.2°	—	—	—	—
V	84.1	14.8	1.1	—	63.9°	—	—	88°29'	89°16'P
E	83.3	14.9	1.8	—	57.6°	90°09'	91°09'M	87°58'	89°05'P
LM3A	82.8	14.3	1.8	1.0	80°	90°19'	91°24'A	—	—
6436	82.5	16.4	1.1	—	69°	—	—	—	—
W	81.6	18.0	0.4	—	81.5°	—	—	86°19'	89°42'A
3708	80.7	17.9	1.4	—	82-84°	—	—	86°45'	89°36'A
X	79.3	19.2	1.5	—	76.0°	—	—	(86.5°	90.0°)P
F	78.8	18.9	2.3	—	52.9°	—	—	—	—
Z	78.2	20.2	1.6	—	70.6°	—	—	88°35'	89°31'P
LM6	77.5	20.9	0.8	0.7	70°	90°21'	91°35'A	86°25'	90°18'A
Y	76.1	22.2	1.7	—	79.4°	—	—	—	—
S347	74.4	24.2	1.4	—	62°	—	—	86°13'	89°19'A
H	72.5	25.8	1.7	—	61.5°	—	—	—	—
4639	71.3	25.8	2.9	—	62-78°	90°27'	92°09'P	—	—
I	69.4	28.9	1.7	—	69.1°	—	—	—	—
J	66.6	32.5	0.9	—	75.0°	—	—	—	—
K	64.4	33.8	1.8	—	61.4°	—	—	—	—
M	57.3	40.3	2.4	—	73.7°	—	—	87°00'	90°32'A
N	53.7	45.6	0.7	—	83.5°	90°50'	92°35'D	86°48'	90°33'A
O	48.5	47.3	4.2	—	82.8°	—	—	86°45'	90°15'A
								86°42'	90°15'P
OF4	46.4	52.5	1.1	—	75°	—	—	86°32'	90°23'A
Q	45.6	50.2	4.2	—	81.7°	—	—	86°52'	90°17'A
R	44.1	51.6	4.3	—	71.3°	—	—	85°44'	90°00'A
								86°45'	89°55'A
								86°48'	89°58'A
OF5	43.3	54.5	2.2	—	90°	—	—	86°29'	90°20'A
								(86.5°	90.5°)P
OF2	43.0	53.7	3.3	—	86°	—	—	86°48'	90°28'A
OF3	41.9	54.5	3.6	—	80°	—	—	86°38'	90°13'A
OF1	39.0	58.8	2.2	—	90°	90°16'	91°12'A	86°23'	90°25'A
1	31.5	68.3	0.2	—	82.0°	—	—	86°39'	90°34'A
2	19.8	72.7	6.0	1.5	78.5°	—	—	86°13'	89°30'P
								86°29'	89°58'A
S	2.6	96.2	1.2	—	97.8°	—	—	—	—
T	1.4	98.2	0.4	—	102°	—	—	—	—

NOTES. Specimens A-Z were described by Spencer (1930, 1937); Specimens 3705, 6436, 3708 and 4639 by Howie (1955); specimen S347 by Howie (Ph.D. Thesis, Cambridge); specimens LM3A and LM6 by Heald (1950); specimens OF4, 5, 2, 3 and 1 by Oftedahl (1948); specimen 1 by MacKenzie and Smith (1955) and specimen 2 by Tilley (1954). The letters A, D, P, M, after the values for the angles α^* and γ^* denote, respectively, albite twinning, the diagonal association, pericline twinning and measurements made on powder patterns by MacKenzie (1954). Weak pericline twinning of a sodium-rich component was given by specimens X and OF5: the measured values of α^* and γ^* were good enough for identification of the component as low albite-oligoclase but not good enough for plotting on Fig. 2.

genuine structural difference between the potassic phases of N and of the other triclinic potassium feldspars, it is possible that the different nature of the associations have led to a modification of the angles by nothing more than lattice strains.

The angles for the sodium components provide the other two groups. Three fall with the anorthoclase series and twenty-one with the sodic

