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DISORDERED AUTHIGENIC FELDSPARS OF THE SERIES $KAlSi_3O_8$-$KBSi_3O_8$ FROM SOUTHERN CALIFORNIA

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ABSTRACT

Published anomalous cell dimensions for one authigenic potassium feldspar from the Barstow Formation have been confirmed in 13 other feldspars formed by similar low temperature replacement of a zeolitic assemblage. A series of experiments on selected specimens suggest that the anomalies are caused by partial substitution of boron for aluminum. This suggestion is confirmed by synthesis of boron-bearing sanidines which duplicate all the anomalies of the natural specimens, but possess more complete Si–Al(B) disorder.

INTRODUCTION

Recent investigations of suites of natural and synthetic alkali feldspars have clarified many interrelationships among members of this most important family of rock forming minerals. In particular, the study of Wright and Stewart (1968, p. 40) has shown that "the axial dimensions of homogeneous alkali feldspars vary smoothly with composition and with structural state in such a way that if *b* and *c* are known, *a* can be closely estimated." However, their study also emphasizes the possibility of anomalous cell dimension in certain natural alkali feldspars that occur in perthitic intergrowths, the *a* cell edge of these feldspars being elongated by strain and orientation effects (Smith, 1961) relative to *b* and *c* as defined by series of homogeneous feldspars. The main objective of this paper is to draw attention to yet another group of anomalous alkali feldspars, of authigenic origin, in which the *a* and *c* dimensions seem completely normal, but in which the *b* dimension falls consistently short of values expected from the series defined by homogeneous feldspars. Furthermore, bulk composition and homogeneity preclude allusion to perthitic intergrowths as an explanation of anomalies in cell dimensions. Two general hypotheses may be considered to explain the anomalies: 1) departure from the ideal alkali feldspar composition, or 2) departure from the ideal alkali feldspar structure, reflecting the very low temperature of formation or the zeolitic precursor of these feldspars. This paper attempts to evaluate these hypotheses, to isolate the cause of anomaly, and to assess the commonness of this type of anomaly in feldspars formed in similar environments.

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DESCRIPTION OF AUTHIGENIC POTASSIUM FELDSPARS

The natural potassium feldspars employed in this study formed during low-temperature diagenesis of rhyolitic tuffs occurring in the Barstow Formation (Miocene), Mud Hills, San Bernardino County, California, and in deposits of Pleistocene Lake Tecopa, Inyo County, California. The monomineralic tuffs consist of euhedral grains to monoclinic K-feldspar ranging from 0.002 to 0.01 mm across. The mean index of refraction of the feldspar and chemical analysis of the bulk tuffs suggest nearly pure potassium feldspar. Detailed investigations in both localities (Sheppard and Gude, 1968; 1969) indicate that rhyolitic glass has devitrified to a zeolitic assemblage, which then was replaced locally by a K-feldspar facies. The authigenic K-feldspar thus seems to have had a zeolitic precursor: at Lake Tecopa, the precursor was predominantly phillipsite, whereas in the Barstow Formation, analcime and clinoptilolite are the zeolites replaced by K-feldspar. Direct devitrification of rhyolitic glass to a K-feldspar-bearing assemblage lacks supporting petrographic evidence at both localities.

The cell dimensions of one authigenic alkali feldspar from the Barstow Formation have been determined by Sheppard and Gude (1965; 1969). They found B_2O_3 concentrations in the range 0.55 to 0.97 percent in the essentially monomineralic feldspar rocks, and noted a lack of boron-rich minerals which could account for these quantities of boron. They assumed that boron was replacing aluminum in the feldspar structure.

EXPERIMENTAL METHODS

Two monomineralic specimens which were at hand early in the study (65-4-5H from the Barstow Formation and 123A from the Lake Tecopa deposits) were subjected to the following types of tests: 1) low pressure heating studies, to find out whether possible structural distortions could be annealed out; 2) high pressure heating studies, to ascertain whether the anomalies were due to metastable departures from stoichiometry toward excess silica; 3) dry ion exchange experiments, to find out whether the anomalies were affected by exchanges in the alkali site. In addition, infrared absorption spectra were obtained to check for H_3O^+ and NH_4^+ in the feldspar structure.

