# WIDTH OF ALBITE-TWINNING LAMELLAE

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## Abstract

The width of albite-twinning lamellae depends on the obliquity of the twin. The smaller the obliquity, the higher the frequency of the twin and the thinner the lamellae.

The curve of obliquity *vs.* composition shows that the lamellae should be narrowest in oligoclase, and increase in width, slowly towards anorthite, rapidly towards albite. For pure anorthite, and even more so for pure albite, one should expect the disappearance of polysynthetic twinning and the appearance of single crystals.

These predictions of the French theory of twinning agree with the observations on record.


## Introduction

Probably every petrographer has read the statement that the polysynthetic lamellae of the albite law are broader in calcic than in sodic plagioclases. This, to be sure, is a very intriguing observation. Has it received general acceptance? I do not know, but I am somewhat inclined to doubt it. Few people, at least among my professional friends, seem to make use of it in routine work. Yet, if it were confirmed, it should provide an easy method of obtaining, in a rough way, a general idea of the composition of the plagioclase. Although such a method, admittedly, could never compare in accuracy with any optical determination, it would prove to be a useful and worth-while tool.

In the present paper I shall attempt to answer a two-fold question—is there a theoretical reason why albite-twinning lamellae should be wider in some plagioclases than in others, and are the predictions of the theory substantiated by the observations on record? This question has long haunted me, and I must credit Emmons and Gates' recent challenging article (1939) for giving me the incentive to solve it.

## Theoretical Considerations

The only theory of twinning truly satisfactory at the present time is that of the French crystallographers. Anticipated in its fundamentals by Haüy himself, originated by Bravais, extended by Mallard, this theory owes its completion and full generalization to G. Friedel (1904, 1933). It is excellently summarized in Friedel's *Leçons* of 1911 and 1926; it is also available, in German, in Niggli's books (1919, 1920).

According to this theory, the fortuitous fact conditioning the occurrence of twins in certain species is the existence, in the space lattice (translation group), of a cell, simple or multiple, endowed, either rigorously or approximately, with more symmetry than the crystal. The lattice having the edges of that cell for its primitive translations, I shall call the *twin lattice*, for convenience. The elements of symmetry (or pseudo-symmetry) which this particular cell possesses, but which the crystal itself does not have as elements of symmetry, function as *twin elements*. The latter should—and can—always be *reticular*, that is to say, a twin plane is a lattice plane, a twin axis is a lattice row (Law of Mallard). The *index of the twin* is the ratio of the total number of lattice nodes to the number of lattice nodes restored by twinning. The *obliquity of the twin*, in the case of a twin plane, is the angle between the true normal to the twin plane and the lattice row quasi-normal to it. The *twin lattice* extends throughout the twinned edifice, in some cases (obliquity $\neq 0$) with a slight deviation at the composition surface. This prolongation is the condition of stability of the twin. The smaller the index and the obliquity, the more frequent the twin. In particular, for twins having the same index, the smaller the obliquity, the higher the frequency. These conclusions as to frequency are remarkably confirmed by an imposing array of facts.

Let us now turn to the plagioclase problem. It may be conceived, and it is reasonable to suppose, that the width of the polysynthetic lamellae depends on the ease with which twinning can take place. This facility is in direct relation to the frequency of the twin and is likewise an inverse function of index and obliquity. Indeed, in the case of very easy twinning, the prolongation of the *twin lattice* from one twinned individual to the other is nearly perfect and the particles that concur to the building of the crystalline edifice (be they ions, atoms, molecules) will, at every moment during growth, be solicited to adopt either one of two orientations, namely that of the original crystal and that of its twinned symmetrical. Then, since there is not much difference between the two positions from which to choose, it will be, so to speak, easier for the crystal to change its mind, and consequently, the crystal *will* change its mind more often than if the prolongation of the *twin lattice* throughout the dual edifice were less closely approximated. If the obliquity is large, it will be easier for the crystal to continue its homogeneous growth than to shift to its twinned position; the changes of orientation will be less frequent; the lamellae will be wider.

Such considerations are open to the objection that they pay no heed to other than internal factors of crystallization. External factors, such as environment, *Lösungsgenossen*, and thermodynamic conditions in general are disregarded insofar as they do not affect the axial elements (shape of the unit cell). I am confident that, with regard to twinning phenomena especially, the mass of available evidence supports the view that internal factors strongly outweigh external ones. At all events, the above discussion can always be made "fool-proof" by inserting the words "all other things being equal" in front of the second sentence of the foregoing paragraph.

