A note on albite twinning in plagioclase felspars.

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Summary.—Previous work by Donnay on the basis of the geometrical theory of twinning related the width of albite twin lamellae to the composition of the plagioclase. The curve derived by Donnay has been recalculated for both high- and low-temperature felspars from X-ray data; the two curves differ markedly in the region between 0 and 20 % An. Some experimental evidence in support of the deductions that can be made is given.

In recent years it has been suggested that felspar twinning may be able to throw some light on the mode of origin of the rock types in which the felspars occur. Turner (1951) presented observations on the frequency of various twin laws for plagioclase in metamorphic rocks; Gorai (1951) attempted to correlate statistically the various twin laws in selected rock types. On the present evidence, it would seem that the method, although holding promise, is not sufficiently reliable to allow any firm deductions about the history of crystallization; far more experimental data are needed before any conclusions can be drawn as to the ultimate value of the method.

The problem is complex, involving both the external factors obtaining during and after crystallization and the innate ability of the crystal to twin according to a particular law. As Donnay (1943) has pointed out, there may be interaction between these two influences; very different external factors may produce the same broad pattern of twinning if, for some reason, the internal factors are changed. It seems probable that the effect of the external factors must be studied by systematic experimental observations. The internal factors, however, have been extensively investigated theoretically by Friedel and other French crystallographers; it is with these internal factors that this note is concerned.

Donnay (1940) elaborated the application of the French geometrical theory to polysynthetic albite twinning in the plagioclases. On this theory, the ease of twinning is related to the obliquity of the twin;[1]

[1] The obliquity of the twin is defined as the angle between the true normal to the twin plane and the lattice row quasi-normal to it, i.e. for albite twinning between [010] and the normal to (010). The ease of twinning is also related to the index of the twin, but this is constant for a particular law and need not be considered here.

the larger the obliquity, the more difficult it is for the crystal to change in orientation—i.e. the wider become the twin lamellae. On the basis of goniometrical data, Donnay calculated the obliquity for a number of plagioclase crystals over the whole composition range; he found that the observations on polysynthetic albite twinning were just those expected from the variation of obliquity.

At the time at which these calculations were carried out, reliable dimensional data on plagioclase were sparse; the most reliable goniometrical measurements were selected by Donnay, though, as he pointed out, the compositions of the crystals were not very certain. Further, the existence of different thermal states of plagioclase had not been fully recognized. Recently the plagioclases have been extensively studied by X-ray methods, and slight, but measurable, changes in cell dimensions with thermal state have been established. Such changes will be reflected in the calculated values of the obliquity. It is of some interest, therefore, to repeat the earlier work using the new data for both 'high' and 'low' plagioclases. This paper contains the results of these calculations together with such conclusions as can be drawn.

Results. The X-ray data which have been used have been obtained from various sources. Some have been obtained from the literature (e.g. Cole, Sörum, and Taylor, 1951) and some have been collected by the author during investigations of the plagioclases. I am particularly indebted to Dr. J. V. Smith and to Dr. J. Goodyear and Mr. W. J. Duffin for many experimental measurements of cell dimensions by powder methods made available prior to publication.

The obliquity has been calculated from the expression

$$\sin^2\phi = (\cos^2\alpha+\cos^2\gamma-2\cos\alpha\cos\beta\cos\gamma)/\sin^2\beta,$$

where α, β, γ are the interaxial angles for the direct cell; this is a simplified form of the expression used by Donnay. If the reciprocal cell angles are known, the expression $\cos\phi = \sin\alpha^*\sin\gamma = \sin\alpha\sin\gamma^*$ may be used. The obliquity for each specimen is plotted against the analysed chemical composition in fig. 1. Curves indicating the general trend of the variation are shown together with the previous curve derived by Donnay. Points on the high-temperature curve have been obtained from measurements on synthetic specimens; points on the low-temperature curve have been obtained from specimens for which the geological environment or other evidence suggests a low-temperature state.

Discussion. The new curves are, at first sight, somewhat different from that derived by Donnay; the variation in obliquity over the series is not so large.[1] For the low-temperature curve, nevertheless, assuming the same external conditions, the albite twin lamellae should be narrowest in the oligoclase-andesine region; their width should increase as the plagioclase becomes more basic. There is also widening of the lamellae from oligoclase-andesine to pure albite though this is not so sharp as

