NEW METHOD FOR THE DETERMINATION OF FELDSPAR TWINS

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Abstract

Subject: Feldspar twins. (1) An appeal for their study from the point of view of their possible exploitation. Can they be used as a basis of igneous rock correlation? What decides which twin laws shall prevail? (2) A description is given of a new, very rapid procedure for the determination of the twin laws. We estimate the time needed for the determination of such twin laws by the new "five-axis method" to be definitely less than 10% of the time required for the original four-axis technique of Fedorov. There is also afforded an increase in both accuracy and range of applicability.

Our purpose is to describe a new method for the determination of feldspar twins—a method in which we have found combined (a) the speed of the Rittmann method without its attendant limitations mentioned below, (b) the accuracy of the Fedorov method at its best. The recognized points of weakness of the Fedorov method, mentioned below, have been found to offer no difficulty here. The great bulk of the Fedorov graphical procedures is eliminated. In fact we feel that this technique of feldspar-twin determination makes this type of study sufficiently rapid and simple to be thoroughly satisfactory for routine use.

The general situation of feldspar-twin study in America may profitably be reviewed as a background. There has been little published study of feldspar twinning in America. The reasons seem to be two—first, at best the method has been a little tedious and slightly involved; second, there has been no recognized practical application of the results to be obtained. The procedure presented in this paper, we believe, completely eliminates all reasonable involvement and tedium. The second question still remains and adequately justified limiting the general practice of the technique. However, a diligent search is now being conducted at Wisconsin hoping to answer several most obvious questions one may ask about the occurrence of feldspar twins. According to the results of these studies we shall either expand such work further or discontinue our part in it almost entirely.

An early concept prevailed that certain twin laws were to be found more prominently in calcic plagioclase and others largely in the more sodic plagioclase. On this basis, composition would be a dominant controlling factor in deciding the twin law. A preliminary study made in the senior writer's laboratory by Chapman (1) on a differentiated sill showed by statistical count that the same twin laws prevailed from bottom to top of the sill. If composition were a controlling factor, then such uniformity would not be possible. Although one such study is not conclusive evidence, it helped to disprove an unfounded idea. It did not reveal the real basis of control of feldspar twinning, which still remains a mystery.

Without understanding this basis it is entirely possible that feldspar twinning may be of practical value, if used empirically. If one intrusive or one phase of one intrusive body is characterized by one twin pattern, then such a pattern may serve as a thumb print for that igneous rock—of value in correlation. Study is now in progress to attempt to answer this question.

We do not know the effect on feldspar twinning of metamorphism which involves the crystallization of feldspars. Such a study is also in progress.

Adjacent twin lamellae quite normally show a difference in anorthite content as revealed by optical study. We do not know if this is apparent or real, that is, due to strain or an actual chemical difference. We hope to answer this question shortly.

Other questions will occur to the reader according to his experience. These are mentioned in the hope that we may enlist the interest and cooperative effort of others in this most fascinating study. The consistent occurrence of feldspars in igneous rocks lends unusual importance to any discovery of twin significance. Our admitted ignorance in this field is a strong incentive. With a new, thoroughly practical method at hand to facilitate the work we hope that more American petrographers will join in this type of study.

The method suggested here is brief. We shall state it first and then illustrate it. Assume a single feldspar twin of two lamellae. Orient either one on the universal stage (2) (10). No graphical construction is needed on the five-axis stage and the procedure involves liberally five minutes in an average case. Record the oriented position. Now make the composition face vertical and north-south (as required for the Rittmann procedure) and rotate on the outer east-west axis till the lamellae are equally bright. Measure the extinction angle of each lamella. This reveals the position of the twinning axis. Record the new readings of the stage. A short graphical procedure, made on a stereogram, follows, namely—rotate the twinning axis from its oriented position just found to the position it occupied when the first lamella was oriented. This is most easily done by merely following the measured curves on a printed stereogram as illustrated below. The stereogram so constructed is now placed on plots already published in several places (3), and the twin law and feldspar composition are read off. Two illustrations follow.

