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Structural state and composition of alkali feldspars in granites of the St. George pluton, south-western New Brunswick

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SUMMARY. The variation in the structural state of potassium feldspars from the St. George pluton, New Brunswick, Canada, is discussed. Monoclinic potassium feldspars occur near the eastern end of the pluton whereas the granites at the western end contain triclinic potassium feldspars. Although the bulk compositions of the host rocks are all very near the granite minimum melt composition there is a systematic increase in the degree of ordering for both the triclinic and monoclinic suites of feldspars with the more ordered variants tending to occur within rocks nearest the minimum melt composition. There is more abundant textural evidence for the presence of a late-stage fluid phase in the granites containing the monoclinic potassium feldspars. It is proposed that a slower post-crystallization cooling rate was also a factor in the nucleation of triclinic domains in the potassium feldspars at the western end of the pluton.

METHODS for determining the structural state and composition of alkali feldspars from refined unit cell parameters obtained from X-ray diffraction data have been developed and refined (Wright and Stewart, 1968; Stewart and Ribbe, 1969; Stewart and Wright, 1974). Stewart (1975) has summarized these methods and their applications to understanding the ordering process in alkali feldspars from natural systems. These techniques have been used to determine the structural states and compositions of a suite of alkali feldspars from granites in the St. George pluton in south-western New Brunswick. These data are used to discuss possible controls of ordering in alkali feldspars.

Geologic setting. The St. George intrusive complex (fig. 1) includes the Bocabec Complex, composed of gabbro and granite (Fyffe, 1971); the Welsford Appendage, an apophysis of granite, granophyre, and syenite (Sharpe, 1958); an oval area of coarse-grained, porphyritic granodiorite, and the St. George pluton, a large, central area of granite. The pluton intrudes the Bocabec Complex and is penecontemporaneous with the formation of the Welsford Appendage. The age relationships between the porphyritic granodiorite and the rest of the complex are unknown. A Rb/Sr whole-rock isochron determined for the Bocabec Complex has given an age of 394 ± 20 Ma (Pajari *et al.*, 1974) and a K/Ar age determination on biotite from granite in the St. George pluton near Lake McDougall has given an age of 381 ± 11 Ma (Tupper and Hart, 1961). The rocks in the complex are not deformed by the Acadian Orogeny.

The alkali feldspars used in this study are from the granites of the St. George pluton, which forms approximately 70% of the surface area of the St. George complex. The pluton is comprised almost entirely of a coarse-grained and a porphyritic granite which are intermingled and give equivocal relative ages, suggesting a penecontemporaneous origin. Characteristics of the pluton are summarized in Table I; a more detailed description is given in Cherry (1976).

Despite the limited variation in textures, mineralogy, and bulk composition of the granites in the pluton, distinct contrasts can be made between its eastern and western ends (Table I). The most

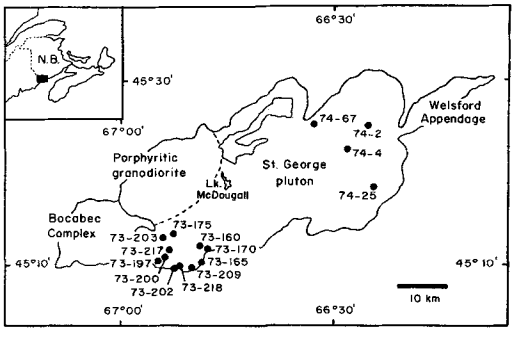

FIG. 1. The St. George complex, showing the domains discussed in the text and the locations of the alkali feldspar samples.