In the light of results to be described below, four feldspars on the join $KAlSi_3O_8$–$KBSi_3O_8$ were synthesized hydrothermally at 1 kbar, 700°C, in runs of 3.5 days, from mechanical mixtures of $KAlSi_3O_8$ and $KBSi_3O_8$ compositions. Methods are as described by Martin (1969). The conditions of all experiments are listed in Table 1.

The monomineralic tuffs and all run products were ground and photographed directly with a Guinier-de Wolff powder camera (copper $K\alpha$, radiation). A spinel internal standard allowed correction of diffraction lines before input into a Fortran IV version of Evans, Appleman, and Handwerker's (1963) least squares unit cell refinement program. The fixed index option was employed in all cases, using the results of Borg and Smith (1969) to insure correct indexing. Infrared absorption spectra were obtained as described in Martin (1970), with the exception that 2.0 mg of sample were diluted with 1.0 g KBr.

TABLE 1. DESCRIPTION OF NATURAL, ANNEALED, AND SYNTHETIC FELDSPARS USED IN THIS INVESTIGATION.

Number	Description
	Natural feldspars
65-4-5H	Skyline tuff, Barstow Formation; "almost certainly from locality 58 of Sheppard and Gude (1969)" (pers. communication, A. J. Gude 3rd, 1970).
ST-1	Skyline Tuff, locality 103 of Sheppard and Gude (1969), east of wash; A base, B 9″ above base
ST-2	Skyline Tuff, locality 103 of Sheppard and Gude (1969), west of wash; A base, B 6″ above base, C 18″ above base, D 27″ above base, E top of tuff
ST-3	Skyline Tuff, locality 66 of Sheppard and Gude (1969), at base
123A	Tuff C, Lake Tecopa, specimen from Sheppard and Gude's (1968) collection
LT-1	Tuff C, Lake Tecopa, near locality 107 of Sheppard and Gude (1968), near base (both A and B)
LT-2	Tuff above tuff C, Lake Tecopa, near locality 113 of Sheppard and Gude (1968), at base of tuff
	Annealed 65-4-5H
1-500	Run 1890, 1 kbar, 500°C, 28 days, 11.3 weight % water
9-500	Run 1580, 9 kbar, 500°C, 7 days, 9.9 weight % water
	Annealed 123A
1-350	Run 1944, 1 kbar, 350°C, 14 days, 9.2 weight % water
9-500	Run 1578, 9 kbar, 500°C, 7 days, 9.5 weight % water
Na exch	Ion exchange in dry subsolidus NaCl, 1 atm, 725°C, 2 days, repeated three times
BE	Back exchange in dry subsolidus KCl, 1 atm, 725°C, 2 days, repeated three times
	Synthetic feldspars
0.0 %	Run 1963, 0.0 mole % $KBSi_3O_8$, 1 kbar, 700°C, 3.5 days, 12.7 weight % water
5.51%	Run 1960, 5.51 mole % $KBSi_3O_8$, 1 kbar, 700°C, 3.5 days, 7.1 weight % water
9.68%	Run 1961, 9.68 mole % $KBSi_3O_8$, 1 kbar, 700°C, 3.5 days, 6.1 weight % water
18.10%	Run 1965, 18.10 mole % $KBSi_3O_8$, 1 kbar, 700°C, 3.5 days, 9.0 weight % water

DISCUSSION OF RESULTS

Unit cell parameters and cell volume are presented for 13 authigenic feldspars (identified in Table 1) and for all run products in Table 2. The authigenic feldspars are compared in Figure 1, a portion of Wright and Stewart's (1968) *a*-contoured *b–c* quadrilateral modified after Stewart and Ribbe (1969). The same diagram without contours serves as base for data