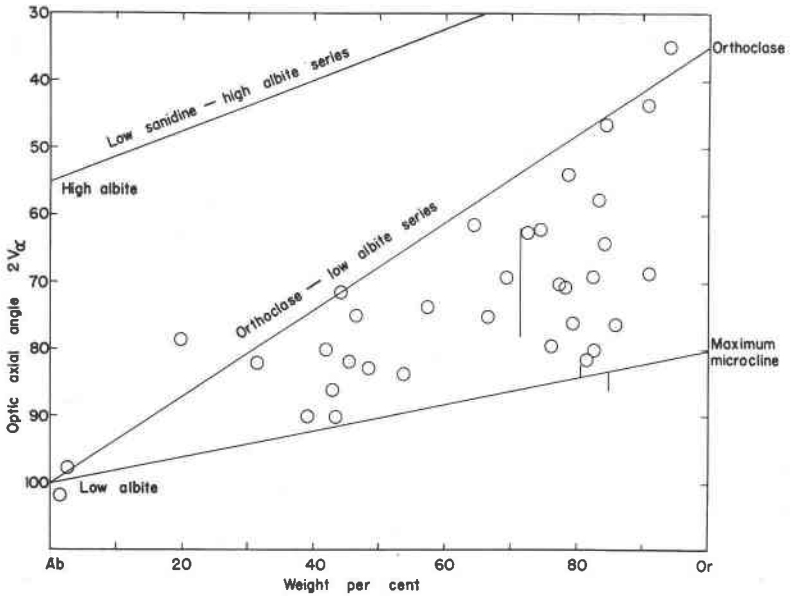


FIG. 1. The relation between the optic axial angle $2V\alpha$ and the bulk chemical composition of the present suite of alkali feldspars. The diagram is a slight modification of the one presented by Tuttle (1952). The short vertical lines indicate a range of variation of optic axial angles.

plagioclases. As described in paper 1, the deviations of angles for the latter group from those of low albites are probably caused by solid solution of potassium and calcium feldspars, though for the latter the duality between structural state and calcium content must be borne in mind.

The triclinic phases consist of two or more components. In addition to the simple albite and pericline twins, pairs of components may occur whose relative orientations lie between those for the albite and pericline twins. In the first described example (Smith and MacKenzie, 1954), the orientation of the components in this *diagonal association* (named from the diagonal directions that relate the pairs of reflections on *b*-axis oscil-

lation photographs) lay half-way between those for albite and pericline twinning (Fig. 3). Further examples have shown orientations that lie in various positions between the two extremes and it seems probable that all variations are possible.

Two further variants in the sodium phases are *albite twin-type superstructure* and *pericline twin-type superstructure* (Laves, 1952; MacKenzie

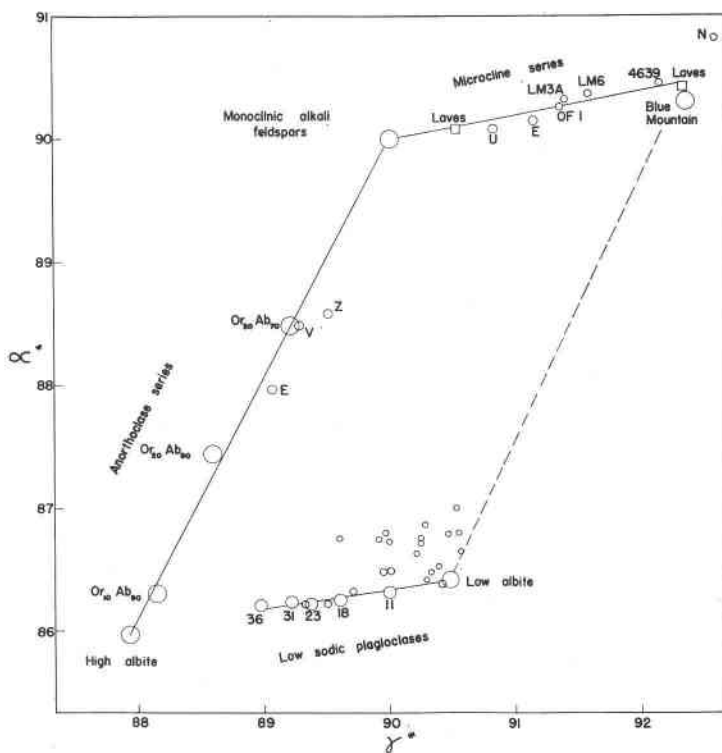


FIG. 2. The relation between the reciprocal lattice angles α^* and γ^* for the sodium and potassium phases. The reference values, shown by large circles, have been obtained for homogeneous feldspars by Donnay and Donnay (1952), MacKenzie (1954) and Smith (1956). The two squares represent the mean of values obtained for adularias and microclines by Laves (1950). The small circles express the data for the present suite of specimens where the lattice angles have been measured. The data are listed in Table 1. Dr. W. L. Brown (private communication) has recently found that large variations in α^* and γ^* can be obtained by heating albite and other feldspars for long periods just under the melting point. This work casts doubt on the determination of composition from α^* , γ^* values, though the authors have found that composition estimated in this way for natural feldspars have generally been very reasonable. Further discussion of this very important point will be given later in this series.

and Smith, 1955). The first type gives reflections which lie along the row lines of b -axis oscillation photographs and has been interpreted (Laves, 1952) as the result of a superstructure produced by regular polysynthetic twinning according to the albite law. Many variations between a very regular superstructure and simple albite twinning have been observed. As the albite-twinned sodium phases are invariably albite-oligoclases in

