The lattice parameters of high-temperature triclinic sodic feldspars

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Summary. The lattice parameters of twenty calcium-bearing anorthoclases and potassium-bearing acid plagioclases have been determined by powder methods. The $20\bar{1}$ spacing of the homogenized anorthoclases gives a good measure of the Or content irrespective of the amount of calcium present; this spacing combined with α^* (010): (001) may be used to determine the ternary composition of homogeneous feldspars more potassic than approximately Or_{15}. The lattice parameters of feldspars less potassic than Or_{15} cannot be used for the determination of their ternary composition.

THE lattice parameters of synthetic alkali feldspars have been determined by Donnay and Donnay (1952), and the cell dimensions and angles of the triclinic members may be used to determine their composition. However, the most widely used X-ray method for the determination of composition of the high-temperature homogeneous alkali feldspars is the variation in the $20\bar{1}$ spacing (Bowen and Tuttle, 1950); this method can be used for the whole range of composition of the alkali feldspars. In contrast, Smith (1956) has shown that there is no reliable X-ray method for the determination of the composition of the sodic plagioclases, because the lattice parameters vary both with thermal state and chemical composition; however, if the composition is known an indication of the thermal state may be obtained. The curves of variation of the lattice-parameters and the spacing of certain pairs of reflections of the high-temperature plagioclases in the range An_0–An_{50} are virtually flat, so that their value for determining composition is minimal even if the specimens are known to be in the high-temperature state.

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Although there are considerable data on the lattice parameters of the two binary series—plagioclase feldspars and alkali-feldspars—there are few data on the ternary feldspars, namely potassic plagioclases and calcium-bearing alkali feldspars; it is with these ternary feldspars that this paper is concerned.

Materials and techniques. Many of the anorthoclase feldspars used for this study have previously been studied (MacKenzie and Smith, 1956; Smith and MacKenzie, 1958) and occur as phenocrysts in lavas or small intrusions. In addition to these previously investigated anorthoclases, a series of analysed plagioclases and anorthoclases occurring as phenocrysts *in pitchstones* and obsidians were available (Carmichael, 1960, 1962).

TABLE I. New chemical analyses of anorthoclases by I. S. E. Carmichael. (For the key to the specimens, see page 957).

	4	5	6	7	8	11	15
SiO_2	63·76	65·88	—	66·03	65·23	—	66·85
Al_2O_3	22·07	20·43	—	19·89	20·68	—	18·70
Fe_2O_3	0·14	0·20	0·30	0·23	0·20	0·18	0·78
CaO	1·78	0·22	0·43	0·19	0·87	0·31	0·04
BaO†	0·18	0·27	0·26	0·36	0·18	0·22	*
SrO†	0·25	0·11	0·14	0·18	0·22	0·27	*
Na_2O	8·34	9·25	8·98	8·90	8·45	8·74	7·91
K_2O	3·14	3·14	3·60	3·66	3·78	3·94	5·59
H_2O^+	0·20	0·55	—	0·36	0·26	—	—
H_2O^-	nil	0·18	—	0·07	0·06	—	—
Total	99·86	100·23	—	99·87	99·93	—	99·87
Total feldspar components (wt.%)‡	99·16	98·89	100·45	99·29	99·28	100·16	100·18
Composition (recalculated to 100 *wt.* %)							
Or	18·7	18·8	21·2	21·8	22·5	23·3	33·0
Ab	71·1	79·1	75·6	75·8	72·0	73·8	66·8
An	8·9	1·1	2·1	0·9	4·4	1·5	0·2
Cn	0·4	0·7	0·6	0·9	0·4	0·5	—
Sr feld.	0·8	0·3	0·4	0·6	0·7	0·8	—
2θ ($20\bar{1}$)§ ...	21·804°	21·808°	21·784°	21·806°	21·755°	21·764°	21·664°

* Below 20 ppm.

† Spectrographic determinations by C. M. B. Henderson.

‡ Feldspar components calculated from Na_2O, K_2O, CaO, BaO, and SrO.

§ The values of 2θ ($20\bar{1}$) are for Cu radiation.

Five of the anorthoclase samples had not previously been analysed, and the results are set down in table I. Although the total feldspar components calculated from the weight percentages of CaO, Na_2O, K_2O (and BaO and SrO where appropriate) approximate to 100 wt. %, the Al_2O_3 determinations are systematically high. By an oversight, the

ignited R_2O_3 ammonia precipitate was not purged of contaminating Pt, Pd, and Au, which in the authors' experience are always notable in amount in the normal classical analysis of small quantities of material. The minor elements Ba, Sr, and Rb have been determined spectrographically in as many samples as possible; Rb is in each case below 50 ppm. Since the feldspar molecules of Ba, Sr do not account for more than 1·5 % by weight of total feldspar components in these feldspars, they have been disregarded in the plotting of the analyses.