Procedure for illustration 1. A rough sketch was made of the crystal and the extinction relationships of the various lamellae were noted. On the basis of these relationships the lamellae were grouped into three units (Fig. 1). First, unit 1 was oriented on the five-axis stage and the attitudes of the optic elements were determined. This was recorded in Table 1 (columns 1 and 2). Second, the composition face was made north-south and vertical by rotations on the outer vertical and north-south axes. Verticality is recognized when the line defining the composition face is finest. The new readings were recorded in the third column under composition face. Therefore the entry N-S 3°W means that the north-south axis has been rotated from 28°E to 3°W, a total of 31° west (to be used later). It is well to let all entries be direct readings from the universal stage in order to avoid confusion. The inner vertical axis should not be involved in this orientation of the composition face. The inner east-west axis should also be excluded whenever possible. Third, a wide rotation was made on the outer east-west axis, which is, of course, normal to the composition face. Two observations were made on this rotation. One, the relative intensities of illumination of units 1 and 3 were found to be constant. This twin relationship was thereby recognized as normal,* the axis being east-west and horizontal, that is, coinciding with the pole of the composition face. This is implied on the data sheet (Table 1) by the entry "normal." Two, the relative intensities of illumination of units 1 and 2 were found to vary. This twin relationship was thereby recognized as parallel or complex, the axis lying somewhere within the composition face. Two further steps locate this twinning axis, namely, one—the rotation on the outer east-west axis was repeated carefully to the position in which units 1 and 2 were equally bright (Fig. 2). The outer east-west axis was read and recorded as T_{1-2}, 24°S. The twinning axis was then known to be either vertical, or horizontal and north-south. Two—the crystal was rotated on the microscope stage to bring one or both of these units to extinction. The extinction values were found to be equal and opposite in sign, indicating the axis to be horizontal (8). This is recorded in the last column by the entry *H*. (If both units had gone to extinction simultaneously the final entry would be *V* instead of *H*, indicating that the axis was vertical.) All recordings for this crystal are now complete.

* Four convenient references are given where twin laws may be reviewed—(4), (5), (6), (7).

TABLE 1. TWIN DETERMINATION—FIVE-AXIS METHOD
Reference Data: G38–5A—Beaver Bay—L. Superior
Hemisphere 1.559. Zero Values: Mic. 359.8° O. V. 90°.

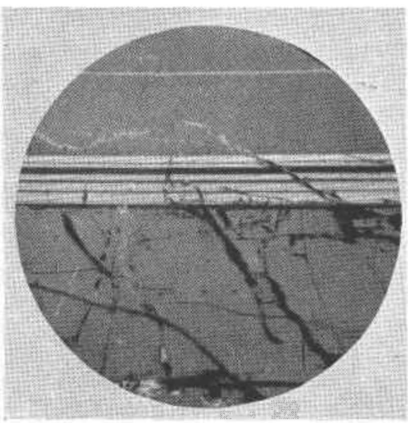
Unit 1:

I. E-W	8°S
N-S	28°E

I. V.	359.2
α	N
β	$\perp$
γ	E

Comp. Face 1.	O. V.	↶ 29°	
	N-S	3°W	
	I. E-W	—	
Twin Axes (O. E-W)	T_{1-3}	Normal	
	T_{1-2}	24°S	H

REMARKS: Composition Face (010)
Twin Laws. T_{1-2} Carlsbad
T_{1-3} Albite
Composition 79–81% An.