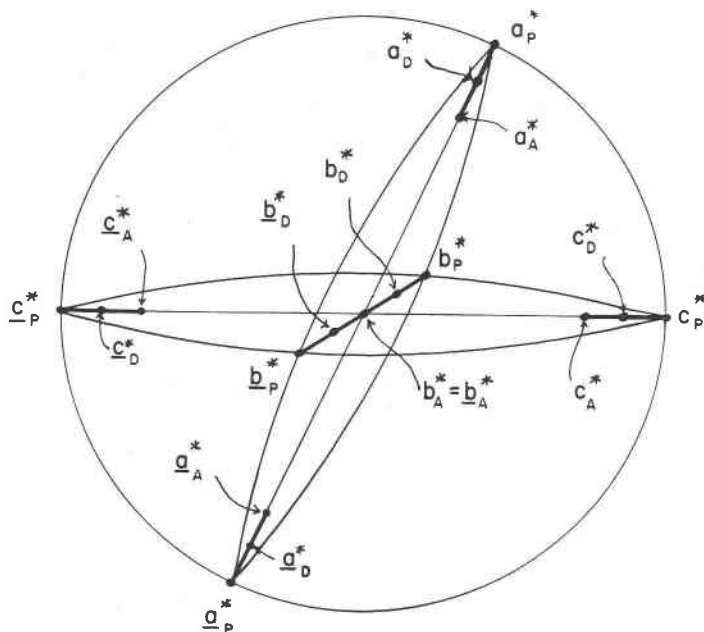


FIG. 3. The relative crystallographic orientation of the two components in a diagonal association. The suffixes A, D and P denote, respectively, albite twinning, diagonal association and pericline twinning. Crystallographic elements from the diagonal association may be anywhere between the extremes for albite and pericline twinning subject to the condition that a^*_D , b^*_D and c^*_D maintain the correct interaxial angles. The deviations of the angles α^* and γ^* from 90° are grossly exaggerated.

this suite of specimens it is natural to suppose that the albite twin-type superstructure is composed of similar material. The pericline twin-type superstructure gives two clusters of reflections lying along the layer lines of b -axis oscillation photographs. Values of α^* , γ^* for the centers of the clusters indicate anorthoclase (Fig. 2) and it seems very reasonable to conclude that the superstructure is composed of anorthoclase. (In the following paper, observations on perthites from the Slieve Gullion area in Northern Ireland are used to show that anorthoclase may occur as albite twin-type superstructure. Thus it cannot be assumed that all

albite twin-type superstructure is formed of albite-oligoclase and all the pericline type of anorthoclase, though usually this implication would be valid.)

Figs. 6, 7 and 8 have been prepared to show in a concise way the nature of the exsolved phases. By the use of symbols plotted on graphs of $2V$ versus bulk composition the nature of the specimens is shown, and what is more important, the relation between the particular displayed property and the optical and compositional variables may be seen.

THE SODIUM-RICH COMPONENTS

Two specimens are composed solely of a sodium-rich feldspar, three of a potassium feldspar, while the remainder are perthitic, five containing an anorthoclase, twenty-three an albite-oligoclase, two that may contain both, and two containing an unidentified sodium feldspar. The latter specimens were obtained from charnockite rocks and the photographs contain reflections streaked along curves of constant θ , thus precluding a positive identification.

The presence of anorthoclase is remarkable for it would not be expected at first thought to persist in specimens such as these that have been subjected to moderate and low temperatures for long periods of time. A clue to the dilemma is offered by the restricted area occupied by the anorthoclase-containing specimens on the composition- $2V$ diagram (Fig. 4). The fields of one and more than one feldspar may be delineated on the composition- $2V$ diagram. The boundary curve between the two fields may be regarded as a distorted projection of the exsolution dome that occurs in the phase diagram of the system $\text{NaAlSi}_3\text{O}_8$ - KAlSi_3O_8 . In fact the whole of Fig. 5 may be imagined as a distorted copy of the solid-phase portion of this system with the optic axial angle being related to the temperature in the phase diagram. (The data for the field boundary has been taken from earlier papers of this series and from other investigations. A full discussion of the phase relations is planned for the concluding paper of this series). It is well known, though not often mentioned in print, that near phase boundaries equilibrium may be established only with difficulty and that unstable forms often develop and persist metastably. Thus it seems reasonable to correlate the presence of the anorthoclase with the proximity of the specimens to the field boundary in Fig. 4. Other specimens in or near the same composition range generally have larger values of $2V$ thus lying further away from the field boundary. They all contain low-temperature albite-oligoclase in accordance with expectation. Specimen B although it lies in the field of two or more feldspars was found to be homogeneous. It is an adularia, a form of feldspar characteristic of a low-temperature

origin, and may very well have not had sufficient opportunity to exsolve its sodium feldspar. Specimens LM6 and S347 contain low-temperature albite-oligoclase and may also contain a little anorthoclase as well, for weak streaks lie along the layer-lines in *b*-axis oscillation photographs. The direct cause of the persistence of the anorthoclase may well be lattice strain, for it is probably not fortuitous that the anorthoclase occurs in the form of a superstructure and that the α^* , γ^* values correspond to potassium-rich anorthoclase near Or₃₀ in composition. For comparison, the α^* , γ^* values of anorthoclase occurring in sanidine perthites indicate compositions more sodium-rich, Or₁₈-Or₂₅. It was suggested in paper 1 of this series that anorthoclase can only invert to low-temperature albite when most of the potassium feldspar has exsolved, and that inversion of anorthoclase in orthoclase perthites was prevented by the presence of a comparatively high content of potassium.

