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Autor(en): **Starkey, John**

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On the Relationship of Pericline and Albite Twinning to the Composition and Structural State of Plagioclase Feldspars

By *John Starkey* (London, Ont., Canada)*)

With 3 figures and 2 tables in the text

Abstract

Published crystallographic data from X-ray analyses of 105 plagioclase feldspars have been collected and, where possible, the complete lattice angles have been calculated. From these data the orientation of the rhombic section and the obliquity of albite twins have been determined and the dependence of these parameters on both composition and structural state is demonstrated.

It is shown how information concerning the history of a plagioclase crystal may be obtained by measuring the orientation of the composition planes of secondary pericline twins. The possible influence of the obliquity on twinning is also discussed.

It is suggested that the ease of development of glide twins in the plagioclase feldspars is related to the crystal structure.

INTRODUCTION

The secondary origin of polysynthetic albite and pericline twins in plagioclase feldspars was first recognised independently by JUDD (1885), LEHMAN (1884) and VAN WERVEKE (1883) and more recently by ALLING (1936) and EMMONS and GATES (1943) among others. The secondary origin of the twinning in chess-board albite has been demonstrated by STARKEY (1959). Polysynthetic twins have been produced experimentally in feldspars by FÖRSTNER (1884), MÜGGE and HEIDE (1931), BORG, HANDIN and HIGGS (1959) and STARKEY and BROWN (1964). There is no

*) Prof. J. Starkey, University of Western Ontario, Department of Geology, London, Ontario, Canada.

compelling evidence that polysynthetic albite and pericline twins in plagioclase feldspars can be of primary origin (i. e. growth twins). This view is opposed to that expressed by VANCE (1961).

The study of secondary twinning in feldspars is of interest not only for its own sake but also because of the information which can be gained about the history of the crystals and therefore of the host rock. Earlier studies along these lines have centered on the variations in the attitude of the twin elements relative to the crystal lattice as a function of both chemical composition and structural state. Unfortunately the earlier conclusions were based on very meagre data and it seems opportune at the present time to attempt to remedy this deficiency.

THE DATA

Published crystallographic data for a large number of plagioclase feldspars have been collected and, where possible, the direct and reciprocal lattice angles have been calculated. The results of this compilation are presented in Tables 1 and 2. The calculations were made with the I.B.M. 7040 Computer at the University of Western Ontario. The sources of the data recorded in Tables 1 and 2 are annotated below.

Table 1: Values for α, γ, α^* and γ^* have been taken from LAVES and CHAISSON (1950, Table 1); the data are all from albites. Specimen number 1[1]) is a natural low albite and specimens 2 and 3 are the same material after heat treatment. Specimens 4 and 5 are synthetic.

Table 2: Reference 1[2]), GOLDSMITH and LAVES (1955, Table 1). Values of α^*, γ^* and β are given for a synthetic anorthite. The remaining lattice angles have been calculated from the following expressions:

$$\cos\beta^* = \left(\frac{\cos\alpha^*\cos\gamma^*}{\sin\gamma^*\sin\alpha^*} - \cos\beta\right)\sin\alpha^*\sin\gamma^*, \tag{1}$$

$$\cos\alpha = \frac{\cos\gamma^*\cos\beta^* - \cos\alpha^*}{\sin\gamma^*\sin\beta^*}, \tag{2}$$

$$\cos\gamma = \frac{\cos\alpha^*\cos\beta^* - \cos\gamma^*}{\sin\alpha^*\sin\beta^*}. \tag{3}$$

Reference 2, BROWN (1960, Tables 2 and 3). BROWN measured α^*, γ^* and β for forty-five natural plagioclase feldspars selected from probable

[1]) The specimen numbers used throughout are those listed in the first columns of Tables 1 and 2 under Js. No.

[2]) The reference numbers are listed in Table 2, column 2.

low temperature environments; he excluded specimens which showed peristerite unmixing. BROWN measured the same parameters for fifteen of the specimens after heating. The compositions of the feldspars were determined optically except for five specimens for which chemical analyses were available (BROWN, op. cit. Table 1), these are specimens 15, 46, 65, 76 and 87. Values for β^*, α and γ have been computed from the expressions given under Reference 1.

