# The alkali feldspars from microsyenitic dykes of southern Greenland

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*Summary.* 26 *b*-axis oscillation photographs of alkali feldspars of microsyenitic dykes of Southern Greenland are presented. The crystals are rather restricted in composition ($Or_{42.4}$ to $Or_{35.3}$) but are rather rich in Ca (up to 14 % An). The range of variation of the optic axial angles, 2 V 45° to 71° (exceptions up to 87°), puts the crystals between sanidine–anorthoclase cryptoperthite and orthoclase microperthite, as classified by Tuttle (1952).

Since the syenitic magma cooled down rather rapidly some peculiarities in the structural state of the alkali feldspars are to be expected. The potassium-rich phase is (nearly) monoclinic. According to the values of the reciprocal lattice angles $\alpha^*$ and $\gamma^*$ the sodium-rich phases can be divided into three groups: high-temperature pericline-twinned and high-temperature albite-twinned phases, high-temperature pericline-twinned and low-temperature albite-twinned phases, and high-temperature pericline-twinned and low-temperature albite-twinned phases with nearly identical values of the reciprocal lattice angle $\gamma^*$.

IN 1938 Wegmann established the structural division of the Precambrian of southern Greenland by introducing the concepts of Ketilidian and Gardar periods. The Ketilidian period (now enlarged into Ketilidian and Sanerutian by recent investigators of the Geological Survey of Greenland, Copenhagen, referred to as GGU in the following) embraces the gneissic and granitic basement. The younger Gardar period starts with the deposition of the Igaliko sandstone on the eroded Ketilidian basement, and shows an extensive magmatic activity in the form of lava flows, intrusive complexes, and a tremendous dyking in some places.

As a member of GGU the author mapped the area N. and NE. of the Ílimaussaq intrusion and NW. of the Igaliko intrusive centres (Scharbert, 1958, 1959, 1962, 1963). The large number of dykes was soon recognized, but their age relationship to the main intrusions was not elucidated. Ussing (1912) had proposed various ages for these dykes, as also did Upton (1962, 1964) and Emeléus (personal communication, 1965).

Especially in the northern part of the Ílimaussaq peninsula a large number of *microsyenitic dykes* occur. These are similar to those described recently by Bondam (1955) from the neighbourhood of Narssaq and Narssarssuaq Air Base and by Upton (1962, 1964) from Tugtutôq. The microsyenitic dykes of the author's area are the scope of a special paper. The subject of these lines is to draw attention to the properties of the *alkali feldspars* forming the main constituents of those dykes, which were placed into Mid-Gardar by Upton (1962). They can be traced over many kilometres. Some develop porphyritic textures, others not. Both varieties sometimes exhibit well-developed flow-textures; other samples have more random textures regardless of whether they are porphyritic or not. The mineralogical composition is very simple: alkali feldspars (usually over 60 %) accompanied by alkali augites or hornblendes or both, olivines, ores. Neither quartz nor nepheline is present in appreciable amount.

In a series of papers on alkali feldspars MacKenzie and Smith (1955, 1956) and Smith and MacKenzie (1955, 1958, 1959) found by measurements of $\alpha^*$ and $\gamma^*$ from single-crystal oscillation photographs that the majority of sanidine–anorthoclase cryptoperthites have sodium-rich phases with reciprocal lattice angles corresponding to high-temperature alkali feldspars (anorthoclase), whereas the orthoclase microperthites and microcline (micro-) perthites almost always show sodium-rich phases with reciprocal lattice angles corresponding to low-temperature albite or oligoclase. They had adopted the classification of alkali feldspars as given by Tuttle (1952). More recently MacKenzie and Smith (1962) published a rather large number of measurements on alkali feldspars from different geological environments and were able to establish a 'cooling sequence' (*op. cit.*, p. 98):

| K-phase | monoclinic | Na-phase anorthoclase |
|---------|------------|------------------------|
| K-phase | monoclinic | Na-phase anorthoclase+plagioclase |
| K-phase | monoclinic | Na-phase two plagioclases |
| K-phase | monoclinic | Na-phase one plagioclase |
| K-phase | monoclinic + triclinic | Na-phase one plagioclase. |

The present investigation was made using single-crystal oscillation photographs (Smith and MacKenzie, 1955), mostly of phenocrysts of the microsyenitic dykes. The attempt to measure crystals from non-porphyritic types as well as from the groundmass led to unreliable results because of the very small size of the individual crystals and they were

therefore omitted with the exception of two samples. Additionally we were supplied by Emeléus with seven specimens from similar dykes collected from the Igaliko intrusives. The results from five are included here, although the chemical compositions are not yet known. The classification of the alkali feldspars as given by Tuttle (1952) is again adopted here.