The low sodium-rich feldspar occurs in three different associations:—albite twinning, albite twin-type superstructure and pericline twinning

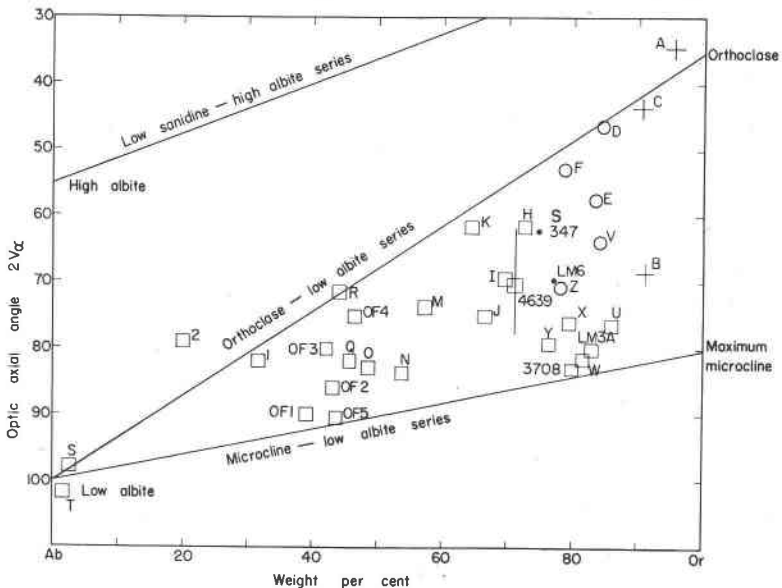


FIG. 4. The nature of the sodium-rich phases. A square indicates that the sodium-rich phase is an albite-oligoclase while a circle indicates anorthoclase. The three specimens represented by plus signs have no sodium phase. Specimens S347 and LM6 (represented by dots) contain two sodium-rich phases, one an albite twinned low-temperature albite-oligoclase and the other a phase which gives weak streaks lying along the layer lines of *b*-axis oscillation photographs. Two specimens, 3705 and 6436, have been omitted from the figure because the reflections were too badly streaked along curves of constant θ for the nature of the sodium-rich phase to be deduced.

(Fig. 6). Pericline twinning is rare, being displayed by only four specimens out of the twenty-five, and even these four also contain albite twinning. It was not possible to determine the type of association for two of the charnockitic specimens. The distinction between albite twinning and albite superstructure is not sharp and it is difficult to evaluate the precise nature of the sodium phase in many specimens. However, an attempt has been made to separate specimens into those in which albite twinning occurs either solely or predominantly and those in which the superstructure is favored. It may be seen from Fig. 6 that the superstructure is more frequent for those specimens with the lower optic axial angles and the greater contents of KAlSi_3O_8 , though two specimens S347 and LM6 with albite twinning also occur in this region. Laves (1952) has suggested that the superstructure results from the need for the strain to be lessened between the triclinic albite and the monoclinic orthoclase and has shown that the structural misfit is less for the superstructure than for the twinning. Thus it would be expected that the

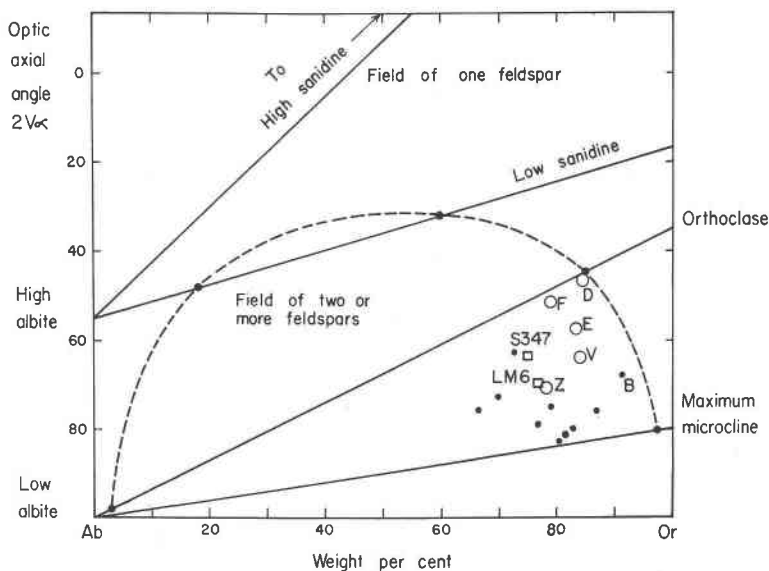


FIG. 5. Correlation of the optical and compositional properties of alkali feldspars with the perthitic or non-perthitic nature of the feldspars. The four straight lines represent the series high albite—high sanidine, high albite—low sanidine, low albite—orthoclase, low albite—maximum microcline. The dotted curve is the approximate boundary between the fields of one feldspar and more than one feldspar. The five circles represent specimens that contain anorthoclase. The squares represent specimens LM6 and S347 which contain low albite-oligoclase and which may also contain anorthoclase (see legend to Fig. 4). The small dots represent specimens that do not contain anorthoclase.

superstructure would be more favored when the proportion of orthoclase increased and this is what is actually found. Nevertheless some of the more potassium-rich specimens such as LM6 contain well-developed albite twinning, and the bulk composition of the sample cannot be the sole factor involved.

