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# Order–disorder paths of alkali feldspars

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**Abstract**

Refined unit-cell dimensions determined for a suite of perthitic alkali feldspars from a near-surface plutonic environment were used to construct standard aluminum occupancy plots. From comparison of natural and dry-heated specimens it is apparent that, on heating, aluminum moves from the $T_1o$ site into the $T_1m$ site faster than into the combined $T_2o$ and $T_2m$ sites. This suggests a two-step disordering path which is nearly the reverse of the ordering path(s) inferred for igneous and metamorphic suites.

## Introduction

It is widely accepted that the degree of order in alkali feldspars is a complex function of temperature, pressure, feldspar composition, fluid composition, host-rock composition, degree of strain, and a number of lesser-known parameters. Martin (1970) has shown that ordering of albites is a one-step process. Disordering of albites is assumed (Ribbe, 1975) to be the reverse of the ordering path, and therefore a one-step process. Stewart and Wright (1974) summarized the structural state data for potassium feldspars from a wide range of igneous and metamorphic rocks, and have suggested that ordering of potassium feldspars is a two-step process. A one-step disordering process for potassium feldspars has been implied by Smith (1974, p. 73) and by Ribbe (1975, p. R28).

The present study was limited to a suite of perthitic alkali feldspars from the St. George pluton, which forms part of a large intrusive complex in southwestern New Brunswick (Fig. 1). The pluton, which crystallized under near-surface conditions, is comprised in its western region dominantly (95 percent) of coarse-grained granite and in its eastern region of coarse-grained (65 percent) and porphyritic (35 percent) granites (Cherry, 1976). The bulk compositions of the rocks from which the perthite samples were selected are near the granite minimum-melt composition. Field relations indicate slight differences in crystallization and post-crystallization conditions across the pluton. These differences probably controlled the development of the different rock textures and the degree of order attained by the alkali feldspars. The alkali feldspars from the eastern region of the pluton appear optically to be monoclinic (polysynthetic twinning absent), and those from the western region of the pluton appear to be triclinic (polysynthetic twinning present). The geologic setting is described in detail in Cherry (1976) and is summarized in Cherry and Trembath (1978).

The ordering 'path' for a suite of alkali feldspars can be investigated by calculating the aluminum occupancies of the tetrahedral sites from refined unit-cell parameters. The variation in aluminum distribution is assumed to represent a single ordering path followed to different degrees by the samples of the suite. Disordering 'paths' may be outlined by determining the effect of dry heating on the unit-cell parameters and comparing the estimated aluminum distributions for individual natural and heated samples. These 'paths' should aid in distinguishing between a one-step and a two-step disordering process.

## Methods

The alkali feldspar samples were handpicked from fresh hand specimens of the coarse-grained granite from the western region of the pluton and of all the textural varieties of granite from the eastern region of the pluton. Sample locations are shown on Figure 1. The samples were ground, and a portion of each was dry-heated at 900° to 1050°C for 3 to 14 days. The majority of the samples was treated at 1000°C for 10 to 12 days. Refined unit-cell parameters for the natural and heat-treated samples were obtained from powder X-ray diffraction patterns, using the methods presented by Wright and Stewart (1968). These techniques are discussed and the refined unit-cell parameters are given in Cherry and Trembath (1978).

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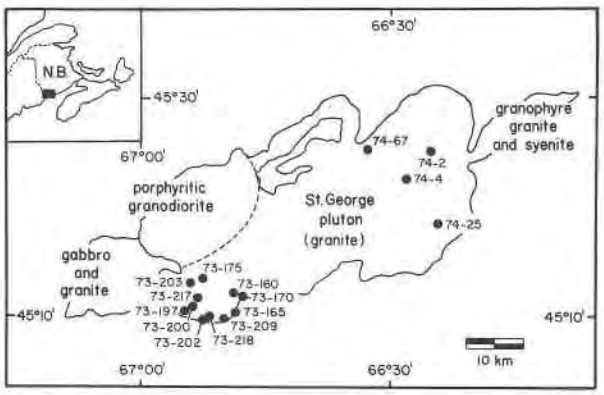


Fig. 1. The St. George Complex in southwestern New Brunswick, showing the St. George pluton and the location of the alkali feldspar samples.

