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A RAPID METHOD FOR THE DETERMINATION OF PLAGIOCLASE BY THE FEDOROV UNIVERSAL STAGE

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Introduction

A feldspar on the Fedorov universal stage, which has four axes of rotation, cannot be turned directly into the position for which the three principal optical directions coincide with the two horizontal and the vertical axes of the microscope respectively, that is into the position of proper orientation. In determining a feldspar, formerly, at least two optical symmetry planes must be located separately, and the optical orientation can be determined only after the completion of the stereographic projection. In 1929 R. C. Emmons[1] modified the Fedorov stage by adding an inner east-west horizontal axis between the inner vertical axis and the north-south axis. The position of orientation is then easily obtained by placing one optical symmetry plane vertical and parallel to the inner east-west (I. E-W) axis, and then tilting the section on the (N-S) axis to the position where the section remains at extinction on rotation about the outer east-west (O. E-W) axis. A method used in the author's laboratory overcomes the tedious procedures, and the position of orientation may be obtained directly on the old Fedorov stage.

Position of Orientation

The present method of operation may be explained by the aid of Figure 1. When the first optical symmetry plane is set in the

[1] Emmons, R. C., A modified universal stage: *Am. Mineral.*, vol. **14,** No. 12, 1929; Plagioclase determination by the modified universal stage: *Am. Mineral.*, vol. **19,** No. 6, 1934.

north-south vertical position in the usual way, two principal optical directions (say α and β) are in this plane, one being inclined southward and the other northward. In order to bring the principal axis α to the microscopic axis, that is the center of the projection, the section is rotated counter-clockwise about the (I-V) axis, which has been inclined toward P, until α meets the (E-W)

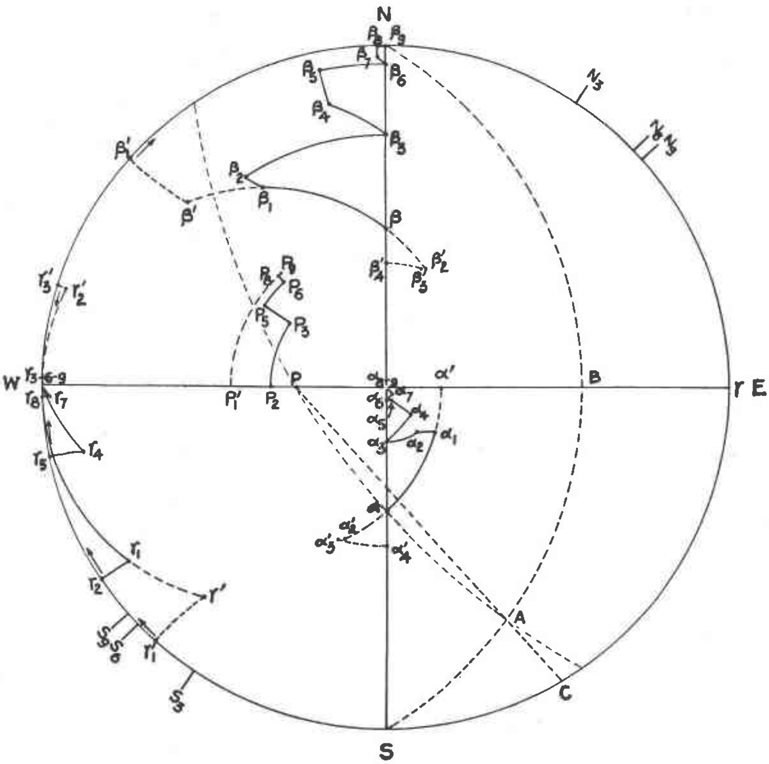

FIG. 1

axis at α', β goes to β', and γ to γ'. The angle of rotation is equal to the great circular arc AB. Then the section is tilted on the (N-S) axis with the left side downward until α' coincides with the center of the projection, and β' and γ' fall on the circumference at β_1' and γ_1' respectively. The normal of the section will go from P to the point P_1'. When the section is rotated clockwise about the (O-V) axis so that β_1' and γ_1' coincide with β_9 and γ_9 respectively, it is always at extinction on the rotation about the (E-W) axis.

The point P_1' will coincide with the point P_9, and the (N-S) axis with the N_9S_9 line. A position of orientation is obtained.