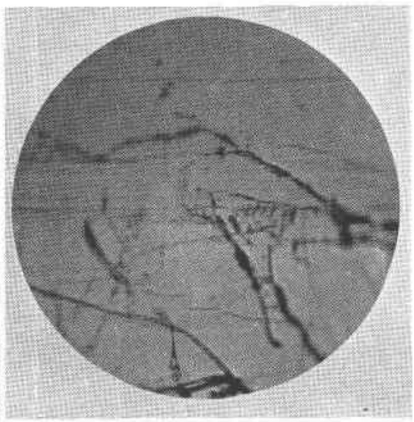
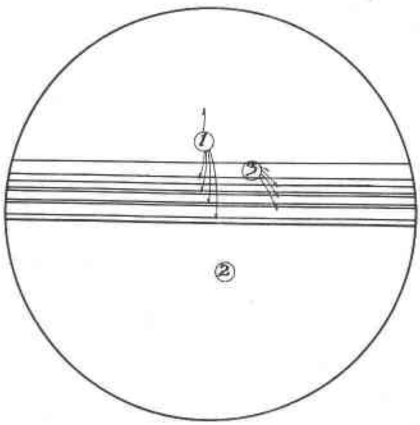


FIG. 1. The plagioclase crystal of example 1 showing the twin lamellae in contrasting illumination.

FIG. 2. The same crystal as that shown in Fig. 1 rotated to a position of equal illumination.

The accuracy of the position of the twinning axis, that is, the position of equal illumination obtained on the outer east-west axis, may be checked by the values of extinction on the microscope stage. These extinction values should be equal and either of the same or opposite sign. If they are not quite equal, then modify slightly the rotation on the outer east-west axis.

The accuracy of this position of the twinning axis may be enhanced also by another slight modification if the first rotation on the outer east-



Key to Figs. 1 and 2

west axis yielded a difficult observation. The position of equal illumination may be determined either when the composition face is north-south or in the 45° position. If the north-south position seems unfavorable, then the 45° position is to be preferred. Secure the 45° position by a rotation on the microscope stage—it is to be measured not estimated.

The remaining steps of the procedure are accomplished briefly on the stereographic projection. The purpose is to rotate the pole of the composition face, *P*, and the twinning axes T_{1-2} and T_{1-3} from the positions of known orientation back to the positions they occupied when unit 1 was oriented. This is done, of course, on the stereographic projection by reversing the rotations which led to the recordings of column three of the data sheet.*

* If hemispheres of index about 1.56 are used, corrections for the difference in index between crystal and hemisphere are negligible. If, however, other standard hemispheres are used, it is necessary to make these corrections for rotations on horizontal axes. The method of making these corrections has been discussed elsewhere (3), (9), (10).

The details for carrying out these rotations on a stereographic projection follow. (See Fig. 3.)* First—to locate the pole of the composition face, P, which is also the twinning axis, T_{1-3}. (a) Since the oriented pole was horizontal and east-west, the rotation of 29° counter clockwise was made as shown in Fig. 3; this brings the north-south axis into its true