Single crystal X-ray photographs were taken of all the anorthoclases; if the crystals had unmixed, they were heated at 900° C for 24 hours and subsequent photographs indicated that the crystals were homogeneous. The homogeneous anorthoclases and the plagioclases before and after heat treatment (see below) were ground with powdered quartz in an agate mortar under acetone for 5–10 minutes. A smear mount was made of the finely ground feldspar–quartz powder, and the sample scanned between 2θ 20° and 52° on a Philips diffractometer using filtered Cu radiation. The settings of the diffractometer were: time constant 4 sec; divergence and scatter slits 1°; scanning speed 0·25° of 2θ per minute; chart speed 400 mm per hour. The quartz was used as an internal standard, sufficient being added to the feldspar samples to give peaks of similar intensity to the feldspar peaks. Each diffractometer chart was measured twice with a vernier scale, and the peak centre was taken at 2/3 of peak height; each specimen was scanned twice, the smear mount being re-mixed between the two scans. For the measurement of the $20\bar{1}$ reflection, the sample was oscillated six times through the range 2θ 20° to 23° to include the $10\bar{1}0$ quartz reflection (2θ, 20·876°) and the feldspar $20\bar{1}$ reflection and the average value of 2θ $(20\bar{1})-2\theta$ $(10\bar{1}0)$ taken. The plagioclases were also scanned six or eight times through the range 2θ 29° to 32° to obtain values for 2θ $(131)-2\theta$ $(1\bar{3}1)$, both before and after heat treatment.

The feldspar peaks were indexed using the data of Donnay and Donnay (1952) and Smith (1956). The average values of 2θ (corrected by the quartz internal standard in each of the two scans) for between 12 and 18 resolved peaks were used to calculate the lattice parameters using a least-squares programme run on the University of Manchester and University of London Mercury Computers. The average discrepancy between 2θ observed and 2θ calculated for each specimen is less than 0·01°, and the best and worst of all the results are shown in table II.

The lattice parameters of one of the anorthoclase specimens used (no. 13, Grande Caldeira) have previously been determined by Donnay

TABLE II. Comparison of 2θ (observed) and 2θ (calculated) for the best (A) and worst (B) set of results.

A (Anorthoclase no. 1.)					B (Anorthoclase no. 5.)				
h	k	l	2θ (obs.)	2θ (calc.) difference	h	k	l	2θ (obs.)	2θ (calc.) difference
2	0	$\bar{1}$	21·899	21·900 −0·00127	2	0	$\bar{1}$	21·808	21·809 −0·00094
1	$\bar{1}$	1	22·870	22·873 −0·00311	1	$\bar{1}$	1	22·870	22·856 0·01385
1	3	0	24·311	24·308 0·00311	1	1	1	23·430	23·429 0·00121
1	1	$\bar{2}$	25·640	25·629 0·01143	1	$\bar{3}$	0	23·660	23·656 0·00428
$\bar{1}$	1	2	26·322	26·320 0·00240	1	3	0	24·181	24·187 −0·00583
0	4	0	27·694	27·687 0·00679	1	1	$\bar{2}$	25·658	25·640 0·01808
0	0	2	27·992	28·001 −0·00853	$\bar{1}$	1	2	26·188	26·177 0·01080
2	2	0	28·324	28·321 0·00255	0	4	0	27·624	27·614 0·00950
1	$\bar{3}$	1	29·658	29·660 −0·00245	0	0	2	27·932	27·923 0·00921
0	4	$\bar{1}$	30·337	30·346 −0·00876	1	$\bar{3}$	1	29·711	29·721 −0·00951
0	2	$\bar{2}$	30·569	30·562 0·00670	0	4	$\bar{1}$	30·437	30·421 0·01636
1	3	1	31·300	31·306 −0·00611	0	2	$\bar{2}$	30·618	30·633 −0·01472
$\bar{1}$	3	2	33·484	33·480 0·00386	0	6	0	41·947	41·953 −0·00594
0	6	0	42·030	42·030 0·00018	2	0	$\bar{4}$	51·165	51·169 −0·00374
1	$\bar{1}$	3	49·761	49·759 0·00194					
2	0	$\bar{4}$	51·304	51·307 −0·00264					

and Donnay (1952) using external calibration for the diffractometer; Smith (1956) suggested that this external calibration could account for the discrepancy between the lattice parameters of synthetic albite as determined by him using an internal standard, and those found by Donnay and Donnay. The discrepancies between our values for no. 13 and the Donnays' determinations are similar in magnitude to those for synthetic albite, again presumably because of the difference in calibration methods.