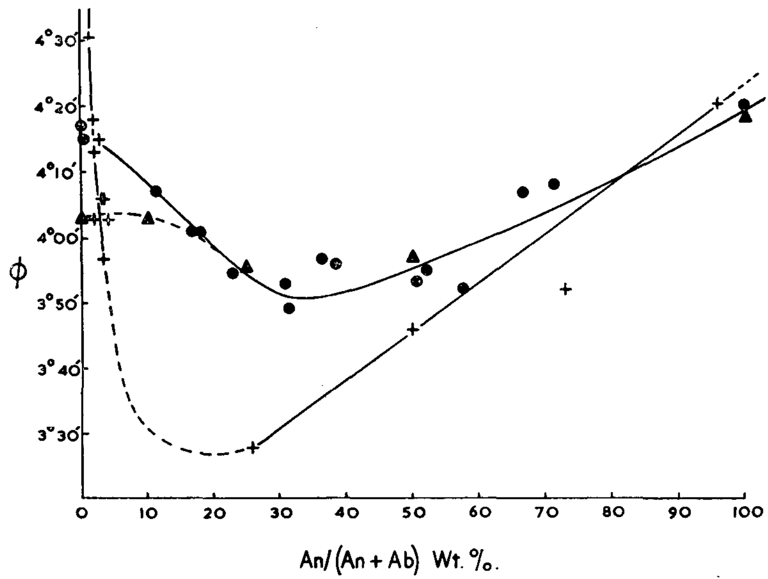

FIG. 1. Variation of obliquity (ϕ) with composition of plagioclase. ●, low-temperature specimens; ▲, synthetic specimens; +, values obtained by Donnay (1940.)

originally proposed. In this region, however, it must be remembered that X-ray evidence has suggested that many of the low-temperature plagioclases are unmixed into two phases of compositions about An_3 and An_{23} (Gay and Smith, 1955); the cell dimensions used in the present calculations for such specimens are averaged parameters for the two phases (it is not possible from powder data to obtain reliable values of dimensions for the two separate phases). The effect of this unmixing may lead to complications in the obliquity curve.

[1] It has been pointed out to the author by Dr. J. V. Smith that the chemical compositions plotted by Donnay are incorrect; the points should be displaced towards the albite end of the diagram. Further, the obliquity plotted for the Vesuvius specimen (26 % An) should be discarded since the material appears to be a high-temperature alkali felspar. If these modifications are made there is better agreement between the morphological and X-ray data.

From the calculations it is seen that there is no marked difference between the high and low curves except in the region between An_0 and An_{15-20}. For more basic plagioclases, the ease of twinning appears to be substantially independent of whether the plagioclase is high or low. It seems probable that for compositions close to pure albite, the high form should tend to show polysynthetic albite twinning on a scale comparable with that found in the oligoclase-andesines.

In the case of the low-temperature specimens, the deductions from the present calculations are in accord with those of Donnay (1940) who was able to show by numerous quotations from the literature that the theoretical predictions are convincingly borne out. As yet, there are few recorded optical data on the high plagioclases. Van der Kaaden (1951) investigated the high-temperature (and presumably transitional) optics for plagioclases more basic than An_{25} in volcanic rocks; he states that it was recognized that a few broad lamellae are common in calcic plagioclase, but that oligoclase and to a less extent sodic andesine show many polysynthetic narrow lamellae. For the predicted difference at albitic compositions, it is extremely interesting to see that Laves and Chaisson (1950) in describing a synthetic albite state that one group of crystals showed fine polysynthetic twinning and only a few crystals could be found with areas sufficiently free of this fine twinning to permit measurements of the optical indicatrix. Tuttle and Bowen (1950) also report difficulties in optical measurements on the synthetic material owing to twinning; they also state that heated low albite develops twins with composition planes parallel to (010) and (001) during the inversion. The scanty evidence available seems to be in accord with the theoretical predictions.

Although these results are encouraging, the problem is more complex than is suggested by the treatment above. The high- and low-temperature states used above are only two limiting forms; transitional states can be recognized and can exist quite stably. There are very few reliable data on these structural states. If obliquity calculations are carried out on the information available at present, some tentative deductions may be made. It seems probable that from the oligoclase-andesine minimum to anorthite, the obliquity for a particular specimen is not significantly different whatever the thermal state. However, calculations for heated and partially inverted specimens in the An_0 to An_{15-20} region suggest that the obliquity can fall to values that are appreciably less than those for the synthetic specimens in this region. It may be, therefore, that in this composition range the finest albite twinning can be developed by felspars in an intermediate structural state. Clarification of this point, and on the effect of potash content, must await more measurements of cell dimensions for such specimens.

Further, it must be pointed out that the geometrical treatment may not in all cases give a complete account of all the internal factors affecting twinning. This treatment could equally well have been applied to pericline twinning for which results identical with those for albite twinning would have been obtained. On this basis, if all external factors are equal, albite and pericline twinning should be equally observed in the same rock types; in fact, this does not generally seem to be true. It is probable that the difference is related to the continuity of the crystal structure across the composition plane; this is not taken into account in the geometrical theory. For a particular twin law, this 'structural factor' may or may not be sufficiently important to modify the geometrical theory.

The occurrence of twinning in plagioclase must be considered in terms of both the external conditions obtaining during and after crystallization and the internal factors which have been discussed above. It seems likely that the assessment of the internal factors may be possible only in certain cases; thus it will be very difficult to derive any independent conclusions on petrogenesis from the evidence of twinned plagioclase alone. Nevertheless, when many more systematic observations of the twinning for selected rock types become available, the method may be fruitful for comparative purposes.

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