## Results and discussion

The distribution of aluminum among the tetrahedral sites of the feldspar structure was calculated from the refined unit-cell parameters (Cherry and Trembath, 1978), using the methods of Stewart and Ribbe (1969) and equations from Stewart (1975). The results (Table 1) indicate a wide range of variation in the aluminum occupancies of the natural alkali feld-

Table 1. Al occupancy data for alkali feldspars from the St. George pluton. Occupancies were calculated using equations from Stewart (1975).

| Sample No. | Al occupancy of tetrahedral sites | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Natural | | | | Heat-treated | | | |
| | $t_1o$ | $t_1m$ | $t_2o$ | $t_2m$ | $t_1o$ | $t_1m$ | $t_2o$ | $t_2m$ |
| (a) Western End. | | | | | | | | |
| 73-160A(c)* | 0.809 | 0.151 | 0.020 | 0.020 | 0.382 | 0.382 | 0.118 | 0.118 |
| 73-165A(c) | 0.764 | 0.185 | 0.026 | 0.026 | 0.322 | 0.322 | 0.178 | 0.178 |
| 73-170A(c) | 0.876 | 0.025 | 0.050 | 0.050 | 0.311 | 0.311 | 0.189 | 0.189 |
| 73-175A(c) | 0.668 | 0.312 | 0.010 | 0.010 | 0.394 | 0.394 | 0.106 | 0.106 |
| 73-197A(c) | 0.742 | 0.195 | 0.032 | 0.032 | 0.357 | 0.357 | 0.143 | 0.143 |
| 73-200A(c) | 0.737 | 0.183 | 0.040 | 0.040 | 0.562 | 0.322 | 0.058 | 0.058 |
| 73-202A(c) | 0.717 | 0.205 | 0.039 | 0.039 | 0.367 | 0.367 | 0.133 | 0.133 |
| 73-203A(c) | 0.461 | 0.461 | 0.039 | 0.039 | 0.373 | 0.373 | 0.127 | 0.127 |
| 73-209A(c) | 0.816 | 0.124 | 0.030 | 0.030 | 0.311 | 0.311 | 0.189 | 0.189 |
| 73-217A(c) | 0.559 | 0.437 | 0.002 | 0.002 | 0.394 | 0.394 | 0.106 | 0.106 |
| 73-218A(c) | 0.807 | 0.153 | 0.020 | 0.020 | 0.563 | 0.279 | 0.079 | 0.079 |
| (b) Eastern End. | | | | | | | | |
| 74-2A(c) | 0.393 | 0.393 | 0.107 | 0.107 | 0.417 | 0.417 | 0.083 | 0.083 |
| 74-2B(m) | 0.442 | 0.442 | 0.058 | 0.058 | 0.336 | 0.336 | 0.164 | 0.164 |
| 74-2B(g) | 0.438 | 0.438 | 0.062 | 0.062 | 0.362 | 0.362 | 0.138 | 0.138 |
| 74-4A(c) | 0.436 | 0.436 | 0.064 | 0.064 | 0.420 | 0.420 | 0.080 | 0.080 |
| 74-4B(p) | 0.435 | 0.435 | 0.065 | 0.065 | 0.393 | 0.393 | 0.107 | 0.107 |
| 74-25A(g) | 0.391 | 0.391 | 0.109 | 0.109 | 0.365 | 0.365 | 0.135 | 0.135 |
| 74-25A(mp) | 0.392 | 0.392 | 0.108 | 0.108 | n.d.** | n.d. | n.d. | n.d. |
| 74-25A(p) | 0.402 | 0.402 | 0.098 | 0.098 | 0.382 | 0.382 | 0.118 | 0.118 |
| 74-67A(mp) | 0.405 | 0.405 | 0.095 | 0.095 | 0.390 | 0.390 | 0.110 | 0.110 |
| 74-67A(p) | 0.404 | 0.404 | 0.096 | 0.096 | 0.390 | 0.390 | 0.110 | 0.110 |

* The letter in brackets gives host rock/feldspar texture: c = coarse-grained, m = miarole filling, g = groundmass in porphyritic granite, p = phenocryst, mp = mantled phenocryst.

