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THE TANCO PEGMATITE AT BERNIC LAKE, MANITOBA.
V. COLOURED POTASSIUM FELDSPARS

PETR ČERNÝ[1] AND JOSEF MACEK[2]

Abstract

The giant Rb-rich microcline-perthite crystals from the uppermost parts of the upper intermediate spodumene + quartz + amblygonite (+ petalite) zone (5) of the Tanco pegmatite have dark grey core, irregular white zone mostly penetrating the grey material, and pale pink rim. The dark grey feldspar is almost free of inclusions, the white material contains abundant dusty light-coloured particles, and the pink feldspar carries reddish hematite-like particles in addition. Obliquity and $2V$ of the microcline phase, K_2O and Rb_2O contents, and coarseness of the perthite veinlets increase from the dark centres to the pink rims, and microcline twinning becomes obliterated. No x-ray detectable solid solution was found in either microcline or albite. The properties of both the perthitic albite and the euhedral platy albite disseminated in the microcline-perthite matrix are those of low albite.

The feldspars are interpreted as originally homogeneous phases with composition of about $Or_{87}Ab_{13}$, crystallized roughly contemporaneously with petalite, quartz, and amblygonite-montebrasite. They were subjected to profound equilibration and recrystallization in the stability field of microcline. The differently coloured zones represent subsequent stages of this process, in the sequence shown above. Dusty inclusions are the main colouring agents. The relative age of the euhedral platy albite could not be determined.

Introduction

In the Tanco pegmatite, a well-known Li, Ta, Cs deposit located on the north shore of Bernic Lake in southeastern Manitoba, giant rubidium-rich potassium feldspars were found that show a striking change in colours, in a more or less regular sequence from the core to the margins of the crystals. We have attempted to determine the character of these differently coloured zones, the factors affecting their colour, and their genetic significance.

Occurrence

In the Tanco pegmatite, potassium feldspar is a major constituent of the wall zone (2) and of the three intermediate zones : lower intermediate K-feldspar + albite + quartz + spodumene (+ amblygonite) zone (4), upper intermediate spodumene + quartz + amblygonite (+ petalite)

[1] Department of Earth Sciences, University of Manitoba, Winnipeg.
[2] Mines Branch, Department of Mines and Natural Resources, Winnipeg.

zone (5), and central K-feldspar + albite + quartz (+ beryl + wodginite) (6) (Crouse & Černý 1972). It is mostly beige-coloured in zone (2), and grey to beige in zones (4) and (6). The conspicuous colour variations described here are characteristic of the K-feldspar in the upper parts of zone (5). They may be observed occasionally also in the underlying zone (4) but are not so well developed.

The following study is based on material collected from several Rb-rich K-feldspars from 0.5 x 1 to 1.5 x 2.5 metres in size, associated with montebrasite, pseudomorphs of spodumene + quartz after partially preserved petalite, and albite. All these minerals are embedded in abundant quartz in the close neighbourhood of a large pollucite body (zone (8)).

The colours of the K-feldspar crystals show a rough zonal arrangement (Fig. 1). Central parts are dark to medium grey, translucent to transparent in thin plates ; they are penetrated and partially rimmed by white, semi-opaque feldspar. The bands and streaks of white material tend to follow the {001} and {010} cleavages and a well developed {110}, {1$\bar{1}$0} parting, but may be also quite irregular in shape and orientation. The outer parts of the K-feldspars are pale pink and opaque. The boundaries between different colours are always transitional over at least a few millimetres ; the grey/white contacts are usually much sharper than those between white and pink or grey and pink.