Results: Anorthoclases. The Or content of each anorthoclase found by chemical analysis has been plotted against the value of 2θ $20\bar{1}$ (feldspar) -2θ $10\bar{1}0$ (quartz, 20·876°) in fig. 1. Also shown in fig. 1 is the determinative curve based on 2θ $(20\bar{1})-2\theta$ $(10\bar{1}0$, quartz) for synthetic alkali feldspars (prepared and kindly provided by Dr. P. M. Orville) and run on the diffractometer at the same time as the natural anorthoclases. This curve[1] is similar to the one given by Orville (1963). With the exception of no. 14 and possibly nos. 7 and 9, the $20\bar{1}$ spacing of the natural anorthoclases agrees reasonably well with the $20\bar{1}$ spacing for synthetic alkali feldspars of comparable Or content, and indicates that this spacing for natural samples is independent of their calcium content (table I). The values of 2θ $(20\bar{1})-2\theta$ $(10\bar{1}0$, quartz) for the analysed

[1] This curve is drawn between 2θ 22·005° for pure albite and 2θ 21·631° for $Or_{35}Ab_{65}$.

plagioclases have also been plotted in fig. 1, together with comparable data from Smith (1956).

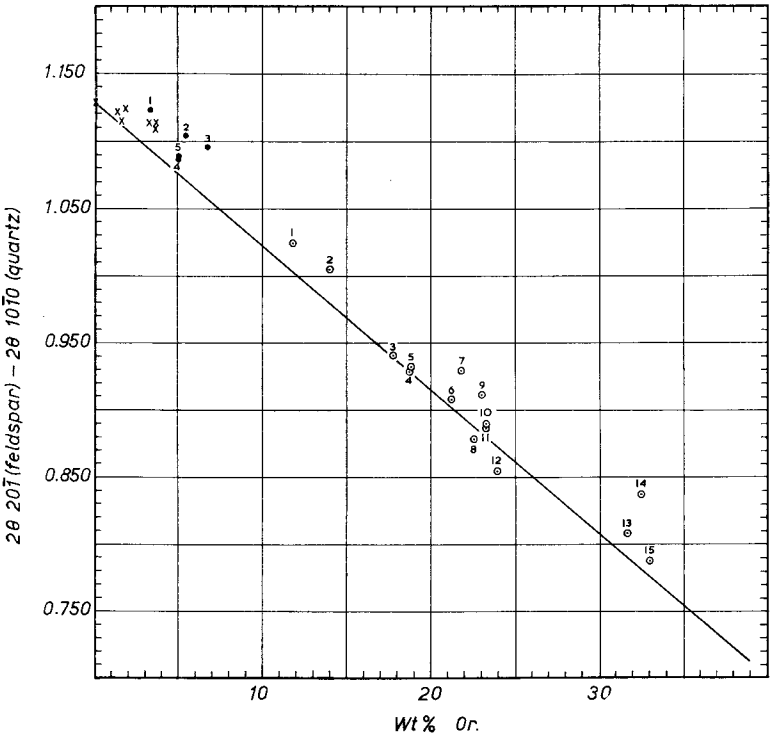

FIG. 1. $2\theta\,(20\bar{1}) - 2\theta\,(10\bar{1}0$, quartz) of the anorthoclases plotted against Or content found by chemical analysis. The enumerated solid circles refer to plagioclases (table IV) and the crosses to sodic plagioclases taken from Smith (1956). The line is the $2\theta\,(20\bar{1}) - 2\theta\,(10\bar{1}0$, quartz) curve for synthetic alkali feldspars.

In fig. 2, curves of variation of $2\theta\,(20\bar{1})$ have been drawn from the values of $2\theta\,(20\bar{1})$ for the anorthoclases (table I) and for the heated plagioclases (table IV). The Or content of nos. 7, 9, and 14 has been corrected to Or_{19}, Or_{20}, and Or_{28}[1] respectively in figs. 2 and 3 so as to coincide with the Or content of these specimens interpolated from fig. 1.

Smoothed curves of variation of α^* (001 : 010) are also shown in fig. 2, based on the data of tables III and IV and the data for synthetic alkali feldspars in Donnay and Donnay (1952).

[1] It is believed that the Or content derived from the $20\bar{1}$ spacing is better in these three samples than that found by analysis.

All the other determined lattice parameters vary with composition in a similar way to α^* and the cell-volume (fig. 3), being almost parallel to

