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The variation of the $\bar{2}01$ reflection in plagioclases

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SUMMARY. The position of the $\bar{2}01$ X-ray reflection in albite varies with the degree of Al/Si ordering. This is also true for binary plagioclases but the $\bar{2}01$ reflection for high-temperature plagioclases is constant and therefore independent of anorthite content. For plagioclases of ternary composition grown in a hydrous silicate melt, the position of the $\bar{2}01$ reflection gives a good estimate of the orthoclase content when a determinative curve is used that was originally drawn from data on high-temperature synthetic binary alkali feldspars.

FOR alkali feldspars the $2\theta_{\bar{2}01}$ method of determining composition is convenient and fairly accurate. The degree of Al/Si ordering has some influence on the $2\theta_{\bar{2}01}$ value and this factor is usually allowed for in one of two ways, viz. choosing determinative curves that have been drawn for feldspars of similar Al/Si order (for example, see Orville, 1967; Parsons, 1968) or heat treating the unknown feldspar until it has a high Al/Si disorder and then using the determinative curve drawn for high-temperature synthetic feldspars. All synthetic feldspars are usually considered to be highly disordered but depending on the temperature of crystallization some degree of ordering will be present. Therefore, some small error must be introduced by using a curve based on data for feldspars crystallized at a certain temperature to determine the composition of a feldspar crystallized at some other temperature (the curve used in Manchester is drawn for feldspars crystallized at 850 °C and 1 kb P_{H_2O}; using this curve to determine the composition of feldspars crystallized in a hydrous melt at, say 650°, will introduce some error). Working curves are usually drawn using the data for feldspars in the $NaAlSi_3O_8$–$KAlSi_3O_8$ binary join, but the composition of natural feldspars and some synthetic ones are not thus restricted in composition. Natural alkali feldspars will contain a small variable amount of anorthite and the $2\theta_{\bar{2}01}$ working curve is thought to give the percentage of orthoclase, the remainder being mostly albite plus a small unknown amount of anorthite. If significant amounts of Rb, Sr, or Ba are present in the feldspar the $2\theta_{\bar{2}01}$ determination may be of doubtful value (Dr. R. Nesbitt, personal communication).

In the case of the plagioclase feldspars no convenient X-ray method is available for composition determination. Since the $2\theta_{\bar{2}01}$ determination of alkali feldspar containing some anorthite is thought to give the percentage of orthoclase, does the $2\theta_{\bar{2}01}$ value of plagioclases and anorthoclases give a reliable estimate of the orthoclase content?

This is the question we set out to answer in this study. A knowledge of the orthoclase content is far from a complete knowledge of the composition of plagioclases and at first sight seems even trivial. However, as lines of equal orthoclase content in the system $NaAlSi_3O_8$–$KAlSi_3O_8$–$CaAl_2Si_2O_8$ are subparallel, for much of their length, to the boundary separating the field of one plagioclase from the two feldspar field, the orthoclase content will have a special significance. In an experimental study a knowledge of the orthoclase content may be used in the positioning of this field boundary at various temperatures; conversely, the orthoclase content of natural feldspars may be a guide to their temperature of crystallization. The problem then is to evaluate the separate effects on the $2\theta_{\bar{2}01}$ of ternary plagioclases of Al/Si ordering, of anorthite content, and of orthoclase content. MacKenzie (1957) made an extensive study of Al/Si ordering in albite and the products of his runs were made available to us. These well-documented synthetic feldspars of fixed composition were a logical choice for a starting point in the investigation of the influence of Al/Si ordering on the $2\theta_{\bar{2}01}$ value of feldspars.

The effect of changing composition on $2\theta_{\bar{2}01}$ was first studied in the binary plagioclase series and then extended to include some ternary feldspars.

Experimental methods

Conventional cold-seal or internally heated pressure vessels were used in the hydrothermal experiments. In both types of apparatus the temperature is considered to be no worse than $\pm 5°$ from the published value. In all the experiments the powdered charge was sealed in a noble metal tube with sufficient water to provide a small excess of water-rich vapour under the P.T. conditions of the experiment.