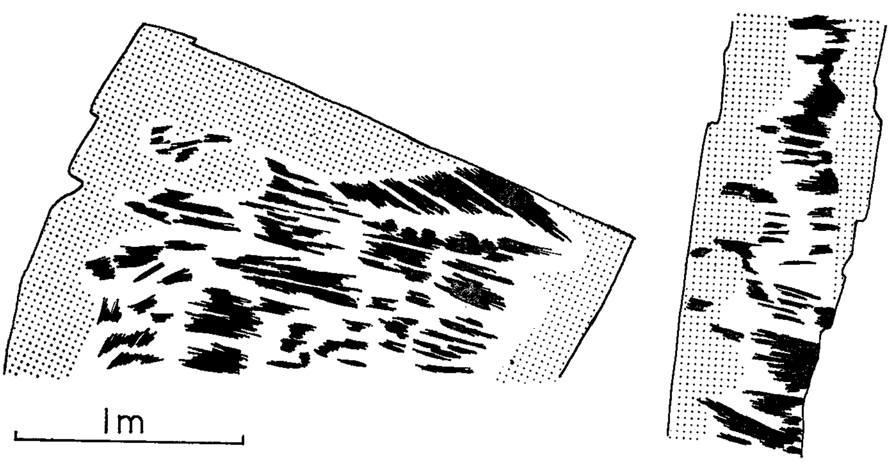

FIG. 1. Some of the studied crystals of microcline-perthite from the uppermost parts of the intermediate spd + qtz + amb (+ pet) zone (5) of the Tanco pegmatite, showing the distribution of colour varieties : black — grey feldspar, white — white feldspar, dotted — pink feldspar.

The mutual relations of the three colours suggest a gradual development and "replacement" sequence grey — white — pink : the grey mineral seems to represent the earliest stage, which is penetrated mainly along fractures by white material, and both grey and white are converted "en masse" into the pink feldspar.

Experimental Methods

Nine hand-picked colour phases were analyzed for Na, K, Ca, Rb, Cs, and some for Fe, by atomic absorption spectrometry (Table 2, Fig. 6). The composition calculated in terms of Or, Ab, An, Rb-f, and Cs-f (wt. %) is always at least slightly short of 100% ; the considerable dilution necessary for determination of potassium and the dusty clouding of most feldspars may be the main sources of error. Unit cell dimensions of two feldspars given in Table 1 were determined according to the method of Wright & Stewart (1968). The obliquity for each of the 35 samples examined was obtained by averaging several *x*-ray powder diffractometer records taken at slow goniometer and fast chart speeds (Fig. 4). Solid solution in the alkali feldspars was checked by the $\bar{2}01$ method (Orville 1967). Refractive indices of albite were checked in immersion liquids in white light (Morse 1968). Universal stage measurements were performed on the Leitz-Wetzlar Dialux Pol microscope and universal stage in white light, using hemispheres with 13.5 mm radius and $n = 1.554$. The accuracy of the $2V$ measurements made on sections $\perp$ to a is estimated to be $\pm$ 1° (Fig. 4).

Table 1. Unit Cell Dimensions of two Microclines

	26g (grey)	30Ap (pink)
Δ meas.	0.850	0.923
Δ calc.	0.880	0.930
a	8.5990 ± 0.0029Å	8.6132 ± 0.0028Å
b	12.9684 ± 0.0021Å	12.9699 ± 0.0021Å
c	7.2183 ± 0.0012Å	7.2257 ± 0.0017Å
α	90°36.3′ ± 1.3′	90°36.3′ ± 1.1′
β	116°1.2′ ± 1.1′	115°58.4′ ± 1.2′
γ	87°52.0′ ± 1.2′	87°46.6′ ± 1.2′
V	722.85 ± 0.22Å^3	725.11 ± 0.22Å^3

Physical and Chemical Characteristics of the Coloured Feldspars

Textural relations

The grey feldspar is a coarsely twinned microcline, showing abundant albite twinning but infrequent pericline lamellae. The twinning boundaries are always sharp, and extinction within each system quite homogeneous. Perthitic albite forms mostly fine strings and flames, regularly distributed over small areas alternating with coarser vein perthite (Fig. 2). In (010) sections, strings and flames of albite make an angle of 67-71° with the {001} cleavage ; veins are inclined at 63-69°. In (001) sections, string albite is elongated normal to the {010} cleavage ; vein albite is similarly oriented orientated or follows the traces of {110} and $\{1\bar{1}0\}$.