TABLE I. All samples without BU or BO were analysed by E. Evans by flame-photometry. BU stands for samples cited in Upton (1964), BO for Bondam (1955). P indicates phenocrysts, NP non-porphyritic types, whereas M indicates matrix feldspars of porphyritic rock types. The specimen numbers are those of the GGU collection, Copenhagen. Compositions in weight per cent.

| Specimen No. | Or | Ab | An | 2 V |
|---|---|---|---|---|
| GGU    7951–P–BO | 50·0 | 40·0 | 10·0 | n.d. |
| GGU  49415–NP | 42·4 | 49·4 | 8·2 | 49–69° |
| GGU  40489–P–BU | 42·0 | 52·0 | 6·0 | n.d. |
| GGU  49483–P | 41·9 | 46·6 | 11·5 | 49–60° |
| GGU  47608–P | 41·7 | 51·2 | 7·1 | 45–64° |
| GGU  30713–P–BU | 41·0 | 54·0 | 5·0 | 74–87° |
| GGU  47760–P | 40·9 | 50·4 | 8·7 | 48–66° |
| GGU  30713–M–BU | 40·5 | 55·5 | 4·0 | n.d. |
| GGU  49554–NP | 40·0 | 53·5 | 6·5 | 52–68° |
| GGU  50226–P–BU | 39·5 | 53·5 | 7·0 | n.d. |
| GGU  40489–M–BU | 38·5 | 57·5 | 4·0 | n.d. |
| GGU  50226–M–BU | 38·5 | 58·0 | 3·5 | n.d. |
| GGU  49464–P | 38·3 | 51·1 | 10·6 | 46–69° |
| GGU  49404–P | 38·0 | 51·8 | 10·2 | 55–71° |
| GGU    7909–P–BO | 37·0 | 54·0 | 9·0 | 9° |
| GGU  49637–P | 36·0 | 57·0 | 7·0 | 47–71° |
| GGU  49463–P | 35·8 | 54·3 | 9·9 | 51–65° |
| GGU  30645–P–BU | 35·5 | 62·0 | 2·5 | 53–74° |
| GGU  47723–P | 35·3 | 50·7 | 14·0 | 45–64° |
| 2 V measurements of Bondam (1955) | — | — | — | 48–72° |

### Chemical and optical properties

As seen from table I, the chemical compositions of eight phenocrysts and two samples from non-porphyritic rocks range from $Or_{42.4}$ to $Or_{35.3}$ (weight-percentages; recalculated to 100). The An-content of some of the samples is remarkably high (up to $An_{14}$). For comparison some results of Upton (1964) and Bondam (1955) are mentioned in table I. Upton published the compositions of both phenocrysts and groundmass feldspars and found a slight increase in the Ab-content of the latter. Bondam mentions two samples whose compositions are: $Or_{37}Ab_{54}An_9$ and $Or_{30}Ab_{40}An_{10}$, respectively. Therefore we can classify these feldspars

mostly as *lime-bearing sodium-rich sanidines*. They all plot closely to the sanidine–anorthoclase dividing line as indicated by Smith and Mac-Kenzie (1958, p. 874).

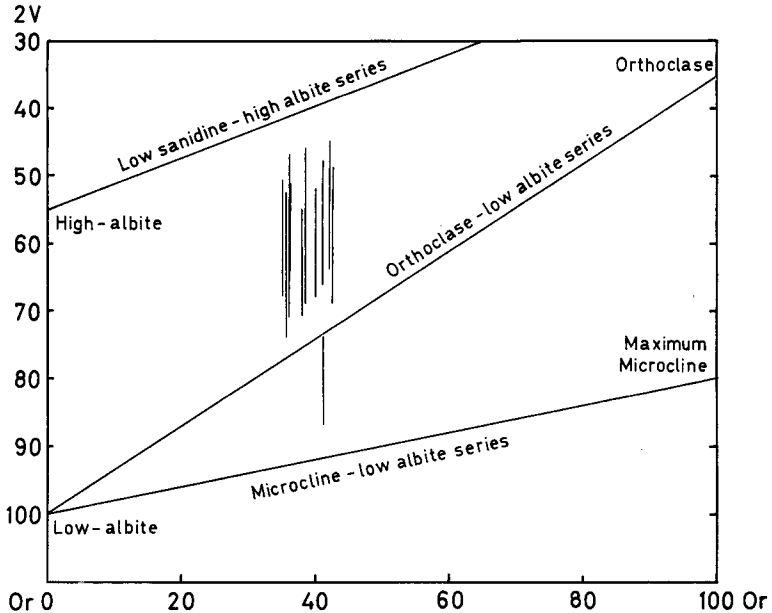

FIG. 1. Relations between optic axial angles 2 V and the bulk composition of alkali feldspars from microsyenitic dykes of southern Greenland, after Tuttle (1952) as modified by Smith and MacKenzie (1959, p. 1172). Note the rather large range of variation of the 2 V values with respect to the more uniform compositions of the samples.

The optic angles of our samples range from 45° to 71° and fall between the curves for sanidine–anorthoclase cryptoperthite and orthoclase microperthite in the slightly modified graph of Tuttle (1952) (fig. 1). Upton (1964) indicates much higher angles for one specimen of similar composition; he found the highest optic angles (2 V 87°) in areas of good exsolution; this sample falls between orthoclase microperthite and microcline perthite in spite of its apparently identical geological environment. Bondam's (1955) sample GGU 7909–P–BO has an optic angle of only 9° (optic plane normal to 010). This plot would lie on the curve for high-sanidine. On the other hand, the same author mentions 2 V between 48° and 72°, which would coincide with the measurements of fig. 1.