X-ray powder patterns were taken using a Philips high-angle diffractometer. In all cases Ni filtered Cu radiation was used, and the settings of the goniometer were: receiving slit 0·1 mm, scatter and divergence slits 1°. Specimens were normally scanned at $\frac{1}{4}°$/min. For $2\theta_{\bar{2}01}$ determinations $KBrO_3$ was mixed with the feldspar as an internal standard (Orville, 1958). The symbol $\Delta\bar{2}01$ used hereafter denotes the distance between the 101 reflection of $KBrO_3$ and the $\bar{2}01$ of a feldspar measured on a diffraction chart.

The distance separating peaks was measured with a rule and vernier (capable of measuring to 0·001 in.) from the centre of the peak $\frac{2}{3}$ above the general level of the background. The position of the 101 $KBrO_3$ peak was taken to be 20·200° 2θ.

The required 2θ range was usually scanned four times but for the poorly crystallized feldspars the range was scanned six or eight times. For well-crystallized feldspars producing sharp nearly symmetrical $\bar{2}01$ peaks the $\Delta\bar{2}01$ is reproducible from pattern to pattern and operator to operator to 0·005° 2θ. Poorly crystallized samples yield smaller, less sharp peaks with a corresponding decrease in reproducibility of measurements.

Albite. The position of the $\bar{2}01$ reflection for a number of MacKenzie's albites has been measured and the $\Delta\bar{2}01$ values are shown plotted against their $\Delta131$ values in fig. 1 and listed in table I. Also included on this figure are Amelia albite, representing a highly ordered form, and also an albite crystallized from a powdered-glass starting material at 905 °C and 1000 bars water pressure, representing a highly disordered form. There appears to be no simple relationship between $\Delta\bar{2}01$ and degree of order (as measured by $\Delta131$). If, however, only feldspars that have reached equilibrium for their temperature of crystallization are considered (i.e. those on the flat parts of

MacKenzie's graphs in his fig. 4) there seems to be more than a random scatter arrangement. The points representing these so-called equilibrium feldspars are shown as stars and a dashed line has been drawn through these points and including Amelia albite. No explanation can be given at this time for the large scatter of the non-equilibrium albites.[1] The composition of the worst (most distant from the line) of these non-equilibrium albites as determined on our $\bar{2}01$ working curve would be

TABLE I. *$\Delta 131$ and $\Delta\bar{2}01$ values for synthetic albites crystallized at various temperatures and pressures and for different durations and also for low albite and heated low albite. Data for LA (low albite) and HA (high albite) taken from Smith (1956); all other $\Delta 201$ values are new. Run data and $\Delta 131$ values for runs prefixed M taken from MacKenzie (1957). H297 new data. Runs marked with an asterisk are shown as stars in fig. 1*