Reference 3, BROWN (1960, Table 4). BROWN measured α^* and γ^* and calculated β^* for two feldspars after successive heat treatments. The compositions were determined optically. Values for α and γ have been derived from expressions 2 and 3. Values for β have been calculated from the following expression:

$$\cos\beta = \frac{\cos\alpha^*\cos\gamma^* - \cos\beta^*}{\sin\alpha^*\sin\gamma^*}. \tag{4}$$

Reference 4, COLE, SÖRUM and TAYLOR (1951, Table 4). Complete lattice parameters are given for three natural feldspars, an albite, a labradorite and an anorthite. The albite has been analysed chemically by SPENCER (1935—1937, Table 1, Specimen T); it occurs in mica-pegmatites and is probably of low temperature origin. The composition of the labradorite has been determined by EMMONS as $An_{56.1}$ from

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Table 1

Data from LAVES and CHAISSON (1950), see text. In column 1 are listed the specimen numbers allocated in the present study; the specimen numbers in column 2 are from the original reference.

Js. No.	No.	An	Type	Alpha	Gamma	Alpha Star	Gamma Star	Sigma	Phi
1	1	0.00	1	94.333	87.650	86.333	90.500	32.686	4.362
2	2	0.00	3	93.733	89.600	86.000	88.583	5.716	3.993
3	3	0.00	3	93.500	90.150	86.000	88.083	−2.149	3.990
4	5	0.00	4	93.433	90.033	86.133	88.250	−0.489	3.853
5	6	0.00	4	93.433	90.067	86.167	88.267	−1.002	3.845

Table 2

The references from which the data have been obtained are numbered in column 2; see text for details. The specimen numbers in column 1 have been assigned in order of increasing anorthite content. Column 3 lists the specimen numbers recorded in the original literature, a 0 indicates that no specimen number was given. Under AN are listed the compositions in Weight % Anorthite. Under Type are listed the nature of the specimen and its probable structural state, 1 = natural, probably ordered; 2 = natural, probably disordered; 3 = heat treated natural material, disordered; 4 = synthetic feldspar, disordered.

