Pericline and acline-A twins in the acid plagioclases.

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THE orientation of the 'rhombic section', the composition-plane of the pericline twin, in the plagioclase felspars as an index of the chemical composition of the felspar was first utilized by G. vom Rath, who measured the angle σ on the face (010) between the trace of the composition-plane and the edge [010,001]. Duparc and Reinhard, in their comprehensive work on the determination of the plagioclases,[1] quote two series of values for this angle, one due to Wülfing and the other to Becke. They comment on the discordance between the two series, most marked at the acid end, and add that they did not then possess suitable material for critical determinations on their own account. Wülfing's [2] values are given in the form of a curve based on data assembled by Schmidt,[3] and those of Becke were first given in a paper on the felspars in crystalline schists.[4]

The apparent enormous discrepancy between these two series of σ values as given by Duparc and Reinhard is partly due to a misquotation from Becke. These writers (loc. cit., p. 4) base their data for albite on a description by Grosspietsch of crystals from Greenland containing 0·5% An. The correct value of σ for this percentage of anorthite has been read from Wülfing's curve, but that quoted as Becke's value is actually his value for a felspar containing 5·0% An. The values originally given by Becke are founded on data by Schuster.[5] Reference to this author's complete list will show that

[1] L. Duparc and M. Reinhard, Mém. Soc. Phys. Hist. Nat. Genève, 1924, vol. 40, p. 26. [Min. Abstr., vol. 3, p. 34.]

[2] E. A. Wülfing, Sitzungsber. Heidelberg. Akad. Wiss., Math.-naturw. Kl., 1915, Abt. A, Abh. 13. [Min. Abstr., vol. 1, p. 390.]

[3] E. Schmidt, Chemie der Erde, 1915, vol. 1, pp. 351–406; Inaug.-Diss. Heidelberg, 1916. [Min. Abstr., vol. 1, p. 390.]

[4] F. Becke, Denkschr. Akad. Wiss. Wien, Math.-naturw. Kl., 1913, vol. 75, p. 105.

[5] M. Schuster, Min. Petr. Mitt. (Tschermak), 1880, vol. 3, p. 24.

one is justified in drawing a smooth curve through these arbitrarily selected values, but extrapolation of this curve still gives a σ value for pure albite much lower than that of Wülfing.

In the Fedorov method of felspar determination by means of the universal stage, the angle measured between (001) and the rhombic section is the true dihedral angle σ', not theoretically identical with the angle σ between the traces of (001) and the rhombic section on the face (010). From the crystallographic constants of the felspars this angle σ' is readily calculated.[1] If the Schmidt-Wülfing values for the angles (001) : (010) and the axial angle γ are employed in this recalculation, the following series is obtained:

An %	...	0.	5.	10.	20.	30.
σ' (calc.)	...	38° 54′	24° 56′	15° 28′	7° 19′	3° 14′

These, it will be observed, differ from the Wülfing values for σ by an amount less than the experimental error. They are plotted in fig. 1.

The literature of felspar determinations by Fedorov methods affords few significant data which can be compared with these theoretical conclusions. T. Barth, however, has recently published the results of fourteen measurements on pericline twins of acid felspars [2] showing values up to 37° for pure albite. On the basis of his measurements, Barth concludes that the position of the rhombic section, though showing a certain tendency to a relationship with the chemical composition, is not determined merely by this factor; that the rhombic section must not be considered a crystallographic constant; and that above all from the orientation of this section one must not draw definite conclusions as to the composition of a plagioclase.

These conclusions appear to leave out of account a number of considerations. Duparc and Reinhard separate from the true pericline twin with twin-axis [010] and variable composition-plane, the twin acline-A, in which the twin-axis is [010] as before but the composition-plane is invariable, being (001). M. Gysin [3] has shown quite definitely that the acline-A twin has a real existence in the more basic plagioclases. His thirty-nine plotted examples show also

[1] See, for example, W. J. Lewis, Crystallography. Cambridge, 1899, p. 550.

[2] T. Barth, Zeits. Krist., 1928, vol. 68, pp. 616–618. [Min. Abstr., vol. 4, p. 37.]