TABLE I. *Characteristics of the St. George pluton*

	Characteristics of the entire pluton	Characteristics of the eastern end of the pluton	Characteristics of the western end of the pluton
		Apophysis (Welsford Appendage) of granite, granophyre, and syenite extends to the north-east. Appendage has features of a hypabyssal intrusion. Granites at this end of the pluton must have crystallized under near-surface conditions. Contact metamorphism reaches hornblende-hornfels facies.	Intruded into the Bocabec Complex and into L. Dev. sedimentary and volcanic rocks. Present as cobbles in the U. Dev. Perry Fm. Granites must have crystallized under near-surface conditions. Contact metamorphism reaches hornblende-hornfels facies.
Geologic setting	Pluton is composed of a coarse-grained and a porphyritic granite and < 1% aplite. The granites are not deformed by the Acadian Orogeny.	Estimated to be 65% coarse-grained and 35% porphyritic granite. Rapakivi mantling abundant in the porphyritic granite and common in the aplites and the coarse grained granite. Granophyric textures common in all the granites. Miarolitic cavities and pegmatite pods common.	Estimated to be 95% coarse-grained and 5% porphyritic granite. Rapakivi mantling rare. Granophyric textures only in aplites. Miarolitic cavities and pegmatite pods rare.
Mineralogy	Essential mineralogy of all the granites is subequal amounts of quartz, plagioclase, and K-feldspar with minor biotite. Minor and accessory minerals are hornblende, sphene, zircon, fluorite, pyrite, and Fe oxides.		
K-feldspar	Microperthitic	Simple twins, or untwinned. Orthoclases, with $t_1o+t_1m = 0.75$ to 0.90 K-rich phase of perthite— 92.3% Or (vol.)[1] 89.1% Or ($\bar{2}01$) Bulk grain composition— 66.0% Or (vol.) 64.1% Or ($\bar{2}01$)	Microcline twinning. Microclines, with $t_1o+t_1m > 0.90$ $t_1o-t_1m = 0.00$ to 0.88 K-rich phase of perthite— 92.8% Or (vol.) 89.6% Or ($\bar{2}01$) Bulk grain composition— 60.9% Or (vol.) 58.2% Or ($\bar{2}01$)
Plagioclase	Albite twinning. Step normal zoning from $\simeq An_{30}$ to $\simeq An_6$. Rapakivi mantles have composition of $\simeq An_{22}\ Or_2\ Ab_{76}$.		
Petrochemistry	The granites have a very limited range in major element composition:		

	Mean Norm.%	Range
Qz	35.7[2]	29.6–39.0
Or	29.4	22.7–34.9
Ab	29.6	23.9–36.9
An	2.2	0.4–9.4
D.I.	95	88–98

No. of samples = 43

	Mean Norm.%	Range
Qz	36.3	32.9–37.3
Or	30.2	27.1–33.5
Ab	28.0	23.9–30.7
An	2.7	1.1–9.4
D.I.	95	88–98

No. of samples = 19

	Mean Norm.%	Range
Qz	35.2	29.6–39.0
Or	28.8	22.7–34.9
Ab	30.9	24.7–36.9
An	1.9	0.4–3.7
D.I.	95	90–98

No. of samples = 24

The granites are peraluminous.

[1] Mean value for the suite of potassium feldspars.

[2] Norms were calculated according to the scheme of Irvine and Baragar (1971). Analyses are listed in Cherry (1976).

striking of these is the difference in relative abundance of the coarse-grained and the porphyritic granites. At its eastern end, the pluton is estimated to be 65% coarse-grained and 35% porphyritic granite, whereas the western end of the pluton is estimated to be 95% coarse-grained and 5% porphyritic granite. Rapakivi texture, miarolitic cavities, pegmatite pods, and granophyric texture are common in all textural types of the granites at the eastern end of the pluton and are rare in the granites at the western end. Microcline twinning is absent from the alkali feldspars at the eastern end of the pluton and present in those at the western end.

These features and others listed in Table I indicate that the granites in the St. George pluton formed by the crystallization of a homogeneous magma that was intruded high in the crust.

Methods. Alkali feldspars were handpicked from fresh hand specimens. Specimen locations are shown on fig. 1. The samples from the eastern end of the pluton include alkali feldspars from the coarse-grained granite, from phenocrysts and groundmass of the porphyritic granite, and from a miarolitic cavity filling. All samples from the western end of the pluton are from the coarse-grained granite. All of the samples except those from the groundmass of the porphyritic granite are fragments of single grains. The samples were crushed to a fine powder and a portion of each was homogenized by dry heating at temperatures of 900–1050 °C for 3–14 days; the majority of the samples were treated at 1000 °C for 10–12 days.

Diffraction patterns were obtained from smear mounts of both the natural and the heated samples using Cu radiation (λ = 1·5418 Å, 40 kv, 30 mA) and a graphite monochromator. Three scans from 60 to 20 degrees 2θ were made for each sample with CaF_2 (a = 5·4626 Å) as an internal standard and goniometer speeds of 1° and 0·5° per minute.