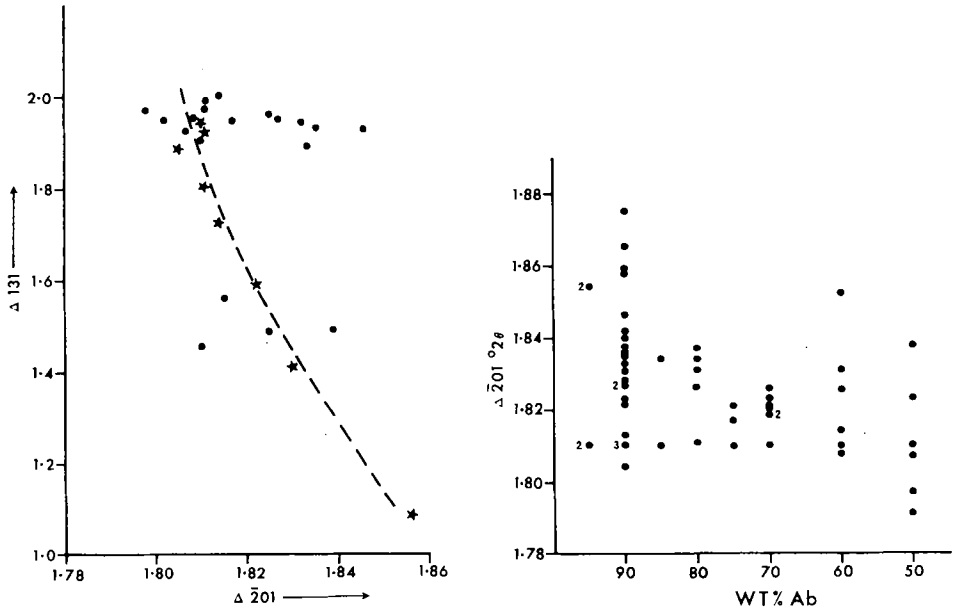
Run no.	Temp. °C	Time hours	P_{H_2O} lb/in.$^2 \times 10^3$	$\Delta 131$	$\Delta\bar{2}01$
M307	1000	66	2	2·008	1·814
H297	905	192	15	1·988	1·811
M330	900	41	7	1·982	1·811
*M227	850	1440	14	1·944	1·810
M226	850	984	14	1·953	1·802
M144	850	360	14	1·951	1·809
*M225	800	1440	14	1·925	1·811
M127	800	24	14	1·954	1·827
M74	800	24	14	1·945	1·832
*M222	750	1422	14	1·883	1·805
M180	750	53	14	1·926	1·807
M179	750	24	14	1·952	1·810
M178	750	24	14	1·944	1·817
*M230	700	1200	14	1·799	1·811
M28	700	74	28	1·891	1·834
M18	700	20	28	1·934	1·846
M19	700	20	28	1·936	1·835
M135	700	12	28	1·959	1·825
*M220	600	1761	14	1·730	1·814
*M295	525	888	14	1·594	1·822
*M219	500	2680	14	1·410	1·830
M252	500	2178	14	1·461	1·810
M248	500	1579	14	1·493	1·825
M218	500	1220	14	1·489	1·839
M247	500	620	14	1·559	1·815
*LA	—	—	—	1·085	1·856
HA	—	—	—	1·975	1·798

$Ab_{103}Or_{\ 3}$ wt %, clearly an impossible result arising because of Al/Si order/disorder phenomena.

MacKenzie (1957) used $\Delta 131$ as an indicator of order/disorder but from his fig. 4 it can be seen that several albites that have had different thermal histories can have identical $\Delta 131$s. That these albites are not structurally equivalent is indicated by their

[1] The reproducibility of $\Delta\bar{2}01$ for the equilibrium albites for up to eight oscillations on the same smear mount is excellent, the largest variation between least and greatest measurements being 0·002° 2θ. The corresponding variation for the non-equilibrium albites is not so small but rarely exceeds $\pm$0·005° 2θ.

different behaviour on X-raying at elevated temperatures (MacKenzie, personal communication). A comparison of their cell parameters seems a possible way to show any difference but in fact there is no significant difference (Grundy, 1966). It is possible that the method of least squares used in the calculation of the cell parameters has smoothed out any small differences, certainly the much simpler plot shown in fig. 1 shows that albites with identical $\Delta 131$s do not necessarily have identical $\bar{2}01$s and are thus not structurally equivalent.



FIGS. 1 and 2: FIG. 1 (left). Plot of $\Delta 131 = 2\theta_{131}-2\theta_{\bar{1}31}$ against $\Delta 201 = 2\theta_{\bar{2}01}-2\theta_{101KBrO_3}$ for albites listed in table I. The stars represent the plot of MacKenzie's 'equilibrium albite' (MacKenzie, 1957) and also Amelia albite. FIG. 2 (right). Plot of $\Delta\bar{2}01$ for synthetic binary plagioclases. 2 = 2 feldspars overplot; 3 = 3 feldspars overplot. The data used to draw the diagram and the thermal history of the plagioclases are presented in table II.

Binary plagioclases. The results from the study of the effect of order/disorder on the $\bar{2}01$ spacing in albite were not very encouraging but nevertheless we have extended this work to the binary plagioclases. The $\Delta\bar{2}01$ values for all our synthetic plagioclases are shown plotted against bulk composition in fig. 2. The conditions of crystallization of the plagioclases are given in table II. The $\bar{2}01$ peaks for these plagioclases are not as large or as symmetrical as the $\bar{2}01$ peaks of MacKenzie's albites. In four measurements of the distance 101_{KBrO_3}–$\bar{2}01_{feldspar}$ there is commonly a difference of about 0·020° between the greatest and least measurement. Thus the reproducibility of the $\Delta\bar{2}01$ values listed in table II is in general $\pm$0·010° 2θ; feldspars produced in high-temperature runs (i.e. >900 °C) have larger X-ray reflections and a smaller spread on several 101_{KBrO_3}–$\bar{2}01_{feldspar}$ measurements.

