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Lattice structural variation in K-feldspar megacrysts of associated charnockite and alkali granite

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ABSTRACT. The perthite megacrysts from charnockitic and non-charnockitic members of a sialic intrusive complex in the Varberg area of south-west Sweden have been investigated by powder X-ray diffraction. The extent of Al/Si order in the K-feldspar host lattices of the megacrysts is restricted in all but the major alkali granite differentiate. A direct relationship between the hydration state of the containing rock and the degree of order of the megacryst lattices is indicated. High lattice strain is common to all the megacrysts but decreases progressively with increasing triclinicity.

ROCKS of charnockitic (orthopyroxene + clinopyroxene; dark coloured feldspar and quartz) and non-charnockitic (biotite + hornblende; light coloured feldspar and quartz) mineralogies are directly associated in a sialic intrusive complex which cuts high-grade gneisses near Varberg in south-west Sweden (fig. 1). The field relationships (Hubbard, 1975, 1978) and geochemistry (Hubbard and Whitley, 1978, 1979; Constable and Hubbard, 1981) of the Varberg Charnockite-Granite Association indicate that the components are consanguineous. The observed progressive change from charnockite to non-charnockite is essentially parallel with the compositional differentiation from adamellite (SiO_2 56%, CaO 5%, Na_2O 4%, K_2O 4%) to alkali granite (SiO_2 74%, CaO 1%, Na_2O 3%, K_2O 5%).

Late-crystallizing perthite megacrysts are common to all units of the association but show a striking change from dark-green or black orthoclase in the charnockitic rocks to pink microcline in the alkali granite. In transitional rocks the megacrysts are brown, commonly with a pink mantling zone. A sensitive control of post-crystallization transformation within the feldspar megacrysts by local variations in environment is suggested. The mafic mineral assemblages of the containing rocks indicate differences in water availability at crystallization.

The detail of the variation in the structural state of the alkali feldspar host phases of the perthite megacrysts of the association units has been examined using refined unit cell parameters obtained from X-ray powder diffraction data following the techniques developed and refined by Wright (1968), Wright and Stewart (1968), Stewart and Ribbe (1969), and Stewart and Wright (1974).

The samples. Samples from each of the five main units of the Charnockite-Granite Association were used in the investigation. Sample 1 is from the Varberg Charnockite; the most basic and least prophyritic member. Samples 2a and 2b are from the charnockitic matrix phase of the Apelviken-Getterön Charnockite compound unit. This unit

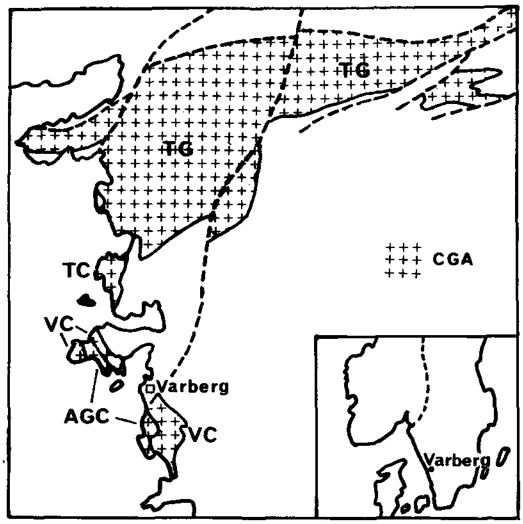

FIG. 1. Location map of the Varberg Charnockite-Granite Association showing distribution of the component units. VC = Varberg Charnockite; AGC = Apelviken-Getterön Charnockite; TC = Trönningenäs; TG = Torpa Granite.

contains sub-charnockitic coarse schlieren (Sample 2c) and discrete, internally differentiated, segregations which range from subordinate charnockitic adamellite (Sample 3a) through a sub-charnockitic transitional phase (Sample 3b) to non-charnockitic alkali granite (Sample 3c). The northern (upper) segment of the complex comprises a large-scale equivalent of the segregations of the Apelviken-Getterön Charnockite with a charnockitic phase, the Trönningenäs Charnockite (Samples 4a and 4b) passing gradationally (Sample 4c) to the Torpa Granite (Sample 5).