Possibly the dimensions of the perthitic units are also of importance for the larger the individual unit the less should be the strain within the unit: consequently the superstructure should decrease as the perthite becomes coarser. In general the perthite should be coarser when the feldspar is in a lower-temperature state, that is when the value of $2V$ is larger. Therefore for a given bulk composition it would be expected that specimens with larger values of $2V$ would have less superstructure. Fig. 6 shows slight evidence in favor of this but it is hardly convincing.

In the first paper of this series it was shown that in the orthoclase—low albite series, specimens could be placed into three groups on the basis of the exsolved sodium-rich phase, each group having a characteristic com-

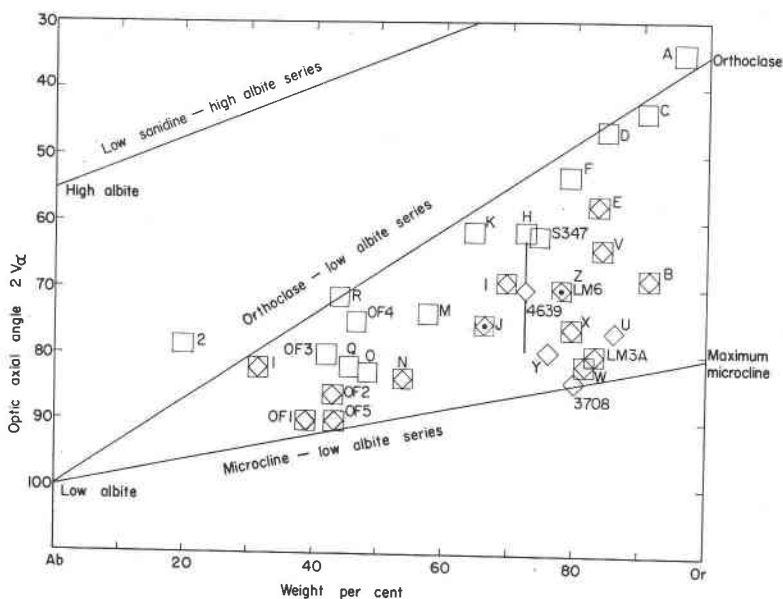


FIG. 6. The occurrence of orthoclase and microcline. The squares indicate a monoclinic potassium phase, the diamonds a triclinic phase and the linked squares and diamonds indicate the presence of both in the same specimen. To avoid confusion the symbols of specimens Z and LM6, both of which contain orthoclase and microcline, are shown as one. The two charnockite specimens 3705 and 6436 are omitted.

position range. The present data shows that this conclusion must be extended and modified. The three groups tend to fall into characteristic areas on the composition— $2V$ diagrams and embrace both orthoclase—and microcline perthites. The group containing anorthoclase with pericline twin-type superstructure is the most potassium-rich and has the lowest values of $2V$. The specimens containing a superstructure of albite-oligoclase occupy an adjacent area with slightly greater values of $2V$ and more sodium-rich compositions. The last group which has mainly an albite twinned, and sometimes pericline twinned, albite-oligoclase covers the largest area including all the sodium-rich specimens and most of the microcline perthites. The areas are not mutually restrictive and some overlap occurs particularly between the last two groups.

THE POTASSIUM PHASE

The potassium phase may be either monoclinic or triclinic and, in many specimens, both a monoclinic and a triclinic phase occur. Often the triclinic phase yields short diffuse streaks centered on sharp reflections that have monoclinic symmetry, and in some crystals it is not easy to distinguish these streaks from the very weak ones that can be found in heavily exposed photographs of orthoclases (Laves, 1950) and low sanidine. This point will be taken up in detail later on. Fig. 7 shows the distribution of orthoclase and microcline in the specimens; when there was doubt whether a diffuse streak resulted from microcline or not, it was ignored and the feldspar listed as having only a monoclinic potassium component. It will be seen that there is a general sort of correlation between the nature of the potassium phase and the position of the containing specimen on the $2V$ -composition diagram. Specimens lying near to the straight line joining low albite with orthoclase contain only a monoclinic potassium phase. Intermediate specimens are variable, the majority containing both monoclinic and triclinic components. Those lying close to the low albite—maximum microcline join contain either a single triclinic phase or both a triclinic and a monoclinic phase. In spite of the rough correspondence it is obvious that other factors enter and that the relationships between the optical and structural properties of a perthitic alkali feldspar is not a simple one. The occurrence of a monoclinic component in specimens lying very close to the low albite—maximum microcline join suggests that there may be microcline specimens whose values of $2V$ lie below the low albite—maximum microcline join in Fig. 1. The specimens of iso-orthoclase described by Barth (1933) and Tsuboi (1936) may be in this category and should be subjected to further investigation.