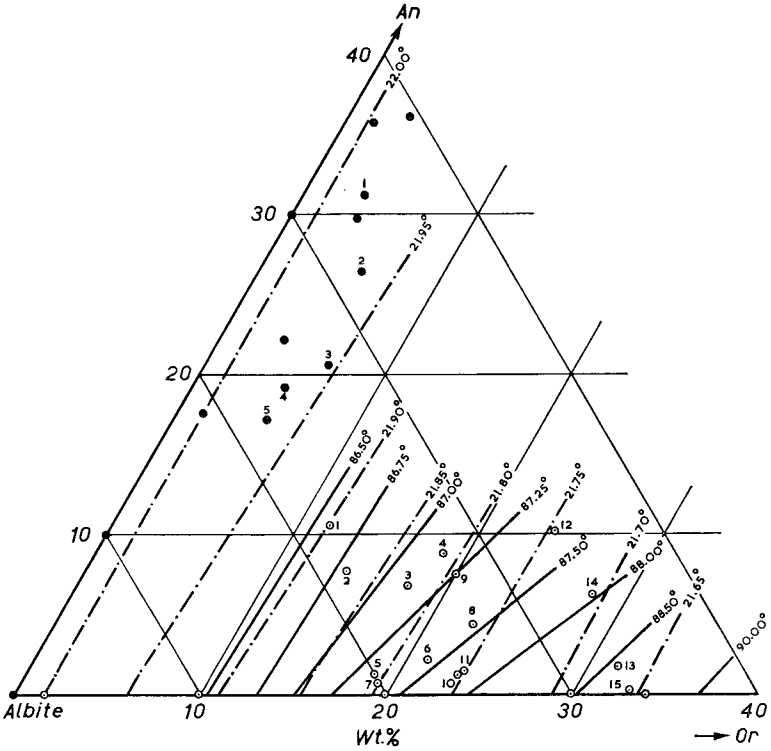

FIG. 2. The analysed homogeneous anorthoclases and high-temperature plagioclases (solid circles) (table IV) plotted in the sodic corner of the ternary feldspar diagram. Dash–dot curves refer to variation in $2\theta\ 20\bar{1}$, and solid curves refer to variation in the angle α^*. Additional data taken from Smith (1956) for high-temperature plagioclases and from Donnay and Donnay (1952) for the alkali feldspars. The monoclinic-triclinic transition at Ab_{63} is taken from MacKenzie (1952).

the $2\theta\ 20\bar{1}$ curves for sodic feldspars, and becoming progressively inclined to the curves with increase in Or content. However, the other lattice parameters are not in general so sensitive to change in composition as α^*. α^* and γ^* may readily be determined from single crystal X-ray photographs (Smith and MacKenzie, 1955) at the same time as the homogeneity of anorthoclases is established, and values so determined are compared with values obtained by the X-ray powder method in table V. The average discrepancy is approximately 0·10° for α^*; in

some cases agreement would be better if several crystals of each specimen had been measured, rather than the one crystal used here. It can

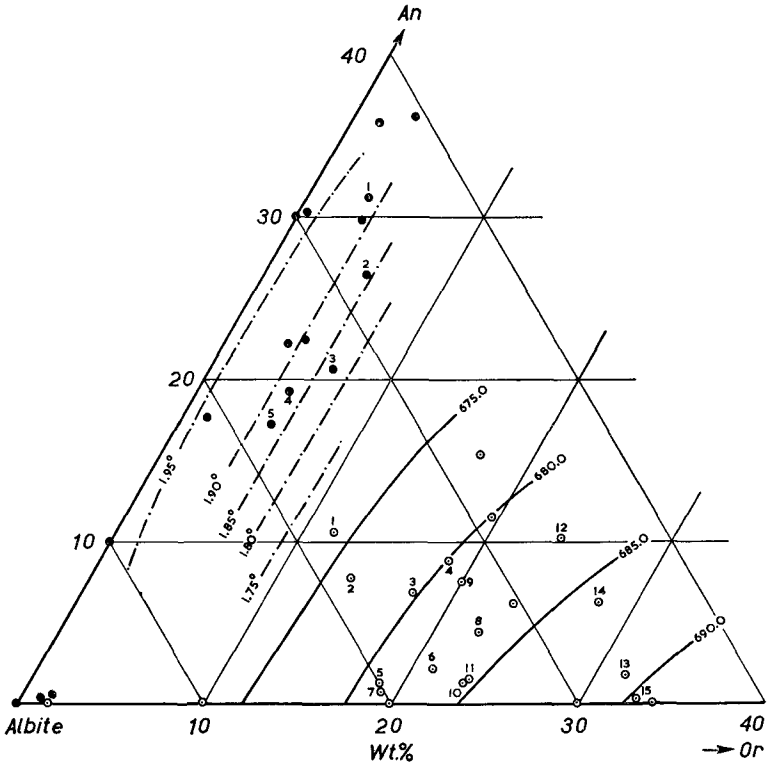

FIG. 3. Variation in the cell-volume of anorthoclases (table III) with additional data taken from Donnay and Donnay (1952) and Hakli (1960). The variation of $2\theta(131) - 2\theta(1\bar{3}1)$ for high-temperature plagioclases (solid circles) is shown as dash–dot curves. Additional data for the high-temperature plagioclases are taken from Smith (1956) and Smith (1958).

reasonably be doubted whether one small crystal is representative of many of the large anorthoclase phenocrysts, which are undoubtedly zoned.