The white material consists of microcline with much coarser and irregular twinning lamellae, and of albite in the form of veins. Strings and flames are absent. The albite/microcline contacts are usually coated with

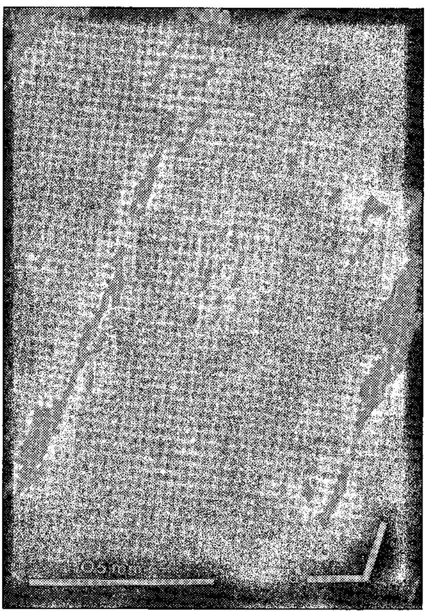

Fig. 2. Different orientation of string albite (fine white streaks) and vein albite (coarse white veinlets) in the grey microcline-perthite ; note the horizontal traces of the (001) cleavage. Thin section // to (010), crossed nicols.

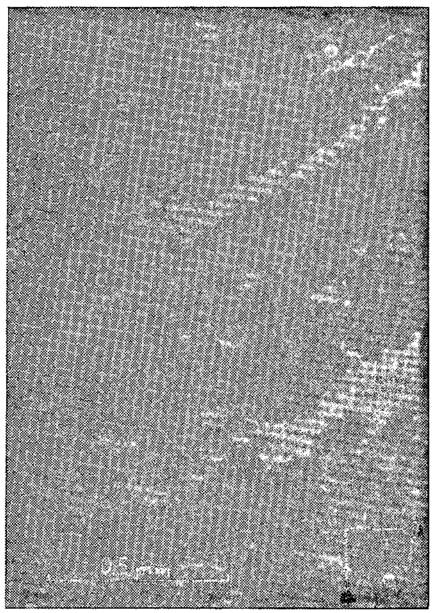

Fig. 3. Coarse vein albite (dark) parallel to (110) in the pink microcline-perthite. The dusty streaks // to *a* in the microcline host locate the remaining twin lamellae (albite law). Thin section // to (001), crossed nicols.

very fine-grained mica resembling muscovite, and the microcline is dusty. Very rare tiny grains of calcite were found in this feldspar type.

In the pink feldspar, microcline twinning is mostly obliterated, and only a few lamellae with rounded corners can be observed in a single crystal matrix. Irregular jagged veins of albite, occasionally with well-rounded outlines, are the only perthite type present (Fig. 3). It is oriented mostly parallel to the {110} and {1$\bar{1}$0} planes, and makes an angle of 66-69° with the {001} cleavage in {010} sections. At the albite/microcline contacts, muscovite occurs accompanied frequently by fine grains of calcite which fills also tiny cracks. The dusty particles disseminated in the microcline have a rusty red colour resembling that of hematite and/or iron hydroxides.

Besides perthitic veinlets, another type of albite is present in highly varying amounts in all colour types. This albite forms euhedral, slightly rounded platy crystals tabular on {010}, 0.5 — 3 mm long. In some cases they compose tiny cross-cutting veinlets, but most are dispersed as individual crystals floating in the microcline-perthite matrix. They seem to be more abundant in the pink feldspar, but highest accumulations estimated at about 5 to 10% vol. can be found in the grey and white mineral as well. A similar albite surrounds frequently the coloured K-feldspar crystals along their contacts with quartz and other associated phases.