Methods. Cleavage flakes were split from four feldspar megacrysts from each of the 11 hand specimens obtained from fresh-blasted outcrops. The dark cores and pink mantles of the megacrysts of the transitional rock and granite of the Apelviken-Getterön Charnockite segregation proved to be separable and were treated individually as Samples 3b(c), 3b(m), 3c(c) and 3c(m) respectively. After removal of any inclusions and adhering matrix the mineral samples were reduced to fine powder.

Diffraction patterns were obtained from smear mounts using Cu-K_α radiation ($\lambda = 1.5417$ Å, 40 kV, 30 mA) and a graphite monochromator. Potassium bromate was used as internal standard. Three runs were made from 60–10° 2θ at 0.5° 2θ per minute for each sample.

The diffraction patterns were indexed using data in Wright (1968) and Borg and Smith (1969). Mean 2θ values for the indexed peaks were then used in a cell refinement programme (Appleman *et al.*, 1972) to obtain the unit cell parameters. Monoclinic/triclinic symmetry restrictions were made on the basis of peak split indications.

Results. The unit cell dimensions of the K-feldspar host phases of the perthite megacrysts listed in Table I confirm the change from monoclinic to triclinic structures on passage from the charnockitic to the non-charnockitic rocks of the complex. The Δ130 triclinicity index values (Smith, 1974) show more clearly the progressive nature of this structural change (Table II).

Following Stewart and Wright (1974), the unit cell dimensions are plotted on $b-c$ and $\alpha^*-\gamma^*$ plots in figs. 2 and 3 respectively to illustrate the variations in structural state. The progressive nature of the structural change from charnockitic to non-charnockitic K-feldspar is shown by both plots. The charnockitic feldspars fall in the $0.70 < t_1o + t_1m \leqslant 0.80$ range and the granite feldspars in the $0.80 < t_1o + t_1m < 0.92$ range (Table II). The dark and light zones of the Apelviken-Getterön Charnockite segregation compound megacrysts are discriminated. The segregation granite K-feldspars have not achieved the high order shown for those of the Torpa Granite.

The estimated a values from the b-c plot (a_{est}) differ markedly from those determined by unit cell refinement (a_{obs}). $\Delta a = a_{obs} - a_{est}$ may be used as an index of strain in the lattice (Stewart and Wright, 1974). All the K-feldspar phases of the perthite megacrysts show significant strain which decreases with increase in triclinicity.

The Al distribution in the t_1 sites derived from figs. 2 and 3 allows calculation of the ratio of distribution [Si = Al/(Al + Si)] and hence the percentage degree of order using the formula of Mackenzie and Smith (1961):

$$\text{percentage degree of order} = \sum_{i=1}^{i=4} \frac{|0.25 - \text{Si}|}{1.5} \times 100.$$

The results (Table II) show this to be a more sensitive discriminant in the study of a feldspar sequence than the triclinicity index.

TABLE I. *Refined cell dimensions*

	a (Å)	b (Å)	c (Å)	α	β	γ	Cell Vol. (Å^3)
1	8.567	12.934	7.174	90	116° 3.7′	90	714.073
2a	8.560	12.935	7.176	90	116° 0.8′	90	714.008
2b	8.577	12.934	7.182	90	116° 9.5′	90	715.151
2c	8.570	12.948	7.182	90	116° 6.0′	90	715.645
3a	8.577	12.951	7.178	90° 4.9′	116° 1.6′	89° 39.8′	716.416
3b(m)	8.578	12.945	7.186	90° 6.4′	116° 3.4′	89° 41.7′	716.824
3b(c)	8.564	12.940	7.179	90° 3.1′	115° 56.6′	89° 42.3′	715.362
3c(m)	8.597	12.954	7.194	90° 11.7′	116° 10.2′	89° 12.1′	718.979
3c(c)	8.589	12.952	7.189	90° 13.9′	116° 9.0′	89° 12.1′	717.822
4a	8.567	12.922	7.174	90°	116° 4.7′	90°	713.321
4b	8.596	12.962	7.179	90° 8.0′	116° 11.6′	89° 37.9′	717.705
4c	8.556	12.938	7.200	90° 39.6′	116° 7.2′	87° 49.2′	715.123
5	8.581	12.940	7.200	90° 42.0′	116° 8.6′	87° 50.2′	717.205

