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THE EFFECT OF TEMPERATURE, STRUCTURAL STATE AND COMPOSITION ON THE ALBITE, PERICLINE AND ACLINE-A TWINS OF PLAGIOCLASE FELDSPARS*

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ABSTRACT

Donnay and Gay, respectively, have shown that the obliquity of albite twins of plagioclase feldspars varies with An-content and structural state. For sodic plagioclase and probably for intermediate plagioclase, it is now shown that the obliquity is affected much more by the temperature. Observations on the frequency of twinning in synthetic and natural plagioclase are in harmony with the theoretical frequency deduced from the estimated variation of obliquity.

In 1940, Donnay used the French geometrical theory of twinning to predict the ease of albite twinning in plagioclase crystals. In this theory, the ease of twinning is taken to be directly governed by the angular misfit of the twin components, known as the obliquity ϕ. For albite, pericline and acline-A twins the obliquity is $b \wedge b^*$ and may be calculated from the inter-axial angles by the formula $\cos\phi = \sin\alpha \sin\gamma^* \equiv \sin\gamma \sin\alpha^*$. Donnay calculated the variations of ϕ with An-content from the sparse morphological data then available and found that ϕ varied in the same way as the observed width and frequency of the albite twin lamellae. Since 1940 it has been found that plagioclase feldspars exist in various structural modifications that depend both on the An-content and the thermal history of the specimen. A by-product of these investigations has been the accurate measurement of cell dimensions and, in 1956, Gay was able to extend Donnay's work. The calculated values of ϕ, together with some new values for heated natural specimens, are shown in Fig. 1. The obliquity of plagioclases in the low structural state falls slightly from albite to oligoclase with a subsequent slow rise to anorthite. The effect of structural state on the obliquity is small and the scatter of points for specimens of the same structural state is of similar size. Nevertheless, the data of Fig. 1 show that low-albite has a higher obliquity than high-albite, the difference decreasing as the An-content increases, until near An_{20} there is a reversal of sign. In the range An_{20} to An_{50} the greater obliquity is generally given by the higher structural state though the difference is very small. For more anorthite-rich specimens the data are too sparse for conclusions to be drawn.

In this note the effect of temperature and of solid solution by potash feldspar will be discussed. MacKenzie (1952) found that the deviation

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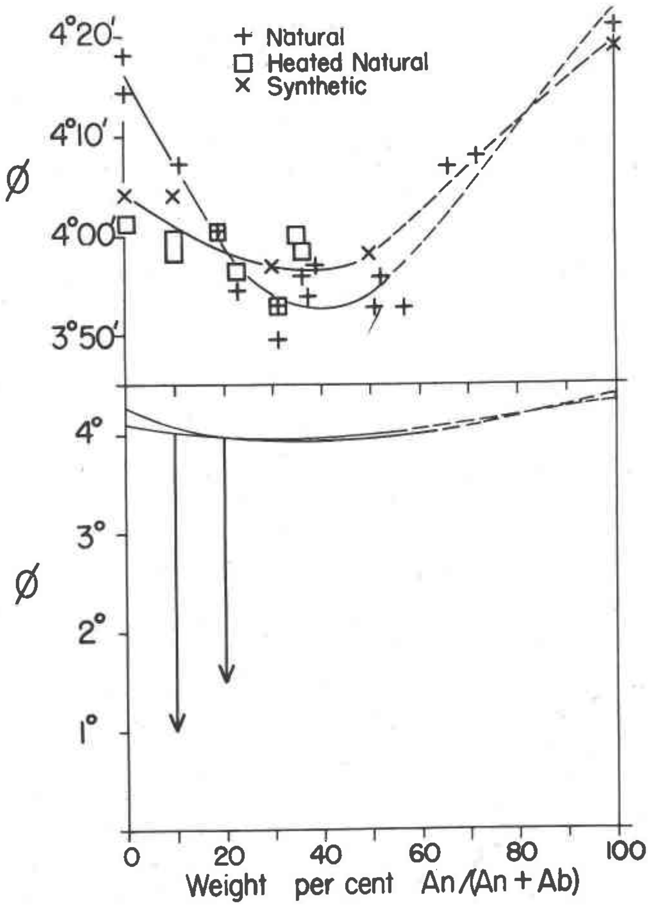

FIG. 1. The variation of obliquity with composition, structural state and temperature. The upper half of the diagram gives on an expanded scale the effect of composition and structural state at room temperature. The lower half shows on a less exaggerated scale the effect of composition and structural state, the two curves being the same as those in the upper diagram. The effect of temperature on high sodic plagioclase is indicated in a qualitative way by the arrowed lines. If the plagioclase becomes monoclinic, the obliquity becomes zero.