Table 2

Js. No.	Ref.	No.	An	Type	Alpha	Beta	Gamma	Alpha Star	Beta Star	Gamma Star	Sigma	Phi
6	2	27	0.00	1	94.199	116.500	87.741	86.433	63.586	90.433	32.381	4.221
7	2	46	0.00	1	94.223	116.517	87.789	86.383	63.567	90.367	31.471	4.238
8	5	10	0.00	1	94.317	116.667	87.617	86.367	63.433	90.500	33.296	4.345
9	5	1	0.00	3	93.567	116.500	89.983	86.033	63.450	88.250	0.242	3.972
10	7	1	0.00	1	94.260	116.580	87.670	86.400	63.510	90.480	32.944	4.287
11	7	10	0.00	3	93.450	116.430	90.280	86.010	63.500	87.970	–4.017	4.002
12	6	0	0.00	4	93.649	116.447	90.192	85.828	63.481	87.967	–2.637	4.176
13	7	18	0.00	4	93.470	116.390	90.330	85.960	63.530	87.900	–4.673	4.055
14	4	0	0.40	1	94.233	116.517	87.700	86.417	63.567	90.450	32.725	4.257
15	2	50	0.40	1	94.336	116.417	87.700	86.300	63.673	90.417	31.896	4.356
16	8	0	0.50	1	94.333	116.567	87.650	86.333	63.533	90.467	32.688	4.358
17	3	63	0.50	3	92.665	116.358	90.219	86.917	63.600	88.433	–4.072	3.091
18	3	64	0.50	3	92.099	116.305	90.220	87.550	63.667	88.717	–5.126	2.460
19	3	65	0.50	3	90.000	116.117	90.000	90.000	63.883	90.000	–29.832	0.000
20	3	66	0.50	3	90.000	116.167	90.000	90.000	63.833	90.000	–29.832	0.000
21	8	0	0.70	3	93.367	116.300	90.283	86.100	63.633	88.017	–4.158	3.907
22	2	26	2.00	1	94.246	116.350	87.700	86.400	63.740	90.467	32.611	4.271
23	2	28	2.00	1	94.287	116.567	87.712	86.350	63.522	90.417	32.108	4.307
24	2	60	7.00	3	92.269	116.033	90.186	87.383	63.936	88.683	–4.077	2.623
25	7	19	10.00	4	93.520	116.370	90.240	85.950	63.560	87.990	–3.394	4.053
26	2	51	11.00	1	94.181	116.633	88.216	86.217	63.422	89.900	25.265	4.182
27	7	2	11.20	1	94.120	116.560	88.170	86.310	63.500	89.990	26.402	4.120
28	7	11	11.20	3	93.830	116.450	89.240	86.100	63.540	88.940	11.036	3.974
29	7	12	11.20	3	93.620	116.440	89.870	86.030	63.510	88.350	1.877	3.978
30	2	9	13.00	1	93.997	116.533	88.528	86.267	63.502	89.650	21.537	4.013
31	2	9	13.00	3	92.662	116.250	90.301	86.883	63.704	88.350	–5.524	3.131
32	3	68	13.00	3	93.144	116.519	90.339	86.317	63.417	88.050	–5.261	3.699
33	3	69	13.00	3	92.997	116.543	90.299	86.500	63.400	88.167	–4.885	3.513
34	3	70	13.00	3	92.900	116.497	90.286	86.617	63.450	88.233	–4.828	3.395
35	3	71	13.00	3	92.603	116.305	90.294	86.950	63.650	88.383	–5.515	3.064
36	3	72	13.00	3	92.479	116.375	90.301	87.083	63.583	88.433	–5.899	2.932
37	3	73	13.00	3	92.386	116.326	90.345	87.167	63.633	88.433	–6.945	2.854
38	2	10	14.00	1	93.988	116.250	88.655	86.217	63.778	89.533	19.585	4.015
39	2	10	14.00	3	92.421	116.333	90.299	87.150	63.627	88.467	–5.994	2.866
40	2	11	14.00	1	93.974	116.417	88.650	86.233	63.612	89.533	19.728	4.001
41	2	17	16.00	1	94.047	116.450	88.586	86.183	63.582	89.567	20.348	4.070
42	2	17	16.00	3	92.324	116.417	90.279	87.267	63.547	88.533	–5.829	2.748
43	7	3	17.90	1	93.990	116.460	88.580	86.250	63.570	89.600	20.758	4.010
44	7	13	17.90	3	93.480	116.350	90.200	86.020	63.580	88.050	–2.879	3.989
45	2	12	18.00	1	94.013	116.500	88.761	86.133	63.520	89.383	17.777	4.060
46	2	47	18.10	1	94.034	116.283	88.618	86.183	63.747	89.550	19.929	4.059
47	2	1	20.00	1	93.925	116.467	88.892	86.167	63.546	89.283	16.135	3.990
48	2	13	20.00	1	93.880	116.300	88.863	86.233	63.715	89.350	16.805	3.934
49	2	13	20.00	3	92.640	116.333	90.276	86.917	63.622	88.383	–5.125	3.096
50	2	14	21.00	1	93.906	116.417	88.904	86.183	63.595	89.283	16.034	3.971
51	2	14	21.00	3	92.691	116.450	90.322	86.833	63.501	88.300	–5.806	3.183
52	2	2	22.00	1	93.875	116.333	89.042	86.150	63.670	89.150	13.980	3.967