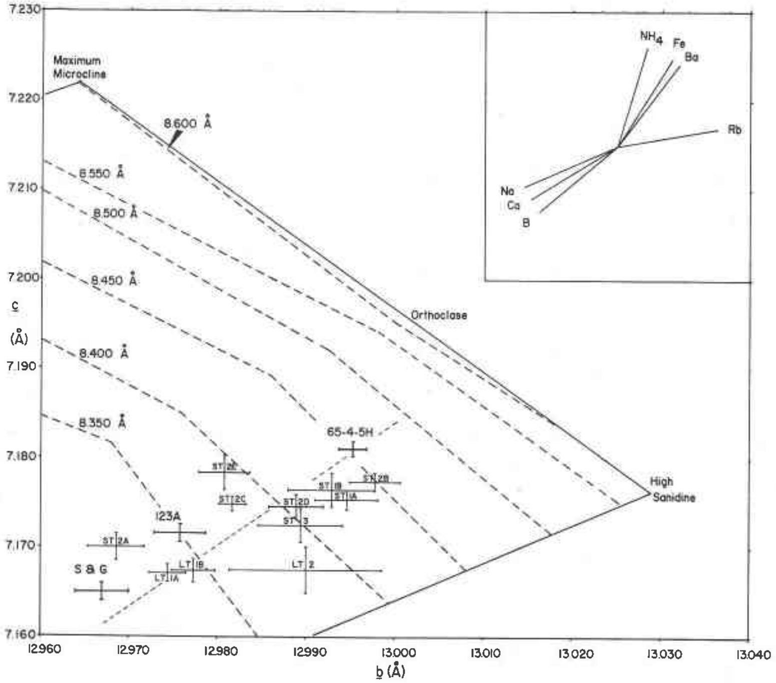

FIG. 1. *b–c* coordinates of thirteen authigenic K-feldspars from altered rhyolitic tuffs in the Barstow Formation and in Lake Tecopa deposits. These are compared with Sheppard and Gude's (1965) feldspar (denoted S & G) on the *a*-contoured *b–c* quadrilateral of Wright and Stewart (1968). Error bars represent ± one standard deviation. Short-dashed line shows the calculated linear relation between *b* and *c* for the fourteen natural feldspars. The inset shows the displacements expected upon substitution of various cations in the highly sanidine structure.

obtained in runs on feldspars 65-4-5H and 123A and for data on the synthetic feldspars (Fig. 2).

Natural K-feldspars. In view of the highly potassic compositions inferred from the mean index of refraction and determined by chemical analyses (Sheppard and Gude, 1965; 1968; 1969), one might expect positions very close to the Or-rich sideline of the *b–c* quadrilateral (Figure 1). Instead, all points depart significantly from this sideline, and plot well within the quadrilateral, in positions that would suggest *a* cell edges of 8.324 Å for Sheppard and Gude's (1965) feldspar (denoted S & G below and in Figure 1), 8.350 Å (123A), and 8.455 Å (65-4-5H). Substitution of these values into a quadratic equation relating *a* to N_{Or} for Orville's (1967) complete sanidine-high albite series (Luth and Querol Suñé, 1970, Table 4) yields compositions of 38.0 (S & G), 43.5 (123A), and 66.1 mol percent Or (65-4-5H). In contrast, substitution of measured *a* values (Table 2)

Table 2. Cell Parameters of Natural, Annealed, and Synthetic Boron-Bearing K-feldspars