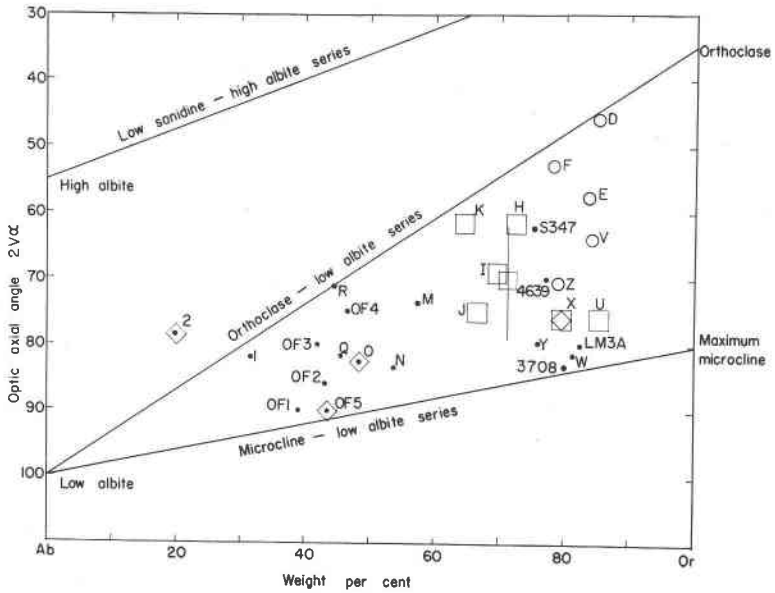


FIG. 7. The nature of the association of the sodium feldspar components. The dots indicate predominant albite twinning, the squares predominant albite twin-type superstructure and the diamonds pericline twinning. The circles show the specimens which contain a pericline type superstructure of anorthoclase. Some specimens contain two types of associations and are indicated by a double symbol. It was not possible to determine with certainty the type of association in the charnockite specimens 3705 and 6436 because of the streaked reflections. Specimens S347 and LM6 which contain an albite-twinned albite-oligoclase also show weak streaks parallel to the layer of b-axis oscillation photographs.

OBSERVATIONS CONCERNING THE POLYMORPHISM OF POTASSIUM FELDSPARS

To form a basis for the discussion of the polymorphism of potassium feldspar in a later paper of this series, pertinent observations are collected in this section. Many observations refer to the present suite of specimens, but others described in earlier and to be described in later papers are also mentioned.

Ideally, a wide range of specimens from a variety of environments should be available for the study of the polymorphism of potassium feldspars, but the range is limited for several reasons. Many specimens from igneous and metamorphic rocks have suffered alteration and it is difficult to measure the optical properties with precision. Other specimens contain large veins or lamellae of exsolved sodium feldspar, again leading to uncertainty in the measurement of the optical properties. Further, the presence of reflections from sodium feldspar seriously in-

terferes with the evaluation of the weak diffuse reflections from the potassium components. Some of the charnockite specimens suffer from a further limitation: x -ray reflections are smeared out along curves of constant θ indicating disorientation, probably the result of the deformation that has left its imprint on the fabric of some of the rocks. Finally, many of the conclusions depend on the estimation of the diffuseness of x -ray reflections, a notoriously difficult operation. Consequently the following conclusions, especially those dealing with diffuse reflections, are not based on as much reliable evidence as would be desired. Some of the variations observed in the x -ray photographs are shown in Figs. 8-12: unfortunately it is extremely difficult to obtain satisfactory illustrations of diffuse reflections.

Many of the observations have been recorded already by Laves (1950,¹ 1952), Goldsmith and Laves (1954a,b), MacKenzie (1954), MacKenzie and Smith (1955), but a complete listing is given so that a logical order may be attained.

1) All the reflections in high sanidine (heated Spencer-A,C,D) and in maximum microcline (Blue Mountain) are sharp and may be indexed on the usual face-centered cell. Strictly speaking, a smaller primitive cell should be used for the triclinic feldspars, but it is customary to retain the larger centered cell.

2) In orthoclase (Spencer-A,C,D) and in low-sanidine (various specimens listed in paper III (MacKenzie and Smith, 1955), both before and after homogenization by heating at 900°C. for a few minutes) two types of reflections occur. The first type are sharp and obey the conditions for the face-centered lattice. The second type occur as weak diffuse streaks, centered on the first type of reflections and extending parallel to the b -axis. They appear to be weaker in low-sanidine than in orthoclase and disappear upon conversion into high-sanidine (Figs. 8 and 9).