53	2	61	22.00	3	92.986	116.150	90.149	86.600	63.803	88.367	−2.502	3.403
54	7	4	22.90	1	93.830	116.450	88.990	86.230	63.560	89.220	15.010	3.909
55	7	14	22.90	3	93.400	116.360	90.240	86.080	63.570	88.040	−3.506	3.924
56	2	52	24.00	1	93.873	116.333	89.147	86.100	63.663	89.033	12.341	3.992
57	2	3	26.00	1	93.838	116.417	89.158	86.133	63.579	89.033	12.298	3.957
58	2	4	27.00	1	93.752	116.500	89.280	86.167	63.489	88.933	10.651	3.900
59	2	6	30.00	1	93.769	116.550	89.373	86.100	63.432	88.817	9.144	3.950
60	2	7	30.00	1	93.761	116.367	89.434	86.083	63.612	88.767	8.235	3.957
61	7	20	30.00	4	93.390	116.270	90.290	86.070	63.660	88.000	−4.223	3.935
62	7	5	31.00	1	93.750	116.440	89.250	86.190	63.550	88.970	11.145	3.889
63	7	15	31.00	3	93.340	116.300	90.290	86.130	63.640	88.020	−4.288	3.882
64	2	18	31.00	3	93.072	116.367	90.276	86.433	63.576	88.167	−4.429	3.577
65	2	48	31.30	1	93.755	116.633	89.433	86.083	63.345	88.750	8.248	3.958
66	2	48	31.30	3	93.279	116.000	90.208	86.250	63.941	88.167	−3.183	3.756
67	2	8	32.00	1	93.745	116.417	89.467	86.083	63.560	88.733	7.753	3.943
68	2	8	32.00	3	92.819	116.267	90.350	86.683	63.679	88.217	−6.028	3.335
69	2	53	32.00	1	93.749	116.283	89.429	86.100	63.696	88.783	8.329	3.941
70	2	53	32.00	3	93.385	116.333	90.214	86.117	63.603	88.083	−3.156	3.889
71	2	19	34.00	1	93.667	116.500	89.571	86.117	63.471	88.650	6.314	3.907
72	2	20	34.00	1	93.738	116.333	89.521	86.067	63.640	88.683	6.953	3.962
73	2	20	34.00	3	93.242	116.383	90.230	86.267	63.556	88.133	−3.520	3.740
74	2	21	34.00	1	93.654	116.417	89.537	86.150	63.557	88.700	6.856	3.878
75	2	22	34.00	1	93.697	116.250	89.514	86.117	63.725	88.717	7.135	3.914
76	2	49	34.70	1	93.639	116.483	89.733	86.067	63.478	88.483	3.889	3.942
77	2	49	34.70	3	93.385	116.267	90.218	86.117	63.669	88.083	−3.220	3.889
78	2	54	36.00	1	93.705	116.383	89.591	86.067	63.586	88.617	5.937	3.954
79	7	6	36.40	1	93.720	116.360	89.520	86.090	63.610	88.690	7.004	3.944
80	7	16	36.40	3	93.460	116.290	90.230	86.020	63.640	88.030	−3.310	3.981
81	2	55	37.00	1	93.591	116.400	89.745	86.117	63.562	88.500	3.760	3.892
82	2	55	37.00	3	93.397	116.300	90.255	86.083	63.633	88.033	−3.732	3.925
83	7	7	37.30	2	93.510	116.300	89.980	86.100	63.650	88.280	0.294	3.908
84	7	17	37.30	3	93.440	116.290	90.280	86.030	63.640	87.990	−4.037	3.984
85	7	8	38.80	1	93.690	116.340	89.590	86.080	63.630	88.630	5.976	3.936
86	2	15	41.00	1	93.568	116.300	89.836	86.100	63.656	88.417	2.403	3.903
87	2	23	41.60	1	93.581	116.383	89.602	86.200	63.588	88.667	5.987	3.821
88	2	29	50.00	1	93.511	115.900	89.994	86.100	64.048	88.300	0.092	3.900
89	2	29	50.00	3	93.324	116.250	90.426	86.083	63.674	87.883	−6.207	3.940
90	7	21	50.00	4	93.360	116.180	90.400	86.060	63.740	87.900	−5.801	3.962
91	7	9	50.90	1	93.520	116.270	89.890	86.120	63.680	88.380	1.625	3.874
92	2	30	52.20	1	93.476	116.250	90.015	86.117	63.697	88.267	−0.224	3.883
93	4	13	56.10	1	93.567	116.100	89.783	86.133	63.867	88.500	3.215	3.869
94	2	33	59.70	1	93.577	116.350	89.815	86.100	63.607	88.433	2.725	3.904
95	2	34	60.00	1	93.476	116.167	90.155	86.050	63.771	88.117	−2.247	3.953
96	2	35	64.50	1	93.428	116.000	90.277	86.050	63.931	88.017	−4.018	3.960
97	2	45	70.20	1	93.461	116.367	90.476	85.900	63.548	87.750	−6.622	4.127
98	2	36	70.70	1	93.425	116.250	90.500	85.933	63.665	87.750	−7.014	4.097
99	2	37	76.80	1	93.417	116.233	90.654	85.867	63.671	87.583	−8.995	4.185
100	2	38	78.40	1	93.361	116.283	90.675	85.917	63.622	87.583	−9.397	4.139
101	2	39	81.50	1	93.328	116.267	90.750	85.917	63.634	87.517	−10.423	4.152
102	2	40	81.50	1	93.261	116.167	90.742	86.000	63.738	87.567	−10.523	4.068
103	2	41	96.00	1	93.206	116.083	91.146	85.867	63.796	87.150	−15.508	4.289
104	4	0	100.00	1	93.167	115.850	91.217	85.883	64.033	87.100	−16.478	4.293
105	1	1	100.00	4	93.231	115.800	91.155	85.850	64.078	87.150	−15.571	4.308