Number	*a*	*b*	*c*	*β*	*V*	Standard error (°2*θ*)
Natural K-feldspars						
65-4-5H	8.5986 Å	12.9953 Å	7.1811 Å	116°00.54′	721.16 Å^3	0.009
	0.0011	0.0016	0.0008	0.59	0.12	
ST-1A	8.5967	12.9946	7.1754	116 00.48	720.39	0.013
	0.0013	0.0036	0.0011	0.85	0.21	
ST-1B	8.5952	12.9929	7.1765	116 01.06	720.23	0.025
	0.0021	0.0049	0.0019	1.39	0.31	
ST-2A	8.5958	12.9686	7.1700	116 00.59	718.33	0.018
	0.0015	0.0032	0.0015	0.97	0.21	
ST-2B	8.5985	12.9978	7.1774	116 00.05	720.97	0.012
	0.0012	0.0029	0.0010	0.68	0.17	
ST-2C	8.5998	12.9817	7.1749	116 00.19	719.92	0.010
	0.0008	0.0016	0.0008	0.54	0.11	
ST-2D	8.6010	12.9889	7.1746	116 00.47	720.36	0.017
	0.0016	0.0031	0.0014	1.03	0.20	
ST-2E	8.5960	12.9808	7.1784	116 00.16	719.91	0.017
	0.0020	0.0029	0.0019	1.22	0.23	
ST-3	8.6023	12.9894	7.1725	116 02.24	720.10	0.020
	0.0024	0.0048	0.0019	1.68	0.32	
123A	8.5973	12.9758	7.1716	115 58.54	719.22	0.013
	0.0013	0.0029	0.0010	0.71	0.17	
LT-1A	8.5926	12.9744	7.1671	116 00.14	718.13	0.014
	0.0012	0.0021	0.0010	0.72	0.15	
LT-1B	8.5911	12.9773	7.1674	115 59.50	718.26	0.014
	0.0013	0.0025	0.0013	0.86	0.17	
LT-2	8.5913	12.9900	7.1675	116 00.59	718.89	0.027
	0.0030	0.0086	0.0026	2.38	0.47	
Annealed 65-4-5H						
1-500	8.5979	12.9955	7.1811	116 00.39	721.13	0.010
	0.0012	0.0017	0.0008	0.61	0.12	
9-500	8.5961	12.9898	7.1800	116 00.58	720.53	0.007
	0.0007	0.0012	0.0006	0.39	0.08	
Annealed 123A						
1-350	8.5918	12.9823	7.1719	116 01.08	718.90	0.011
	0.0012	0.0031	0.0009	0.70	0.18	
9-500	8.5829	12.9787	7.1735	115 58.36	718.39	0.010
	0.0011	0.0015	0.0008	0.63	0.11	
Na exch[a]	8.1519	12.8497	7.1208	116 32.40	665.68	0.027
	0.0074	0.0057	0.0047	3.40	0.52	
BE	8.6021	12.9782	7.1689	115 58.96	719.44	0.018
	0.0026	0.0060	0.0014	1.25	0.32	
Synthetic feldspars						
0.0 %	8.6034	13.0234	7.1812	116 00.57	723.14	0.009
	0.0010	0.0013	0.0007	0.49	0.09	
5.51%	8.6017	13.0112	7.1711	116 00.14	721.34	0.010
	0.0009	0.0015	0.0007	0.54	0.11	
9.68%	8.6002	12.9979	7.1634	116 00.39	719.68	0.007
	0.0006	0.0011	0.0006	0.43	0.08	
18.10%	8.5908	12.9827	7.1486	116 00.55	716.55	0.008
	0.0009	0.0013	0.0011	0.76	0.14	

[a] $\alpha = 93°32.49' \pm 4.29'$; $\gamma = 90°03.44' \pm 3.95'$.

into the same equation yields values of 95.9 (S & G), 96.7 (123A), and 97.0 mol percent Or (65-4-5H). These very large discrepancies between the two estimates of composition imply highly anomalous cell dimensions. However, they are not anomalous in the sense described by Wright and Stewart (1968), who categorize their anomalous feldspars (all perthitic) as having an *a* cell edge too long relative to *b* and *c* to fit the series defined by homogeneous feldspars. On the contrary, these feldspars seem to have *a* cell edges that are completely normal, as they agree closely with dimensions inferred from mean indices of refraction. The *b* cell edge seems shortened by up to 0.060 Å, and is highly anomalous in terms of the series $KAlSi_3O_8$–$NaAlSi_3O_8$. The *c* dimension approaches expected values for pure monoclinic $KAlSi_3O_8$, but may be somewhat anomalous also, depending on the actual degree of Si–Al order in these feldspars.