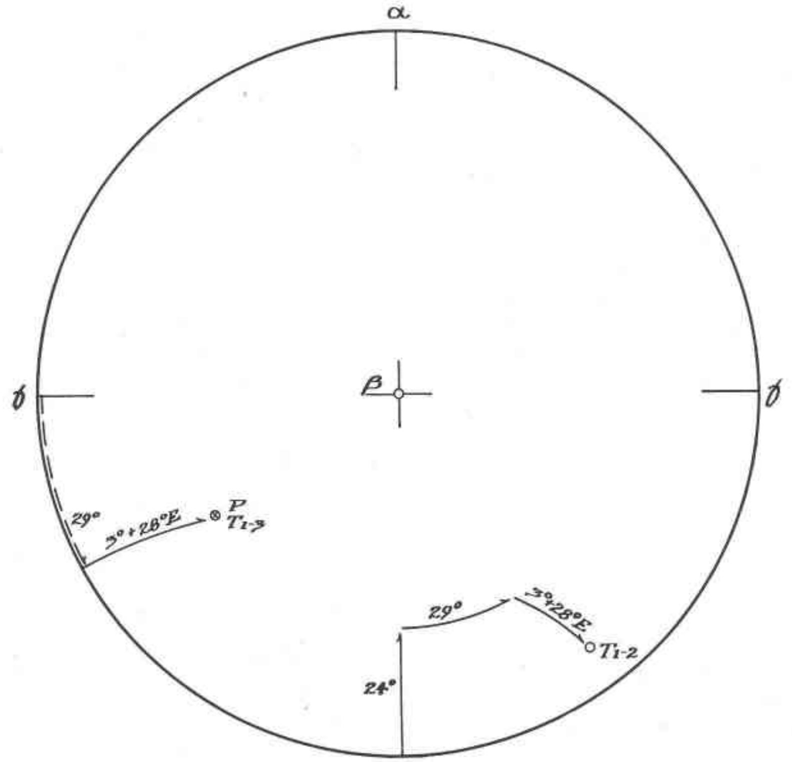


FIG. 3. The graphical rotations given in Table 1 employed to locate the pole and twinning axes on the plot of unit 1 in oriented position.

north-south position. (b) Since the north-south axis was rotated from the position 28°E to the position 3°W, a reversal requires a rotation of 31°E. This gives the position of the pole of the composition face and the normal twinning axis, T_{1-3} when unit 1 was oriented. Second—to locate

* The rotations are perhaps most simply made on a blank stereogram on which the cardinal orientation of unit 1 is indicated by placing α, β, and γ in their proper positions. This is superposed on some combination of Wolff and Fedorov nets.

the twinning axis T_{1-2}. (a) Since this axis was horizontal and north-south when oriented, and since the outer vertical axis was inclined by the rotation of 24°S on the outer east-west axis, therefore, the rotation of 24°N was made as shown in Fig. 3. This brings the outer vertical axis to its true vertical position. The remaining two rotations, 29° counter clockwise and 31° east were made as for the pole of the composition face. This is the position of T_{1-2} when unit 1 was oriented.

The projection thus completed may now be superposed on the proper Fedorov stereogram (3). The points P, T_{1-2} and T_{1-3} should fall reasonably close to the migration curves which in turn indicate the composition face, the twin laws, and the anorthite content. This crystal was found to have a composition face (010) and an anorthite content of 79–81%. T_{1-2} falls on the migration curve of the Carlsbad law and T_{1-3} the albite law. The graphical execution of this last step is reserved for the second example in Fig. 6.

Procedure for illustration 2. This second example is expanded to show that any number of twin relationships, true or theoretical, will be revealed by the positions of the twin axes on the Fedorov migration curves. The data for this crystal are recorded in Table 2. This crystal is illustrated in Fig. 4. Notice that only T_{1-3} and T_{3-4} for (010) and T_{1-2} in (001) have true twin relationships. The following twin relationships are regarded as purely theoretical since the lamellae represented have no mutual composition face: T_{2-3} and T_{1-4} in (010). T_{2-3} in (001) and the normal twin T_{2-4} for (001). In other words, it is to be borne in mind that any value that may accrue to this type of study lies wholly revealed by actual composition face relationships. Since the remaining theoretical relationships can be deduced inferentially, their measurement on the stage leads only to redundancy.

The details follow: As described for the first illustration, unit 1 (Fig. 4) chosen arbitrarily, was oriented and the details recorded in Table 2. Similarly, too, the most convenient composition face was brought to the required north-south and vertical orientation, and the new readings recorded as before. The inner vertical and the inner east-west axes remained unchanged. And again as before, a rotation was made on the outer east-west axis to distinguish the normally twinned lamellae; and a repeated rotation on this axis located the parallel and complex twinning axes. In completing this step by comparing the extinction angles of the respective units on the microscope stage, two of the twinning axes were found to be vertical—that is, the units went to extinction simultaneously. The other two recorded twinning axes introduced nothing which has not previously been discussed.

TABLE 2. TWIN DETERMINATION—FIVE-AXIS METHOD
Reference Data: WRC-37—Bridgland Tp., Ont.
Hemisphere 1.559. Zero Values: Mic. 0° O. V. 90°.