chemical analysis and as An_{51} from the refractive index (see Cole et al., op. cit., Table 1). The composition of the anorthite has been given as approximately An_{100} on the basis of refractive index and extinction (Gay, 1953—1955, Table 1) and as An_{95-100} on the basis of universal stage measurements (Kempster, Megaw and Radaslovich, 1962, p. 1007). Gay (op. cit., p. 175) points out that the anorthite is of low temperature origin.

Reference 5, Laves (1952, Table 2). The complete lattice parameters of both a low and high temperature albite are given.

Reference 6, Donnay and Donnay (1952, Tables 5 and 10). The complete lattice parameters are listed for a synthetic albite.

Reference 7, Smith (1956, Table 4). Smith has calculated complete lattice parameters from powder data for nine natural plagioclase feldspars (eight of low temperature origin and one of high temperature origin), for seven of these feldspars after heat treatment (one of them heated for two different periods of time) and for four synthetic plagioclase feldspars. The specimen numbers listed in column 3, Table 2 are consecutive numbers, 1 to 21, which have been allocated to Smith's samples since his specimen numbers are unwieldy.

Reference 8, Ferguson, Traill and Taylor (1958, Table 3). Complete lattice parameters are given for a natural low temperature albite and for a natural albite after heat treatment. The compositions of both materials were determined chemically by Emmons (see Ferguson et al., op. cit., Table 1).

PERICLINE TWINNING

In pericline twins the twin axis is the b crystallographic axis and the twin plane and composition plane are the rhombic section. The rhombic section is an irrational plane, it can be defined as the plane which includes both the b axis and the normal to b in (010). The orientation of the rhombic section is specified by the angle σ, which is the angle between the trace of the rhombic section and the trace of (001) on (010), σ is considered positive if the trace of the rhombic section on (010) lies between $+a$ and $+c$. The angle can be calculated from the relationship $\cot \sigma = \cos \alpha^*/\cot \gamma$. Calculated values for σ are listed in Table 1, column 9 and Table 2, column 12. The values for σ are plotted against composition in Figure 1.

In Figure 1 the data points for albite-rich compositions are distributed in two groups, those representing ordered feldspars (i. e. of low temperature origin) lying above those for more disordered ones. The groups tend to merge towards more anorthite-rich compositions. Unfortunately there are no data for plagioclase feldspars of high temperature origin within the composition range An_{50} to An_{100}. However it is probable that the trend indicated by the more sodic feldspars continues until at An_{100} the