Can these anomalous positions within the *b–c* quadrilateral be attributed to cationic substitution of alkalis or of tetrahedrally coordinated cations in the disordered $KAlSi_3O_8$ structure? To test this possibility, the direction of migration of *b–c* coordinates expected in response to substitution of a number of common cations are shown in the inset, Figure 1. Data are directly available to depict the effects of substituting Na^+ (Stewart and Ribbe, 1969), Rb^+ (Martin and Lagache, in press), NH_4^+ (Erd *et al.*, 1964), Ca^{2+} (Stewart, 1967), and Ba^{2+} (Roy, 1965), for K^+ in the high sanidine structure. Data on the effect of Fe^{3+} substituting for Al^{3+} in this structure are from Wones and Appleman (1961). The expected effect of B^{3+} substituting for Al^{3+} in potassic feldspars can be inferred from the known differences between low albite and reedmergnerite (Appleman and Clark, 1965). Perhaps the only additional constituent to be entertained seriously is H_3O^+. Bondam (1967) has succeeded in replacing some of the K^+ by H_3O^+ in adularia, in low temperature leaching experiments, and has noted evidence suggesting expansion of the unit cell. No well documented examples of $(K, H_3O)AlSi_3O_8$ have been found in nature. Any substitution of these cations can be expected also to cause recognizable concomitant effects on the *a* cell edge. Rb^+, Ba^{2+}, and Fe^{3+} are expected to increase the size of *a*, whereas NH_4^+, Na^+, Ca^{2+}, and B^{3+} are expected to decrease it.

All feldspars shown in Figure 1 delineate a field roughly parallel to the high albite-high sanidine edge of the *b–c* quadrilateral. This strongly suggests that all 14 feldspars are anomalous for the same fundamental reason(s), though the degree of anomaly certainly varies. Evidently, only substitution of Na^+, Ca^{2+}, and/or B^{3+} could cause migration of points from the Or sideline in the observed direction. Analyses of comparable monomineralic rocks from the Barstow Formation (Sheppard and Gude, 1965) suggest that of these three cations, only Na^+ and B^{3+} must be considered seriously. No evidence has been found in infrared spectra of specimens 65-4-5H and 123A to justify further consideration of substitution of H_3O^+ and NH_4^+ in the alkali site.

Serious constraints on extent of substitution of K^+ by Na^+ are placed by observed *a* dimensions and mean index of refraction. Any substitution of Na^+ should be readily noticed in indices of refraction, by analogy with published data on natural and synthetic feldspars. Similarly, the extent of substitution by Na^+ necessary to cause the observed values of *b* must also be reflected in *a*. However, the *a* dimension suggests approximately 4 mole percent $NaAlSi_3O_8$, in accord with amounts calculated from the Na_2O in available analyses (Sheppard and Gude, 1965).

No data are available on the effects of boron substitution in $KAlSi_3O_8$, although its boron analogue $KBSi_3O_8$ has been synthesized (Eugster and McIver, 1959). However, by analogy with the differences in cell dimensions between low albite and reedmergnerite (Appleman and Clark, 1965), one should find significant decreases in *a* and *c* if enough boron is present to cause the observed reduction in *b*. It is true that *c* decreases, but equivalent changes in *a* are not observed, suggesting to the writer that reasons for the anomaly should perhaps be sought in structural distortions.

Annealed Natural K-feldspars. Specimens 65-4-5H and 123A annealed at low pressure (Figure 2; Table 2) plot within one standard deviation of the starting materials; the *a* dimension also remains unchanged. Prolonged heating at temperatures of up to 500°C thus does not rectify the anomalous cell constants. In view of Sheppard and Gude's (1965) observation that the amount of Al_2O_3 is slightly deficient in analyses of related monomineralic specimens, a similar experiment on 123A at 9 kbar, 500°C, was designed to test the possibility of nonstoichiometry toward silica (Carman and Tuttle, 1967). This annealed feldspar similarly yields cell dimensions essentially identical to the starting material (Figure 2; Table 2) without any trace of exsolved SiO_2. These annealing experiments thus suggest that the cell dimension anomalies cannot readily be attributed to metastable structural distortions reflecting zeolitic parentage, very low temperature of formation, or departures from stoichiometry in the aluminosilicate framework.