Strings and flames of perthitic albite seem on the optical scale to be untwinned. Veiny perthitic albite shows abundant albite-twinned lamellae and frequent Carlsbad twins, coupled with albite twins in incomplete triads (Vardanyants 1950). In euhedral albite, infrequent albite twinning is only rarely combined with Carlsbad twins in incomplete triads ; in a few cases the complex Baveno twin axis, as defined by Vardanyants (1951) was found.

Optical properties

As shown in Fig. 4, the $2V$ values of the microcline phase increase slightly but distinctly from the grey mineral through white towards pink in the 75-82° range.

The refractive index α', measured on {001} and {010} cleavage fragments, varies between 1.528 and 1.529 for both perthitic and euhedral albite in all colour types of microcline and indicates a pure albite composition (Morse 1968). Optic axial angles, + 77 to + 79° for perthitic albite and +78 to +82° for euhedral albite, correspond to that of low albite (Wright & Stewart 1968, Fig. 4). In both perthitic and euhedral albite, the optical orientation of the twins matches well that of low albite on Nikitin's graphs (in Fediuk 1961).

X-ray diffraction data

The obliquities of microclines demonstrated in Fig. 4 show an increasing trend in the grey-white-pink sequence from 0.86 to 0.96. The difference between the grey and white feldspars is much less conspicuous than that between white and pink, but it should be emphasized that feldspars separated from closely adjacent white and grey areas of single hand specimens have always shown a difference in Δ of at least 0.02, mostly 0.03.

The $KBrO_3$ method of Bowen and Tuttle modified by Orville (1967) revealed practically no solid solution in the two alkali feldspar phases. The Ab_{ss} values for microclines vary between −1 and +1% ; the Or_{ss} content for the perthitic albite (or mixture of perthite and euhedral albite), where accurately measurable, is invariably zero.

The changes in unit cell dimensions of microcline induced by high rubidium contents (demonstrated for monoclinic phases by Gordiyenko & Kamentsev 1967) could affect the $2\theta_{(\bar{2}01)}$ values, and Orville's graph is probably not applicable to such microcline phases. However, the *x*-ray determined Ab_{ss} 4% and the value of 5% calculated from chemical and modal analyses for Orville's untreated Hugo microcline coincide very well, although this feldspar contains 0.62% Rb.

Unit cell dimensions were calculated for two microclines, showing different obliquities, one from a grey sample with Δ = 0.850 and the other

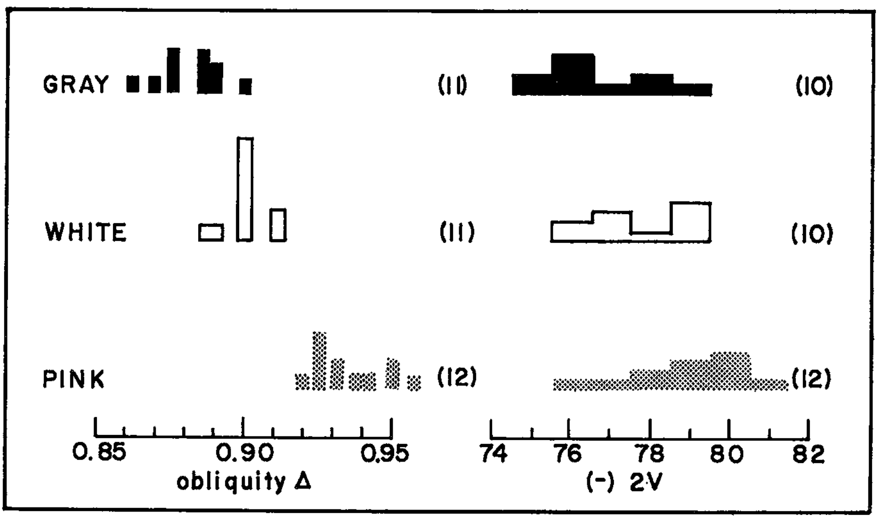

FIG. 4. Obliquity and optic axial angle of the grey, white and pink types of the studied microcline-perthite. Figures in brackets indicate the number of examined samples.