from monoclinic symmetry of natural and synthetic sodic feldspars decreased as the temperature was raised, until finally some of the feldspars became monoclinic. The rate of decrease depended mainly on the composition, but the method of formation and the subsequent thermal treatment had important effects. Specimens crystallized dry became monoclinic at the following temperatures:—$Ab_{95}An_5$, 960° C.; $Ab_{90}An_{10}$, 1035° C.; $Ab_{80}An_{20}$, 1380° C. Specimens crystallized hydrothermally at 800° C. and $P_{H_2O}=1000$ kg./cm.^{2} became monoclinic at the following temperatures:—Ab_{100}, 1180° C.; $Ab_{90}An_{10}$, 1270° C.; measurements on specimen $Ab_{80}An_{20}$ indicated that it would become monoclinic at a temperature greater than 1500° C. Thus sodic plagioclases grown from a melt will have a zero or very small obliquity and the frequency of twinning should be high if the twinning is governed by the obliquity. Upon cooling at a rate sufficiently rapid to inhibit inversion to the low structural state, the obliquity would increase to the value calculated by Gay, but it is not likely that the lamellae would broaden. If the rate of cooling were so slow that the plagioclase inverted to the low state, it is possible that the twin lamellae would broaden, for the structural upheaval might aid a re-adjustment to the coarser lamellae theoretically required by the lower temperature. MacKenzie's results for the composition range An_0 to An_{20} show that solid solution of lime feldspar inhibits the inversion from triclinic to monoclinic symmetry. In the absence of other information these data may be extrapolated to indicate that the obliquity of structurally high andesine and more basic plagioclases falls with temperature but at a slower rate. The effect of heating on the lattice angles of low plagioclase is unknown but some qualitative studies of x-ray powder patterns by the author showed that low-albite becomes "less triclinic" as the temperature increases.

The obliquity of high-temperature sodic feldspars decreases markedly with solid solution of potash feldspar as the data obtained by Donnay and Donnay (1952) shows.

Composition	Or_0Ab_{100}	$Or_{10}Ab_{90}$	$Or_{20}Ab_{80}$	$Or_{30}Ab_{70}$
α	93.65°	93.07°	92.15°	91.31°
γ^*	87.97°	88.29°	88.61°	89.22°
ϕ	4°11′	3°34′	2°34′	1°43′

The same implication follows from the observations of Laves (1952) and MacKenzie (1952) who found that anorthoclases underwent the triclinic- monoclinic inversion at lower temperatures as the content of K-feldspar increased. Sodic plagioclases crystallized at high temperature contain up to 10–20 per cent potash feldspar in solid solution but the amount decreases sharply for the basic plagioclases. Thus for high plagioclase the effect of solid solution of potash feldspar on the obliquity may be expected to decrease rapidly with An-content. In low plagioclase the solid solution of K-feldspar is on a smaller scale and little effect on the obliquity is expected. The Or-contents of plagioclase specimens used in the construction of Fig. 1 vary from 1 to 4 per cent, but there is no recognizable correlation between the obliquity and the Or-content. Thus for practical purposes, the effect of K-feldspar on the obliquity of low plagioclase may be neglected.

From the above considerations the following deductions may be made.

(1) Plagioclase grown from a melt should be finely twinned, the frequency in volcanic specimens being somewhat higher than in plutonic specimens, for three reasons:—the temperature of crystallization is probably lower in plutonic rocks, the expected presence of water in plutonic rocks would raise the temperature of the triclinic-monoclinic inversion, and volcanic plagioclase tends to carry more potash feldspar in solid solution. In addition, the frequency of twinning in the sodic plagioclase should be higher than in calcic plagioclase because the obliquity falls more rapidly with temperature. If re-crystallization occurs in the plutonic specimens the twin lamellae may become coarser in conformity with the decreased obliquity.

(2) In metamorphic rocks twinned plagioclase should be less common than in igneous rocks, for the temperatures attained under metamorphic conditions are generally lower than in igneous bodies. With increase of metamorphic grade a transition towards igneous conditions may be expected for the obliquity falls with rising temperature. The chemical composition may be expected to play some part, but only a small part, in governing the frequency of the twinning.