## CALCULATIONS

Let $a{:}b{:}c$ be the axial ratios and $\alpha$, $\beta$, $\gamma$ the interaxial angles. If, through the origin, a plane (HKL) is perpendicular to a straight line [UVW], the following relations are known to hold true:

$$(a/\mathrm{H})\ (a\mathrm{U}+b\mathrm{V}\cos\gamma+c\mathrm{W}\cos\beta)=(b/\mathrm{K})\ (a\mathrm{U}\cos\gamma+b\mathrm{V}+c\mathrm{W}\cos\alpha)$$
$$=(c/\mathrm{L})\ (a\mathrm{U}\cos\beta+b\mathrm{V}\cos\alpha+c\mathrm{W}),$$

in which the indices of the plane and straight lines need not be integers. These equations yield directly the indices $(h'k'l')$ of a plane, not reticular, exactly normal to the twin axis $[uvw]$; the reversed equations will give the indices $[u'v'w']$ of the straight line, not reticular, exactly normal to the reticular plane $(hkl)$ to which $[uvw]$ is quasi-normal. Not all the primed indices are integers.

In the case of albite twinning, $[uvw]=[010]$ and $(hkl)=(010)$. The formulae simplify as follows:

$$\frac{ab\cos\gamma}{h'}=\frac{b^2}{k'}=\frac{bc\cos\alpha}{l'}$$

and

$$\frac{\cos\alpha\cos\beta-\cos\gamma}{ab\ u'}=\frac{\sin^2\beta}{b^2v'}=\frac{\cos\beta\cos\gamma-\cos\alpha}{bc\ w'}.$$

The obliquity is the angle $\phi$ between $[uvw]$ and $[u'v'w']$. It is given by the known formula

$$\cos\phi=\sqrt{\frac{\epsilon}{\epsilon'}}\ \frac{uh+vk+wl}{\sqrt{uh'+vk'+wl'}\sqrt{u'h+v'k+w'l}},$$

in which

$$\epsilon=\frac{b}{k}\ (au'\cos\gamma+bv'+cw'\cos\alpha)$$

and

$$\epsilon'=\frac{b}{k'}\ (au\cos\gamma+bv+cw\cos\alpha).$$

In the present case, the formula reduces to $\cos^2\phi=\epsilon/v'$.

The data necessary for the calculations are axial elements for plagioclases of known composition. The usual values of the axial elements, given by Dana and Hintze, are tabulated below, together with the composition expressed in *An* percentages.

| No. | Plagioclase | $a{:}b{:}c$ | $\alpha$ | $\beta$ | $\gamma$ | % *An* |
|---|---|---|---|---|---|---|
| I | Albite | 0.6335:1:0.5577 | 94° 3′ | 116°29′ | 88° 9′ | 2 |
| II | Oligoclase | 0.6321:1:0.5524 | 93° 4′ | 116°22½′ | 90° 4½′ | 26 |
| III | Andesine | 0.6356:1:0.5521 | 93°23′ | 116°28½′ | 89°59′ | 50 |
| IV | Labradorite | 0.6377:1:0.5547 | 93°31′ | 116° 3′ | 89°54½′ | 73 |
| V | Anorthite | 0.6347:1:0.5501 | 93°13′ | 115°55½′ | 91°12′ | 96 |

The albite data were obtained on material from St. Gotthard. The composition $Ab_{98}An_2$, calculated from a chemical analysis given in Hintze for St. Gotthard albite, is tentatively assigned to the first set of axial elements.

The oligoclase data refer to a specimen from Vesuvius for which a chemical analysis is available. The composition is calculated to be $Ab_{74}\,An_{26}$. In this calculation, as in the following ones, $K_2O$ is counted in the albite molecule.

The andesine listed comes from Arcuentu. Two chemical analyses, one by Fouqué, the other by Duparc, made on the same material, yield 48.8% *An* and 51.5% *An*, respectively. This "andesine" is, in fact, very close to $Ab_{50}\,An_{50}$.

The axial elements given for labradorite come, partly from Aetna material and partly from Kiev material. The analyses of labradorite specimens from these two localities are very much alike, but they lead to a calculated composition $Ab_{27}An_{73}$, which corresponds to a bytownite rather than a labradorite. This composition must be held in doubt.

Finally, the analysis available for the anorthite material, from Vesuvius, leads to the composition $Ab_4\,An_{96}$.