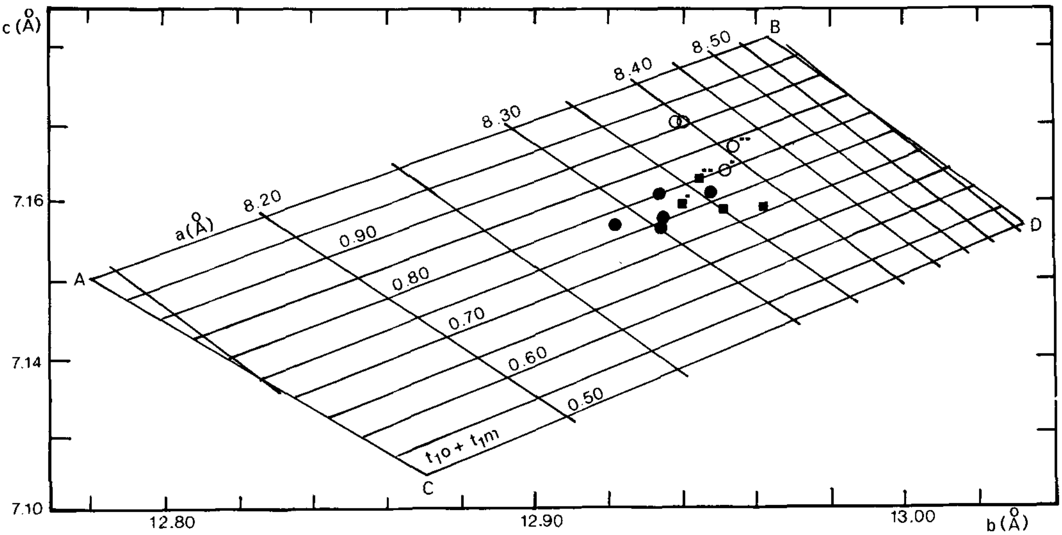

FIG. 2. $b-c$ cell dimension plot for the K-feldspar of the CGA megacrysts, cross-contoured for a and t_1o+t_1m. The diagram is from Stewart and Wright (1974). Solid circles = charnockites; open circles = non-charnockitic granites; solid square = transitional rocks. The core and mantle feldspar samples from the AGC magma segregation are denoted by one and two superscript dots respectively. A–B: low albite–maximum microcline; C–D: high albite–sanidine.

Stewart and Wright (1974) related Al/Si order with equilibriation temperature and provided a plot of $(t_1o+t_1m)v.\ T\,°C$. The equilibriation temperatures indicated for the Charnockite-Granite Association perthite megacryst host phases derived from this plot, given in Table II, require an initial crystallization temperature in excess of 700 °C.

In view of the strained lattices involved, the compositional Or contents of the host K-feldspars (Table II) were calculated from the cell volumes (Stewart and Wright, 1974). There is a weak correlation of increase of Or with increase in host rock acidity and feldspar triclinicity.

Discussion. The petrography and field relationships of the Charnockite-Granite Association rocks show that the perthite megacrysts are relatively late crystallizations of the intrusion-differentiation cycle. The K-feldspar host-phase compositions show a limited but rational range of Or % which parallels the compositional differentiation of the host rocks. Local variations in the levels of hydration established during the rise and

TABLE II. *Structural and derived data*

	Δ130	t_1o+t_1m	t_1o	Degree of order (%)	Δa	Equ. T (°C)	Or (%)
1	0	0.74	0.37	32	0.27	675	76.7
2a	0	0.76	0.38	35	0.24	660	76.6
2b	0	0.80	0.40	40	0.25	630	79.2
2c	0	0.76	0.38	35	0.21	660	80.4
3a	0.15	0.73	0.45	31	0.23	685	82.3
3b(c)	0.13	0.77	0.46	37	0.23	650	79.7
3b(m)	0.13	0.80	0.48	40	0.22	630	83.3
3c(c)	0.34	0.80	0.57	43	0.20	630	85.8
3c(m)	0.35	0.83	0.58	45	0.19	600	88.8
4a	0	0.78	0.39	37	0.28	640	75.0
4b	0.15	0.71	0.44	29	0.22	710	85.5
4c	0.92	0.92	0.92	89	0.17	510	79.2
5	0.90	0.91	0.92	89	0.18	520	84.2

emplacement of the anatectic crustal sialic magma were sustained during the slow post-emplacement cooling. For example, the micaceous, relatively water-rich granite of the Apelviken–Getteron Charnockite segregation is in knife-sharp contact with anhydrous, pyroxene-bearing charnockite (Specimens 3c and 2c were collected from either side of the contact). The maintainance of such hydration disequilibrium suggests that the complex was unaffected by penetrative deformation which would be expected to suppress or eliminate sharp interfaces of this type. Without the influence of penetrative tectonism, post-crystallization transformations are likely to be relatively restricted and more subject to control by variations in local conditions.