Ion-exchanged Natural Feldspar. Specimen 123A, more anomalous than 65-4-5H, was exchanged in crystalline NaCl, then back-exchanged in crystalline KCl. Cell dimensions of the sodium analogue (Na exch, Table 2) are not markedly anomalous; they compare well with data for more disordered members of the series high albite-low albite (Martin, 1970).

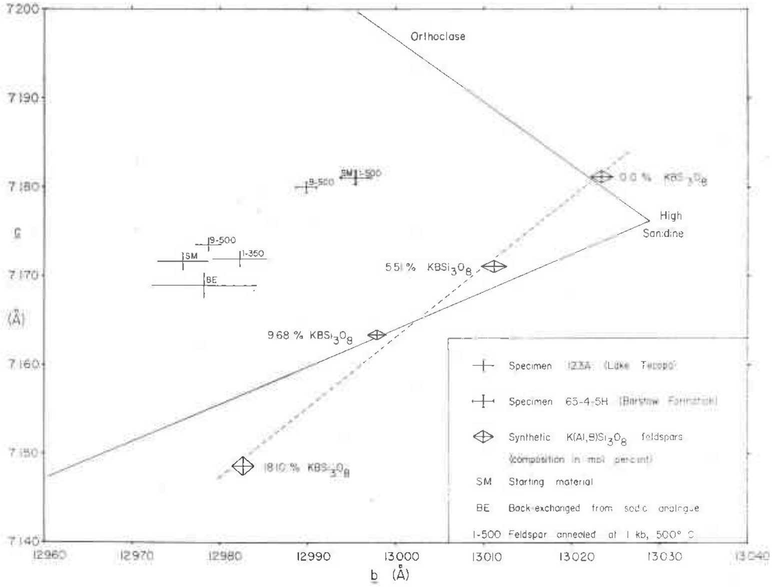

FIG. 2. *b–c* coordinates of annealed natural feldspars and of four synthetic members of the series $KAlSi_3O_8$–$KBSi_3O_8$. Error bars represent ± one standard deviation. Short-dashed line shows the calculated linear relation between *b* and *c* of the four synthetic feldspars.

However, the back-exchanged feldspar (Be, Table 2) apparently retains the anomalous characteristics of the starting material; *a*, *b*, and *c* have virtually returned to their original values. This simple experiment indicates that the cause of the anomalous cell dimensions cannot be sought in substitution in the alkali site; rather, the anomaly must be localized in the Al-Si framework.

Synthetic Feldspars. Four members of the series $KAlSi_3O_8$–$KBSi_3O_8$ were synthesized to test directly the effect of substituting boron for some of the aluminum in relatively disordered K-feldspars (Table 1). The shift in *b–c* coordinates with increasing degree of substitution is found to parallel the linear trend observed in the suite of authigenic feldspars examined (*cf.* Fig. 1 and 2). In terms of the *b–c* quadrilateral, the substitution seems to be mainly reflected in the *b* dimension (0.31 percent decrease); in reality, *c* decreases more markedly (0.45 percent), whereas the *a* dimension decreases by only 0.15 percent in this series of four synthetic feldspars. In contrast, complete substitution of B for Al in the ordered albite structure (Appleman and Clark, 1965) produces a decrease in *a* of 4.14, in *b* of 3.32, and in *c* of 4.96 percent. The relative decrease in *b* and *c* are in nearly the same proportion in both ordered (reedmergnerite) and disordered structures (these feldspars) whereas one would expect the disordered structure to reflect the substitution more extensively in *b* and slightly less so in *c*, from the data of Stewart and Ribbe (1969). Further analysis of this point, and of the large discrepancy in the extent of shrinkage of *a*, will have to await an investigation of more complete substitution of boron in ordered as well as disordered K-feldspar structures. It is evident, however, that the limited extent of substitution in these synthetic feldspars accounts for all the apparent anomalies found in the authigenic K-feldspars shown in Figure 1.