In view of the uncertainty attached to the composition of the albite, other data were sought. Hintze gives axial elements for a number of albite specimens, together with the angle $\sigma$ which the trace of the pericline twin plane (rhombic section) makes, on the *b* face, with the edge *c b*. These data are reproduced below.

| No. | $a:b:c$ | $\alpha$ | $\beta$ | $\gamma$ | $\sigma$ | % *An* |
|---|---|---|---|---|---|---|
| VI | 0.6356 :1:0.5589 | 94°29′ | 116°39′ | 87°28′ | 34° 6′ | 1.5 |
| VII | 0.6350 :1:0.5586 | 94°16′ | 116°43′30″ | 87°45′20″ | 31°37′ | 2.1 |
| VIII | 0.63973:1:0.56067 | 94°12′ | 116°34′10″ | 87°48′19″ | 31°23′50″ | 2.2 |
| IX | 0.63385:1:0.56062 | 94°15′20″ | 116°25′43″ | 87°49′20″ | 29° 6′ | 3.0 |
| X | 0.63697:1:0.56485 | 94° 5′33″ | 116°54′35″ | 88° 1′54° | 28°45′ | 3.2 |
| XI | 0.6358 :1:0.5536 | 93°56′ | 116°35′ | 88°10′ | 27°47′ | 3.5 |
| XII | 0.63412:1:0.55738 | 94° 5′22″ | 116°26′54″ | 88° 6′45″ | 27°30′16″ | 3.6 |

The composition of these specimens can be tentatively determined from E. Schmidt's curve,[1] which gives the $\sigma$ angle for the plagioclases. It is realized, of course, that this curve is not very accurate near the sodic end of the series (*cp.* Tom. Barth, 1928), but this is the only method available in this case to estimate the composition. The *An* percentages given above are read from the curve.

[1] This curve is readily available in Rogers and Kerr, *Thin-Section Mineralogy*, p. 208, McGraw-Hill (1933).

Finally, one good set of elements was given by Lewis (1914), with accompanying chemical analysis:

XIII $a:b:c=0.6335:1:0.5564$, $\alpha=93°58'$, $\beta=116°21'$, $\gamma=87°31\frac{1}{4}'$. The calculated composition is 4.2% *An*.

The *index* of albite twinning is obviously equal to one in all plagioclases. This type of twinning is known as *twinning by pseudo-merohedry;* the unit cell whose pseudo-symmetry determines the twinning (both albite and pericline laws) is known to be *c*-centered, from structural results, but it is easy to see that all nodes are restored by twinning (hence index = 1).

The values of the indices $(h'k'l')$ of the plane exactly perpendicular to [010] and the indices $[u'v'w']$ of the straight line exactly normal to (010), were computed to seven decimal places by means of a calculating machine, not that the author believed in this fallacious accuracy, but simply as a matter of convenience in working with seven-place tables of natural trigonometric functions. These values are listed here for the purpose of giving an idea of the deviations involved.

| No. | $h'$ | $k'$ | $l'$ | $u'$ | $v'$ | $w'$ |
|---|---|---|---|---|---|---|
| I | 0.020 4513 | 1 | −0.039 3887 | −0.001 2435 | 0.801 1397 | 0.100 8263 |
| II | −0.000 8274 | 1 | −0.029 5522 | 0.039 6696 | 0.802 6470 | 0.097 8990 |
| III | 0.000 1849 | 1 | −0.032 5827 | 0.040 9359 | 0.801 2559 | 0.106 1743 |
| IV | 0.001 0203 | 1 | −0.034 0247 | 0.039 7325 | 0.807 1427 | 0.109 3137 |
| V | −0.013 2921 | 1 | −0.030 8672 | 0.071 6468 | 0.808 8612 | 0.118 6472 |
| VI | 0.028 0939 | 1 | −0.043 6887 | −0.014 3781 | 0.798 8127 | 0.104 3897 |
| VII | 0.024 8684 | 1 | −0.041 5591 | −0.008 9846 | 0.797 7621 | 0.101 6590 |
| VIII | 0.024 4989 | 1 | −0.041 0625 | −0.008 6563 | 0.799 9387 | 0.100 0753 |
| IX | 0.024 0864 | 1 | −0.041 6009 | −0.007 8465 | 0.801 9016 | 0.102 1947 |
| X | 0.021 8781 | 1 | −0.040 3116 | −0.003 0497 | 0.795 1660 | 0.098 8299 |
| XI | 0.020 3406 | 1 | −0.037 9746 | −0.002 0379 | 0.799 7446 | 0.098 0477 |
| XII | 0.020 8861 | 1 | −0.039 7488 | −0.001 8572 | 0.801 6273 | 0.101 6278 |