from pink feldspar with $\Delta = 0.923$ (Table 1). The $\alpha^* - \gamma^*$ plots in Fig. 5 (based on Fig. 3b of Wright & Stewart 1968) show a shift along the orthoclase-microcline join expectable from the difference in obliquity. The b — c plot (based on Fig. 2b of Wright & Stewart 1968) shows the grey microcline in the maximum microcline corner and the pink feldspar well outside the generalized alkali feldspar field boundaries. This may be due to the influence of the high Rb admixture which can be expected to increase the unit cell dimensions of potassic feldspars (*cf.* Gordiyenko & Kamentsev 1967).

Chemical composition

The partial chemical analyses of 9 samples are shown in Table 2, and the differences between the individual specimens and colour groups are illustrated in Fig. 6. Within each colour group, the samples are arranged according to decreasing sodium content. Because of difficulties in finding a third grey and pink specimen free of euhedral albite, specimens 26g and 30Ap have been chosen that were rich in this feldspar phase. Their difference in Na_2O against the other feldspars that are considered to contain only perthitic albite is 0.7 to 0.9 wt. %, corresponding to 5 — 7 vol. % of euhedral platy albite. This corresponds well with the visual estimate.

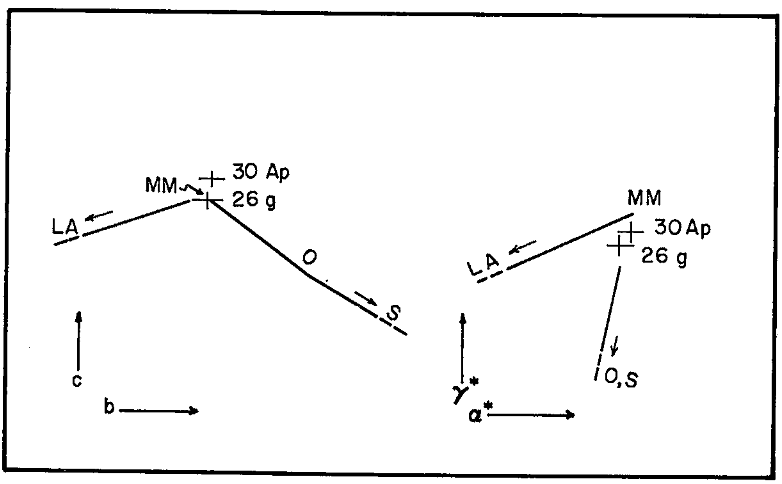

FIG. 5. The b — c and $\alpha^* - \gamma^*$ plots of the potassic phases of a grey (26g) and pink (30Ap) type of microcline perthite, in relation to the maximum microcline (MM), low albite (LA), orthoclase (O), and high sanidine (S) values (from Figs. 2b and 3b by Wright & Stewart 1968). The crosses indicate double standard deviations of the cell dimensions.

Besides these variations due to a "foreign" phase, and the highly irregular traces of CaO reflecting the varying amount of calcite present, the bulk compositions of the three colour groups show only small differences. Their trends are indicated by dotted lines in Fig. 6, and should be verified by analyzing further specimens from the same K-feldspar crystals to obtain a statistically significant number of data. However, these trends correspond well to those found in similar feldspar types from two Czechoslovak pegmatites (Černý & Macek 1972b), and thus are taken as true : a slight decrease in Na_2O, a slight increase in K_2O and Rb_2O, and an initial increase with a subsequent decrease in Cs_2O seem to characterize the grey — white — pink sequences of feldspars.