The diffraction patterns were indexed using data in Wright and Stewart (1968) and Borg and Smith (1969). Mean 2θ values for the indexed peaks were then used in a cell refinement programme (Evans *et al.*, 1963) to obtain refined unit cell parameters. As all of the alkali feldspars were microperthitic it was necessary to remove the reflections that were either due to or affected by the albite phase prior to refinement. Initial monoclinic and triclinic symmetry restrictions were assigned on the basis of appreciable splitting or broadening of the symmetry sensitive pairs such as 131, $1\bar{3}1$ and 130, $1\bar{3}0$. As a final check on the distinction between triclinic and monoclinic unit cells refinements were attempted using both monoclinic and triclinic symmetry restrictions. When samples with triclinic refined cells were submitted with monoclinic symmetry restrictions the programme did not converge. When samples with monoclinic refined cells were submitted with triclinic symmetry restrictions the programme converged to a monoclinic unit cell within the precision of the measurement. The alkali feldspar phase may well be composed of a number of 'domains' or volumes with different Al/Si order so obviously the refined cell constants would represent an 'average' order. Fixed indexing was used for final refinements and all reflections were given unit weight in the programme. Acceptances and rejections of the diffraction peaks by the programme were similar to data given in Wright and Stewart (1968).

Detailed accounts of sample preparation, X-ray diffractometry, and unit cell refinements are given in Cherry (1976).

Results. The refined unit cell parameters for the alkali feldspars are listed in Table II. The data confirm the distribution of potassium feldspar polymorphs inferred from petrography: the samples from the eastern end of the pluton are monoclinic structures and ten of eleven samples from the western end are triclinic structures.

Refined unit cell parameters of the natural samples are plotted on b–c and α^*–γ^* cell-dimension plots in figs. 2 and 3 respectively to illustrate the variations in their structural state. The derivations, limitations and applications of these plots are summarized in Stewart (1975); the plots are from Stewart and Wright (1974). The cell dimensions of several feldspars for which structural determinations are available are included on the plots for comparison; their cell dimensions are listed in Smith (1974).

The alkali feldspars from the western end of the pluton plot near maximum microcline with $t_1o + t_1m > 0{\cdot}90$ on the b–c cell dimension plot (fig. 2). The monoclinic sample (73-203A) in this suite has a very high degree of order for a monoclinic structure. The samples from the eastern end of the pluton, which have monoclinic cell dimensions, plot as less ordered structures with $0{\cdot}75 < t_1o + t_1m < 0{\cdot}90$. The two suites of samples have much the same variation in estimated a cell dimensions.

The difference ($\Delta a = a_{obs} - a_{est}$) between the a cell dimension determined by unit cell refinement (a_{obs}) and the a cell dimension estimated from the b–c cell dimension plot (a_{est}) for each of the alkali feldspars is listed in Table II. This difference has been attributed to strain in the feldspar structure (Brown and Williame, 1974); strained structures have been related to coherency between the sodic and potassic phases of cryptoperthites (ibid). Stewart and Wright (1974) used Δa as an index of strain with Δa = 0·05 as a threshold value. Stewart (1975) stated that monoclinic feldspars are usually

TABLE II. *Crystallographic data for potassium feldspars from the St. George pluton from powder diffraction data*