The obliquity $\phi$ was calculated for the thirteen sets of axial elements. The results are tabulated below, together with the plagioclase composition, listed according to increasing anorthite content.

| | VI | I | VII | VIII | IX | X | XI | XII | XIII | II | III | IV | V |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| % *An* | 1.5 | 2 | 2.1 | 2.2 | 3.0 | 3.2 | 3.5 | 3.6 | 4.2 | 26 | 50 | 73 | 96 |
| $\phi$ | 4°31′ | 4°3′ | 4°18′ | 4°13′ | 4°15′ | 4°6′ | 3°57′ | 4°6′ | 4°3′ | 3°28′ | 3°46′ | 3°52′ | 4°20′ |

## Discussion

These results are presented in the form of a graph (Fig. 1), giving the obliquity of the albite twin in terms of plagioclase composition.

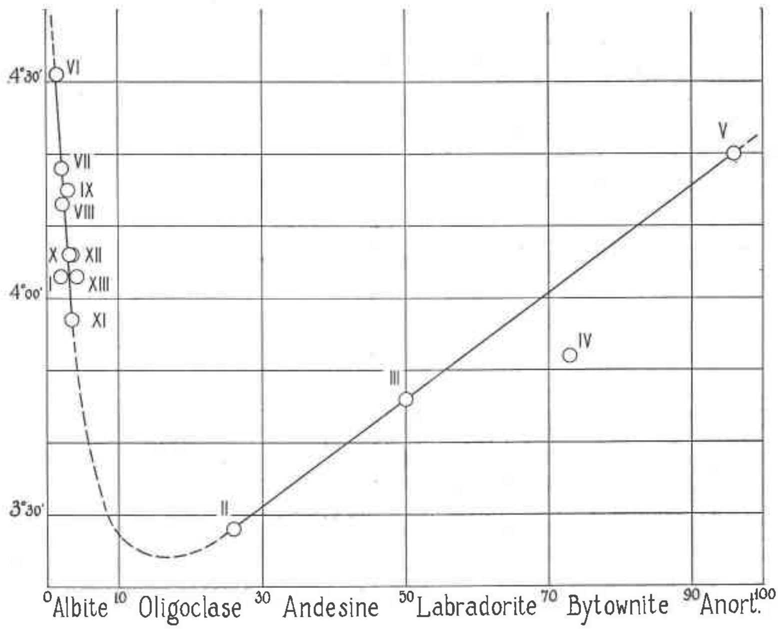


Fig. 1. Albite twin obliquity *vs.* plagioclase composition. The smaller the obliquity, the more frequent the twin and the thinner the lamellae.

For lack of data the curve cannot be plotted for abscissae ranging from 5% to 25% anorthite content. The points plotted for the albite end of the series are quite satisfactory, with the possible exception of point I, whose reliability was questioned in the preceding section. These points indicate a steep rise of the curve towards pure albite. As to the remaining data, the points II, III, and V, which have been judged most reliable, practically lie on a straight line. The doubtful point IV, if treated as a bytownite, shows an appreciable departure from this curve. It is remarkable, nevertheless, that the value of the obliquity for point IV corresponds to a labradorite composition, about $Ab_{40}An_{60}$, according to the curve II–III–V. In view of the meagre data available, these results are gratifying; they definitely establish the general trend of the curve for a range of about three-fourths of the plagioclase series, rising steadily from 26% to 96% anorthite.

The only way to fill the gap in the curve is to postulate a minimum somewhere in the oligoclase region. This part of the curve is shown in dash (Fig. 1).

From the above discussion, the predictions of the twinning theory are clear: (1) the albite-twin lamellae should be narrowest in oligoclase; (2) their width should increase as the plagioclase becomes more calcic, the lamellae being widest in anorthites; (3) in the short range from oligoclase to albite, one should expect a rapid widening of the lamellae, to such an extent that for pure or almost pure albite, twinning may cease to be polysynthetic at all.

