The orientation of the pericline twin lamellae in triclinic alkali felspars.

(With Plate II.)

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Summary.—Cross-hatched twinning is characteristic of two alkali-felspar species, microclines and anorthoclases. Because of the difference in the crystallographic angles of these two species, the cross-hatched twinning is most clearly seen in (001) sections of microcline and in sections perpendicular to the *a* crystallographic axis in anorthoclases. If pericline twinning is present it is generally seen in (010) sections of microclines, but if the microcline is microperthitic the twin lamellae may not be seen. Strings or lamellae of perthitic albite can be distinguished from pericline twin lamellae by refractive index differences and also by the angle that their trace makes with the trace of (001) in (010) sections.

CROSS-HATCHED twinning is commonly seen both in microclines and in some sodium-rich alkali felspars, and because of the optical similarity between these two felspars many investigators have looked for a solid-solution series from microcline to albite. Recent studies of the alkali felspars have indicated that the complexly twinned sodium-rich felspars are high-temperature forms, whereas microcline is generally accepted to be a low-temperature form.[1] The observed sodium content of natural microclines is uniformly low (MacKenzie, 1954), so that the practical significance of a possible solid-solution series from microcline to albite is trifling. The purpose of this note is to draw attention to the difference between the twinning shown by microcline and that seen in some sodium-rich alkali felspars, of the type properly referred to as anorthoclase.[2]

[1] The term 'high-temperature' here implies that the felspar has been quickly cooled in a volcanic rock and so has retained the characteristics of its high-temperature origin. A low-temperature felspar may have crystallized at high temperature but on slow cooling inverted to a low-temperature form.

[2] The vague and imprecise usages of the name anorthoclase adopted by some writers obscure the value of the original definition of the word. The mineral name anorthoclase was first proposed by Rosenbusch (1885, p. 549) for certain *anorthic* sodium-rich alkali felspars multiply twinned after the albite and pericline laws, but

Anorthoclases are sometimes unmixed on a sub-microscopic scale, but usually they can be homogenized by heating at 900° C. for a few minutes. Cross-hatched twinning may be observed optically both in unmixed and homogeneous crystals.

Microclines are generally perthitic and are not readily rendered homogeneous. The lattice parameters of the potassium phase of a microcline-perthite may vary considerably (MacKenzie, 1952), and this variation is sometimes found even within a single small cleavage fragment. Specimens with the maximum deviation from monoclinic symmetry ($\alpha = 90° 41'$ and $\gamma = 87° 30'$) are very common and will be described as maximum microclines; those with less than the maximum deviation will be termed intermediate microclines.

Both microclines and anorthoclases are characterized by two sets of multiple twin lamellae which in certain orientations give the cross-hatched appearance in thin section. Laves (1950, 1952) established by X-ray methods that in the specimens he studied, both microclines and anorthoclases, the twin laws were albite and pericline. Other twin laws producing polysynthetic twin lamellae are possible in these felspars, but so far the writer has not observed multiple twinning based on any other laws. The albite twin law is defined as reflection across the (010) plane or as 180° rotation about an axis perpendicular to (010) and inversion through the centre. The composition plane is (010). The pericline twin law is 180° rotation about the *b*-axis, and the composition plane is an irrational plane that contains the *b*-axis and intersects the (010) plane in a line perpendicular to the *b*-axis. This plane is known as the rhombic section. The orientation of the rhombic section is sensitive to small changes in lattice angles, and some mineralogy textbooks give a method for determining the composition of plagioclase felspars from a measurement of the angle σ, which the trace of the pericline twin lamellae makes with the *a*-axis in (010) sections.

The angle σ may be calculated from the relation $\cot \sigma = \cos(001) \wedge (010)/\cot \gamma$ (Story-Maskelyne, 1895; Lewis, 1899; Tunell, 1952). The sign of the angle σ will be positive if measured from the positive direction of the *a*-axis towards the positive direction of the *c*-axis, and negative if

with a cleavage angle very close to 90°. From specimens known at that time Rosenbusch gave the limits of chemical composition of the anorthoclase series as $Or_{33}Ab_{67}$–$Or_{17}Ab_{83}$ with some anorthite in solid solution. From the work of Foerstner (1884), Rosenbusch knew that the anorthoclases when heated became optically monoclinic and reverted to anorthic symmetry even on rapid cooling. The name anorthoclase will be used here in essentially the same sense as proposed by Rosenbusch; but I hope to discuss this matter separately in another place.

measured from the negative direction of the a-axis, towards the positive direction of the c-axis.

TABLE I. The position of the rhombic section in triclinic alkali felspars, calculated from the relation $\cot\sigma = \cos(001) \wedge (010)/\cot\gamma$.