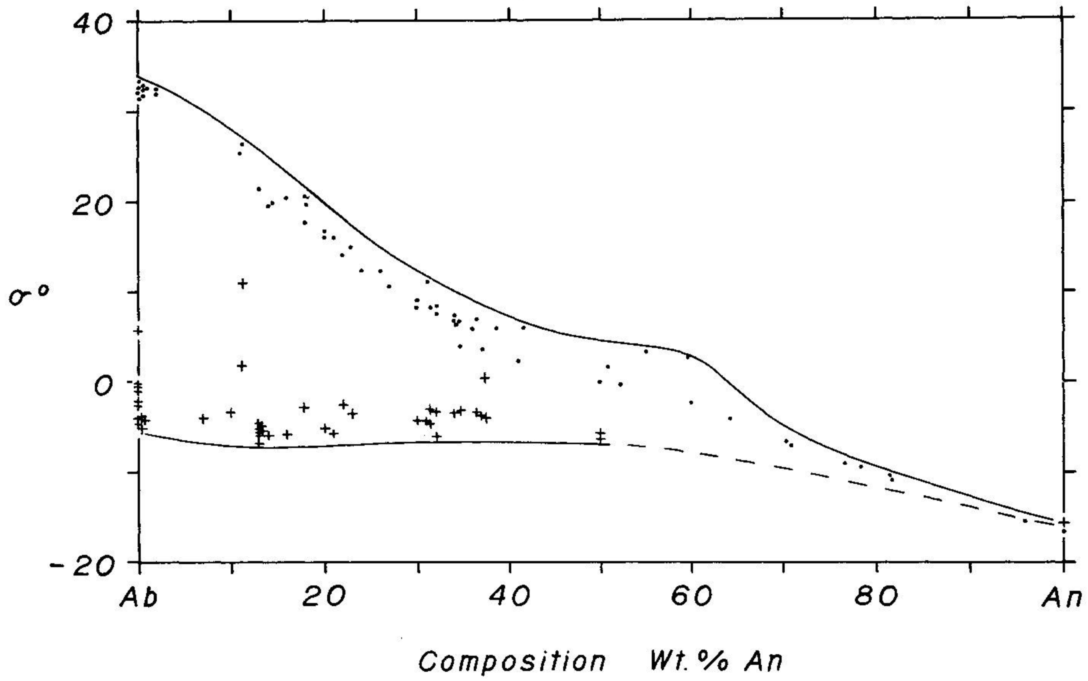

Fig. 1. The variation of σ with composition and structural state of plagioclase feldspars. The upper curve is for ordered feldspars and the lower one for disordered feldspars. The data are from Tables 1 and 2: dots represent ordered feldspars (Type 1) and crosses represent disordered feldspars (Types 2, 3 and 4). Brown's monalbites, specimens 19 and 20, are not included since the calculated value for σ has no meaning in a monoclinic crystal.

distinction between feldspars of high and low temperature origin disappears as is indicated by the data points for specimens 104 and 105 in Figure 1. This must be the case since anorthite occurs only in a highly ordered structural state. Since it is not certain that any of the feldspars considered here are in a state of maximum order or disorder, curves indicating the variation of σ with composition for ordered and disordered feldspars have been drawn along the "outer" margins of the data. These two curves are in general agreement with those of SMITH (1958, Figures 1 and 5), although the present curve for disordered feldspars indicates slightly larger negative values of σ for compositions more sodic than An_{55}, and both curves indicate slightly smaller negative values for anorthite-rich specimens. It should, however, be remembered that SMITH's curves are based on fewer data and, further, for compositions more calcic than An_{55} his curves are actually those for Γ and not σ!

ALBITE TWINNING

In albite twinning the twin plane and composition plane are (010) and the twin axis is [010]. The angular misfit between the two individuals on either side of the twin plane is termed the obliquity and this can be defined as the angle between the normal to the twin plane and the lattice row quasi-normal to it. In albite twinning this is the angle between [010] and the b crystallographic axis, it is designated ϕ. The value of ϕ can be calculated from the expression, $\cos\phi = \sin\alpha^* \sin\gamma$. The computed values for ϕ are listed in Table 1, column 10 and Table 2, column 13.