DISCUSSION OF RESULTS

Results of a sequence of experiments suggest that observed variations in cell dimensions of authigenic K-feldspars, found to be anomalous in terms of the *b–c* quadrilateral, may be attributed to partial substitution of B^{3+} for Al^{3+}. This suggestion has been amply confirmed by synthesis and characterization of boron-bearing K-feldspars which plot in a trend parallel to that defined by the natural specimens (*cf.* Figures 1 and 2). The displacement between the two trends is adequately explained by the greater degree of Si–Al order attained in the natural specimens.

Appleman and Clark (1965) suggest that it may be difficult or impossible for boron and silicon to occur in a fully disordered configuration. For example, synthetic reedmergnerite (Eugster and McIver, 1959) seems identical in powder pattern to natural reedmergnerite (Appleman and Clark, 1965). However, three boron-bearing monoclinic K-feldspars reported in this study plot in an unbroken linear trend from a boron-free sanidine (Figure 2), away from the high sanidine-high albite sideline of the *b–c* quadrilateral. The distribution of boron over the two structurally distinct tetrahedral sites a pattern of complete disorder in these synthetic feldspars. By analogy, the monoclinic authigenic feldspars are inferred to have a partially disordered distribution of boron (and aluminum) among the tetrahedral sites, approaching more closely the degree of Si–Al order found in orthoclase. As the very fine grain size of natural and synthetic crystals now available precludes single crystal work, direct substantiation of these inferences may long remain elusive.

Contrary to Appleman and Clark's (1965) suggestion, it may in fact be virtually impossible to synthesize the fully ordered polymorph of $KBSi_3O_8$. Christ (1965) proposed that a disordered structure would seem more favorable because of the smaller nominal adjustment in bond length required. No cell parameter data have been obtained on the synthetic $KBSi_3O_8$ of Eugster and McIver (1959) to clarify this point. More information will be necessary before the question of stability of disordered $NaBSi_3O_8$ and ordered $KBSi_3O_8$ can be resolved satisfactorily.

Boron must henceforth be considered an important constituent of authigenic feldspars and probably of other aluminosilicates formed in alkaline, highly saline environments. The work of Oftedal (1964) suggests that alkali feldspars from certain boron-rich pegmatites contain very low concentrations of boron. However, the possibility of boron substitution should be kept in mind when interpreting anomalous cell dimensions in pegmatitic feldspars. An occurrence of reedmergnerite in peralkaline silicic rocks (Dusmatov, *et al.*, 1967) demonstrates the importance of boron-bearing feldspars in certain types of igneous rocks. Knowledge of the influence of boron on the physical properties of K-feldspar remains incomplete; this paper provides some preliminary information on the effects of boron substitution on cell dimensions and cell volume.

If the relative location of authigenic feldspars away from the maximum microcline-high sanidine sideline of the *b–c* plot (Figure 1) can be taken as a rough measure of extent of boron substitution, one may infer that all 13 specimens studied possess an important amount of boron in their structure. One may further infer that the amount of boron substituting for aluminum varies markedly among specimens closely associated in space. Enough information is now at hand to warn future investigators that the *b–c* plot and the *a* cell edge (or the $\bar{2}01$ or unit cell volume) cannot be used directly to determine composition and structural state of boron-bearing K-feldspars. The general statement of Wright and Stewart that "the axial dimensions of homogeneous alkali feldspars vary smoothly with composition and with structural state in such a way that if *b* and *c* are known, *a* can be closely estimated" (1968, p. 40) obviously cannot be applied to this group of homogeneous boron-enriched alkali feldspars.

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REFERENCES

APPLEMAN, D. E., AND J. R. CLARK (1965) Crystal structure of reed-mergnerite, a boron albite, and its relation to feldspar crystal chemistry. *Amer. Mineral.* **50,** 1827–1850.

BONDAM, J. (1967) Structural changes in adularia in hydrolytic environments. *Medd. Dan. Geol. Foren.* **17,** 357–370.

BORG, I. Y., AND D. K. SMITH (1969) Calculated x-ray powder patterns for silicate minerals. *Geol. Soc. Amer. Mem.* **122,** 896 p.

CARMAN, J. H., AND O. F. TUTTLE (1967) Experimental verification of solid solution of excess silica in sanidine from rhyolites. [abstr.] *Geol. Soc. Amer. Spec. Pap.* **115,** 33–34.