Sample	*a*	*b*	*c*	α	β	γ	Volume Å^{-3}	*d*(2̄01)	α*	γ*	Δ*a*	Weight Volume	% Or *d*(2̄01)	No. of reflec.
(a) Natural, Western End														
73-160A(c)[1]	8·571(7)Å	12·963(9)Å	7·216(4)Å	90·39(7)°	116·14(5)°	88·41(8)°	719·37(63)	4·223	90·35(6)°	91·58(7)°	0·01	90·3	88·1	26
73-165A(c)	8·585(6)	12·962(7)	7·214(4)	90·36(6)	116·06(4)	88·58(6)	720·96(48)	4·228	90·29(5)	91·40(5)	0·05	94·5	90·8	25
73-170A(c)	8·590(6)	12·977(6)	7·212(4)	90·62(6)	116·02(4)	88·00(5)	721·96(47)	4·228	90·29(5)	91·93(4)	0·00	97·3	90·8	27
73-175A(c)	8·550(5)	12·949(9)	7·214(3)	90·11(7)	116·16(5)	89·10(7)	716·80(52)	4·215	90·33(6)	90·95(6)	0·07	84·0	84·5	23
73-197A(c)	8·576(4)	12·973(6)	7·215(3)	90·41(5)	116·02(4)	88·66(5)	721·13(42)	4·224	90·19(4)	91·29(4)	−0·01	95·0	88·7	28
73-200A(c)	8·591(4)	12·963(5)	7·210(3)	90·37(4)	116·13(4)	88·65(5)	720·69(38)	4·231	90·26(3)	91·33(4)	0·07	93·8	92·2	29
73-202A(c)	8·588(3)	12·969(5)	7·212(2)	90·34(4)	116·10(3)	88·74(4)	721·17(33)	4·230	90·24(4)	91·24(4)	0·03	95·1	91·6	32
73-203A(c)	8·579(3)	12·971(3)	7·213(1)	90·00	116·03(2)	90·00	721·27(24)	4·226	90·00	90·00	0·01	95·4	89·9	22
73-209A(c)	8·584(4)	12·958(6)	7·211(3)	90·39(5)	116·04(4)	88·33(4)	720·34(40)	4·227	90·38(5)	91·67(4)	0·08	92·9	90·0	36
73-217A(c)	8·576(3)	12·945(4)	7·215(2)	90·09(3)	116·07(2)	89·58(3)	719·42(28)	4·226	90·10(3)	90·42(3)	0·11	90·5	89·5	26
73-218A(c)	8·578(4)	12·962(6)	7·215(3)	90·44(5)	116·09(4)	88·42(5)	720·13(39)	4·225	90·29(4)	91·55(4)	0·04	92·3	89·3	30
(b) Heat-treated, Western End														
73-160A(c)	8·373(10)	12·959(4)	7·185(2)	90·00	115·85(4)	90·00	701·65(80)	4·132	90·00	90·00	−0·06	53·4	45·9	12
73-165A(c)	8·422(10)	12·985(7)	7·176(3)	90·00	115·88(11)	90·00	706·10(121)	4·153	90·00	90·00	−0·01	61·5	55·9	15
73-170A(c)	8·412(9)	13·003(23)	7·180(5)	90·00	115·97(7)	90·00	705·98(119)	4·150	90·00	90·00	−0·10	61·3	54·1	11
73-175A(c)	8·445(5)	12·966(4)	7·191(2)	90·00	115·94(3)	90·00	708·05(48)	4·165	90·00	90·00	0·02	65·3	61·4	14
73-197A(c)	8·439(5)	12·969(4)	7·181(2)	90·00	116·07(4)	90·00	705·88(36)	4·163	90·00	90·00	0·03	61·1	60·5	13
73-200A(c)	8·449(17)	12·939(4)	7·196(2)	90·12(5)	116·11(4)	89·38(9)	706·27(125)	4·169	90·17(3)	90·63(8)	0·07	61·9	63·0	11
73-202A(c)	8·437(5)	12·961(9)	7·181(3)	90·00	116·10(5)	90·00	705·11(59)	4·163	90·00	90·00	0·06	59·7	60·2	17
73-203A(c)	8·460(2)	12·980(3)	7·190(2)	90·00	116·03(2)	90·00	709·37(24)	4·172	90·00	90·00	−0·02	67·9	64·8	24
73-209A(c)	8·425(6)	12·984(5)	7·173(4)	90·00	116·04(5)	90·00	704·96(50)	4·156	90·00	90·00	0·00	59·4	57·2	22
73-217A(c)	8·431(4)	12·961(5)	7·189(2)	90·00	115·96(3)	90·00	706·34(39)	4·159	90·00	90·00	0·02	62·0	58·5	14
73-218A(c)	8·422(8)	12·942(9)	7·190(5)	90·29(10)	116·14(7)	89·29(10)	703·46(84)	4·157	90·03(10)	90·65(10)	0·06	56·6	58·1	22
(c) Natural, Eastern End														
74-2A(c)	8·577(7)	12·984(6)	7·197(3)	90·00	116·00(6)	90·00	720·41(54)	4·224	90·00	90·00	0·05	93·1	88·9	13
74-2B(m)	8·568(4)	12·955(5)	7·202(3)	90·00	116·01(4)	90·00	718·44(38)	4·221	90·00	90·00	0·13	88·0	87·3	26
74-2B(g)	8·576(3)	12·977(4)	7·208(2)	90·00	115·99(3)	90·00	721·00(30)	4·224	90·00	90·00	0·01	94·6	88·9	15
74-4A(c)	8·580(7)	12·976(5)	7·207(2)	90·00	115·99(6)	90·00	721·22(57)	4·226	90·00	90·00	0·02	95·3	89·7	15
74-4B(p)	8·571(6)	12·970(6)	7·205(3)	90·00	115·99(4)	90·00	719·90(48)	4·222	90·00	90·00	0·05	91·7	87·7	22
74-25A(g)	8·566(3)	12·986(3)	7·197(2)	90·00	116·04(2)	90·00	719·38(27)	4·220	90·00	90·00	0·03	90·4	86·7	18
74-25A(mp)	8·571(1)	12·981(2)	7·196(1)	90·00	116·04(1)	90·00	719·29(14)	4·222	90·00	90·00	0·06	90·1	87·7	22
74-25A(p)	8·582(3)	12·973(4)	7·196(2)	90·00	116·06(2)	90·00	719·74(25)	4·227	90·00	90·00	0·10	91·3	90·1	17
74-67A(mp)	8·586(3)	12·981(3)	7·200(1)	90·00	116·06(2)	90·00	720·83(23)	4·229	90·00	90·00	0·05	94·2	91·0	20
74-67A(p)	8·595(4)	12·972(4)	7·196(2)	90·00	116·04(2)	90·00	720·89(29)	4·233	90·00	90·00	0·13	94·3	92·7	16