The conclusion that can be drawn from fig. 2 is that the thermal history of a binary

plagioclase can affect the position of its $\bar{2}01$ reflection. The amount of data at our disposal is insufficient to enable us to draw any conclusions about the relationships between time and temperature of crystallization, anorthite content, and position of the $\bar{2}01$ reflection, except for plagioclases crystallized at high temperatures. For plagioclases crystallized at temperatures near to their solidus temperature (either just below

TABLE II. *Run and X-ray data for synthetic binary plagioclases. All the $\Delta\bar{2}01$ values have been used in plotting fig. 2; products of runs marked with an asterisk are considered to be highly disordered and data from these have been used to draw two curves in fig. 3*

Starting composition Ab	Run No.	Temp. °C	Time days	P_{H_2O} kb	$\Delta\bar{2}01$ °2θ	Starting composition Ab	Run No.	Temp. °C	Time days	P_{H_2O} kb	$\Delta\bar{2}01$ °2θ
95	E1	850	7	1	1·834	80	214	850	6	1	1·837
	E2	700	14	1	1·834		E6	700	11	1	1·834
	*299	900	8	1	1·810		A47	750	21	1	1·831
	49	756	5	5	1·810		A48	750	21	1	1·826
90	A71	700	10	1	1·875		*302	900	8	1	1·811
	A101	600	21	1	1·866	75	303	905	8	1	1·821
	A112	600	10	1	1·859		E7	850	7	1	1·817
	A31	800	11	1	1·858		*320	965	7	1	1·810
	A44	725	22	1	1·846	70	E8	800	7	1	1·826
	A111	700	30	1	1·842		E9	800	6	1	1·823
	A66	750	21	1	1·840		304	905	8	1	1·821
	A13	700	21	1	1·837		E10	700	10	1	1·820
	E3	700	10	1	1·836		184	850	12	1	1·819
	E4	850	14	1	1·835		E11	775	21	1	1·818
	A110	800	30	1	1·833		*319	965	7	1	1·810
	A103	800	21	1	1·831	60	E12	700	10	1	1·852
	A90	850	15	1	1·828		E13	800	7	1	1·831
	A64	700	15	1	1·827		215	850	6	1	1·826
	A115	800	45	1	1·827		305	900	8	1	1·814
	A65	850	21	1	1·823		*318	965	7	1	1·810
	A6	850	6	1	1·822		E14	800	21	1	1·808
	A63	700	15	1	1·813	50	E16	800	9	1	1·838
	A89	850	10	1	1·810		E15	700	11	1	1·823
	A78	850	35	1	1·810		*317	865	7	1	1·810
	*300	900	8	1	1·810		E17	825	21	1	1·807
	A96	850	45	1	1·804		183	850	13	1	1·797
85	E5	850	7	1	1·834		306	900	8	1	1·791
	*301	900	8	1	1·810						

or just above) the $\Delta\bar{2}01$ value is constant and hence independent of anorthite content. The $\Delta\bar{2}01$ values for these high-temperature feldspars are shown in fig. 3 together with their $\Delta131$ values. One possible explanation of the fact that both the $\Delta\bar{2}01$ and $\Delta131$ values of these high-temperature plagioclases are essentially constant over the considered range of anorthite content is that they all have the same high degree of Al/Si disorder and $2\theta_{\bar{2}01}$ is truly independent of anorthite content.

For comparison, fig. 3 includes the $\Delta131$ and $\Delta201$ values of a number of low-temperature natural plagioclases. The data for these natural feldspars have been taken from Smith (1956) and Grundy (1966). All these feldspars are described as 'low-temperature' by Smith and Grundy. Two dashed lines have been added to fig. 3, which show, in a very general way, the changes of $\Delta\bar{2}01$ and $\Delta131$ with plagioclase

composition for the natural feldspars. Intermediate-temperature plagioclases might be expected to have $\Delta 131$ and $\Delta\bar{2}01$ values that plot in the areas between the two sets of data representing high-temperature and low-temperature examples respectively, but many of the other plagioclases of fig. 2 do not plot in these areas.