[3] M. Gysin, Schweiz. Min. Petr. Mitt., 1925, vol. 5, pp. 128–146. [Min. Abstr., vol. 3, p. 520.]

considerable divergence from the standard curves of migration, and he accounts for this partly in the experimental error incidental to the method and partly in the modifying influence, at present undeter-

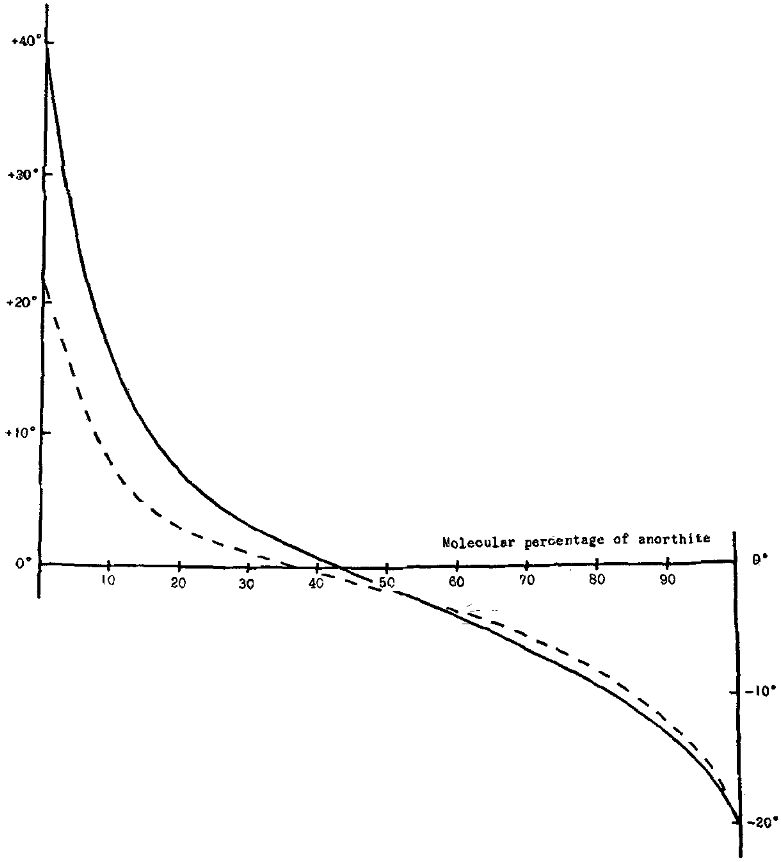

FIG. 1. Graph showing the variation of the angle σ' with composition of plagioclase. The full curve is that due to Wülfing, the dotted curve that obtained from the Schuster-Becke values.

mined quantitatively, of other terms such as a potassic one in the albite-anorthite series.[1] Yet another factor is the possible presence of rarer twins which would yield an orientation practically coincident, though not exactly so, with that of the pericline law. If the true

[1] See also R. Sabot, Compt. Rend. Soc. Phys. Hist. Nat. Genève, 1918, vol. 35, pp. 72–76. [Min. Abstr., vol. 3, p. 515.]

character of these were not recognized, they would mark apparent divergences from the pericline migration curve. In particular, the complex ⊥ [100]/(001), as noted by Berek,[1] can scarcely be separated from the true pericline or acline-A twins. In Barth's values, the determination of σ as 3° in a felspar containing 7% An presumably marks an acline-A twin. If the remaining thirteen values are referred to the Wülfing curve, in only three cases does the composition thus deduced differ by more than 5% An from that determined by extinction on (010). The average departure of the thirteen values is less than 2% An. It should be observed also that these measurements were carried out on material either associated with potash-microcline, or even forming one member of a microcline-microperthite.

In an attempt to obtain further data, I have prepared a series of sections of albite crystals (obtained from the collection in the Department of Mineralogy at Cambridge, by kind permission of Prof. A. Hutchinson) from the neighbourhood of the Ofenhorn and Wälschen Ofen in the Binn Valley, Switzerland.[2] The majority of the sections were cut approximately parallel to *a* (100), and eight showed twin traces parallel to the trace of the (001) cleavage. Measurement of these, however, showed that they were in every case acline-A twins. In some cases this could be verified directly, since the pole of the (001) cleavage could also be measured, and was found coincident with P_{1-2},[3] or nearly so; in others it became evident on plotting in projection normal to [010].[4]

Acline-A twins.

		n_α.	n_β.	n_γ.	
$T\text{-}A_{1-1'}$	Average	+89°	+73½°	+16½°	(010)
	Variation (3 crystals)	± ½	± 0	± ½	
$T\text{-}A_{1-2}$	Average	+88½	+77	+13	[010]
	Variation (8 crystals)	± 1	± 1	± ½	
P_{1-2}	Average	−74	+20½	−77	(001)
	Variation (8 crystals)	± 5	± 3½	± 1½	

(Where the positions of the optic axes A and B could be obtained, check values of the optic axial angle 2V, of the angles between the optic axes of different kinds, and of the angles between the optic axial planes were obtained, but it does not seem necessary to list all these in detail.)