(d) Heat-treated, Eastern End

74-2A(c)	8·428(4)	12·956(6)	7·194(3)	90·00	116·17(4)	90·00	705·06(43)	4·160	90·00	90·00	0·01	59·6	59·2	27
74-2B(m)	8·480(5)	12·994(4)	7·184(2)	90·00	116·03(3)	90·00	711·27(38)	4·181	90·00	90·00	−0·01	71·8	68·8	17
74-2B(g)	8·438(2)	12·979(5)	7·186(2)	90·00	116·12(3)	90·00	706·63(32)	4·164	90·00	90·00	−0·01	62·5	60·7	26
74-4A(c)	8·457(9)	12·955(4)	7·195(2)	90·00	116·09(3)	90·00	707·95(66)	4·172	90·00	90·00	0·04	65·1	64·6	14
74-4B(p)	8·441(2)	12·971(3)	7·193(2)	90·00	116·09(2)	90·00	707·27(21)	4·165	90·00	90·00	−0·02	63·8	61·4	23
74-25A(g)	8·471(2)	12·986(3)	7·190(2)	90·00	116·08(2)	90·00	710·42(22)	4·178	90·00	90·00	−0·03	70·0	67·4	21
74-25A(p)	8·462(2)	12·978(4)	7·192(2)	90·00	116·06(2)	90·00	709·46(28)	4·174	90·00	90·00	−0·02	68·1	65·5	23
74-67A(mp)	8·458(2)	12·976(4)	7·193(2)	90·00	116·08(3)	90·00	709·05(27)	4·172	90·00	90·00	0·02	67·3	64·8	20
74-67A(p)	8·455(3)	12·969(3)	7·191(2)	90·00	116·08(2)	90·00	708·20(23)	4·171	90·00	90·00	−0·02	65·6	64·1	21

[1] The letter in brackets gives the host rock/feldspar texture: c = coarse-grained, m = miarole filling, g = groundmass, p = phenocryst, mp = mantled phenocryst.

more strained than triclinic feldspars from the same environment and suggested that inversion to triclinic structure of the potassium feldspar reduces coherency between the sodic and potassic phases of perthites, thus reducing strain. The Δa values in Table II show that five of ten triclinic and eight of eleven monoclinic feldspars from the St. George pluton have strained structures, in agreement with Stewart's observation.

The α^*-γ^* dimensions of the natural triclinic alkali feldspars are shown on fig. 3. The samples, from the western end of the pluton, plot along the monoclinic K-feldspar–microcline line with $0{\cdot}20 < t_1o - t_1m < 0{\cdot}90$, thereby indicating a range in Al/Si order.