Unit 1:

I. E-W	37° S
N-S	35° W

I. V.	346
α	N
β	$\perp$
γ	E

Comp. Face 1.	O. V.	22.5°	
	N-S	55° W	
	I. E-W	—	
Twin Axes (O. E-W)	T_{1-3}	30°N	H
	T_{3-4}	Normal	
	T_{2-3}*	27°N	N
	T_{1-4}*	24°N	N

Comp. Face 2.	O. V.	77.5°	
	N-S	0°	
	I. E-W	19°N	
Twin Axes (O. E-W)	T_{1-2}	22°S	H
	T_{2-3}*	23°S	N
	T_{2-4}*	Normal	

REMARKS: Composition Planes 1) (010) 2) (001)
Composition 70% An.
Twin Laws: T_{1-3} in (010)-Carlsbad
T_{3-4} $\perp$ (010)-Albite
T_{1-2} in (001)-Acline

* For purposes of illustration the following theoretical twin relationships were determined on the stage. No actual composition face is represented. Instead (010) and (001) of the units were used. T_{2-3} and T_{1-4}-Albite-Carlsbad, in (010). T_{2-3} in (001)-Ala. T_{2-4} in (001) Manebach.

The other composition face (001) was next oriented, studied, and recorded with the following differences in the procedure. It was found inconvenient to make this composition face north-south and vertical by means of the north-south axis alone. The north-south axis was therefore

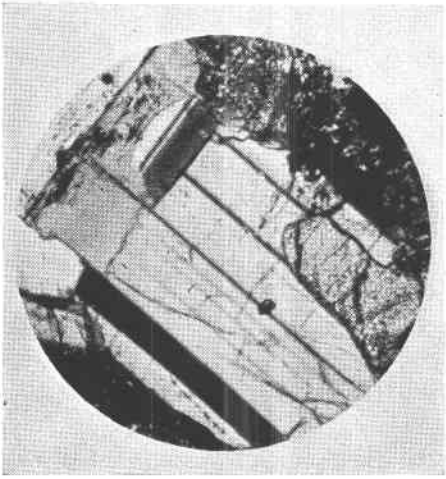
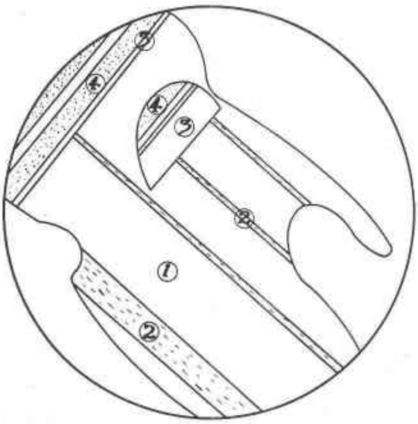


FIG. 4. The plagioclase crystal of example 2.



Key to Fig. 4

rotated to its zero position and the orientation was accomplished on the inner east-west axis in conjunction, of course, with the outer vertical axis. The north-south axis was reduced to its zero position to facilitate subsequent graphical rotations. When it is necessary to employ the inner east-west axis for this step, it is desirable, always, to set the north-south axis as done here.

Three twinning axes were located and recorded as before.

The graphical procedure again consists, as in illustration 1, of those steps which are necessary to bring the poles and the several twinning axes, each, from the position which it occupied when its orientation be-