One anorthoclase (no. 12, Spencer, Pa.) has lattice parameters (table III), particularly α^* and cell-volume, that are incompatible with its calcium content as found by chemical analysis ($An_{10.1}$). As this feldspar has a $20\bar{1}$ spacing appropriate to its Or content (fig. 1), there would seem to be an error in the analysis for Na_2O and CaO. The lattice

TABLE III. Lattice parameters of homogeneous anorthoclases. (For key to specimens, see opposite page)

Anal.	a	b	c	α	β	γ	V	a^*	b^*	c^*	α^*	β^*	γ^*
1	8·203 Å	12·909 Å	7·126 Å	92·90°	116·39°	90·22°	674·9 Å^3	0·136 Å^{-1}	0·078 Å^{-1}	0·157 Å^{-1}	86·65°	63·56°	88·32°
2	8·210	12·911	7·128	92·80	116·37	90·21	675·9	0·136	0·078	0·157	86·77	63·59	88·38
3	8·236	12·921	7·136	92·56	116·34	90·15	679·6	0·136	0·077	0·157	87·07	63·62	88·57
4	8·239	12·930	7·133	92·40	116·29	90·27	680·4	0·135	0·077	0·157	87·19	63·67	88·52
5	8·239	12·935	7·141	92·26	116·38	90·28	681·0	0·136	0·077	0·156	87·34	63·59	88·56
6	8·249	12·944	7·139	92·19	116·30	90·16	682·2	0·135	0·077	0·156	87·47	63·68	88·74
7	8·240	12·929	7·139	92·34	116·33	90·14	680·9	0·135	0·077	0·156	87·32	63·64	88·68
8	8·263	12·935	7·138	92·26	116·33	90·18	683·0	0·135	0·077	0·156	87·39	63·64	88·68
9	8·248	12·934	7·134	92·42	116·28	90·18	681·6	0·135	0·077	0·157	87·20	63·68	88·60
10	8·259	12·938	7·147	92·15	116·36	90·15	683·6	0·135	0·077	0·156	87·53	63·62	88·76
11	8·260	12·944	7·145	91·94	116·31	90·21	684·2	0·135	0·077	0·156	87·74	63·67	88·80
12	8·279	12·949	7·150	91·79	116·29	90·11	686·8	0·135	0·077	0·156	87·95	63·69	88·99
13	8·287	12·972	7·156	91·05	116·26	90·15	689·8	0·135	0·077	0·156	88·76	63·74	89·31
14	8·279	12·952	7·150	91·47	116·32	90·20	686·9	0·135	0·077	0·156	88·26	63·67	89·05
15	8·296	12·975	7·156	91·03	116·28	90·11	690·5	0·134	0·077	0·156	88·80	63·71	89·37

parameters indicate that this feldspar has a very low calcium content, probably less than 1 % anorthite (figs. 2 and 3), in agreement with more modern analyses of anorthoclases from the pantellerites of Pantelleria, which are characterized by their very low anorthite content (Carmichael, 1962).

Results: Plagioclases. The values of 2θ (131)—2θ ($1\bar{3}1$) of the five plagioclases in their natural state have been determined, and the results are set down in table VI and plotted in fig. 4. The values fall nearer the high-temperature synthetic plagioclase curve (Smith, 1956) than the low-temperature curve. The plagioclases were heated dry at 1100° C for 14 days and the values of 2θ (131)—2θ ($1\bar{3}1$) were again determined (table VI). Heating for a further 14 days at 1100° C produced little change (table VI), and it is assumed that the feldspars had been converted fully to the high-temperature state. The values of 2θ (131)—2θ ($1\bar{3}1$)

Key to Anorthoclase specimens

(Compositions in weight per cent.)