These conclusions may be tested by comparison with observations recorded in the literature. Oftedahl (1948) from a study of the igneous rocks of the Oslo region in Norway found that in the volcanic rocks the twinning of the plagioclase phenocrysts was very fine, and specimens more sodic than An_{42} were optically monoclinic, indicating sub-microscopic twinning. In the plutonic rocks the twinning, although still very fine, was somewhat coarser and the boundary between the triclinic and pseudomonoclinic specimens lay at An_{30}. Van der Kaaden (1951) has also noted that in volcanic rocks the frequency of twinning varies with the An-content, the frequency decreasing markedly from oligoclase to calcic plagioclase. Tuttle and Bowen (1950) reported that albite originally in the low state developed very fine twin lamellae parallel to (010) and (001) as a result of conversion to the high structural state at temperatures near the solidus. Laves and Chaisson (1950) found that in synthetic albite the twinning was so fine that it was difficult to determine the optical properties.

In metamorphic rocks, the twinning is quite different from igneous rocks. Several quotations from Turner (1951) and Gorai (1951) are pertinent.

> "(1) Prevalence of untwinned plagioclase in metamorphic rocks of all types is too well known to merit further comment. There is scattered evidence in petrographic literature

> suggesting that twinning of plagioclase is more frequent in rocks of moderate to high metamorphic grade than in albite-bearing schists of the greenschist facies. Thus Phillips (1930, pp. 244, 245) records increasing abundance of twinned grains of albite in passing from the chlorite zone to the biotite zone of the Scottish Daldradian schists. My own observations confirm this general tendency. . . .
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> (2) There seems to be no general correlation between abundance of twinning in metamorphic plagioclase and degree of deformation experienced by the enclosing rock. . . .
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> (3) Various writers have contrasted the simple twinning of metamorphic plagioclase with the characteristically complex twinning of plagioclase in igneous rocks. (Phillips, 1930, p. 27; Harker, 1932, p. 213). In the great majority of metamorphic rocks which I have examined, twinned grains of plagioclase consist of few subindividuals and only one twin law is represented in most grains. This contrasts very strikingly with the variety and complexity of twinning exhibited by igneous plagioclase and with the large number of lamellae that occur in many grains in igneous rocks. There are, however, certain exceptions. In pyroxene granulites, and in certain hornfelses of relatively high grade, grains of plagioclase may consist of many closely-spaced lamellae, though there is still a marked tendency for only one twin law to be represented in any grain. . . .
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> It seems likely that the differences noted above may reflect generally prevalent differences in the physical conditions of magmatic and metamorphic crystallization. It is possible, for example, that twinning behavior, as well as crystal habit and the nature of crystal boundaries, is affected differently by metamorphic crystallization of plagioclase in an essentially solid medium and by magmatic crystallization in a liquid medium. Temperature may well exert an even more important influence. Metamorphic temperatures in general are lower than magmatic temperatures. . . . " Turner.
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> "It is noteworthy, moreover, that the frequency of twinned plagioclase . . . in these metamorphic rocks (schists and gneisses of amphibolite facies) has nothing to do with the average composition of the plagioclase, but depends on the average grain size of the plagioclase in each rock" Gorai.

The general correspondence between the above observations and the predicted frequency of the twinning is clear though the comparison has been implicitly simiplified in two ways. First, it has been assumed that the frequency of twinned grains and the width of twin lamellae are directly dependent on the ease of twinning. This is not strictly true for the size and shape of the grains may also influence the nature of the twin lamellae. The influence of grain size on the frequency of untwinned grains in metamorphic plagioclase has been experimentally demonstrated by Gorai, who found, as might be expected, that there are more untwinned grains in the finer-grained schists. In spite of this complication, there can be no reasonable doubt that the twinning occurs more easily in igneous than in metamorphic plagioclase.

The second simplification has been the neglect of other twin laws. Gorai has studied in great detail the distribution of the various twin laws. He has grouped the twin laws into two classes, the A class (albite, pericline, and acline-A laws) and the C class (the other twin laws). C twins are very rare in metamorphic rocks though a few occur, especially in the higher grade rocks. In igneous rocks, C twins are more frequent, the percentage increasing with the basicity of the rock and with the An-content of the plagioclase. The complexity of twinning in igneous plagioclase is composed of two parts, the larger number of twin laws and the greater frequency of the twin lamellae. For the present purpose only the frequency of the C twin lamellae is of interest and there is little doubt that the frequency is higher in igneous than in metamorphic plagioclase.

In conclusion it should be pointed out that, while the frequency of albite and pericline twinning appears to be adequately explained in a general way by variation of the obliquity in response to changing temperature, structural state and composition, other factors are of importance. As Gay has pertinently remarked, if the obliquity provides the sole control of the twin frequency, then albite and pericline twinning should be equally developed, whereas marked disproportion between the twin laws is commonly observed. The presence of impurities, which are known to have marked effects on the habits of many crystals, may also affect the frequency of twinning. Thus the broad agreement between the twin frequency and the obliquity should not be expected to hold in all cases and genetic implications of the twin frequency should be treated with caution.

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