Ternary plagioclases. From the previous section it seems possible that the position of the $\bar{2}01$ reflection of the most highly disordered binary plagioclases is independent

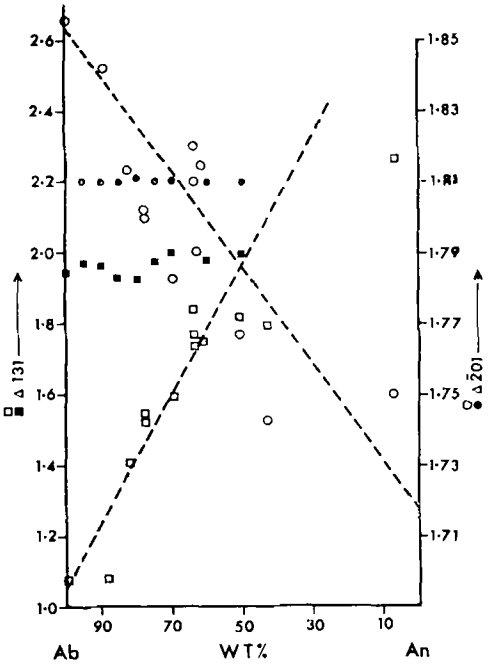


FIG. 3. Plots of $\Delta 131$ and $\Delta\bar{2}01$ against composition for both synthetic and natural plagioclases: ■ = $\Delta 131$ and ● = $\Delta\bar{2}01$ for synthetic plagioclases; □ = $\Delta 131$ and ○ = $\Delta\bar{2}01$ for natural plagioclases. Data for the natural plagioclases have been taken from Smith (1956) and Grundy (1966) and are for low-temperature varieties. The synthetic feldspars have been selected from table II as representing a high temperature state, and are marked with an asterisk in table II. The dashed lines show the general trend of the natural feldspars.

of composition. To test the influence of orthoclase content on $\Delta\bar{2}01$, a number of ternary feldspar compositions were crystallized at high temperature. The results of these experiments are set out in table III. There is fairly good agreement between the actual and determined orthoclase content for the feldspars of low anorthite content, the degree of disagreement increasing with increasing anorthite. Two of the plagioclases with 40 % anorthite that were crystallized at low temperatures actually give negative orthoclase contents. Ternary plagioclases are notoriously difficult to crystallize and the $\bar{2}01$ peaks for these high-anorthite plagioclases are significantly broader and shorter than the $\bar{2}01$ peaks of albite. This poor crystallinity may be responsible

for the shift of the $\bar{2}01$ peak to higher 2θ values; to test this assumption several plagioclases grown in a water-saturated silicate melt were X-rayed. Plagioclases grown in such a melt form larger, better shaped crystals than those grown hydrothermally but in the absence of melt the position of the X-ray peaks should be unaffected by poor crystallinity. Table IV shows the details of the experiments performed to grow ternary plagioclases; in all cases the products of the experiments were crystals plus glass. The plagioclase crystals were kindly analysed on a microprobe by Dr. J. V. Smith.

TABLE III. *Run and X-ray data for a number of synthetic ternary feldspars. The* Or* *content in the last column has been determined from a graph of* $\bar{2}01$ *v. composition drawn for synthetic feldspars crystallized at 850 °C and 1 kb* P_{H_2O}

Composition		Run	Temp.	Time	P_{H_2O}	$\Delta\bar{2}01$	
An	Or	no.	°C	days	kb	°2θ	Or*
5	9·5	506	870	10	½	1·705	9·5
		80	810	5	1	1·714	8·5
		228	700	13	5	1·719	8
10	9·2	489	905	11	½	1·711	9
		513	870	10	½	1·719	8
		92	805	8	1	1·714	8·5
		459	795	12	1	1·730	7
		171	700	2	5	1·714	8·5
40	3	321	965	7	1	1·797	1
		314	900	7	1	1·795	1·5
		174	800	14	1	1·810	0
		433	695	26	1	1·824	−3
20	10	494	905	11	½	1·760	4·5
		520	868	10	½	1·744	6
		409	828	7	1	1·734	6·5
		432	695	26	1	1·829	−4
40	6·2	316	900	7	1	1·786	2
		158	850	10	1	1·810	0
		136	850	10	1	1·810	0
		175	800	14	1	1·810	0
		103	730	5	5	1·810	0
		8	700	18	1	1·832	−2·5

By comparing the last two columns of table IV it can be seen that there is good agreement between the orthoclase content determined by the two methods even for crystals having up to 27 % anorthite. The probe results show that the crystals were zoned; the orthoclase content determined by X-rays is in every case within the compositional spread indicated by the probe analysis.