The compositions of the feldspars listed in Table II were calculated from the refined unit cell volumes, using the equation in Stewart and Wright (1974) and confirmed by $d(\bar{2}01)$ using the relationship determined by Jones *et al.* (1969). The compositions listed for the natural samples are those of the potassic phase of the perthites; those for the heat-treated samples are the bulk grain compositions of the homogenized perthites. The K-rich phase of the perthites is approximately the same composition in both sample suites. The mean bulk grain composition of the samples from the eastern end of the pluton is approximately 5 wt% richer in Or than that of the samples from the western end.

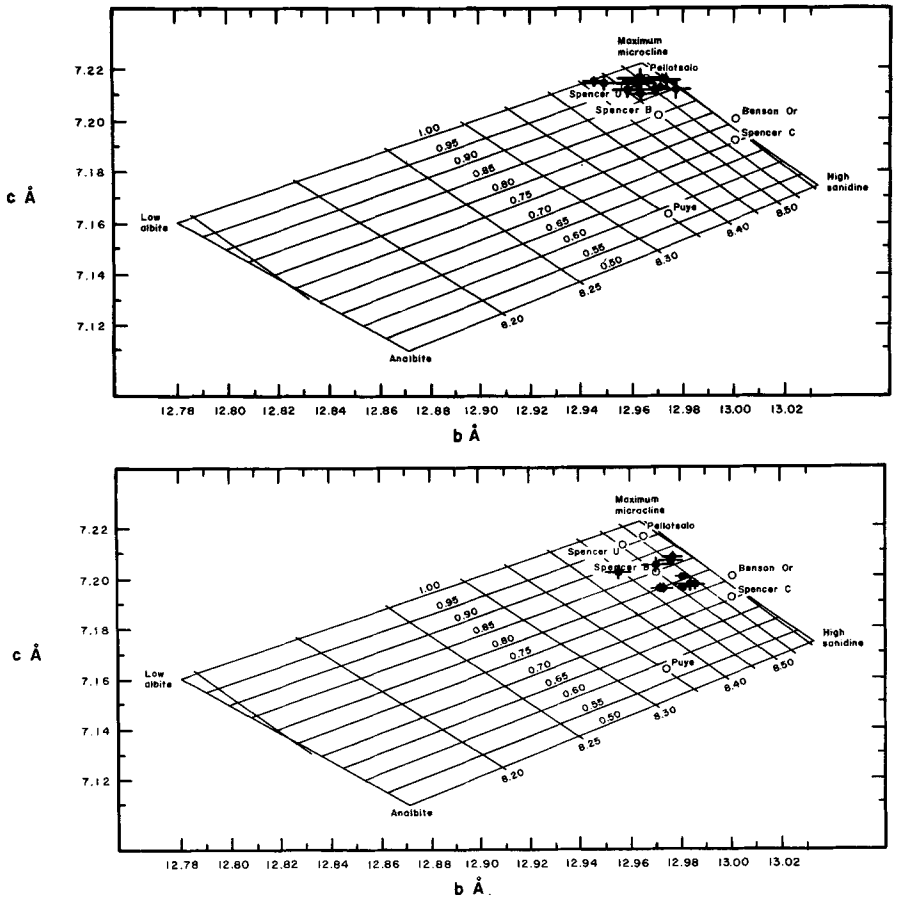

FIG. 2. *b*–*c* cell dimension plots for alkali feldspars from the St. George pluton. The refined *b* and *c* cell dimensions are plotted with error bars of ± 1 standard error as calculated in the refinement programme. Contours parallel to the low-albite–maximum-microcline line give estimated $t_1o + t_1m$; contours parallel to the maximum-microcline–high-sanidine line give estimated *a* cell dimensions. The diagram is from Stewart and Wright (1974). Cell dimensions of the Puye, Spencer, Benson, and Pellatsalo feldspars are from Smith (1974). *a* (*top*): Samples from the western end of the pluton. *b* (*bottom*): Samples from the eastern end of the pluton.

