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OPTIC ANGLE DETERMINED CONOSCOPICALLY ON THE SPINDLE STAGE: II. SELECTED ROTATION METHOD[1]

DONALD C. NOBLE,[2] *U.S. Geological Survey Denver, Colorado.*

ABSTRACT

The spindle axis is placed parallel to a crosshair and a melatope is placed in the crosshair by rotation about the spindle axis. Rather than using a micrometer ocular as in Part I, the spindle axis is then placed at a known angle to the crosshair by rotating the microscope stage, and the amount of rotation about the spindle axis required to return the melatope to the crosshair is found. The complement of the angle between the optic axis and the spindle axis is readily determined from these two angles and thence the optic angle.

INTRODUCTION

A conoscopic method for determining the angle between the optic axis of a biaxial crystal and the spindle (horizontal) axis of a spindle stage solely from angles measured on the scales of the microscope stage and spindle axis is here described. The procedure permits the determination of the optic angle and orientation of the optical indicatrix without recourse to extinction angle measurements or to ancillary techniques such as Mallard's method.

Rosenfeld (1950) and Wilcox (1959) have described how the prinicpal axes X, Y, and Z of the indicatrix can be oriented with considerable accuracy under conoscopic illumination. Implicit in their method is the fact that the positions of the principal axes may be stereographically plotted directly from readings made on the scales of the microscope stage and the spindle axis, thus providing a permanent record of the optic orientation of the crystal fragment. If Mallard's method is applied when the optic plane is vertical and a melatope is within the conoscopic field of view, the optic angle can be determined. Noble (1965) has given a method by which $2V$ can be determined in this manner without recourse to stereographic plotting. Wilcox and Izett in Part I of this paper, describe an improved method of determining optic angle which allows both optic axes to be measured in a greater percentage of cases, thereby increasing the accuracy of the determination.

Both the method of Noble (1965) and that of Wilcox and Izett utilize Mallard's method in determining the position of the optic axes. Any error in calibrating the micrometer ocular produces a systematic, although not constant, error in the values of $2V$ obtained. In addition, the scales of micrometer oculars provided with some microscopes are too coarse to

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[2] Present address: Department of Geological Sciences, Harvard University, Cambridge, Massachusetts.

accurately measure the position of an optic axis in the conoscopic field. For these reasons the procedure described below is proposed as an alternative to micrometer ocular measurement.

Basis of Method

Under conoscopic illumination an optic axis can be placed precisely in the plane defined by the spindle and microscope axes. To do this the microscope stage is turned until the spindle axis is parallel to an ocular crosshair and the melatope is then centered on the crosshair by rotation

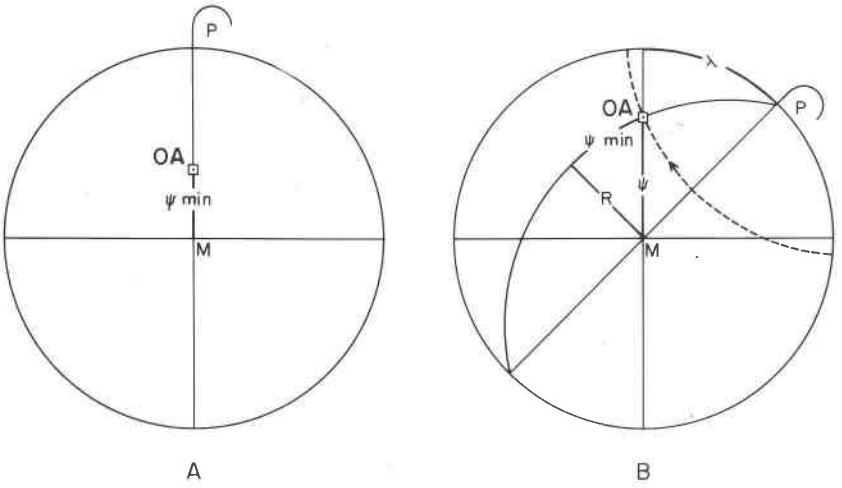

Fig. 1. Stereographic plots showing (A) optic axis oriented in vertical plane defined by spindle axis and (B) optic axis reoriented in vertical plane lying 45° from spindle axis by rotation about spindle axis. Solid lines are great circles; dashed line is small circle. Angles discussed in text, some of which are exaggerated in size, are shown by heavy solid lines. *P*, spindle axis; *M*, microscope axis; *OA*, optic axis. Ocular crosshairs are N-S and E-W.

about the spindle axis (Fig. 1A). Simultaneous rotation of both polars, or other methods discussed in Part I, are used to correctly orient the melatope.