Natural feldspars. During a study of feldspar phenocrysts from basalt xenoliths[1] in a nordmarkite Kempe found a very poor correlation between their orthoclase contents from chemical analysis and from a $\bar{2}01$ determinative curve (Kempe, 1966, and personal communication). The phenocrysts were originally microperthites of the low-albite–orthoclase series but had been heated to 1025 °C in air to homogenize them

[1] From the Kangerdlugssuaq alkaline intrusive, East Greenland.

TABLE IV. *A comparison of the orthoclase content of feldspar crystals determined on the probe and from a standard $\bar{2}01$/composition graph. The feldspar crystals have been grown in a hydrous melt; the bulk composition of crystals+melt is shown in the first two columns. The compositions of the feldspar crystals determined on the probe are shown in columns 7 and 8 and by the $\bar{2}01$ method in the last column. Probe analyses by J. V. Smith*

Bulk composition			Run	T °C	Time days	P_{H_2O} kb	Probe composition		Or $\bar{2}01$
Ab	An	Or					An	Or	
80·8	10	9·2	18	780	4½	5	18·1–20·1	1·4–2·8	2·5
72	10	18	29	800	3	5	20·8–24·3	4·3–7·1	4·5
			51	780	3	5	18·7–23·6	3·6–5·0	4·5
			105	770	6	5	23·6–27·8	2·1–3·6	3·5

TABLE V. *A comparison of orthoclase content determined on a standard $\bar{2}01$/composition curve for three natural feldspars after dry homogenization and after hydrothermal recrystallization. The analysed specimens were kindly provided by Dr. D. R. C. Kempe who also did the dry homogenization*

Specimen no.	Chemical analysis			Or content determined from $\bar{2}01$	
	Ab	An	Or	Homogenized dry at 1025 °C	Recrystallized hydrothermally
4655	69·9	11·2	18·9	14·5	16·5 (large) 37·6 (small)
4656	70·8	11·7	17·5	10·0	12·0 (large) approx. 46 (small)
4658	71·2	9·6	19·2	13·0	18·0

before determining the position of the $\bar{2}01$ peaks. The orthoclase contents determined by X-rays were lower (by as much as 7·5 wt % in the worst case) than that determined by wet chemical analysis. Suspecting that the dry homogenization may have only been effective with respect to the alkalis[1] but not to the Al/Si ordering, one of us (D. L. H.) offered to hydrothermally melt and recrystallize several specimens. Dr. Kempe kindly provided three feldspars, the details of which are set out in table V. In all three examples the orthoclase content given by the $\bar{2}01$ position for the specimens after dry heating is too low. Assuming that the dotted line in fig. 1 describes the effect of ordering on the

[1] Parsons (1968) has discussed the problem of the homogenization of alkali-feldspars by heat treatment and has suggested that the probable cause of the poor correlation of feldspar composition determined by chemical analysis and the $\bar{2}01$ method is incomplete homogenization of the Na and K atoms during heating. For feldspars having less than about 20 wt % Or, failure to homogenize with respect to alkalis and to become highly disordered with respect to Al/Si will both cause the position of the $\bar{2}01$ peak to be at too high an angle. Enough data is not available for us to decide which of these two imperfections is responsible for the low orthoclase content of the feldspars heat-treated by Dr. Kempe. The discrepancy between wet chemical and $\bar{2}01$ analysis is unusually large and probably the heat treatment was insufficient on both accounts.

$\bar{2}01$ position of Na-rich feldspars in general, this low orthoclase content would be expected from applying the $\bar{2}01$ value from an ordered feldspar to a determinative curve drawn for disordered feldspars.