The extent of ordering achieved by the K-feldspar is, indeed, restricted in all but the most differentiated and hydrous units. In the true charnockites, monoclinic symmetries are retained and, even in the granite of the Apelviken–Getterön Charnockite segregation, triclinicity is limited. Only in the transitional and granitic rocks of the large Trönningenäs Charnockite–Torpa Granite sequence is maximum microcline structure closely approached.

The controls of feldspar ordering are complex and a number of influences may be involved to varying extents. In the case of the Charnockite-Granite Association rocks the degree of ordering apparently varies in parallel with the extent of hydration indicated for the containing rock, i.e. disordered in the 'dry' charnockites with order increasing to a maximum in the micaceous Torpa Granite. Rock bulk composition may also have had some influence on the degree of ordering but the striking difference between the K-feldspar of the granite of the Apelviken–Getterön Charnockite unit segregation and the compositionally similar Torpa Granite (45 versus 89% ordered) suggests a low significance. The differences in ordering between the external and internal parts of the compound megacrysts of the transitional rocks highlight both the control of an influence outwith the megacrysts and the relative difficulty and sluggishness of the ordering mechanism.

The high degree of strain throughout the megacryst suite is striking. The level of lattice strain decreases significantly with increasing order ($r = -0.80$) but it is not a simple linear relationship. There is a parallel progressive increase in the coarseness of the perthite fabric which may have significance in this context.

The progressive nature of the post-crystallization transformation in the K-feldspar megacrysts is particularly well displayed in the examined segregation from the Apelviken–Getterön Charnockite compound unit [samples 3a to 3c(m)]. There are many such segregations of identical pattern but varying size. The more complete and apparently more abrupt approach to maximum microcline indicated for the Trönningenäs Charnockite–Torpa Granite sequence is believed to be a consequence of the vastly greater size of this segregation and the relative sparseness of the sampling.

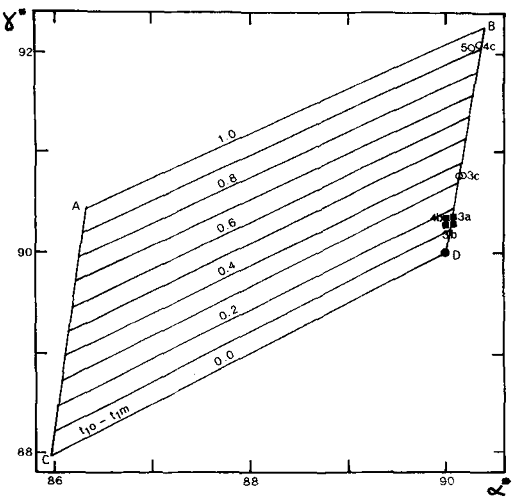

FIG. 3. $\alpha^* - \gamma^*$ cell dimension plot for the K-feldspar of the CGA megacrysts, cross-contoured for $t_1o - t_1m$. Symbols as in fig. 2. Monoclinic feldspars plot together at $\alpha^* = \gamma^* = 90°$.

Conclusions. The pattern of lattice structural change in the K-feldspar of the perthite megacrysts of the Varberg Charnockite–Granite Association supports the view that the charnockitic and non-charnockitic components of the association are consanguineous.

Post-crystallization ordering during slow cooling from high temperatures (> 700 °C) was restricted, constrained by local variations in the subsystems of the intrusive complex. The associated host-rock mineralogies suggest that the major controlling influence was the level of hydration of the containing rock. Inhomogeneities in water distribution which developed in the intrusion–differentiation cycle were essentially maintained during the period of slow cooling and affected the efficiency of the feldspar lattice ordering mechanism.

The close maintenance of hydration disequilibrium, the restriction of feldspar inversion and the retention of high lattice strain were all favoured by the absence of penetrative deformation.

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