However, as the position of α is not previously known, there is only the method of trial to reach the required position by the following procedures. The section is first rotated a convenient angle on the (I-V) axis (counter-clockwise in this particular case), so that α goes to α_1, β to β_1, and γ to γ_1. It is evidently not in the position of extinction, for the optical symmetry plane $\alpha_1\beta_1$ is slightly inclined toward the northeast. Then the optical symmetry plane is returned into the north-south vertical position by the mutual movements on the (O-V) and (N-S) axes. When the α-β plane is vertical the mineral must always be in extinction on the rotation of the (E-W) axis.[2] The movements are equivalent to tilting on the (N-S) axis so that the principal optical axes are transferred to α_2, β_2, and γ_2, followed by rotating on the (O-V) axis to α_3, β_3, and γ_3. The normal of the section goes from P_2 to P_3, and the (N-S) axis to the N_3S_3 line. α_3 is evidently nearer to the center of the the projection than in the preceding position, and if the section is rotated 90° either clockwise or counter-clockwise about the (O-V) axis to the second position of extinction, a rotation about the (E-W) axis will prove that the intensity of the interference color must be lower than that when the preceding position was brought to the direction of the (E-W) axis. When the optical symmetry plane is returned into the north-south vertical direction, the section is continued by the rotation about the (I-V) axis for a convenient angle in the same direction as before, and the plane $\alpha_3\beta_3$ is changed into the position of $\alpha_4\beta_4$, which is inclined again toward the northeast. Consequently the section does not remain at extinction. By the mutual movements of the (O-V) and (N-S) axes as before, the latter of which is in the direction of the N_3S_3 line, the optical symmetry plane reaches again the north-south vertical position, and the principal optical axes pass by the successive points α_4, α_5, β_4, β_5, γ_4 and γ_5, and reach the positions of α_6, β_6 and γ_6. The normal of the section will be turned from P_5 to P_6, and the (N-S) axis to the N_6S_6 line. α_6 is evidently nearer to the center, and the same test as before will prove that the interference color must be much lower than that in the preceding position. By con-

[2] If the (O-V) axis is rotated too much, the movement of the (E-W) axis is often prevented by the vertical graduated arcs, which may be unscrewed or folded if necessary.

tinuing the successive movements as stated above, the principal optical axis α will move gradually from the positions α_1, α_2, α_3 . . . etc. until it reaches the center of the projection, when both β and γ reach the circumference at β_9 and γ_9, and are parallel to the NS and EW lines respectively. The normal of the section will go to the point P_9, and the (N-S) axis to the N_9S_9 line. The angles of rotation on the (I-V), (N-S) and (O-V) axes determine the position of orientation with respect to the section.

Care must always be taken that after the section begins to be rotated about the (I-V) axis, the tilting on the (N-S) axis should be very small, for a large rotation on the (I-V) axis does not cause, in general, the optical symmetry plane to incline greatly, especially when the principal optical axis is near the vertical position.

If the section is rotated about the (I-V) axis in the wrong direction, or clockwise in this particular case, α will be transferred to α_2', β to β_2', and γ to γ_2'. When the optical symmetry plane is brought to the north-south vertical position $\alpha_4'\beta_4'$ by the mutual movements on the (O-V) and (N-S) axes, α_4' is farther away from the center than in the preceding position, and consequently a stronger intensity of the interference color can be seen during rotation about the (E-W) axis as the optical symmetry plane $\alpha_4'\beta_4'$ is brought by the (O-V) axis to the rotating axis. This proves that the nearest principal optical axis is gradually moving away from, while the farther one is approaching nearer and nearer to the center of the projection. If the procedure is continued, β could be brought to the vertical position, but in practice the farthest one cannot be commonly brought to the vertical on the universal stage, and too great an inclination should always be avoided by the operator.

In order to simplify the processes, an approximate determination of the position of the nearest principal optical axis is necessary. After the first optical symmetry plane is found, it is rotated on the microscopic stage (M) 45° from the nicols, and about the (E-W) axis. The change of the interference colors gives a rough indication of the position of the two principal optical axes. If the first optical symmetry plane is $\alpha\beta$, the position of the lowest interference color is seen, as α is vertical, and of the highest interference color, as β is vertical, because the birefringence changes from (γ-β) to (γ-α); if it is the axial plane, one of the optic axes can always be seen, and the interference color will increase from darkness to the highest color and then again decrease, for the birefringence changes on either side of the optic axis from 0 to (γ-β) or (β-α). If two optic axes are seen, the bisector determines the position of the principal optical axis. Instead of watching for the highest or lowest interference colors, the Berek compensator may be introduced, and a maximum or minimum compensation is easily measured on the graduated drum. When the nearest principal optical axis is approximately determined, the direction of rotation about the (I-V) axis, whether clockwise or counter-clockwise, and the approximate amount of rotation may be determined by the stereographic net, as shown in Fig. 1. α is the axis, and P the normal of the section. The great circular arc AB is the angle in the counter-clockwise direction.