		$(001) \wedge (010)$.	γ.	σ.
High-temperature albite and anorthoclases (synthetic) (Donnay and Donnay, 1952).	Ab	85° 50′	90° 11′	−2° 31′
	$Or_{10}Ab_{90}$	86° 29′	90° 10′	−2° 43′
	$Or_{20}Ab_{80}$	87° 27′	90° 18′	−6° 43′*
	$Or_{30}Ab_{70}$	88° 29′	90° 07′	−4° 24′
Microclines (MacKenzie, 1954).	Blue Mt., Ontario	90° 18′	87° 31′	−83° 07′
	Spencer E†	90° 09′	88° 48′	−82° 53′
	Spencer U†	90° 05′	89° 11′	−84° 11′

* This value appears to be high and is probably due to an error in the value of γ. Very slight errors in the determination of lattice angles produce a marked effect on the value of σ.

† Specimens described by Spencer (1937). The letters E and U were those given by Spencer to designate these specimens.

The angle σ has been calculated for three anorthoclases and high-temperature albite from the lattice angles given by Donnay and Donnay (1952) and also for a maximum microcline and two intermediate microclines (MacKenzie, 1954). From the values given in table I it can be seen that the trace of the pericline twin lamellae makes a small angle with the trace of the (001) cleavage in the anorthoclases and high-temperature albite, whereas in microclines it is more nearly at right angles to the trace of the (001) cleavage. In both cases the variations in σ are not sufficiently large to be useful in determining the departure of the lattices from monoclinic symmetry. Plate II, fig. 1A, is a photomicrograph of a thin section of a crystal of anorthoclase from a volcanic bomb from Camperdown, Victoria, Australia, cut perpendicular to the a-axis. The lamellae twinned according to the albite law are parallel to the long dimension of the photograph, and those twinned according to the pericline law are approximately at right angles. A section of the same crystal cut parallel to (010) is illustrated in fig. 1B, and here the c-axis is parallel to the long dimension of the photograph. The angle between the trace of the pericline twin lamellae and the trace of (001) measured from this photograph is about $-3\frac{1}{2}°$, a value which compares well with the calculated values for synthetic anorthoclases.[1]

Plate II, fig. 2A, shows an (001) cleavage section of a crystal of microcline from the Hugo mine, Black Hills, South Dakota. This felspar poikilitically encloses albite crystals but is almost entirely free from

[1] Rosenbusch (1885, p. 550) gives the value of σ as 4–6° and, rarely, 8°.

microperthitic albite. The lamellae parallel to the long dimension of the photograph are twinned according to the albite law, and those approximately at right angles are twinned according to the pericline law. Fig. 2B is a section of the same crystal cut parallel to (010), and the *c*-axis is parallel to the long dimension of the photograph as in fig. 1B. The angle between the trace of the pericline lamellae and the trace of (001) in this photograph is about -83°, a value close to the calculated values for microclines. An exact value for the angle σ cannot be measured since the traces of the composition planes of the pericline twin lamellae are not straight lines; variations of the lattice angles within this crystal undoubtedly account for the deviations from straight lines.

An (001) section of a microcline-perthite from the Diamond Match Company mine, Topsham, Maine, is illustrated in plate II, fig. 3A. Albite veins appear grey in the photograph, and the twin lamellae in the microcline, particularly those twinned on the pericline law, are much narrower and are clearly defined adjacent to the albite veins. A section of the same crystal cut parallel to (010) is shown in fig. 3B. Microperthitic albite strings, too small to be seen in fig. 3A, are oriented so that their trace makes an angle of $-107\frac{1}{2}^\circ$ or $+72\frac{1}{2}^\circ$ with the trace of (001) in the (010) plane. This value of $72\frac{1}{2}^\circ$ for the acute angle is close to that generally given for the orientation of albite strings or lamellae in microcline- or orthoclase-microperthites (Bøggild, 1924; Andersen, 1928; Spencer, 1930), although other orientations have been reported (Bøggild, 1924; Spencer, 1930). The trace of the microperthitic strings in the (010) plane therefore makes an angle of about 25° with the trace of the rhombic section, but pericline twin lamellae, although clearly visible in the (001) section, can be seen only in a few places in this section and then only after very careful examination. Study of a number of microcline-microperthites reveals that when microperthitic albite strings are clearly seen in (010) sections the pericline twin lamellae are not readily visible and sometimes cannot be seen at all. Since microclines are commonly microperthitic it would appear that (010) sections would be extremely difficult to distinguish from (010) sections of orthoclase-microperthite in the absence of visible pericline twinning. Statements regarding the relative amounts of orthoclase and microcline in acid plutonic rocks should therefore be made only with the greatest caution, not only because microcline may be untwinned, but also because the twinning may not be readily observed in sections nearly parallel to (010).