The values for 2 V in individual samples have a rather large scatter if one considers different crystals in the same specimen as well as different parts of individual crystals. For such observed scatters in the sanidine–anorthoclase cryptoperthites, Tuttle (1952) takes into account the variable An-content, increasing An-content accompanying increasing 2 V. If, as in our cases, the plots for the optic angles fall intermediate between sanidine–anorthoclase cryptoperthite and orthoclase micro-perthite, Tuttle and Keith (1954) considered the influence of the sodium-rich phase being partly inverted into the low-temperature modification. On the other hand, MacKenzie and Smith (1955) suggested that the 2 V of a low-temperature perthite is also affected by the nature of the potas-sium-rich phase, thus the presence of a triclinic potassium-rich phase leads to higher optic angles. Since all our samples have (Ab+An) greater than Or, we are inclined to think the nature of the sodium-rich phase to be the controlling factor for the optic angles, rather than the nature of the potassium-rich phase, since this is for all practical pur-poses monoclinic. The high values of 2 V given by Upton (1964) from well-exsolved areas in alkali feldspars may be due to rather highly tri-clinic states of the potassium-rich phase.

## The degree of unmixing

Under the microscope the crystals show different degrees of visible perthitic exsolution. Especially along cleavages and cracks rather well-developed microperthitic exsolution could be detected. This is an indi-cation that the degree of unmixing is not equally distributed throughout the crystals and this may be related to the transition from sanidine–anorthoclase cryptoperthite to orthoclase microperthite.

The X-ray powder diffraction patterns show unmixing in all specimens. In the first column of table II the compositions of the separate phases are compiled, deduced from the $\bar{2}01$ determinative curve as given by Orville (1958), modified from Bowen and Tuttle (1950). It is known from the work of Laves (1952), Coombs (1954), and others that the compositions of the separate phases of perthites determined from the positions of the $\bar{2}01$ spacings sometimes give impossible values and Smith (1961) has ex-plained this anomaly as due to strain in the lattices of the two intimately intergrown phases. Not too improbable values have been obtained for the compositions of the separate phases in the present study (the Ab-content is sometimes improbable), but it is not intended to convey the impression that these values represent the true compositions of the un-mixed phases, since it has been shown (Smith and MacKenzie, 1958) that

very different values for the compositions of the separate phases are ob-
tained using two different methods, viz. the $\bar{2}01$ method and the method
of measuring the $\alpha^*$ and $\gamma^*$ values of triclinic sodium-rich phases. It is
even doubtful whether the values obtained by the $\bar{2}01$ method give an

TABLE II. Symbols as indicated in table I; EM, specimens provided by Emeléus.
Col. A, composition of the unmixed phases, as deduced from the $\bar{2}01$ method. Col. B,
bulk composition (% Or) deduced from the third reflection ($\bar{2}01$ method). Col. C,
bulk composition (% Or) found by chemical analysis

| Specimen No. | A Or | A Ab | B | C |
|---|---|---|---|---|
| GGU 47760–P | 99·5 | 99 | 42 | 40·9 |
| GGU 49483–P | 96 | 100 | 43 | 41·9 |
| GGU 49464–P | 95 | 104 | 35·5 | 38·3 |
| GGU 47608–P | 97·5 | 103·5 | 35·5 | 41·7 |
| GGU 47723–P | 94 | 100 | 18·5 | 35·3 |
| GGU 49404–P | 93 | 102 | 34 | 38 |
| GGU 49463–P | 93 | 100 | 24·5 | 35·8 |
| GGU 58329–P–EM | 88 | 105 | 44 | n.d. |
| GGU 58330–P–EM | 81 | 86 | — | n.d. |
| GGU 49415–NP | 98·5 | 102 | — | 40 |
| GGU 49554–NP | 98·5 | 104 | — | 42·4 |

indication of the relative degree of unmixing in different specimens
since the strain existing in individual specimens may differ. The com-
positions given in table II are thus only for comparison with those ob-
tained in other studies.

   In the powder diffraction patterns of almost all the phenocrysts a third
$\bar{2}01$ reflection has been observed between the two above mentioned re-
flections thus giving an intermediate composition. Only sample GGU
58330–P–EM, which may be less completely unmixed than the others,
shows no indication of a third $\bar{2}01$ reflection. Three samples show a
reasonable agreement between the composition as determined from this
third reflection and that obtained from chemical analysis. In their
paper on high-temperature feldspars, MacKenzie and Smith (1956,
p. 410) indicate that a third $\bar{2}01$ reflection from an anorthoclase from
Grande Caldeira, Azores, gives a composition from the $\bar{2}01$ determinative
curve that corresponds fairly well with the composition as determined by
chemical analysis. It is suggested that in cases of good coincidence this
third reflection may represent a relict part of a homogeneous feldspar.
In cases of disagreement there may be still faint homogeneous relics,
which, however, are strongly influenced by strain.

## The separate phases

The reflections of the *potassium-rich phases* reveal a monoclinic symmetry in many cases. In other cases elongation of the reflections with strong centres indicate deviations from purely monoclinic geometry. In still other cases elliptic reflections of rather high and equally distributed intensity occur. These elongations are usually parallel to the row-lines of the photographs, thus giving reason for accepting the presence of some albite-twinned triclinic material. No $\alpha^*$ or $\gamma^*$ for any triclinic potassium-rich phase could be measured with accuracy and reliability. Where one sodium-rich phase is represented by strong reflections of pericline-twinning some merging between these and the potassium-rich phase reflections occurs. Also streaks along the layer-lines of the photographs may give the impression of some intermediate geometry. No diagonal association has been observed (Smith and MacKenzie, 1959).