** n.d. = not determined.

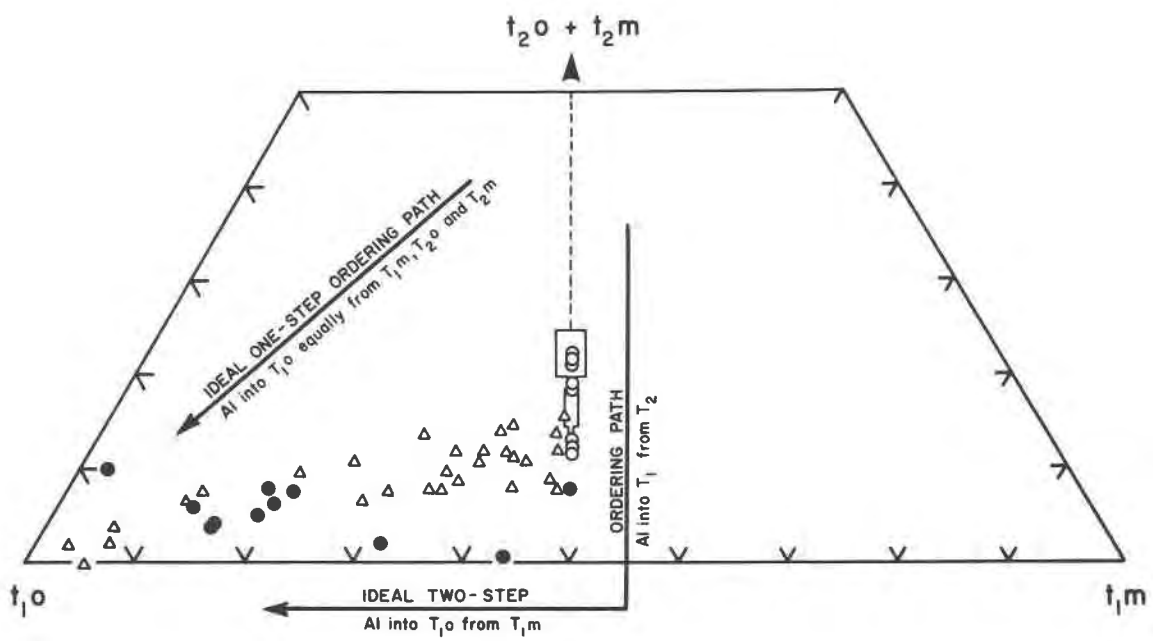


Fig. 2. Aluminum ordering paths in alkali feldspars with Al:Si = 1:3. The open triangles and the rectangular areas are data from Stewart and Wright (1974) for a suite of metamorphic potassium feldspars (Guidotti *et al.*, 1973). Filled circles are alkali feldspars from the western end of the St. George pluton; open circles are alkali feldspars from the eastern end of the St. George pluton. The dashed lines are possible ordering paths for the potassium feldspars.