CHRIST, C. L. (1965) Substitution of boron in silicate crystals. *Norsk Geol. Tidsskr.* **45,** 423–428.

DUSMATOV, V. D., A. N. POPOVA, AND L. K. KABANOVA (1967) The first occurrence of reedmergnerite in Russia. *Dokl. Akad Nauk Tadzhik SSR* **10,** 51–54.

ERD, R. C., D. E. WHITE, J. J. FAHEY, and D. E. LEE (1964) Buddingtonite, an ammonium feldspar with zeolitic water. *Amer. Mineral.* **49,** 831–850.

EUGSTER, H. P., AND N. L. MCIVER (1959) Boron analogues of alkali feldspars and related silicates [Abstr.] *Geol. Soc. Amer. Bull.* **70,** 1598–1599.

EVANS, H. T., JR., D. E. APPLEMAN, AND D. S. HANDWERKER (1963) The least squares refinement of crystal unit cells with powder diffraction data by an automatic computer indexing method [Abstr.]. *Amer. Crystallogr. Ass. Meet., Cambridge, Mass.*, 42–43.

LUTH, W. C., AND F. QUEROL-SUÑÉ (1970), An alkali feldspar series. *Contrib. Mineral. Petrology,* **25,** 25–40.

MARTIN, R. F. (1969) The hydrothermal synthesis of low albite. *Contrib. Mineral. Petrology,* **23,** 323–339.

———, (1970) Cell parameters and infrared absorption of synthetic high to low albites. *Contrib. Mineral. Petrology,* **26,** 62–74.

———, AND M. LAGACHE (1970) L'effet de la substitution du potassium par le rubidium sur les paramèters de la sanidine et de la leucite. *Bull. Soc. Fr. Mineral. Cristallogr.* **93,** (in press).

OFTEDAL, I. (1964) On the occurrence and distribution of boron in pegmatite. *Norsk Geol. Tidsskr.* **44,** 217–225.

ORVILLE, P. M. (1967) Unit-cell parameters of the microcline-low albite and the sanidine-high albite solid solution series. *Amer. Mineral.* **52,** 55–86.

ROY, N. N. (1965) Binary system: $KAlSi_3O_8$–$BaAl_2Si_2O_8$. *Nature,* **206,** 501–502.

SHEPPARD, R. A., AND A. J. GUDE, III (1965) Potash feldspar of possible economic value in the Barstow Formation, San Bernardino County, California. *U. S. Geol. Surv. Circ.* **500,** 7 p.

——— AND ———, (1968) Distribution and genesis of authigenic silicate minerals in tuffs of Pleistocene Lake Tecopa, Inyo County, California. *U. S. Geol. Surv. Prof. Pap.* 597, 38 p.

——— AND ——— (1969) Diagenesis of tuffs in the Barstow Formation, Mud Hills, San Bernardino County, California. *U. S. Geol. Surv. Prof. Pap.* **634,** 35 p.

SMITH, J. V. (1961) Explanation of strain and orientation effects in perthites. *Amer. Mineral.* **46,** 1489–1493.

STEWART, D. B. (1967) Four-phase curve in the system $CaAl_2Si_2O_8$–SiO_2–H_2O between 1 and 10 kilobars. *Schweiz. Mineral. Petrog. Mitt.* **47,** 35–59.

———, AND P. H. RIBBE (1969) Structural explanation for variations in cell parameters of alkali feldspar with Al/Si ordering. *Amer. J. Sci.* **267**-*A* (Schairer volume) 444–462.

WONES, D. R., AND D. E. APPLEMAN (1961) X-ray crystallography and optical properties of synthetic monoclinic $KFeSi_3O_8$, iron-sanidine. *U. S. Geol. Surv. Prof. Pap.* **424-C,** C309–C310.

WRIGHT, T. L., AND D. B. STEWART (1968) X-ray and optical study of alkali feldspar. I. Determination of composition and structural state from refined unit-cell parameters and 2V. *Amer. Mineral.* **54,** 38–87.

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