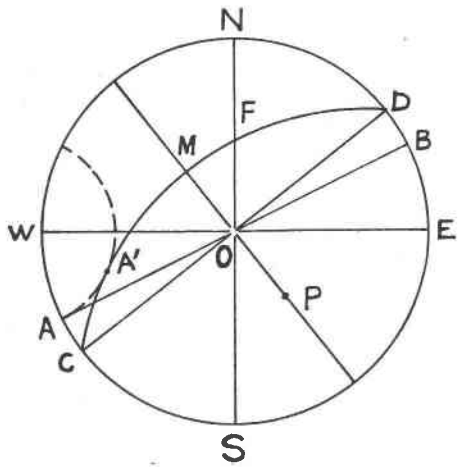

FIG. 2

In determining the composition of the feldspar, any crystallographic constant, such as composition face, cleavage plane or crystal face, should be measured after the position of orientation is obtained. It is convenient to measure the inclination of a cleavage plane or composition face on the (E-W) axis, and the direction of the vertical position from the east-west wire on the (O-V) axis, as pointed out by Emmons. Because the (O-V) axis is dependent on the (E-W) axis, and both movements will interfere with each other, the writer measures on the microscopic stage (M) the direction of the cleavage or composition face from the east-west wire when it is tilted to the vertical by the (E-W) axis, without disturbing the position of orientation. In table I, it may be seen that the compositions

ROCK: *Gabbro.*
LOCALITY: Choyang, Jehol, China.
MINERAL: Labradorite, $N_m = 1.56$
HEMISPHERE: $N = 1.554$
ZERO POSITION: (M) = 0.4°; (O-V) = 270°

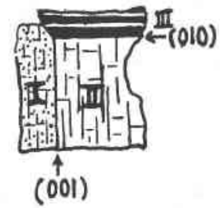

TABLE I

		(I-V)	(N-S)	(O-V)	(E-W)	(M)	Composition	Remarks
I	Position of orientation, $\alpha\perp;\beta\|\|E;\gamma\|\|N$.	348.4°	38° E	293.2°	0°	0.4°		
	(001), the composition face of I–II	—	—	—	37.7° S	316.1°	57% An	
	(010)	—	—	—	16.5° N	27.7°	56% An	
II	Position of orientation, $\alpha\perp;\beta\|\|E;\gamma\|\|N$.	40.5°	18° E	310°	0°	0.4°		2E = 105° ± about α
	(001), the composition face of I–II	—	—	—	37.5° N	46.4°	56% An	
	(001), the composition face of I–II*	—	—	2.2°	23° N	—	56% An	
	(010), the composition face of II–III	—	—	—	14.5° S	331.7°	56% An	
	(010), the composition face of II–III*	—	—	278.5°	12° S	—	54% An	
III	Position of orientation, $\alpha\perp;\beta\|\|E;\gamma\|\|N$	22°	20° E	320°	0°	0.4°		2E = 105° ± about α
	(010), the composition face of II–III	—	—	—	11.5° S	334.2°	51% An	
	(010), the composition face of II–III*	—	—	292.5°	5° S	—	?	Lamellae too narrow
	(001)	—	—	—	37.2° N	49°	55% An	
	(001)*	—	—	15.2°	21.5° N	—	54% An	

* Angles measured on the (O-V) and (E-W) axes.

of the twinning members II and III determined by the angles measured on the (O-V) and (E-W) axes are occasionally uncertain. In the present procedure, the vertical angle is measured on the (E-W) axis, and the direction measured on the microscopic stage (M). They are not the true dip and strike of the cleavage on the position of orientation, but they may be obtained indirectly by the stereographic projection as shown by Fig. 2. AB is the direction of the cleavage plane when tilted to the vertical, and OF, the vertical angle measured on the (E-W) axis southward. If the section returns to the original position of orientation, A will fall on A′ on the small circle, and O on F. The great circle CA′FD is the trace, CD the strike, and OM the true dip of the cleavage plane, whose pole is at P. Transfer the stereographic projection on the corresponding feldspar orientation chart, and its composition is determined as usual.