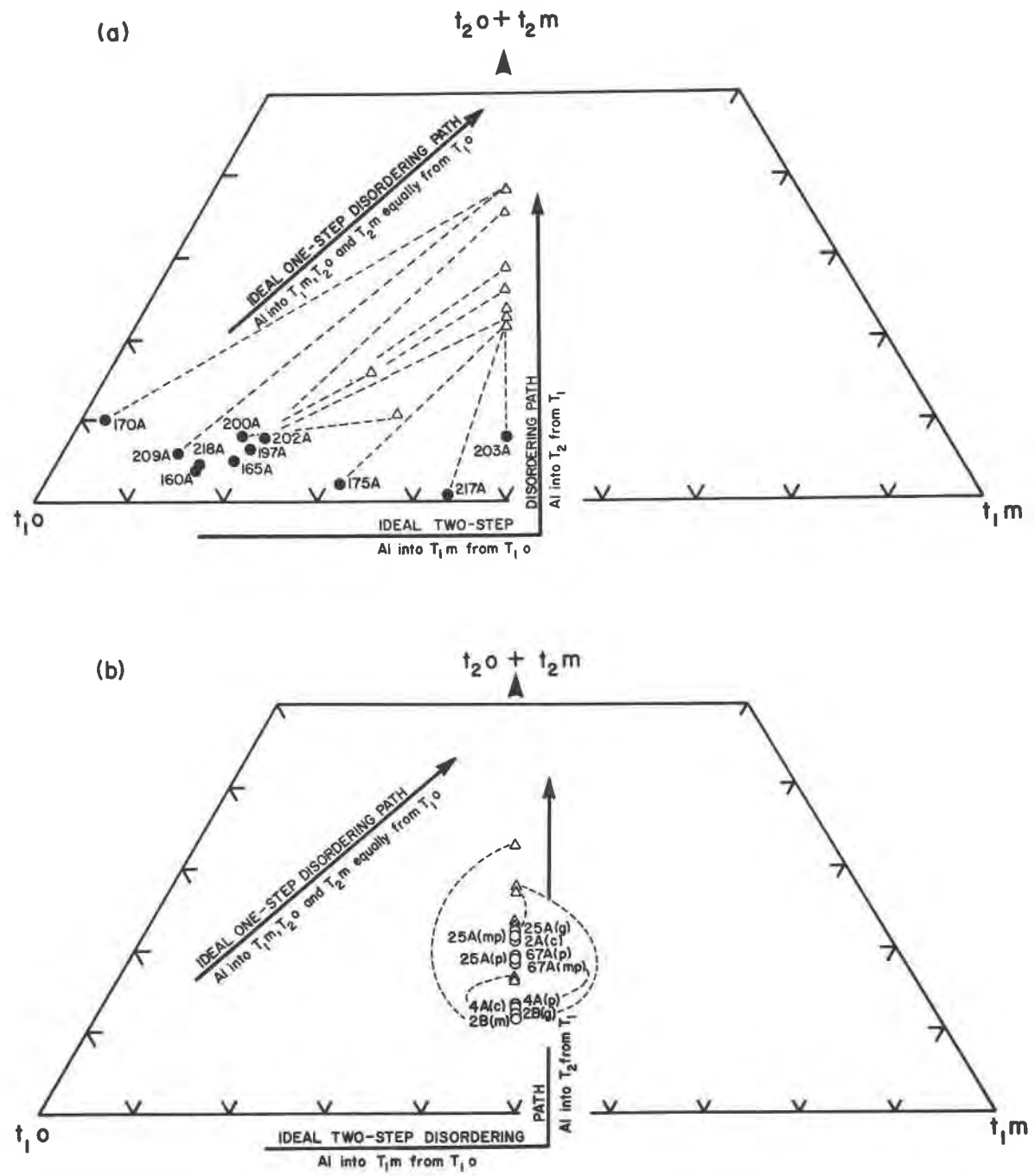


Fig. 3. Aluminum disordering paths in alkali feldspars from the St. George pluton. (a) Feldspars from the western end of the pluton. (b) Feldspars from the eastern end of the pluton. Circles give the aluminum distribution in the natural samples and triangles give the aluminum distribution in the heat-treated samples. The dashed lines join pairs of natural and heated samples but are not meant to show disordering paths.

spars from the western region of the pluton. The feldspars from the eastern region of the pluton have a smaller range of variation in aluminum occupancies.

The data also show that all samples from the eastern region of the pluton have monoclinic unit cells and that ten of eleven samples from the western region have triclinic unit cells. The samples from the eastern end are of several textural varieties, yet all

have monoclinic unit cells, indicating that the symmetry of the alkali feldspar samples is independent of host-rock texture.