## Facts of Observation

After having presented theoretical predictions, an author is virtually deprived of the right to offer factual observations of his own to substantiate the forecasts. Such *a posteriori* observations could never be free from suspicion. In order to prove (or disprove) my point, I must, therefore, appeal to previous investigators and their observations on record as given in the literature.[2]

A relevant remark is found in Dufrénoy (1859), who says that anorthite crystals are frequently twinned, but that twinning is "less habitual than for albite and labradorite." Delafosse (1862), describing the polysynthetic repetition of albite twinning, states that "this repetition, however, is fairly rare in albite; it is seen much more frequently in crystals of the next two species,[3] oligoclase and labradorite." Des Cloizeaux (1862) furnishes very valuable information concerning the frequency of twinning and the size of the lamellae. His brief remark on andesine ("simple or double twins") is not, of course, very significant.[3] His estimation of frequency is as follows: for anorthite, "macles fréquentes"; for labradorite, "macles très-habituelles"; for oligoclase, "macles excessivement fréquentes"; for albite, "macles fréquentes." As to the lamellar character, he makes no special mention of striae or repeated lamellae either for albite or for anorthite; for labradorite, he writes that "lamellar varieties are generally composed of a series of thin strata twinned on $g^1$ (010) or $p$ (001)"; he describes the Arendal oligoclase crystals as being "apparently single crystals . . . usually traversed by a multitude of thin twinned lamellae joined together parallel to $g^1$ (010)."

Data on albite are scant. One obvious reason for this is that pure albite is rarely encountered. Fouqué and Michel-Lévy (1879), in their

[2] Contrary to usual practice and for the sake of clarity, I shall refrain, as much as possible, from quoting in the original language. Crystallographic symbols will be translated as well as words.

[3] The validity of andesine was not generally recognized at the time.

discussion of acidic rocks, mention "the extreme abundance of oligoclase and, certainly, the great scarcity of albite." The plagioclase syntheses, which these investigators succeeded in producing, are of special interest. In contrast to synthetic microlites of albite, which were "generally untwinned," it is instructive to read their description of synthetic oligoclase microlites, which showed "very narrow striations," of labradorite microlites, in which they mention "up to twenty twinned lamellae perfectly distinct from one another," and of anorthite microlites "whose twinned lamellae completely resemble natural anorthites, by their arrangement and their great breadth (grande largeur)."

Fouqué and Michel-Lévy also provide relevant observations on natural albite ("isolated crystals," "microlites rarely twinned") and natural labradorite ("lamellae often very unequal in size, their thickness exhibiting no regularity"), but their statement on natural anorthite is particularly illuminating: "the lamellae often are of large size, regularly spaced; their appearance is typical enough to permit one to sense anorthite crystals before any measurement of extinction angles and any chemical test."

Further quotations seem well nigh unnecessary. I shall mention two more, which confirm the preceding ones. Tschermak (1897) writes about anorthite: "single crystals are frequent; in repeated twinning, the lamellae are much thicker than in the other plagioclases." A. de Lapparent (1899) remarks that oligoclase shows "twins after the albite law, with numerous striae on $p$ (001)" and that "in thin slices, oligoclase is distinguished by the extreme fineness and regularity of its twinned lamellae"; about anorthite, he states that "its lamellae are wide and fairly well defined."

The consensus seems to be in favor of the theoretical predictions. One discordant note, however, is struck by Luquer (1925) who makes a misleading attempt at generalization when he writes, on the subject of albite twinning in plagioclases, that "the lamellae . . . seem to be broader in the basic than in the acid series." The evidence gathered here shows that exception must be taken to his statement, which is true only in the range extending from oligoclase to anorthite.

## Conclusions

The predictions of the theory are seen to be in excellent agreement with the observations on record.

The width of albite twinning lamellae is in relation to the frequency of the twin. The lamellae are narrowest, and the twinning most frequent, in oligoclase. The universality of finely polysynthetic twinning in oligoclases certainly accounts for the lack of goniometric data on those plagioclases. The width of the lamellae increases as the plagioclase composition varies from oligoclase to anorthite. In anorthite, the lamellae are broad and twinning is less frequent, as shown by the fact that even single crystals are known. On the sodic end, the same decrease in the frequency of the twin has been noted, many albites having been observed as single crystals. Between sodic oligoclases and calcic albites, with narrow lamellae, on the one hand, and nearly pure albite, found in single crystals, on the other hand, no special mention of albites with broad lamellae has been found in the literature. This is not surprising, in view of the steep slope of the obliquity curve in the albite region. Indeed, it is easy to see (Fig. 1) that only for more than 1.8% and less than 2.3% *An* content can albites be expected to exhibit the same width of lamellae as anorthites. For a more sodic composition, one soon passes into higher obliquities with the consequent disappearance of the polysynthetic character of twinning and even the appearance of single crystals; for a more calcic composition, smaller obliquities demand narrower lamellae, albeit not as thin as those of oligoclase; all of which has been observed.

Finally, it may be remarked that the variations in width of albite-twin lamellae could be presented as strong evidence in favor of the French theory of twinning, were not such additional support wholly superfluous.

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