Determination of Twinning

The method of locating the twinning axis is the same in principle as that proposed by Emmons on his modified universal stage. Here an additional procedure should be made before changing the optical and crystallographical constants of the twinned members to the cardinal position of the unit one which is chosen as reference, because the (N-S) axis does not remain in the same direction for the different measurements. It is better to explain the procedure by means of the following example.

The poles of the cleavage planes as well as the composition faces of the three members are plotted first on the position of orientation, as shown by Fig. 3. N_1S_1 is the direction of the (N-S) axis of member I, 23.2° clockwise from the NS line; N_2S_2 is the direction of the (N-S) axis of member II, 40° clockwise from the NS line; and N_3S_3 is the direction of the (N-S) axis of member III, 50° clockwise from the NS line. Member II is chosen as reference for the determination of twinning. Rotate all the optical and the crystallographical constants to the plane of the section, so that the constants of member I are inclined 38° E[3] about the N_1S_1 line, those of member II inclined 18°E about the N_2S_2 line, and those of member III inclined 20°E about the N_3S_3 line. Individual II being chosen as reference, so its constants are not rotated, for they will turn back

[3] No corrections are made because the difference of the indices of the hemisphere and the mineral is very small.

to their original positions at the end of the procedure. Rotate all of I and III to the position of orientation of II by the following procedures. Because I has been rotated 52.1°(=40.5°+360°−348.4°) counter-clockwise from II about (I-V), and 16.8°(=310°−293.2°) counter-clockwise from II about (O-V), all the constants of I have therefore to be rotated 68.9°(=52.1°+16.8°) clockwise from their preceding position, and then rotated 18°W about the N_2S_2 line in

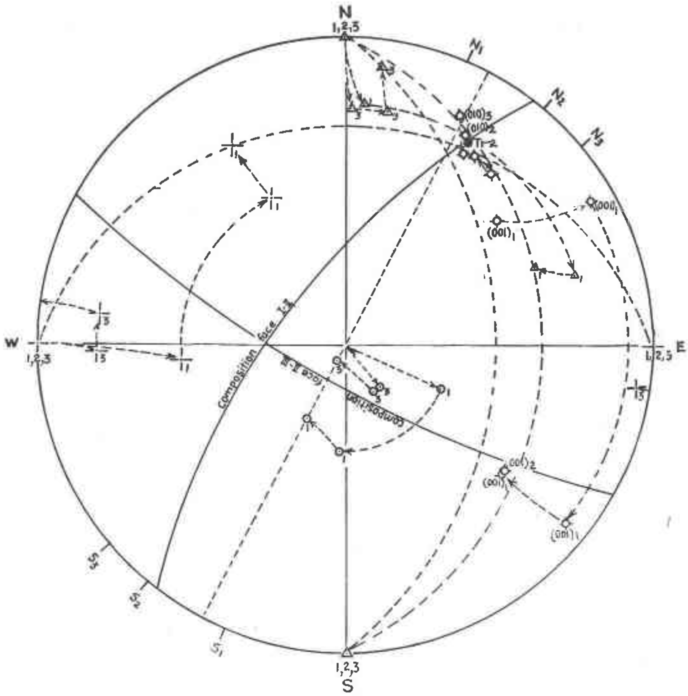

Fig. 3

order to reach the position of orientation of II; and III has been rotated 18.5°(=40.5°−22°) counter-clockwise from II about (I-V), and 10°(=320°−310°) clockwise from II about (O-V), so all of III must be rotated 8.5°(=18.5°−10°) clockwise from their preceding positions, and then rotated also 18°W about the N_2S_2 line to reach the reference position. The successive movements of the principal optical axes and the poles of the cleavage planes of both I and III are shown in the figure by the arrows. The pole of $(001)_1$ nearly coincides with that of $(001)_2$, which is the pole of the composition face of I and II. T_{1-2}, the intersection of the three great circles joining similar optical constants, is the twinning axis of I and II. It is the Manebach-Ala A. The axis of albite twinning of II and III should fall on the pole $(010)_2$, but here no intersection is definitely located, for the twinning lamellae of III are too narrow for accurate determinations.

Correction of the Vertical Angles

All the vertical angles should be corrected before plotting according to the method suggested by Emmons, if the difference between the indices of the glass hemisphere and the mineral is large.

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