1. Pitchstone phenocrysts, Iceland. P.258. $Or_{11\cdot8}Ab_{76\cdot8}An_{10\cdot7}Cn_{0\cdot6}Sf_{0\cdot1}$.† 2θ ($20\bar{1}$), 21·899°. BaO 0·23; SrO 0·03. (Carmichael, 1960, No. 7F.)
2. Pitchstone phenocrysts, Iceland. E.868. $Or_{14\cdot0}Ab_{77\cdot4}An_{7\cdot8}Cn_{0\cdot8}$. 2θ ($20\bar{1}$), 21·881°. BaO 0·30; SrO 0·02. (*Ibid.*, No. 4F.)
3. Phenocrysts in analcime-basalt. $Or_{17\cdot8}Ab_{74\cdot1}An_{6\cdot9}Cn_{0\cdot3}Sf_{0\cdot9}$. 2θ ($20\bar{1}$), 21·818°. (Wilkinson, 1962, table 4.)
4. Phenocrysts, East Hill, Mt. Anakie, Victoria, Australia. (Table I.)
5. Phenocrysts in volcanic neck, Kellie Law, Fife, Scotland. (Table I.)
6. Camperdown, Victoria, Australia. (Table I.)
7. Phenocrysts in volcanic neck, Brownhills, Fife, Scotland. (Table I.)
8. Loose crystals, Mt. Erebus, Antarctica. (Table I.)
9. Phenocrysts in soda-trachyte, Ropp, Nigeria. $Or_{23\cdot0}Ab_{69\cdot3}An_{7\cdot4}Cn_{0\cdot3}$. 2θ ($20\bar{1}$), 21·788°. (Joyce and Game, 1952.)
10. Victoria, Australia. $Or_{23\cdot2}Ab_{75\cdot2}An_{1\cdot2}Cn_{0\cdot2}Sf_{0\cdot2}$. 2θ ($20\bar{1}$), 21·756°. BaO 0·08; SrO 0·08. (Tuttle, 1952.)
11. Mt. Franklin (nr. Daylesford) Victoria, Australia. (Table I.)
12. Phenocrysts from Pantelleria. $Or_{24\cdot0}Ab_{65\cdot9}An_{10\cdot1}$ (sum of feldspar components 95·52). 2θ ($20\bar{1}$), 21·731°. (Spencer, 1937, Specimen Pa.)
13. Grande Caldeira, Azores. $Or_{31\cdot7}Ab_{66\cdot3}An_{1\cdot8}Cn_{0\cdot2}$. 2θ ($20\bar{1}$), 21·685°. BaO 0·07; SrO*. (Tuttle, 1952.)
14. Mt. Kenya, Kenya, East Africa. $Or_{32\cdot5}Ab_{61\cdot4}An_{6\cdot1}$ (sum of feldspar components 95·68). 2θ ($20\bar{1}$), 21·714°. (Spencer, 1937, Specimen Ky.)
15. Phenocrysts in obsidian, Pantelleria. (Table I.) Alkali values only given in Carmichael, 1962 (No. 3114F). BaO*, SrO*.

† Sf denotes strontium feldspar.

BaO and SrO, where given, are spectrographically determined by C. M. B. Henderson. * below limit of sensitivity, 20 ppm. The values of 2θ ($20\bar{1}$) are for Cu radiation.

TABLE IV. Lattice parameters of sodic plagioclases. Compositions taken from Carmichael (1963)

Anal.	a	b	c	α	β	γ	V	a^*	b^*	c^*	α^*	β^*	γ^*
Unheated													
1	8·171 Å	12·874 Å	7·114 Å	93·49°	116·34°	90·05°	669·1 Å^3	0·137 Å^{-1}	0·078 Å^{-1}	0·157 Å^{-1}	86·08°	63·60°	88·21°
2	8·177	12·882	7·115	93·39	116·31	90·09	670·4	0·136	0·078	0·157	86·18	63·64	88·22
3	8·179	12·886	7·121	93·36	116·34	90·03	671·1	0·136	0·078	0·157	86·23	63·61	88·30
4	8·179	12·873	7·119	93·43	116·39	90·00	670·0	0·137	0·078	0·157	86·17	63·56	88·29
5	8·170	12·881	7·118	93·45	116·33	89·96	669·9	0·137	0·078	0·157	86·17	63·62	88·34
Heated for 28 days at 1100° C													
1	8·170	12·874	7·112	93·39	116·25	90·20	669·3	0·137	0·078	0·157	86·12	63·68	88·10
4	8·171	12·882	7·111	93·38	116·32	90·14	669·4	0·137	0·078	0·157	86·16	63·62	88·17

No.	*Composition (recalculated to 100 wt. %)* Or	Ab	An	2θ ($20\bar{1}$) *Unheated*	*Heated for 28 days*
1 G. 151	3·3	65·6	31·1	21·973°	22·000°
2 P. 946	5·4	68·0	26·6	21·980°	—
3 H. 270	6·7	72·7	20·6	21·972°	—
4 P. 410	5·0	75·9	19·1	21·964°	21·976°
5 P. 186	5·0	77·9	17·1	21·994°	—

TABLE V. Values of α^* and γ^* for the analysed anorthoclases by powder and single-crystal methods

Anal.	Powder methods (table III)		Single-crystal methods	
	α^*	γ^*	α^*	γ^*
1	86·65°	88·32°	86·79°	88·35°
2	86·77°	88·38°	86·65°	88·37°
3	87·07°	88·57°	86·98°	88·63°
4	87·19°	88·52°	87·13°	88·48°
5	87·34°	88·56°	87·32°	88·78°
6	87·47°	88·74°	87·51°	88·70°
7	87·32°	88·68°	87·30°	88·72°
8	87·39°	88·68°	—	—
9	87·20°	88·60°	87·25°	88·58°
10	87·53°	88·76°	—	—
11	87·74°	88·80°	87·80°	89·08°
12	87·95°	88·99°	88·18°	89·08°
13	88·76°	89·31°	88·59°	89·27°
14	88·26°	89·05°	88·48°	89·27°
15	88·80°	89·37°	—	—