[1] M. Berek, Mikroskopische Mineralbestimmung mit Hilfe der Universaldrehtischmethoden. Berlin, 1924, p. 82. [Min. Abstr., vol. 2, p. 365.]

[2] L. Desbuissons, La Vallée de Binn (Valais.). Lausanne, 1909, pp. 177–178. C. Hintze, Handbuch Min., 1905, vol. 2, p. 1460.

[3] For the nomenclature of poles of twin-planes and twin-axes, see W. Campbell Smith, Min. Mag., 1928, vol. 21, p. 544.

[4] L. Duparc and M. Reinhard, loc. cit., p. 116.

The average values for T-A_{1-1}' and T-A_{1-2} coincide almost exactly with the pure albite ends of the corresponding curves for (010) and [010], as plotted by Duparc and Reinhard (loc. cit., pl. 9), but that for P_{1-2} falls a few degrees distant from (001). The larger values for the maximum variations in the case of this pole are of course due to the greater uncertainty of the practical measurements. A probable cause of the displacement of the average position, and indeed of much of the uncertainty of the whole of the question under discussion, is suggested by one section, of which a sketch is given in fig. 2. The lamellae 2 are bounded against 1 by two quite sharply defined sets of boundaries. The pole of one set, as determined under the microscope, obviously coincided with that of the (001) cleavage well displayed in 1, giving an angle $\sigma' = 0°$ and an obvious acline-A twin. The pole of the other set gave an angle $\sigma' = 12°$ only, and by itself would constitute an apparently anomalously low inclination of the 'rhombic section'.

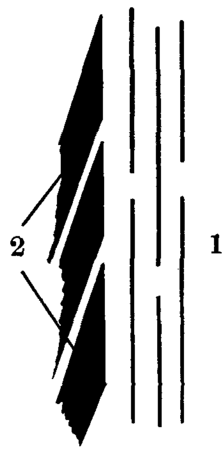

FIG. 2. Diagram showing the relationship of twin-lamellae (2) to the main portion of the crystal (1) in a measured acline-A twin.

Two instances of the true pericline twin in pure albite have been observed in porphyroblasts in chlorite-albite-epidote-schists ('Green Beds') from the Dalradian succession of Scotland, measurement of which gave:

Pericline twins.

		n_α.	n_β.	n_γ.	
T-A_{1-2}	Average (2 crystals)...	+88°	+77°	+13½°	[010]
P_{1-2}	Average (2 crystals)...	+76	+20	−76½	Rhombic section.

Angle $\sigma' = 36°$.

It is perhaps worth noting that this association with stress conditions is not unnatural. Mügge[1] has pointed out that the rhombic section as composition-plane is to be expected if the twins are produced by simple gliding; but that the presence of isomorphous zoning would have as consequence a composition-plane curved around [010], and would therefore make difficult the mechanical

[1] H. Rosenbusch, Mikrosk. Physiogr. der petr. wicht. Min., 1927, vol. 1, pt. 2, p. 747, footnote 2.

production of such twins. Actually the pericline twin assumes a special importance in metamorphic schists and gneisses (where zoned felspars are rare, and stress is of the required kind) as observed by Becke, by Duparc and Reinhard (loc. cit., p. 9), and by myself. The well-formed albites of the Binn Valley occurrences are presumably growth-twins, and nothing is at present known of the factors determining twinning under these conditions.

In the light of this discussion, the following conclusions seem justifiable:

I. At the acid end of the series, as at the basic, there exists, in addition to the true pericline twin, a twin on the acline-A law.

II. In the true pericline twin, with variable composition-plane, the high values of σ' suggested by theory are actually met with in practice, and the Wülfing curve is to be regarded as the true locus of the pole of this composition-plane.

III. Though the two kinds of twin can readily be separated in a special projection, or directly where the pole of the cleavage is also determined, no error of serious significance to the petrologist is likely to arise if the pole is arbitrarily referred to whichever of the migration-curves—that for (001) or that for the rhombic section—with which it more nearly coincides.

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