Only in one specimen (GGU 49464–P1) were we able to detect an albite-twinned and therefore triclinic potassium-rich phase. The values for $\alpha^*$ (88° 46′) and for $\gamma^*$ (89° 24′) fall close to those characteristic of an anorthoclase (the square in fig. 2). The oscillation photograph resembles closely that given by MacKenzie and Smith (1956, p. 423) and Smith and MacKenzie (1958, p. 886) for an anorthoclase from Victoria, Australia. There are four reflections lying at the corners of a trapezium, the corners of which are linked by diffuse streaks. The composition of the Australian sample is $Or_{23.3}Ab_{75.5}An_{1.2}$, whereas ours is $Or_{38.3}Ab_{51.1}An_{10.6}$. Therefore, as pointed out by the cited authors, the Australian anorthoclase lies very close to the intersection of the solvus as determined by Smith and MacKenzie (1958, fig. 4) and the monoclinic–triclinic inversion curve; unmixing began just after the inversion to triclinic symmetry of the dominating sodium-rich phase. If we adopted a similar explanation for the present case, we should have to take into account the composition near the crest of all three possible solvi (Smith and MacKenzie, 1958, fig. 4). According to the shape of the solvi different temperature ranges (40 to 150°) must be passed during the process of unmixing in the monoclinic state, before the composition of the sodium-rich phase reaches the monoclinic–triclinic inversion curve. This means that unmixing proceeded in the microcline range, in contradiction to the Australian sample. We may be faced with the presence of two anorthoclase phases of different composition, but albite-twinned.

The *sodium-rich material* may be present either in one, or more commonly in two or even in three phases. If the Greenland alkali feldspars contain only one sodium-rich phase it may have reciprocal lattice

angles corresponding to high-temperature anorthoclase or to low-temperature albite-oligoclase (pericline-twinning in the former instances, albite-twinning in the latter). If, however, two sodium-rich phases appear they may fall both on the high-temperature line (pericline- and albite-twinned) or on this line (pericline-twinned) and on the low-temperature plagioclase line (always albite-twinned). On many photographs the sodium-rich-phase reflections have streaks and mergings between the spots indicating transitional states. Frequently monoclinic spots are preserved, as well as asymmetrical alignments of spots. Phenomenologically and according to the plots of the reciprocal lattice angles $\alpha^*$ and $\gamma^*$ we can divide the sodium-rich phases into three groups (table III). $\gamma^*$ never exceeds $90°$ on the low-temperature plagioclase line. It has been found that different crystals from the same specimen may differ appreciably from each other, even belonging to different groups.

The *first group* embraces reciprocal lattice angles corresponding to high-temperature alkali feldspars exclusively (fig. 2). The compositions of these phases (after the graph given by Smith and MacKenzie, 1958, p. 876) range from $Or_{32}Ab_{68}$ to $Or_{14}Ab_{86}$. Only two out of ten plots, however, are more sodic than $Or_{20}Ab_{80}$. The compositions of these phases as determined from the $\alpha^*$ and $\gamma^*$ values are very different from those obtained using the position of the $\bar{2}01$ spacing (cf. table II) and we are unable to state which represents more closely the true composition. This difficulty has been encountered by Smith and MacKenzie (1958), who were in favour of using the values of $\alpha^*$ and $\gamma^*$ as an indication of the composition of the sodium-rich phase and we have accepted the same procedure here. It seems to be a rule that the albite-twinned phases show slightly higher concentrations of sodium than the corresponding pericline-twinned sodium-rich phases. If the plots for both twin-laws belonging to one exsolved sodium-rich phase are situated on the high-temperature anorthoclase line, their reciprocal angles $\alpha^*$ and $\gamma^*$ might be expected to be identical (within the limits of error) or only slightly different. This is valid for the samples GGU 47723–P2, GGU 49464–P2, and GGU 49554–NP. The sample GGU 58357–P–EM2, given to us by Emeléus, has rather differing values for the two twinned phases, but again, the pericline-twinned sodium-rich phase contains less Na than the albite-twinned phase.

In the *second group* are those sodium-rich phases (fig. 3) that have a distinct difference in the thermal state of their twinned phases, i.e. a high-temperature alkali feldspar phase (pericline-twinned anorthoclase), with a more restricted range of composition than in the first group

TABLE III

| Specimen no. | Potassium-rich phase | Pericline-twinned α* | Pericline-twinned γ* | Albite-twinned α* | Albite-twinned γ* |
|---|---|---|---|---|---|
| | | Sodium-rich phase | | | |