In Figure 2 ϕ is plotted against composition, again curves for maximum ordered and maximum disordered feldspars have been drawn along

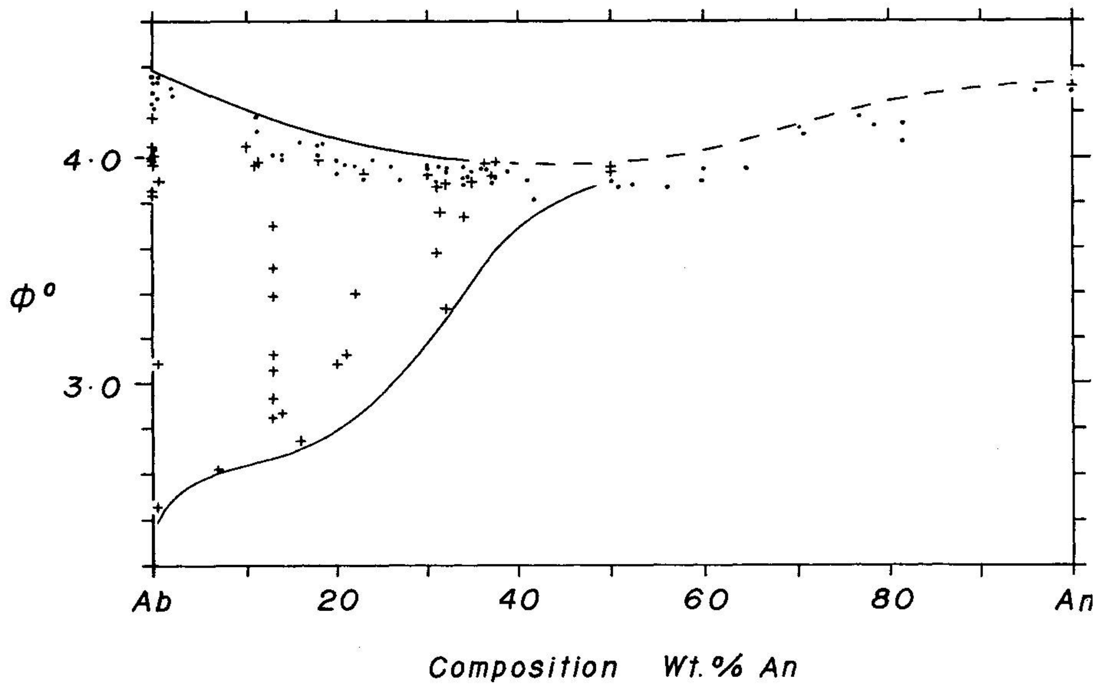

Fig. 2. The variation of ϕ with composition and structural state of plagioclase feldspars. The upper curve is for ordered feldspars and the lower one for disordered feldspars. The data are from Tables 1 and 2: dots represent ordered feldspars (Type 1) and crosses represent disordered feldspars (Types 2, 3 and 4). Brown's monalbites, specimens 19 and 20, are not included, they would plot at $\phi = 0°$.

the "outer" margins of the data. Figure 2 shows that for ordered plagioclase feldspars ϕ is at a minimum around An_{40} and increases towards An_0 and An_{100}. For the disordered feldspars the picture appears to be more complex, it is also, unfortunately, less complete. Data are lacking for compositions between An_{50} and An_{100} and it is therefore not possible to draw a curve with any certainty. However it is probable that the curves for ordered and disordered feldspars are sub-parallel and close together over this composition range, finally converging on anorthite (see the discussion under Pericline Twinning above). For disordered feldspars with compositions more sodic than An_{50}, ϕ decreases sharply and is 0° for BROWN's monalbite (specimens 19 and 20) as is dictated by the monoclinic symmetry.

The curves of Figure 2 differ considerably from those previously published (DONNAY 1940, GAY 1956—1958, SMITH 1958), the difference is particularly noticeable in the curve for disordered feldspars. In view of the well documented trend towards monoclinic symmetry exhibited by sodic plagioclase feldspars on heating it is thought that the trend of the curve for disordered feldspars proposed here is at least in the right direction.

CONCLUSION

The significance of the variation of σ and ϕ with composition and structural state have been discussed at length by SMITH (1958, 1962) so that detailed reiteration is not necessary here.

In the case of pericline twins the argument, briefly, is that, since the composition plane of the twins at the time of their formation was parallel to the rhombic section at that time, measurement of the composition plane and the determination of the present attitude of the rhombic section can give information on the thermal history of the feldspar and hence of the host rock.