One sodium-rich alkali felspar that cannot be classed as an anorthoclase has been found to have cross-hatched twinning. Tilley (1954) described a felspar of composition $Or_{19\cdot8}Ab_{72\cdot7}An_{6\cdot0}Ce_{1\cdot5}$ from a nepheline-syenite in Mogok, Burma, as an orthoclase-cryptoperthite. Optical examination of a sample kindly provided by Professor C. E. Tilley revealed that, although most of the crystals were optically monoclinic, one or two had cross-hatched twinning. X-ray study revealed that the sodium felspar phase was similar to low-temperature albite in lattice angles, and heating at 1050° C. for 65 hours was not sufficient to homogenize completely the two phases (MacKenzie and Smith, 1955). The specimen probably crystallized as a homogeneous anorthoclase, unmixed to an anorthoclase-cryptoperthite with a sodium felspar phase of high-temperature albite, and finally, when the sodium-rich phase inverted to low-temperature albite, reached its present state. This felspar is best described as an orthoclase-cryptoperthite or orthoclase-microperthite, indicating that it has a low-temperature sodium felspar phase (MacKenzie and Smith, 1955).

To summarize, cross-hatched twinning is characteristic of two alkali felspar species, namely microclines and anorthoclases. Because of the difference in the crystallographic angles of these two species, the cross-hatched twinning is most clearly seen in (001) sections of microcline and in sections perpendicular to the *a* crystallographic axis in anorthoclase. If pericline twinning is present it is generally seen in (010) sections of microclines, but if the microcline is microperthitic the twin lamellae may not be seen. Strings or lamellae of perthitic albite can be distinguished from pericline twin lamellae by refractive index differences and also by the angle which their trace makes with the trace of (001) in (010) sections.

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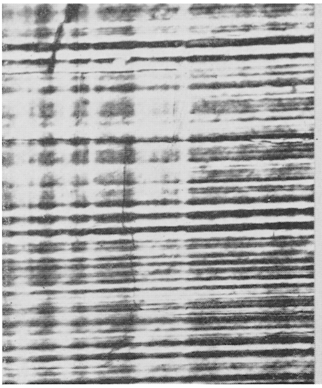
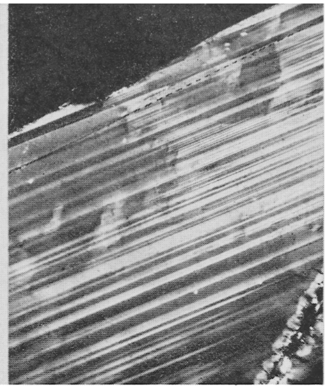
PLATE II.

FIG. 1. Photomicrographs of thin sections of anorthoclase from a volcanic bomb, Camperdown, Victoria, Australia. A. Section perpendicular to the a-axis showing albite and pericline twinning. Crossed nicols; ×60. B. Section parallel to (010) showing pericline twin lamellae whose trace is inclined to that of the (001) cleavage at $-3\frac{1}{2}°$. Crossed nicols; ×50. The trace of the (001) cleavage is marked by a broken line since it does not show clearly in the photograph.

FIG. 2. Photomicrographs of thin sections of microcline from Hugo mine, Black Hills, South Dakota. A. Section parallel to (001) showing albite and pericline twinning. Crossed nicols; ×50. B. Section parallel to (010). The traces of the pericline twin lamellae do not form straight lines but make an angle of approximately 83° with the trace of the (001) cleavage. Crossed nicols; ×200.

FIG. 3. Photomicrographs of thin sections of microcline-perthite from the Diamond Match Company mine, Topsham, Maine. A. Section parallel to (001). Veins of perthitic albite appear grey in the photograph, and adjacent to these veins the pericline twin lamellae in the microcline are much narrower and more clearly defined than elsewhere in the section. Crossed nicols; ×50. B. Section parallel to (010). Strings of microperthitic albite lie at $72\frac{1}{2}°$ to the trace of the (001) cleavage. Crossed nicols; ×200.

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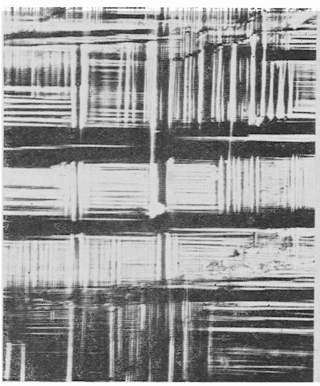
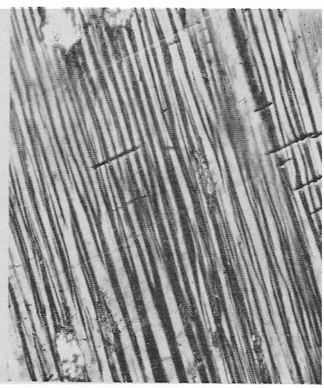

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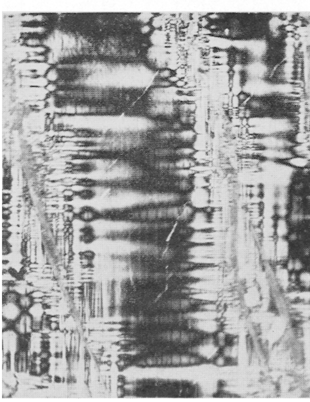


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