| Specimen no. | Potassium-rich phase | $\alpha*$ | $\gamma*$ | $\alpha*$ | $\gamma*$ |
|---|---|---|---|---|---|
| *Group 1* | | | | | |
| GGU 47723–P2 | slightly elongated monoclinic spot (row-line) | 87° 42′ | 88° 45′ | 87° 26′ | 88° 45′ |
| GGU 49404–P1 | monoclinic | 87° 43′ | 88° 35′ | absent | |
| GGU 49404–P2 | monoclinic | 88° 00′ | 88° 50′ | absent | |
| GGU 49464–P1 | albite-twinned ? 88° 46′  89° 24′ | absent | | 88° 9′ | 89° 12′ |
| GGU 49464–P2 | no indication of potassium-rich phase | 87° 12′ | 88° 44′ | 86° 57′ | 88° 34′ |
| GGU 49554–NP | monoclinic | 87° 32′ | 88° 45′ | 87° 19′ | 88° 51′ |
| GGU 58357–P–EM2 | weakly monoclinic | 88° 53′ | 89° 32′ | 87° 51′ | 89° 1′ |
| *Group 2* | | | | | |
| GGU 47608–P1 | diffuse monoclinic | uncertain | | 86° 19′ | 88° 51′ |
| GGU 47723–P3 | elongated streaking parallel row-lines | 87° 42′ | 88° 58′ | 86° 20′ | 89° 27′ |
| GGU 49463–P | monoclinic | absent | | 86° 14′ | 89° 1′ |
| GGU 49483–P2 | elongated parallel row-line | 87° 29′ | 88° 51′ | 86° 10′ | 89° 47′ |
| GGU 49637–P2 | fat elongation parallel row-line | absent | | 86° 26′ | 89° 21′ |
| GGU 58326–P–EM1 | elongated parallel row-line | 87° 35′ | 88° 42′ | 86° 20′ | 89° 39′ |
| GGU 58326–P–EM2 | elliptic in row-line | uncertain | | 86° 18′ | 89° 3′ |
| GGU 58329–P–EM | fat elongation parallel row-line | uncertain | | 86° 29′ | 89° 48′ |
| GGU 58357–P–EM1 | diffuse monoclinic | 87° 10′ | 88° 36′ | 86° 21′ | 88° 56′ |
| GGU 63765–P–EM | strongly diffuse elongated parallel row-line | 87° 57′ | 89° 2′ | 86° 20′ | 89° 21′ |
| *Group 3* | | | | | |
| GGU 47608–P2 | diffuse, row- and layer-lines | 89° 25′ | 89° 40′ | 86° 11′ | 89° 23′ |
| GGU 47723–P1 | streaking parallel row-line | 88° 49′ | 89° 19′ | 86° 15′ | 89° 11′ |
| GGU 47760–P1 | elongated parallel row-line | 88° 51′ | 89° 31′ | 86° 24′ | 89° 28′ |