3) In intermediate microcline and especially in adularia a variety of structures occur, ranging between the extremes of orthoclase and maximum microcline. The effects may be grouped into two (*a*) those that maintain the C face-centering and (*b*) those that require a primitive symmetry (for the usual size cell, not the smaller one). In the first group the reflections may be either sharp or diffuse, and if of triclinic symmetry are commonly arranged according to the albite and/or pericline law. If both laws occur the albite and pericline units bear to each other the special relation indicative of inversion from monoclinic symmetry. In addition the "diagonal" association may also occur in which two units are formed with orientation $(xA_1+(1-x)P_1)$. $(xA_2+(1-x)P_2)$

¹ This paper contains some excellent illustrations of diffuse reflections.

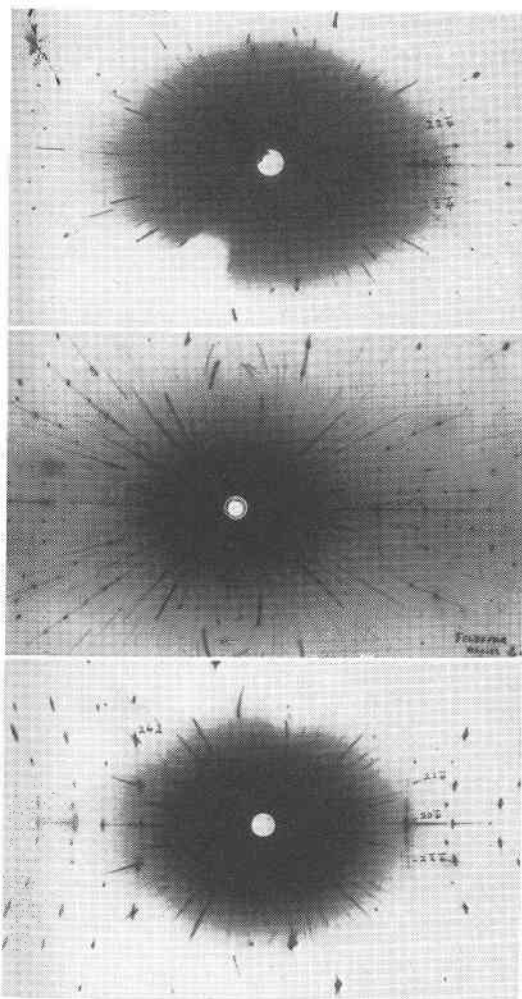


FIG. 8 (above). *b*-axis oscillation photograph of an orthoclase specimen (Spencer C). 5° oscillation used to give greater effective exposure for the $20\bar{4}$, $22\bar{4}$ and $2\bar{2}4$ reflections. A very weak streak is centered on the $20\bar{4}$ reflection and weaker ones can just be distinguished for some of the other reflections.

FIG. 9 (middle). *b*-axis oscillation photograph of a low-sanidine taken with the *x*-ray beam in the center of a 15° oscillation (specimen from Pine Creek described in paper 3: homogenized by heating a few minutes at 900°C .). Unfiltered radiation. Only one weak streak is visible, centered on the $20\bar{4}$ reflection.

FIG. 10 (below). *b*-axis oscillation photograph of specimen Spencer B, an adularia, taken with the *x*-ray beam parallel to (001) in the center of a 15° oscillation. The main reflections with $(h+k)$ even each consist of a strong sharp component lying in or near the center of a

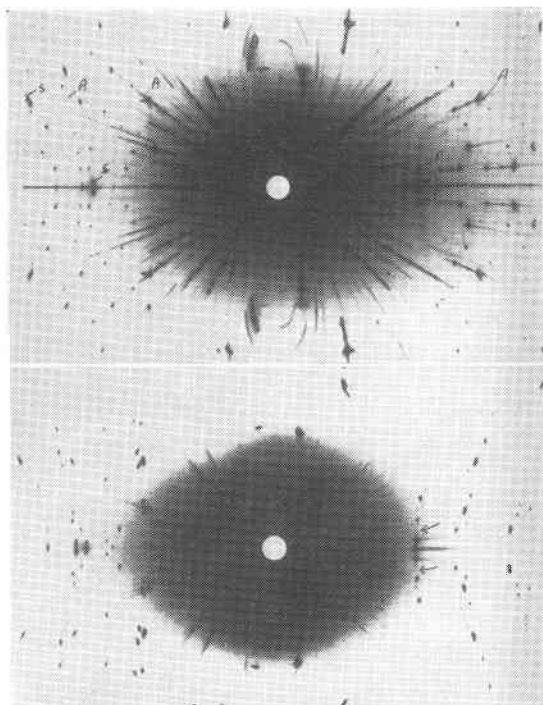


FIG. 11 (above). *b*-axis oscillation photograph of specimen Z, a microcline perthite, taken with the *x*-ray beam parallel to (001) in the center of a 15° oscillation. Unfiltered CuK radiation. The reflections from the potassium phase each have a central sharp reflection lying in a streak (S) that is parallel to the row lines, thus indicating the occurrence of both a monoclinic K-feldspar and an albite-twinned microcline (P) of the potassium phase also occur as in Fig. 8. Weak pericline superstructure of an orthoclase (A) is also visible.