Providing the melatope remains in the field of view, the optic axis can be placed as accurately in *any* plane passing through the microscope axis. The selected plane is placed parallel to a crosshair and the melatope placed on the crosshair by rotation about the spindle axis (Fig. 1B).

The angle between the optic axis and the spindle axis can be determined from the amount of rotation about the spindle axis, R, required to move the optic axis from the plane defined by the microscope and spindle axes into another plane through the microscope axis lying at a known angle, λ, to the spindle axis. For practical application in the determina-

tion of optic angle it is more convenient to make use of the complement of the angle between the optic axis and the spindle axis, ψ_{min}, which is also the minimum angle that the optic axis makes with the microscope axis upon rotation about the spindle axis. These angles (Fig. 1B) are related by the equation

$$\tan \psi_{min} = \sin R \cdot \cot \lambda. \quad (1)$$

In addition, ψ, the angle between the optic axis and the microscope axis when the optic axis is in the plane oblique to the spindle axis (Fig. 1B), is related to R and λ by the equation

$$\tan \psi = \frac{\tan R}{\sin \lambda} \cdot \quad (2)$$

Alternatively, it may be visualized geometrically that, after rotation of the spindle through angle R (Fig. 1B), the position of the optic axis is uniquely defined by the intersection of two great circles, one through P at angle R from M and the other through M at angle λ from P.

Thus either ψ_{min} or ψ may be determined by placing a melatope on a crosshair when the spindle axis is parallel to the crosshair and again when the spindle axis is at an angle to the crosshair. The angle ψ_{min} or ψ is then calculated from R, as measured on the scale of the spindle axis, and λ, as measured on the scale of the microscope stage. Equations (1) and (2) may be solved either (a) stereographically (Fig. 1B), (b) by using a slide rule equipped with trigonometric scales, or (c) by using specifically prepared rectangular graphs (Fig. 2). The resultant angles then may be utilized in exactly the same manner as the same angles measured by the use of a calibrated micrometer ocular.

The size of the angle λ that can be used, and in turn the size of the angle R obtained, is limited when ψ_{min} is relatively large. Moreover when λ is limited to 30° or less, it is advantageous to make settings of λ on both sides of the spindle axis and the amount of rotation required to go from the first to the second setting halved to obtain R. (The grain, of course, also may be nudged into a more favorable orientation on the spindle tip, as discussed in Part I.)

Procedure

A sequence of manipulations for use with the method of Wilcox and Izett (Part I) is given below. The sequence replaces step 6 of their method. Measurement begins with the spindle axis parallel to the NS crosshair and a melatope lying exactly on the crosshair.

Step 6′a. Rotate a selected angle λ (preferably 20°, 25°, 35°, 45°, or 60°) either clockwise or counterclockwise on the microscope stage and clamp. (The amount of rotation should be