| GGU 47760–P2 | streaking parallel row-line | 89° 3′ | 89° 34′ | 86° 5′ | 89° 34′ |
| GGU 49415–NP1 | diffuse monoclinic | 88° 00′ | 88° 59′ | 86° 31′ | 89° 7′ |
| GGU 49415–NP2 | slight streaking along row-line | 88° 22′ | 89° 17′ | 86° 17′ | 88° 55′ |
| GGU 49483–P1 | elongated parallel row-line | 88° 55′ | 89° 27′ | 86° 19′ | 89° 10′ |
| GGU 49637–P1 | elliptic spot in row-line | 88° 11′ | 89° 43′ | 86° 19′ | 89° 10′ |
| GGU 58330–P–EM | thick elliptic spot in row-line | 88° 13′ | 89° 23′ | 86° 17′ | 89° 14′ |
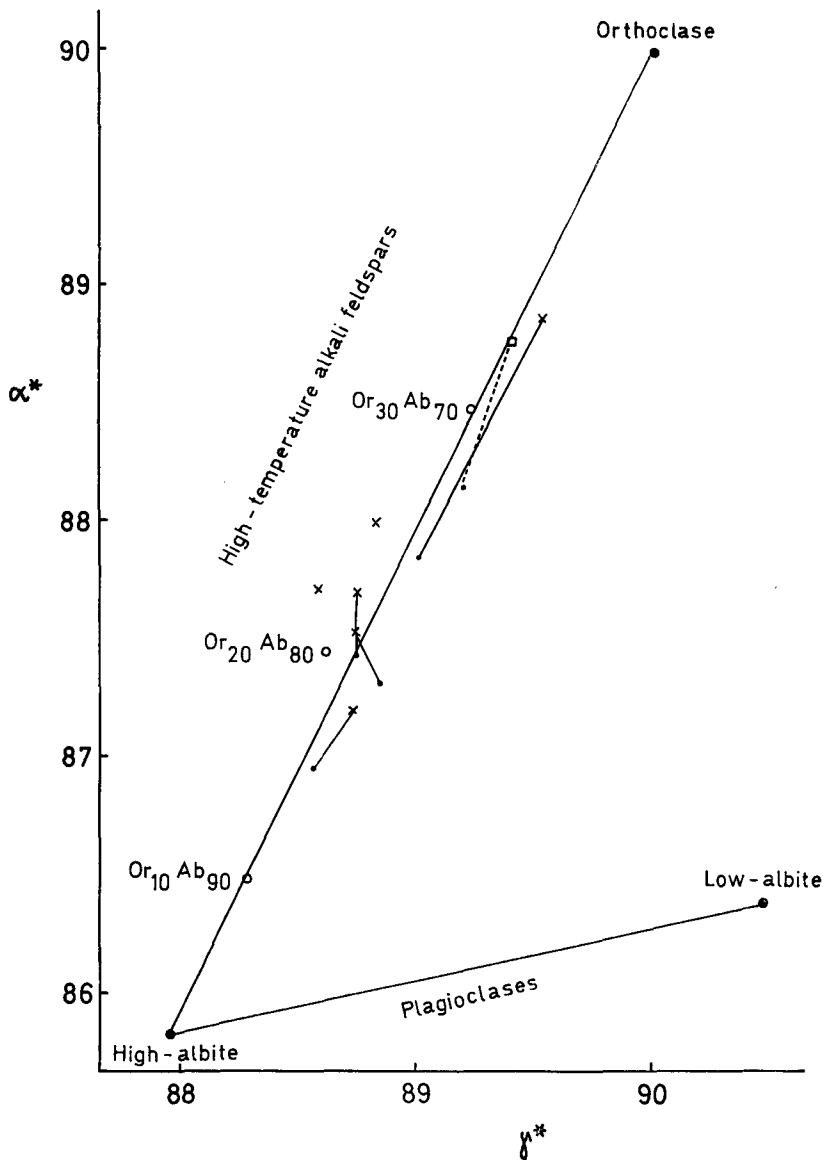
FIG. 2. Plot of the reciprocal lattice angles $\alpha^*$ and $\gamma^*$ for group 1 of the triclinic sodium-rich phases. The diagram is the same as used by MacKenzie and Smith (1955). Crosses indicate pericline-twinning, dots albite-twinning. Apart from one specimen (GGU 58357–P–EM2) the reciprocal lattice angles $\alpha^*$ and $\gamma^*$ of the pericline-twinned and albite-twinned sodium-rich phases coincide fairly well. It is thought that they developed simultaneously. Some of the specimens only show one high-temperature pericline-twinned sodium-rich phase. The dashed tie-line (GGU 49464–P1) links a high-temperature albite-twinned sodium-rich phase with a presumed albite-twinned potassium-rich phase (the square); the reason for its impossible values for $\alpha^*$ and $\gamma^*$ is not known.
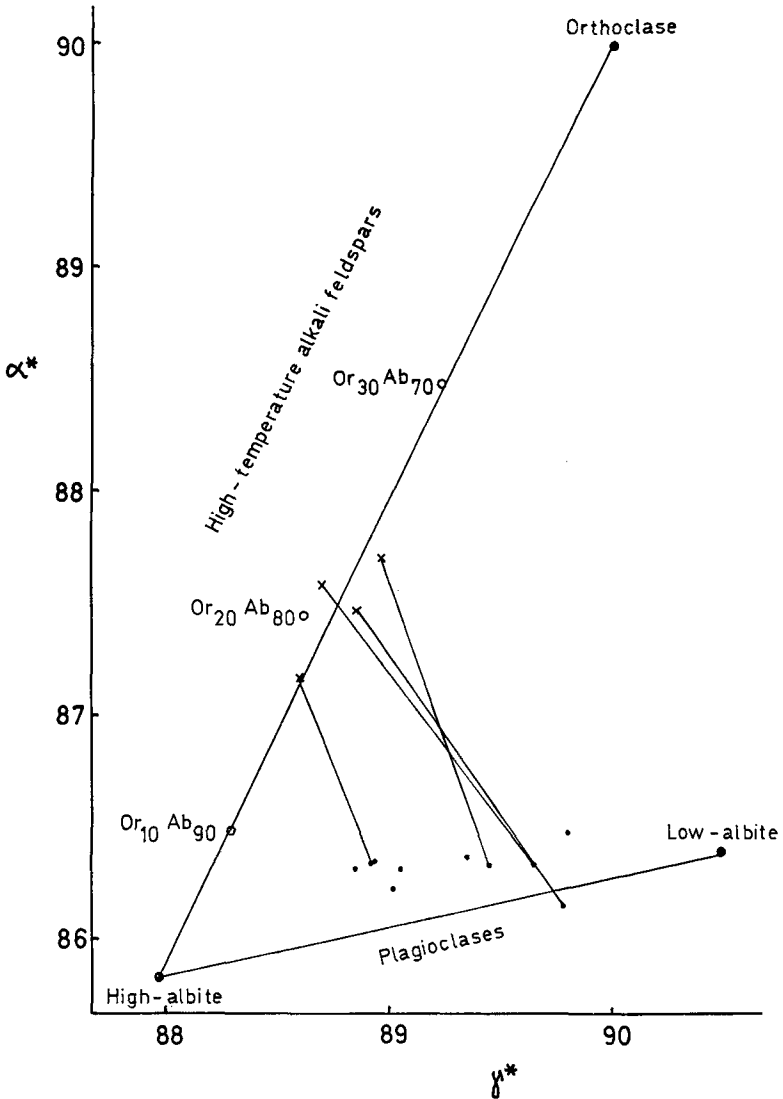
FIG. 3. Plot of the reciprocal lattice angles $\alpha^*$ and $\gamma^*$ for group 2 of the triclinic sodium-rich phases. We notice high-temperature pericline-twinned (crosses) and low-temperature albite-twinned phases (dots). The tie-lines for such specimens are indicated and show that $\gamma^*$ is smaller in the pericline-twinned phase and $\alpha^*$ is smaller in the albite-twinned phase. Those specimens having only one low-temperature sodium-rich phase are included in group 2.