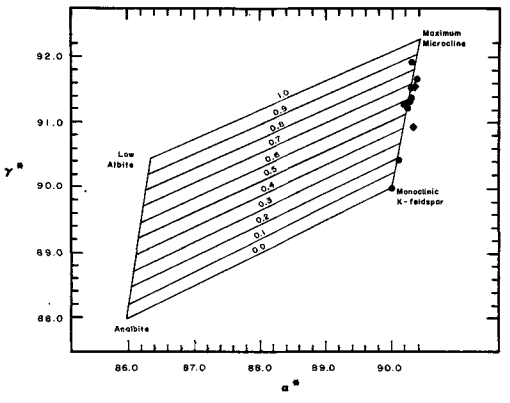

FIG. 3. α^*-γ^* cell dimension plot for triclinic alkali feldspars from the St. George pluton. Contours parallel to the low-albite-maximum-microcline line give estimated $t_1o - t_1m$. The diagram is from Stewart and Wright (1974).

Discussion. The degree of Al/Si order in alkali feldspars is generally considered to be a complex function of the host rock composition, the bulk composition of the feldspar, the presence or absence of volatiles during crystallization and post-crystallization cooling of the feldspar, the composition of the volatile phase, the rate of cooling, and any number of other, unknown parameters. It is probably not possible to separate the effect on the ordering process of any one of these variables. However, it is possible to establish the relative importance of at least some of these controls of ordering for the alkali feldspars in an individual occurrence such as the St. George pluton.

Parsons and Boyd (1971) suggested that increasing fractionation of a magma results in increased degree of ordering in the alkali feldspars, so that microcline predominates over orthoclase with progressive fractionation. The granites in the St. George pluton have compositions approximating petrogeny's residua system and are, therefore, representative of a highly differentiated magma. The normative Ab–Or–Qz contents of the granites from which the alkali feldspars were taken are plotted on the phase equilibrium diagram determined by James and Hamilton (1969) for the system $(Ab–Or–Qz)_{97}An_3$ at 1 kb H_2O pressure in fig. 4*a*. These equilibria are applicable for the discussion because the mean normative anorthite content of the granites is 2·7% and geological evidence indicates that the granites crystallized under low confining pressure (Cherry, 1976). The data indicate that granites representative of highly differentiated magmatic suites do contain either monoclinic or triclinic alkali feldspars.

The normative Ab–Or–An contents of the granites are plotted on the quartz-saturated ternary feldspar liquidus (James and Hamilton, 1969) at 1 kb H_2O pressure in fig. 4*b*. The granites containing monoclinic alkali feldspars plot, with two exceptions, further into the primary crystallization field of potassium feldspar than do those containing triclinic alkali feldspars. Although the effects of decreasing H_2O pressure on the ternary feldspar liquidus have not been examined experimentally, studies in the Ab–Or–H_2O system (Tuttle and Bowen, 1958) showed that the liquidus minimum on the Ab–Or join shifts to higher Or values with decreasing H_2O pressure. If a similar change occurs for the ternary feldspar liquidus, a plot of the normative ternary feldspar contents of the granites at an H_2O pressure less than 1 kb could show the granites containing triclinic alkali feldspars within the plagioclase primary crystallization field and those containing monoclinic alkali feldspars within the orthoclase primary crystallization field. This distribution is also indicated in fig. 4*a*. The distributions of alkali feldspar polymorphs in figs. 4*a* and 4*b* suggest that triclinic alkali feldspars occur in

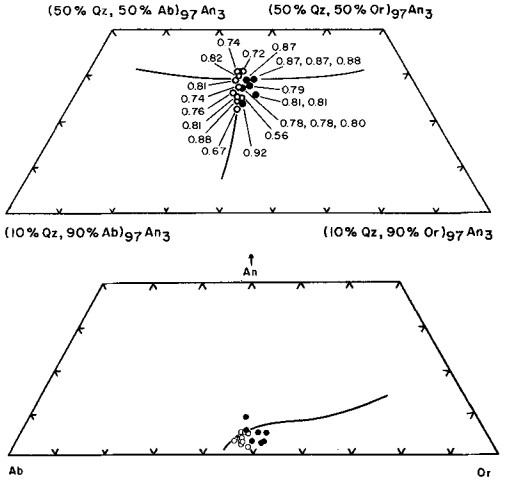

FIG. 4. *a* (*top*). Normative Ab–Or–Qz contents of the granites from which the alkali feldspar samples were taken plotted on the phase equilibrium diagram for the system $(Ab–Or–Qz)_{97}An_3$ at 1 kb H_2O pressure determined by James and Hamilton (1969). *b* (*bottom*). Normative Ab–Or–An contents of the granites from which the alkali feldspar samples were taken plotted on the quartz-saturated ternary feldspar liquidus at 1 kb H_2O pressure determined by James and Hamilton (1969). Filled symbols are samples containing monoclinic alkali feldspars; open symbols are samples containing triclinic alkali feldspars. The numbers in fig. 4*a* give the calculated t_1o for triclinic alkali feldspars and t_1 for monoclinic alkali feldspars.

rocks in which a triclinic phase (plagioclase) is the first to crystallize and that monoclinic alkali feldspars occur in rocks in which a monoclinic phase (alkali feldspar) is the first to crystallize.