Discussion

All the changes in twinning and perthite types, structural and optical characteristics, and in chemical composition can be correlated with the sequence of colour changes apparent from field observation. The changes indicate a series of simultaneous processes : obliteration of microcline twinning and segregation of perthitic albite (decrease in surface energy), structural changes in the potassium feldspar directed towards maximum micro-

Table 2. Chemical Composition of the Coloured Feldspars

	grey			white			pink		
	26g	29g	27g	24w	29w	30w	30Ap	21p	22p
K_2O	12.34	12.58	12.58	12.50	12.80	12.58	12.36	13.30	13.20
Na_2O	2.28	1.40	1.18	1.52	1.32	1.16	2.02	1.36	1.16
Rb_2O	2.03	2.40	2.40	2.40	2.43	2.65	1.99	2.51	2.51
Cs_2O	0.142	0.196	0.208	0.260	0.251	0.263	0.106	0.230	0.204
Li_2O	0.047	0.025	0.039	0.026	0.031	0.041	0.032	0.037	0.040
CaO	0.000	0.000	0.058	0.017	0.008	0.013	0.118	0.035	0.033
Fe_2O_3	0.024	0.033	0.041	0.032	0.028	0.037	0.045	0.021	0.041
Or	72.8	74.1	74.1	73.7	75.5	74.1	72.9	78.4	77.9
Ab	19.0	11.8	9.9	12.6	11.0	9.6	16.9	11.2	9.6
Rb-f	7.1	8.4	8.4	8.4	8.6	9.4	6.9	8.8	8.8
Cs-f	0.4	0.5	0.6	0.7	0.7	0.7	0.3	0.6	0.5
Σfsp	99.3	94.8	93.0	95.4	95.8	93.8	97.0	99.0	96.8

Analyst, R. M. Hill 1970.

cline (ordering process), and a slight impoverishment in sodium (probable segregation of albite around the margins of the K-feldspar crystals). Thus the feldspars appear to have undergone equilibration and recrystallization process under conditions of the stability field of microcline, accompanied by conspicuous colour changes that most probably do not reflect any properties of the feldspar phases themselves.

The earliest grey stage suggests the presence of an original homogeneous alkali feldspar with about 12-14 wt. % Ab_{ss}, later exsolved and ordered into a clear, inclusion-free string-perthite microcline. This feldspar was subjected to further ordering, recrystallization and grain coarsening along cleavage and parting fissures and other disjunctions, accompanied by the formation of fine mica and unidentified dusty particles causing the white colour and semi-opaque character of the resulting feldspar. The presence of solutions promoting this process is indicated by the occurrence of calcite which is still more abundant in the outer shell of the pink feldspar; this material reached the most advanced stage in the triclinization and ordering of the potassium feldspar and in "Sammelkristallisation" of both microcline and albite. Again the colour change from white to pink can be attributed to an abundance of dusty inclusions, some of which resemble hematite