TABLE VI. Values of 2θ (131) -2θ ($1\bar{3}1$) of unheated and heated plagioclases (table IV); the accuracy of measurement varies between 0·005° and 0·02°

Anal.	Unheated	Heated 14 days at 1100° C	Heated 28 days at 1100° C
1 (G. 151)	1·843°	1·902°	1·906°
2 (P. 946)	1·825	1·836	1·838
3 (H. 270)	1·791	1·813	1·810
4 (P. 410)	1·796	1·857	1·850
5 (P. 186)	1·818	1·858	1·865

after heating have been plotted in fig. 4, and, with the exception of no. 1, the heated plagioclases do not closely approach the high temperature synthetic curve. It is considered that this synthetic curve will only be approached by plagioclases with a low content of potassium, so that with increasing Or the values of 2θ (131) -2θ ($1\bar{3}1$) for high temperature plagioclases will decrease. This decrease is illustrated in fig. 3 where curves of variation of 2θ (131) -2θ ($1\bar{3}1$) for heated natural plagioclases show a progressive decrease with increase in Or. The curves could be continued into the anorthoclase field, but with considerable Or, the 131 peak approaches the $04\bar{1}$ and $02\bar{2}$ peaks, and as the feldspar becomes richer in potassium, the 131 and $1\bar{3}1$ peaks move closer together to eventually coincide in monoclinic feldspars.

The lattice parameters of the five unheated and two heated plagioclases are given in table IV. On heating, the parameters change in the same direction as that found by Smith (1956), and the unheated

parameters again indicate an intermediate thermal state, but closer to the synthetic high-temperature plagioclases.

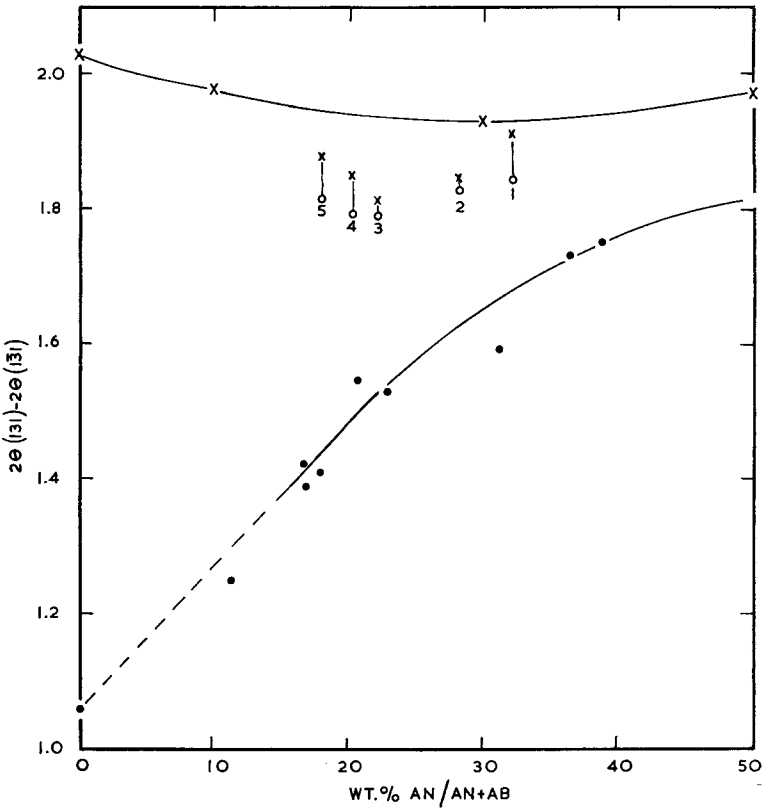

FIG. 4. Plot of 2θ (131)-2θ ($1\bar{3}1$) of the analysed plagioclases (table IV) before (open circles) and after (crosses) heat treatment (table VI). The upper curve is for the high-temperature synthetic plagioclases, and the lower curve for the low-temperature plagioclases (Smith, 1956).

Conclusions. The curves of variation of α^* and 2θ ($20\bar{1}$) indicate that the ternary composition of feldspars more potassic than approximately Or_{15} can be determined by X-ray methods. For feldspars less potassic than Or_{15}, the results obtained confirm Smith's (1956) conclusion of the impossibility of determining the plagioclases by X-ray methods.