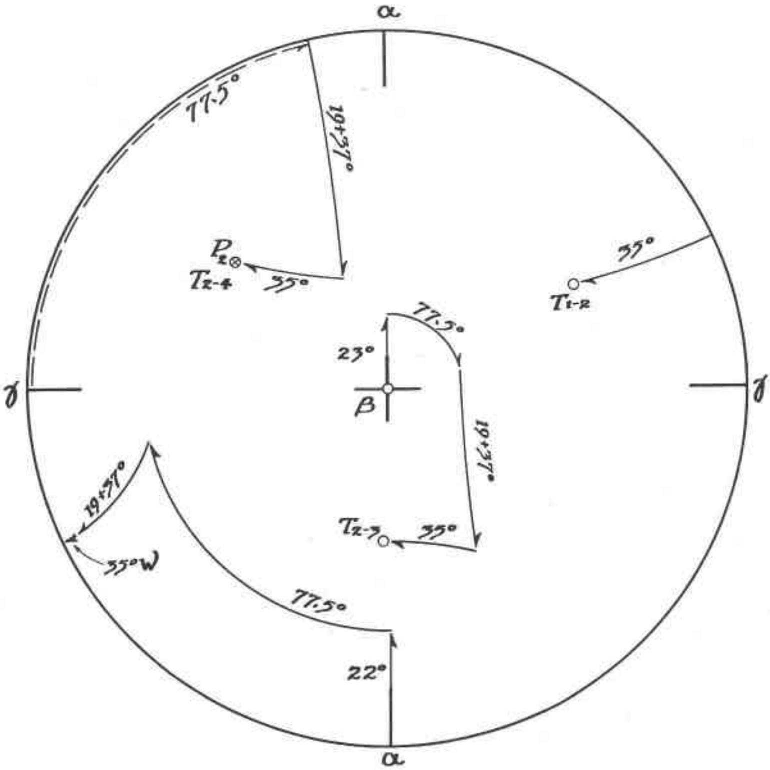


FIG. 5. The graphical rotations for the crystal of example 2 from the data of Table 2 employed to locate the pole and twinning axes for (001) on the plot of unit 1 in oriented position.

came known and recorded, back to its position when unit 1 was oriented. This was done as before by reversing the rotations which led to the entries in column 3, Table 2. We shall note mainly the differences introduced by the use of the inner east-west axis in orienting the composition face.

The order in which the graphical rotations are made alone needs explanation.* Consider T_{1-2}. From the oriented position of the twinning axis rotate first 22°N to make the inclined outer vertical axis vertical. See Fig. 5. Then rotate 77.5° clockwise (opposite to the direction recorded in Table 2) on the outer vertical axis to make the north-south axis north-south. Since the north-south axis was set at zero we may make next the rotation 19+37°S on the inner east-west axis. (If the north-south axis were at any other setting, it would be necessary to bring this value to zero before any graphical rotation could be made on the inner east-west axis.) Lastly, rotate west 35°,—the original setting for the north-south axis.

If an axis is vertical, the only difference in the procedure is that the rotations commence at the center of the stereogram.

The three rotations T_{1-2}, T_{2-3}, T_{2-4} are illustrated in Fig. 5.

The completed stereogram was superposed in proper orientation on the Fedorov migration curves as described in illustration 1 and the twin relationships read off. Figure 6 illustrates these two stereograms in proper superposition.† The twin laws are found to be T_{1-2}—acline, T_{2-3}—Ala, T_{2-4}—Manebach.

The procedure may be summarized.

1. Choose unit 1 arbitrarily and orient it. If there is any range of selection, then chose unit 1 for its quality of extinction (avoiding wavy or patchy extinction) and for its many contacts with other twin lamellae.
2. Make the most convenient composition face north-south and vertical.
3. Rotate on the outer east-west axis to sort out the normal and parallel or complex laws.
4. Rotate again on the outer east-west axis to equal illumination for the parallel or complex twins.
5. Determine the positions of the twin axes from the extinction angles.
6. Repeat steps 2–5 for other composition faces.
7. Rotate the recognized poles and twinning axes to the positions they occupied when unit 1 was oriented.
8. Superpose the completed drawing on the proper Fedorov stereogram to obtain the results.