The three samples were melted at 1000 °C and 5 kb P_{H_2O}, held for several hours and quenched, and the resulting clear glass was ground and run again at 860 °C and 1 kb for four days. Under these conditions the hydrous glass crystallized entirely to feldspar; the orthoclase content of these recrystallized feldspars is listed in column 4 of table V. Only one of the three recrystallized samples had a single $\bar{2}01$ peak and its orthoclase content from the $\bar{2}01$ determinative graph is 18·0 compared with 19·2 from wet chemical analysis and 13·0 for the sample after the dry heating (Kempe 1966). The other two recrystallized samples each had two $\bar{2}01$ peaks but in each case the orthoclase content of the major feldspar represented by the larger $\bar{2}01$ peak is closer to the orthoclase content of the chemical analysis than is the orthoclase content deduced from the single $\bar{2}01$ peak of the dry-homogenized sample. The orthoclase content of the major plus minor feldspars will be even closer to that of the chemical analysis.

Summary and conclusion. The data plotted in fig. 1 indicates that there is a simple straight-line relationship between the degree of ordering of Al/Si and the position of the $\bar{2}01$ reflection for albites that have reached equilibrium at their temperature of crystallization. For non-equilibrium albites there seems to be no such simple relation.

The position of the $\bar{2}01$ peak and $\Delta 131$ of binary plagioclase crystallized with a hydrous silicate melt present are independent of anorthite content. By analogy with the case of pure albite and because the results are highly reproducible these feldspars may be considered to have reached equilibrium at their temperatures of crystallization. For binary plagioclases crystallized hydrothermally but without melt there appears to be no simple relationship between composition, degree of Al/Si order, and position of the $\bar{2}01$ reflection. This apparent lack of any correlation may be due to the difficulty of reaching the equilibrium state of Al/Si order for a given temperature. This latter statement is pure supposition, based only on a comparison with the clearer state of affairs for albite, on the many inconsistencies and poor reproducibility of results found in this part of the study, and on the poor intensities and diffuse nature of the X-ray peaks for plagioclases crystallized in the absence of a hydrous silicate melt.

The main conclusions that are apparent from the work so far are that the $2\theta_{\bar{2}01}$ value of plagioclases is independent of anorthite content but dependent on the state of Al/Si ordering; further, $\Delta 131$ of ternary plagioclases is dependent on temperature of crystallization, on degree of attainment of Al/Si equilibrium, and on orthoclase content. A knowledge of $\Delta 131$ will therefore be of no help in deducing the degree of Al/Si order or which $\bar{2}01$ determinative curve to use (Orville, 1967, has presented $\bar{2}01$ determinative curves for high-temperature and intermediate-temperature feldspars). With the present state of our knowledge the use of $2\theta_{\bar{2}01}$ for determining the orthoclase content should be restricted to synthetic plagioclases crystallized in a high-temperature melt or plagioclases crystals that have been disordered by a suitable heat treatment. The work done on the three feldspars provided by Kempe suggest that in some cases even prolonged heating at high temperatures is not adequate to prepare feldspars for a $\bar{2}01$ determination. If, however, the feldspar is totally recrystallized

at high temperatures the orthoclase content determined from the $\bar{2}01$ peak is in good agreement with the wet chemical analyses.

Carmichael and MacKenzie (1964) have presented the analysis and $2\theta_{\bar{2}01}$ for a number of plagioclase phenocrysts (G.P. 946, H. 270, P. 410, P. 186), all of which come apparently from quenched high-temperature assemblages. In their fig. 1 these plagioclases are plotted on the wt % orthoclase *v.* $2\theta_{\bar{2}01}$ diagram and compared to a high-temperature $\bar{2}01$ determinative curve. The fit of these four points on the curve is not good but there is no simple correlation between anorthite content and deviation from the curve, which indicates that the $2\theta_{\bar{2}01}$ value is being influenced by some other property and may in fact be independent of anorthite content. The points all plot above the curve, that is in the direction of higher 2θ values, and in fact they plot very close to Orville's (1967) curve for low-temperature alkali-feldspars. The obvious explanation for the facts is that the plagioclases are low-temperature varieties and the phenocrysts (especially 1, 2, and 3) may have crystallized from a relatively low-temperature melt at some depth in the earth's crust.

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