FIG. 12 (below). *b*-axis oscillation photograph of an orthoclase-microcline-albite-perthite from the Dartmoor pluton, S. W. England. The potassium phase is mainly monoclinic, but some microcline, occurring in a diagonal association close to the orientation for albite twinning, is also present. The sodium phase is mainly albite-twinned but there is some disorientation. This photograph is reproduced chiefly to show that there are no diffuse streaks lying half-way between the reflections $20\bar{4}$, $22\bar{4}$, $22\bar{4}$, the possible positions for the streaks being marked by the arrows.

short streak elongated along the row lines. For (242) an additional streak elongated along the layer lines can just be seen. The streaks indicate microcline of variable intermediate geometry, both albite and pericline twinned in the "M-type" relation (Smith and MacKenzie, 1958) that indicates inversion from an original monoclinic phase. Lying between the reflections $20\bar{4}$, $22\bar{4}$ and $22\bar{4}$ are two weak diffuse streaks elongated along the row lines. These streaks indicate deviation from face-centered symmetry, for the centers of the diffuse streaks lie at the positions where $(h+k)$ would be odd.

where A_1 , A_2 , P_1 , P_2 are the angular positions for albite and pericline twins lying in the aforementioned special association and x is a fraction lying between 0 and 1 (Fig. 3). Untwinned microcline crystals occur but rarely (some crystals of specimen U are untwinned, but most are twinned: Laves and co-workers have discovered several examples). The reflections may be sharp (E, LM3A, OF1, LM6, for example) or diffuse (B, some crystals of U (see above), most crystals of V, W, X, Y, Z, specimens from the Dartmoor granite). If sharp, the deviation from mono-

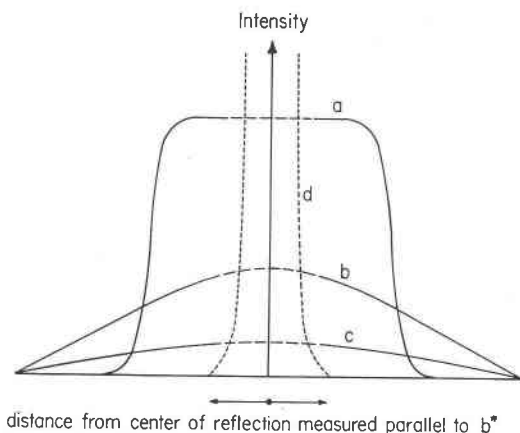


FIG. 13. Intensity variation estimated by eye for reflections from potassium feldspar. Curve d shows the distribution for a sharp reflection of monoclinic symmetry: curve a gives the variation for the diffuse streak of an adularia such as Spencer B and Spencer Z (see Figures 10 and 11): curve b is for an orthoclase such as Spencer C (Figure 8) and curve c for a low-sanidine or an orthoclase partly converted into a high-sanidine.

clinic geometry may take all values up to $\alpha^* 90^\circ 30'$, $\gamma^* 92^\circ 20'$ (the values for maximum microcline). If diffuse, the streaks extend only as far as the separation of the reflections of twinned maximum microcline. Frequently sharp reflections in monoclinic positions occur in addition to the ones with triclinic symmetry. (See Figs. 10, 11 and 12.)

In some crystals, extra diffuse reflections occur that extend parallel to the b -axis and are centered on the positions rendered vacant by the C face-centering restriction. These diffuse reflections occur most strongly for Spencer B and U (the twinned crystals) and are absent for orthoclase (Spencer A, C and D) and maximum microcline, and are not observed in specimens from the Dartmoor granite (Figs. 8, 9, 10, 11 and 12). Although the data are admittedly subject to some limitations it seems probable that these extra reflections are strongest in intermediate

microclines and that they are more pronounced in adularia than in granitic specimens. To explain these reflections, it seems necessary to assume primitive symmetry as stated by Laves (1952).

Although the diffuse reflections in orthoclase and low sanidine occupy the same positions as the first type of diffuse reflections in intermediate microclines it is thought that they have a different character, and this difference is thought to be important (Fig. 13). The diffuse reflections in orthoclase and low-sanidine are much weaker than those in intermediate microclines and a distinction can be made on this basis for most specimens. Further, it appears that the diffuse reflections in orthoclase and low-sanidine have a more uniform drop of intensity and extend a little further than the diffuse reflections in intermediate microclines (as in Fig. 13). However, visual estimation of diffuseness is very difficult, and until quantitative measurements of the streaks have been made, the above conclusion should be treated with some caution. In view of the conflicting views on the nature of orthoclase, such quantitative measurements would appear to be of considerable importance.

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