The Al occupancy of the T_1 sites in the alkali feldspars is also shown on fig. 4*a*. In general, the Al occupancy of the T_1 sites in each suite increases as the piercing point is approached; i.e. the degree of ordering for samples of the same crystal system increases with increasing differentiation.

The mean bulk grain composition of the alkali feldspars from the eastern end of the pluton is richer in Or than that of the feldspars from the western end of the pluton. There is, however, a considerable overlap in the range of compositions within each of the suites. It is improbable, therefore, that the bulk composition of the feldspar controlled the Al/Si ordering process. The composition of the Or phase of the perthites is the same for all of the samples, indicating that exsolution has continued to the same final temperature at both ends of the pluton.

Parsons and Boyd (1971) suggested that the absence of a volatile phase at the time of initial crystal growth might prevent later development of triclinic alkali feldspars. Volatiles, present during post-crystallization cooling, have been suggested (Emeleus and Smith, 1959; Parsons, 1965; Martin, 1974) to act as a catalyst to the ordering process: their absence prohibits, or at least inhibits, ordering. Martin (1974) presented evidence that the composition of the fluid phase influences the rates of ordering: peralkaline fluids increase ordering rates. The miarolitic cavities, granophyric intergrowths, and pegmatite pods present in the granites of the St. George pluton are textures that are generally assumed to indicate the presence of a fluid. These textures are especially abundant in the granites at the eastern end of the pluton, which contain monoclinic feldspars. Although experimental studies (Steiner *et al.*, 1975) indicate that there are marked differences in late stage fluid compositions, there is no textural or compositional reason to suggest a difference in the fluid phases at the two ends of the pluton. The only retained textural evidence suggests that there was a difference in the amount of fluid in the late stages or that there was a difference in the stage of crystallization at which the fluid became a separate phase. In the suite of samples it appears that the most ordered alkali feldspars occur in the rocks with the least retained evidence of a separate fluid phase.

The granites in the western end of the St. George pluton intrude gabbro and granite of the Bocabec Complex and are in close proximity to the porphyritic granodiorite. The rocks in the Bocabec Complex are undeformed and must have been intruded only shortly before the intrusion of the St. George pluton. The age of the porphyritic granodiorite relative to those of the Bocabec Complex and the St. George pluton is unknown, but both the granodiorite and the pluton are overlain by Lower Carboniferous volcanic rocks. Either or both the Bocabec Complex and the granodiorite might have been sources of heat to prolong the cooling of the granites in the west end of the St. George pluton. The distribution of triclinic and monoclinic alkali feldspars in the granites is probably a reflection primarily of this difference in cooling rates.

Conclusions. The X-ray diffraction study of perthites from the St. George pluton showed that:

The alkali feldspars in the eastern end of the pluton are ordered orthoclases and those in the western end of the pluton are ordered microclines. There is a limited variation in Al/Si order within each of these suites.

Strained structures as measured by Δa occur in feldspars of both suites but are more common in the monoclinic feldspars, in agreement with the observation made by Stewart (1975).

The alkali feldspars in the eastern end of the pluton have bulk grain compositions approximately 5 wt % richer in Or than those in the western end of the pluton.

The composition of the potassic phase of the perthites is the same for both suites of samples, reflecting equilibration to the same sub-solvus temperature.

These data, combined with evidence from field, petrographic and petrochemical studies of the St. George pluton suggest that slower cooling, i.e. increased 'residence time in the temperature range where nucleation of triclinic domains is possible' (D. B. Stewart, pers. comm., 1976) controlled the ordering in the alkali feldspars. It must be stressed that the ordering process is a complex one and must be separately determined for each occurrence of alkali feldspars.

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