* Students sometimes experience difficulty in determining the order of the graphical rotations, and an error here leads, of course, to complete failure. Since the Fedorov net provides for graphical rotations on only three mutually perpendicular axes, namely, north-south, east-west, and vertical, then each graphical rotation is possible only if the axis involved is graphically in one of these three cardinal positions. To illustrate—if a rotation is to be made on the inner east-west axis and the data indicate that the north-south, outer vertical, and outer east-west axes are inclined, then, since the inner east-west axis is dependent on (supported by) each of these, each of them must be reduced to its zero position before the inner east-west rotation may be made. Otherwise the inner east-west axis is inclined and the Fedorov net is not adapted. Furthermore, in bringing these supporting axes to zero, the same rules of order must be applied.

† The four possible positions of superposition are described elsewhere (3), (4), (5), (7).

To recapitulate: The advantages of this technique are: (1) It greatly shortens the time required for a determination. (2) Unlike the Rittmann method it may be applied to all twin laws. (3) Unlike the Rittmann method it is applicable to plagioclase of any composition, not merely the

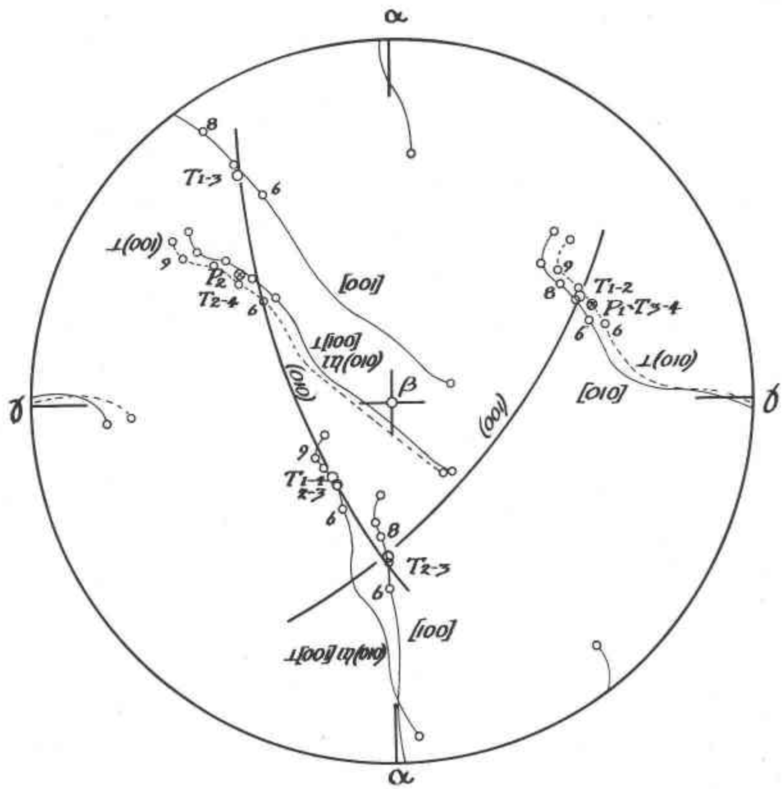


FIG. 6. Graphical representation of the crystal shown in Fig. 4 (in heavy lines) in superposition on the Fedorov migration curves of both the parallel and complex twinning axes (in light lines) and the poles of the composition faces (in broken lines). The migration curves are in inverted position instead of as customarily printed. This avoids the confusion of showing the plot inverted.

sodic two-thirds. (4) It will, like the Fedorov method, reveal a new twin law if present. (5) Unlike the Fedorov method it may be applied to those fine twin lamellae which are too narrow to be oriented optically. This method requires only that one lamella of one unit of a crystal be large enough to orient, and that the others be suitably visible under the microscope. (6) In that this method is based on the use of the Fedorov migration curves, it sacrifices none of the completeness and accuracy of the Fedorov method. In that it eliminates much of the orientation procedure and most of the graphical procedures of the Fedorov method, it eliminates the greatest hazard of inaccuracy of that technique.

This method is applicable only on the five-axis universal stage. We refer to this, therefore, as the *Five Axis Method of Feldspar-Twin Determination.*

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