($Or_{26}Ab_{74}$ to $Or_{18.5}Ab_{81.5}$) and a low-temperature albite-twinned sodium-rich phase. The tie-lines have the same directions as those cited by MacKenzie and Smith (1962) for sodium-rich phases of alkali feldspars from the Beinn an Dubhaich granite, Skye, or by Emeléus and Smith (1959) from Slieve Gullion felsite and granophyre, Northern Ireland. These directions of the tie-lines result from larger values for $\alpha^*$ in the pericline-twinned than in the albite-twinned domains and vice versa for $\gamma^*$. Differences of more than $10'$ for $\gamma^*$ have been put into this group. Additionally, there are some sodium-rich phases that are low-temperature albite-twinned phases alone. These photographs show either no pericline-twinned phases or unmeasurable superstructure streaks.

In the *third group* a number of sodium-rich phases have been gathered (fig. 4) all of which have a high-temperature pericline-twinned phase and a low-temperature albite-twinned, as have most of the members of the second group. But the compositions of the pericline-twinned domains depart from those of the first two groups in so far as they are distinctly richer in Or ($Or_{35}Ab_{65}$ to $Or_{26.5}$ to $Ab_{73.5}$); and a second remarkable difference lies in the reciprocal lattice angles of the twinned areas. Here only one tie-line (for GGU 49415–NP1) has the same direction as those in the second group, but its value for $\gamma^*$ of the albite-twinned domains is less than $10'$ larger than $\gamma^*$ of the pericline-twinned domains. All other tie-lines stress either the identity of both $\gamma^*$ values or $\gamma^*$ of the albite-twinned sodium-rich phases is smaller than $\gamma^*$ of the pericline-twinned sodium-rich phases. Emeléus and Smith (1959, p. 1196, fig. 3) give one such tie-line from Slieve Gullion felsite and granophyre without discussing its meaning. Otherwise no such tie-lines have been described, except those linking the low-albite pole with the pole of the maximum microcline, or highly oblique states of potassium-rich phases.

*Summary and conclusions*

Summarizing the results one can draw the conclusion that the alkali feldspar may be coordinated to the 'cooling sequence' of MacKenzie and Smith (1962, p. 98; see above) in that they either belong to the first or to the second type. Very seldom is the fourth type realized. We can concentrate the discussion on to the first two types of the 'cooling sequence'.

Both of these types have been found in rapidly cooled rocks: specimens from volcanic rocks (MacKenzie and Smith, 1956) and from ring dykes of Slieve Gullion, Northern Ireland (Emeléus and Smith, 1959). The geological evidence of our microsyenitic dykes reveals a rather rapid
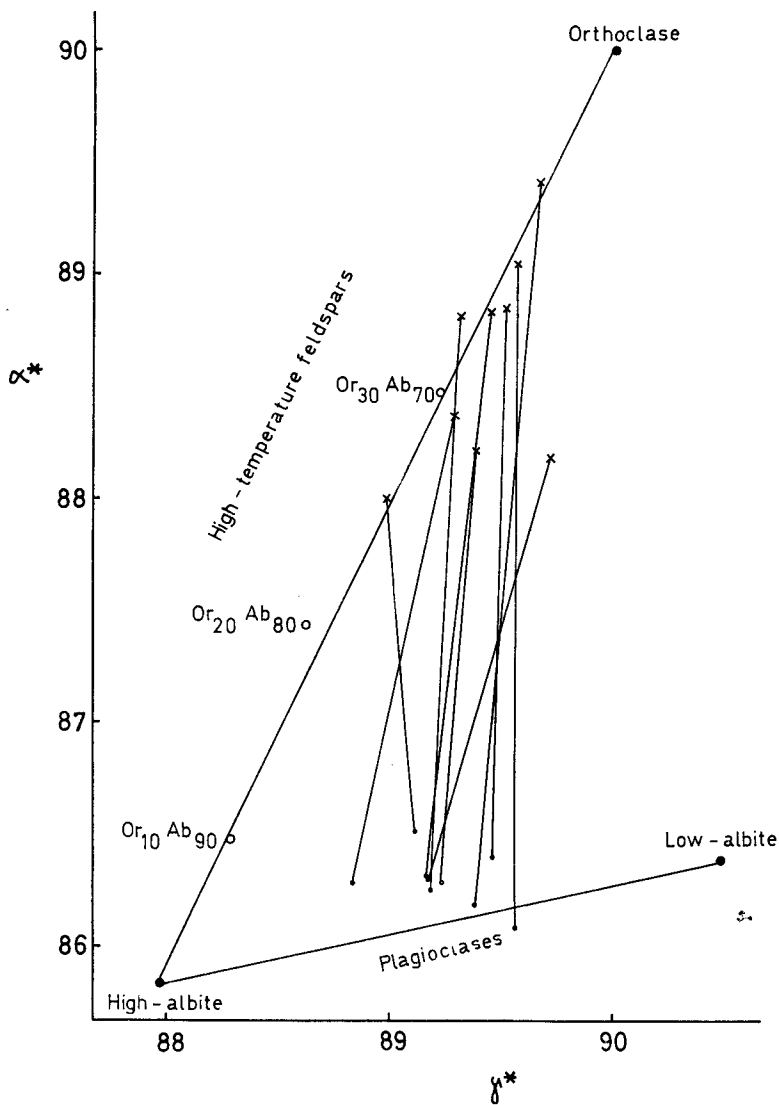
Fig. 4. Plot of the reciprocal lattice angles $\alpha^*$ and $\gamma^*$ for group 3 of the triclinic sodium-rich phases. We again notice high-temperature pericline-twinned (crosses) and low-temperature albite-twinned (dots) phases. The directions of the tie-lines reveal a close similarity in the $\gamma^*$ values for the sodium-rich phases. Although two measurements of the pericline-twinned phases are rather unreliable they have been plotted here to show that the narrow separation of the pericline spots is responsible for this phenomenon. Also superstructures, if the widest distance is measured, may give bad results. It is thought that the albite-twinned phase is dominating the process of twinning as a whole. The pericline-twinned phases are less rich in Ab than those in the other groups.

cooling by intrusion of the syenitic magma into congealed and cooled country-rocks at rather high intrusion levels.