## Ordering path

Stewart and Wright (1974) used a trapezoidal plot of the aluminum occupancy of the tetrahedral sites in alkali feldspars to discuss possible ordering paths in the alkali feldspars. Their diagram is consistent with ordering of the potassium feldspars by a two-step process, with aluminum moving from the $T_2$ site into the $T_1$ site before 'inversion' to a sensibly triclinic distribution of aluminum and silicon occurs, after which aluminum moves into the $T_1o$ site from $T_1m$, $T_2o$, and $T_2m$.

As an example of this two-step ordering path, Stewart and Wright (1974) plotted the aluminum occupancies of alkali feldspars from a metamorphic terrain (Guidotti *et al.*, 1973). These data are shown on Figure 2, along with the data for the samples from this study. Two possible ordering paths are indicated for the latter. The first is similar to that followed by the metamorphic feldspars. Aluminum is concentrated in the $T_1$ sites of the monoclinic structure until $T_2 \simeq 0.10$, when 'inversion' to a triclinic distribution occurs. The aluminum distribution in the intermediate microclines indicates that the subsequent movement of aluminum into the $T_1o$ site is four times as fast from $T_1m$ as from the $T_2$ sites (Stewart and Wright, 1974). The monoclinic feldspars from the present study are somewhat more highly ordered than those from the metamorphic rocks. Stewart and Wright (1974) suggested that this higher degree of order had been reached in the metamorphic rocks but was lost when the 'inversion' to a triclinic distribution occurred.

A second possible ordering path is suggested for two triclinic specimens with very little aluminum in the $T_2$ sites. Ordering of the monoclinic feldspars may be complete, *i.e.* $T_2 = 0.0$, or nearly so, before 'inversion' to a triclinic distribution occurs, and subsequent ordering of the triclinic structures then requires only that aluminum move into the $T_1o$ site from the $T_1m$ site. This path differs from the first only in the degree of order achieved in the monoclinic feldspars during the first step of the ordering process.

## Disordering path

It is convenient to discuss the disordering process in terms of ideal one- and two-step processes, using the trapezoidal diagram of aluminum occupancies (Fig. 3). An ideal one-step disordering path requires that aluminum move from $T_1o$ into $T_1m$, $T_2o$, and $T_2m$ simultaneously. On the trapezoidal diagram, this path is a straight line from the aluminum distribution of the ordered natural sample to the point of complete disorder. The ideal two-step disordering process requires that aluminum move from $T_1o$ only into $T_1m$ until 'inversion' to monoclinic symmetry occurs, after which aluminum moves from $T_1$ into $T_2$. On the trapezoidal diagram, this path comprises two straight-line segments: the first extends parallel to the $t_1o$–$t_1m$ join from the aluminum distribution of the natural sample to the line $t_1o = t_1m$, and the second extends from this intersection at $t_1o = t_1m$ to the point of complete disorder.

The disordering 'paths' for individual perthite samples from the St. George pluton (Fig. 3) are two-step paths that lie between the above limiting cases. The most highly ordered triclinic samples (170A, 209A) have attained the greatest disorder upon heating. The least ordered triclinic samples (175A, 217A) have assumed a highly ordered monoclinic aluminum distribution. Two samples (200A, 218A) have assumed more disordered triclinic aluminum distributions. The diagram indicates that a wide range of disordering paths is possible, and that the degree of monoclinic order reached after heating reflects the degree of order in the initial perthite. Considering that the duration of heating has not been taken into account, there is a minimal crossing of 'paths' on the diagram. The most ordered triclinic feldspars disorder more (more readily) for a given duration of dry heating than do less ordered triclinic feldspars.

A similar pattern is observed for initially monoclinic samples. The most ordered natural samples [2B(m), 2B(g)] have attained the greatest degree of disorder after heating. Heat-treatment of monoclinic feldspars with an intermediate degree of monoclinic order [67A(mp), 67A(p)] has less effect.

## Conclusions and implications

Dry heating is useful in defining the disordering process in alkali feldspars. Although the degree to which the disordering process is two-step is uncertain, it is clear that the process for this suite of perthites involves a two-step trend. The duration of heating is obviously important, and timed experiments will be essential to establishing detailed paths for the disordering of alkali feldspars.

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