In the case of secondary pericline twins which may result from deformation at different times during the cooling, and consequent ordering, of the plagioclase crystals, the values of σ for successively younger twins will decrease. The maximum value of σ will give an indication of the structural state in which the feldspar originally crystallized, remembering that it may have crystallized in a still more disordered state but that no twins developed at that time. The structural state in which the crystal originally grew can only be ascertained with certainty from the orientation of growth twins after the pericline law.

Rocks undergoing heating and in which the plagioclase feldspars are becoming increasingly disordered might preserve evidence of this so that the earlier formed pericline twins would yield smaller values for σ. Further cooling could of course be accompanied by further generations of twins.

It has been thought that the ease of formation of albite twins reflects variations in the obliquity, ϕ (Donnay 1940, Gay 1956—1958, Smith 1958). The less the obliquity the easier the development of twins. In support of this idea Smith (op. cit.) correlates his predictions with the observations of Turner (1951) and Gorai (1951). However where the twinning results from deformation the problem is almost certainly more complex. Since glide twinning of an ordered plagioclase feldspar produces a markedly different structure in the twinned individual (Starkey 1963), one can expect that where this structure is sufficiently unstable the crystal will resist twinning. On the basis of this Figure 3 has been prepared to show, in a purely qualitative way, how the ease of twinning can be expected to vary with composition and structural state. In deformation twinning the structural control will probably be more significant

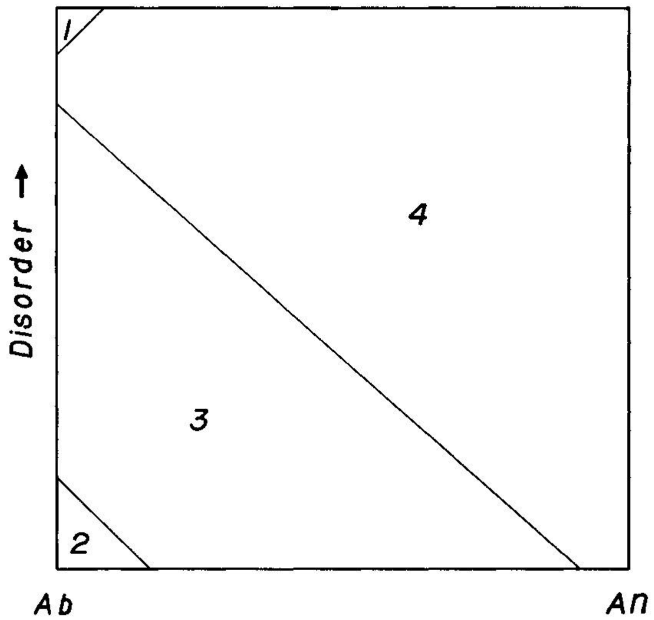

Fig. 3. The postulated effect of composition and structural state of plagioclase feldspars on the ease of formation of pericline and albite twins by gliding. Area 1 represents the possible field of monalbite, twinning is precluded by the monoclinic symmetry. Twinning is precluded on structural grounds in feldspars in area 2. In feldspars occurring in area 3 twinning is possible but not easy. Twinning is easy in feldspars occurring in area 4.

than variations in obliquity. The obliquity may exercise a control over the development of growth twins (see VANCE 1961).

Figure 3 is in general accord with the observations of TURNER (1951) and GORAI (1951). With increasing grade of metamorphism the plagioclase feldspars become more calcic and are in a structural state more favourable to twinning. Therefore frequency of twinning should increase with metamorphic grade. Secondary twinning should also be common on hornfelses and igneous rocks where temperatures are still higher and the structural state of the feldspars consequently more disordered.

Since the data which have been used to prepare Figures 1 and 2 were obtained at room temperature it might be supposed that the conclusions based on them apply only to feldspars which twin at room temperature. However SMITH (1958, p. 919) has pointed out that the orientation of the rhombic section is probably independent of temperature, this is perhaps also true in the case of the obliquity. As far as the boundaries indicated on Figure 3 are concerned, elevated temperatures and the accompanying increase in thermal vibration would tend to reduce the effect of the degree of structural order present so that the boundaries should shift towards the abscissus: the effects of this are not likely to be present in nature since prolonged heating would change the structural state. It is therefore felt that the conclusions presented above can be extended to natural environments.

Acknowledgements

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