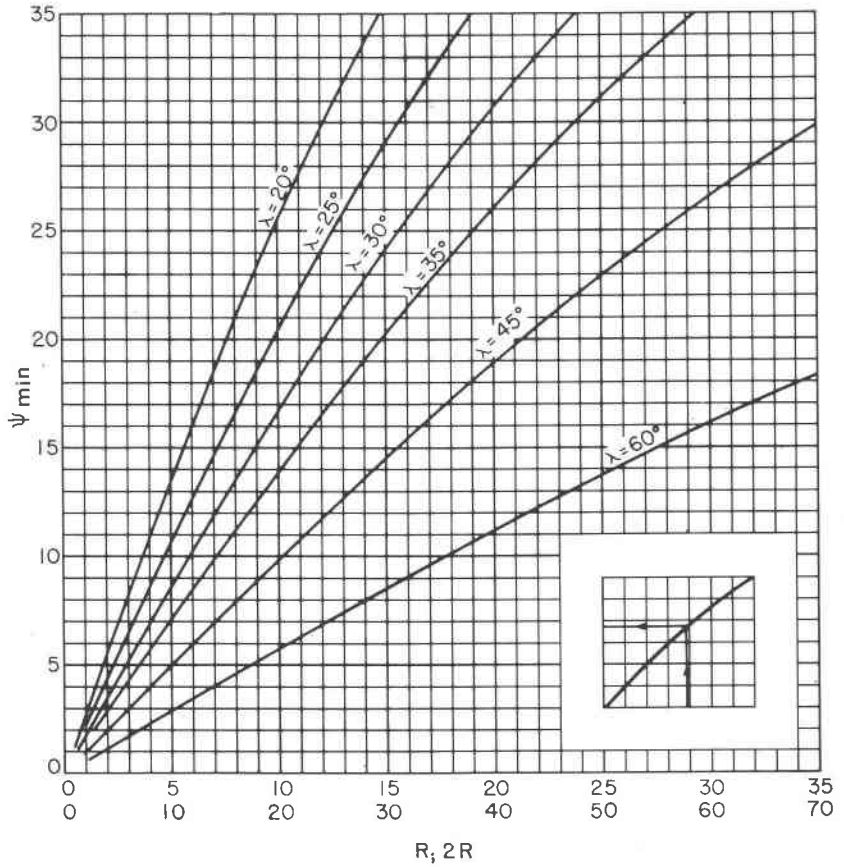

FIG. 2. Determinative graph for calculating ψ_{min} as a function of R or $2R$ and λ. Method of using graph is shown in lower right-hand corner of figure.

as large as possible and still allow the subsequent placement of the melatope on the crosshair.)

Step 6′b. Return the melatope precisely to the NS crosshair by rotation about the spindle axis in conjunction with simultaneous rotation of the nicols. Record the reading on the scale of the spindle axis.

Step 6′c. If λ is small or if the optic axial plane lies at a small angle to the spindle axis, rotate the same number of degrees about the microscope axis in the opposite sense from the zero point and again place the melatope on the NS crosshair. Record the reading on the scale of the spindle axis.[1]

[1] When the optic axial plane makes a small angle with the spindle axis, the accuracy of the $2V$ determination depends mainly on the accuracy with which ψ_{min} is determined. In such cases double settings may advantageously be made even if angles of λ greater than 30° can be used. The symmetry inherent in a λ setting of 45° allows the second optic axis setting to be made with very little or no additional rotation of the nicols providing the crosshair ocular can be precisely rotated 45° in the microscope tube.

Step 6′d. Determine R, the absolute difference between the spindle scale reading obtained in Step 6'b and that noted in Step 5 (Part I), or determine $2R$ from the readings recorded in Steps 6'b and 6'c.

Step 6′e. Determine ψ_{min} from R or $2R$ and λ using (a) the appropriate curve on Figure 2, (b) a stereographic net following the procedure illustrated in Figure 1B, or (c) a slide rule and equation (1). Record ψ_{min} and whether the melatope is north or south of the EW crosshair.

A slightly different procedure is followed when using the method of Noble (1965). The following sequence replaces Step 3.

Step 3′a. With the optic plane in the 45° position, determine by use of a compensator if the microscope axis lies within $2V_X$ or $2V_Z$.

Step 3′b. Place the spindle axis parallel to a crosshair. (The angle λ ($=90°-\theta$) is here the angle between the spindle axis and the optic plane.)

Step 3′c. Place the melatope on the same crosshair by rotation about the spindle axis in conjunction with simultaneous rotation of both nicols. Record the reading on the scale of the spindle axis.

Step 3′d. Calculate R, the absolute difference between the spindle scale reading obtained in Step 3'c and that recorded in Step 1 of Noble (1965).

Step 3′e. Calculate ψ from R and λ stereographically or by using equation (2). (A determinative graph giving ψ as a function of R and λ may be prepared if desired.)

Discussion

When $2R$ is determined instead of R, the method is slightly more lengthy than measurement using Mallard's method, especially when a bar for simultaneous rotation of the polars is not available. This disadvantage is offset by the elimination of micrometer ocular calibration. Also, β need not be precisely determined on the grain under study, although an immersion oil near the mean index should be used. Finally, because the positioning of the optic axes can be done without knowledge of the angles measured, repeated settings can legitimately be made and averaged to increase the accuracy of the determination.

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