It is the authors' opinion that much of the internal inconsistency in the variation curves of figs. 2 and 3 is due not so much to inaccuracies in the lattice parameters, as to inferior chemical analyses. If the feldspar

sample is pure, then the feldspar composition calculated from the weight percentages of CaO, Na_2O, and K_2O (and BaO and SrO where appropriate) should be within the limit 98·0 to 102·0 in a reasonably good analysis. Furthermore, the amounts of SiO_2 and Al_2O_3 ($+Fe_2O_3$) should be somewhere near the correct proportions, so that if these determinations are made, great care should be taken to ensure the complete separation of SiO_2 from R_2O_3, and also the separation of Pt, Pd, and Au (from the utensils) from the R_2O_3 precipitate.

Chayes and Zies (1962) have suggested that 'the possibility of systematic departure from the assumed 1:1:6 ratio of $RO:R_2O_3:SiO_2$ in alkali feldspars deserves more than casual consideration'. However, until much better analytical data on carefully purified material become available, we prefer to assume that the 1:1:6 ratio will be closely adhered to.

With the determination of the lattice parameters of synthetic ternary feldspars, the curves of figs. 2 and 3 could acquire some precision, but until then they should be used with caution.

The existence of different structural states in the plagioclase series is well known but the possibility of different structural states among anorthoclases has not been investigated in detail. The correspondence between the lattice parameters of synthetic alkali feldspars and those of homogeneous natural calcium-poor anorthoclases suggests that the natural feldspars are structurally very similar to their synthetic counterparts, and this in turn suggests that there is a tendency for the K atoms to hinder ordering within the Al/Si framework. (Heating at 900° C for 24 hours to homogenize those anorthoclases that were unmixed in their natural state is unlikely to have appreciably affected the Al/Si distribution in these feldspars.) Although the data are admittedly limited, this view is supported by the results obtained for the change in 2θ (131)$-$ 2θ ($1\bar{3}1$) in the plagioclase feldspars (table VI). The plagioclases that have the highest potassium content (nos. 2 and 3) show the least change in 2θ (131)-2θ ($1\bar{3}1$) as a result of heat treatment at 1100° C.

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References

Bowen (N. L.) and Tuttle (O. F.), 1950. The system $NaAlSi_3O_8$–$KAlSi_3O_8$–H_2O. Journ. Geol., Chicago, vol. 58, p. 489 [M.A. **11**–325].

Carmichael (I. S. E.), 1960. The feldspar phenocrysts of some Tertiary acid glasses. Min. Mag., vol. 32, p. 587.

CARMICHAEL (I. S. E.), 1962. Pantelleritic liquids and their phenocrysts. Min. Mag. vol. 33, p. 86.

—— 1963. The crystallization of feldspar in volcanic acid liquids. Quart. Journ. Geol. Soc., vol. 119, p. 95.

CHAYES (F.) and ZIES (E. G.), 1962. Sanidine phenocrysts in some peralkaline volcanic rocks. Ann. Rept. Geophysical Laboratory, Yearbook 61.

DONNAY (G.) and DONNAY (J. D. H.), 1952. The symmetry change in the high-temperature alkali-feldspar series. Amer. Journ. Sci., Bowen vol., p. 115.

HAKLI (A.), 1960. On high-temperature alkali feldspars of some volcanic rocks of Kenya and Northern Tanganyika. Bull. Comm. Géol. Finlande, vol. 32, p. 99.

JOYCE (J. R. F.) and GAME (P. M.), 1952. Note on anorthoclase from Nigeria. Bull. British Museum (Natural History), vol. 1, p. 85.

MACKENZIE (W. S.), 1952. The effect of temperature on the symmetry of high-temperature soda-rich feldspars. Amer. Journ. Sci., Bowen volume, p. 319.

—— and SMITH (J. V.), 1956. The alkali feldspars. III. An optical and X-ray study of high-temperature feldspars. Amer. Min., vol. 41, p. 405.

ORVILLE (P. M.), 1963. Alkali ion exchange between vapour and feldspar phase. Amer. Journ. Sci., vol. 261, p. 201.

SMITH (J. R.), 1958. The optical properties of heated plagioclases. Amer. Min., vol. 43, p. 1179.

SMITH (J. V.), 1956. The powder patterns and lattice parameters of plagioclase feldspars. I. The soda-rich plagioclases. Min. Mag., vol. 31, p. 47.

—— and MACKENZIE (W. S.), 1955. The alkali feldspars. II. A simple X-ray technique for the study of alkali feldspars. Amer. Min., vol. 40, p. 733.

—— —— 1958. Alkali feldspars. IV. The cooling history of high-temperature sodium-rich feldspars. Ibid., vol. 43, p. 872.

SPENCER (E), 1937. The potash-soda feldspars. I. Thermal stability. Min. Mag., vol. 24, p. 453.

TUTTLE (O. F.), 1952. Optical studies of alkali feldspars. Amer. Journ. Sci., Bowen vol., p. 553.

WILKINSON (J. F. G.), 1962. Mineralogical, Geochemical, and Petrogenetic aspects of an analcite-basalt from the New England district of New South Wales. Journ. Petrology, vol. 3, p. 192.