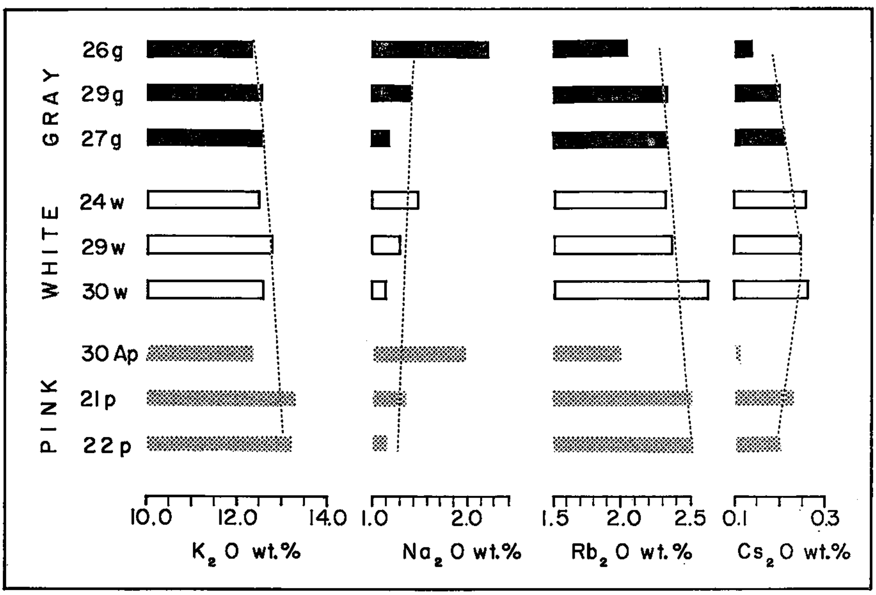

FIG. 6. Variations in the K_2O, Na_2O, Rb_2O, and Cs_2O contents of the grey, white and pink microcline-perthite. The specimens are arranged according to decreasing Na_2O in each colour group.

and/or iron hydroxides. The iron content varies irregularly in all analyzed feldspars but within the same limits and it seems probable that exsolution of iron from the feldspar structure in the last stage of recrystallization caused the colour change, without any introduction of iron from outside the feldspar crystals.

The absence of any "cross-cutting" phenomena or distinct "jumps" in properties does not make it possible to choose between a continuous process which reached different levels of perfection in different loci, and an interrupted step-wise process superimposed locally on a feldspar equilibrated earlier at the "grey stage" or "white stage" level.

The role of these feldspars in the evolution of the pegmatite and the conditions of their origin will be evaluated at a later date. At present, however, at least some other matters related to this study are deserving of comment :

(i) The origin of the euhedral platy albite still remains to be resolved. In some respects it resembles indisputable inclusions of independent, coexisting albite as found in microcline-perthite of the wall zone (2), but on the other hand it shows certain characteristics of metasomatic albite (fracture-controlled veinlets in some cases). It seems to be genetically quite distinct from perthitic albite, both texturally and chemically, increasing the bulk sodium content over a distinct perthite-based level (Fig. 6).

This euhedral albite corresponds most probably to albite (1) of Bachinski & Orville (1968), to the blocky grainy albite of Orville (1967, Fig. 1), and to the cleavelandite plates of Laves & Soldatos (1963). Bachinski & Orville state that this albite originated prior to perthite exsolution, Laves & Soldatos regard it as late metasomatic phase formed after perthitization.

(ii) Gordiyenko & Kamentsev (1967) have studied 24 rubidium-bearing potassic feldspars from different pegmatites of the southwestern U.S.S.R. They have found that in these specimens the amount of the monoclinic phase increases, and the volume of the triclinic phase as well as its obliquity decrease with increasing Rb-content. The authors concluded that the larger ionic radius of Rb^{1+} inhibits the decrease in the $alk.^{1+}-O$ distances characteristic of ordering in potassic feldspars, and rubidium thus stabilizes the monoclinic structure.

This could be true only under the assumption that the present crystallochemical state of the examined feldspars was attained under identical conditions, and this can hardly be expected for a series of samples coming from different pegmatites. Even if this would be the case, the presence of both monoclinic and highly triclinic ($\Delta = 0.80 - 0.97$) phases in most specimens indicates that these feldspars are not equilibrated and are far from the lowest attainable state. Whatever may be the actual cause of the correlated variations observed by Gordiyenko & Kamentsev (1967), the present results show that Rb-rich microclines with very high obliquity and devoid of a monoclinic phase do exist, even in the compositional range where these authors found only monoclinic phases. Thus the influence of rubidium on the structural state of potassic feldspars seems to be rather negligible.

(iii) It is noteworthy to mention that no plate perthite was found in the pink feldspar. This perthite type is claimed by Laves & Soldatos (1962) and Soldatos (1962) to be typical of recrystallized microclines that show large single-crystal areas, which is quite characteristic of the "pink stage" in the studied feldspars.