The unmixing of the homogeneous alkali feldspars has taken place in the temperature range in which they are monoclinic. As cited several times, the potassium-rich phase is monoclinic or has only a slight obliquity. In many photographs reflections representative of mono-clinic sodium-rich phases underline the unmixing in the monoclinic state. The monoclinic spot does not necessarily indicate a monoclinic phase of pure $NaAlSi_3O_8$, referred to as monalbite by Laves (1960). In this respect one must be careful, since first of all one should know the chemical composition of the unmixed phases. As already pointed out by MacKenzie and Smith (1956, p. 415), a monoclinic reflection appears also in sodium-rich material between $Or_{50}Ab_{50}$ and $Or_{37}Ab_{63}$, where the trans-formation into triclinic symmetry takes place. It can easily be deduced from the monoclinic–triclinic inversion curve, as given by Smith and MacKenzie (1958, p. 878) that the higher the temperature the more the curve is shifted toward $NaAlSi_3O_8$. Very recently Soldatos (1965) pub-lished some indications of an unmixed monoclinic albite in a sanidine cryptoperthite from Greece; no chemical composition is given. The author remarks on the lack of sharpness of the sodium-rich reflections on his precession photographs in comparison with the sharp monoclinic potassium-rich-phase reflections. He attributes this to variable chemical composition of the sodium-rich phase. In our opinion we are probably dealing with a superstructure. On the other hand, if the chemical com-position is not known, the so-called monalbite can be a sodium-rich sanidine between $Or_{50}Ab_{50}$ and $Or_{37}Ab_{63}$.

The process of unmixing of a monoclinic feldspar as seen on $b$-axis oscillation photographs was discussed in some detail by MacKenzie and Smith (1956, p. 415). First some diffuse streaks develop parallel to the layer-lines, with development of an intensity maximum later on, repre-senting an untwinned sodium-rich phase. Later the development of some superstructure appears until a well-defined pericline-twinned phase occurs. Somewhere in this process our group 1 samples fall. Certainly, the process of unmixing has some influence upon the chemical composi-tion of the unmixed phases. When the unmixing starts (depending on the composition of the homogeneous phase and on the respective solvus temperature) a progressive impoverishment of the other component is to be expected. The rapid cooling of the syenitic magma would give rise to different stages of disequilibrium. We do not see any reason, then, why the pericline-twinned sodium-rich phase should not exhibit different

compositions, lying even on the monoclinic side of the inversion curve, as discussed above. We can conclude that the impoverishment of Or in the sodium-rich phases proceeds with the development of the pericline-twinned material.

It is believed that the different appearance of the reflections of the pericline-twinned sodium-rich phases is connected with the different behaviour of the tie-lines (cf. figs. 3 and 4). None of the crystals investigated was completely homogeneous nor are the unmixed phases represented by perfectly sharp reflections. In all cases we have to think of some variation in the geometrical relations. Therefore it is sometimes rather difficult to measure $\alpha^*$ and $\gamma^*$ for the pericline-twinned phase with the accuracy claimed. This is expressed in the sometimes fairly strong deviation from the high-temperature alkali-feldspar line, especially if some measurements of fig. 4 (group 3) are considered. In group 2 the pericline-twinning is readily measurable and the separation of the spots distinctive. In group 3, however, the $\alpha^*$ and $\gamma^*$ values deduced from the measurements of the distances from the central ('monoclinic') to the inner spot plot towards the Or-pole on the graph of MacKenzie and Smith (1955) and give almost no variation in $\gamma^*$ for both the pericline-twinned and the albite-twinned sodium-rich phases. Sometimes the albite-twinning is asymmetrically arranged on the photographs. Laves and Soldatos (1962) have described a similar case in Spencer 'R' which contains $Or_{43.3}$ and has cryptoperthitic exsolution; unmixing began in the monoclinic range; by some 'accidental' influence the exsolution did not proceed 'monoclinic-symmetrically', and one albite reflection is more intensely developed than the other. These conditions fit perfectly into our cases and have possibly even some influence on the unequal distribution of the pericline-twinning reflections of the group 3 samples. It is to be assumed that the 'monoclinic' spot might not represent a truly monoclinic sodium-rich phase relic and that the pericline-twinned phase is mainly dominated by the amount of albite-twinning. From the asymmetric arrangement of the reflections it might be concluded that the $b$ and the $b^*$ axes did not coincide in the original monoclinic and homogeneous feldspar.

In specimens with a high-temperature and a low-temperature sodium-rich phase there are two possibilities: either the anorthoclase develops earlier than the plagioclase, or both phases develop simultaneously. In the latter case the anorthoclase stays disordered because of the remaining K content, and the plagioclase orders because of its Ca content. In those specimens having pericline- and albite-twinned high-temperature

alkali feldspars (anorthoclase line) a simultaneous development of both phases seems to be warranted. We know (Carmichael and MacKenzie, 1964) that the effect of high Ca-contents on the reciprocal lattice angle $\gamma^*$ is small but may become appreciable in $\alpha^*$ with increasing orthoclase content. It might be concluded that the anorthoclase, as a highly disordered phase, contains all the Ca. No definite conclusions can be drawn at the moment, whether the invariably albite-twinned plagioclase phase formed simultaneously with or later than the combined and invariably pericline-twinned anorthoclase phase. Conditioned by the high Ca-content of our samples it seems reasonable that all the Ca goes into the plagioclase phase. But the question whether the Ca only gives the impression of an ordered and therefore low-temperature plagioclase or whether in high-temperature alkali feldspar a truly low-temperature modification may be present should be a matter of further investigations.

Since the rocks were cooled down rather quickly we may expect some peculiarities in the lattices of the feldspars that are not present in the ordered phases of a microcline perthite.

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