EFFECTS OF ROTATION OF OBJECTIVES ON THE OPTICAL PROPERTIES OF OPAQUE MINERALS IN POLARIZED LIGHT

George J. Neuerburg, *University of Idaho, Moscow, Idaho.*

Abstract

It has been found that rotation of the objective causes a change in the configuration of opaque mineral figures, and, in some cases, in their color patterns. Analogous changes are produced in the rotation colors and reflected pleochroism of anisotropic opaque minerals. The changes in the optical figures are apparently governed to an extent by the type of figure viewed. It is suggested that this phenomenon is due to lack of rotational symmetry in the objective.

Introduction

M. N. Short (5) states in his bulletin on the microscopic determination of the ore minerals that he was unable to duplicate the rotation colors (1) (polarization colors) listed by Van der Veen and Farnham. He points out that rotation colors vary with the adjustment of the nicols, the source of light (arc or incandescent), the intensity of illumination, and the perfection of polish, in addition to the effects produced by the mineral itself.

There is yet another, hitherto unknown, factor, which effectively makes it nearly impossible for different workers to obtain accurately comparable results in the determination of rotation colors. In a continuing investigation of the optical figures obtained with the reflecting microscope (4) (opaque mineral optical figures), the author, at the suggestion of G. T. Hammond (2), Bausch & Lomb Optical Company, investigated the effect of rotation of the objective on the configuration of these optical figures, with some very interesting results.

Experimental Procedure

Bausch & Lomb Optical Company recently lent the author an objective rotating adapter. The adapter consists of two brass rings, with appropriate threading for insertion between the microscope tube and the objective; by using these rings an objective can be rotated about the axis of the microscope. Use of the adapter changes the tube length of the microscope, but has no other effect.

The objective rotating adapter is used by Bausch & Lomb for the express purpose of detecting strain in an objective. The author is indebted to G. T. Hammond (2) for the following description of the procedure employed: "When using the rotating adapter to detect strain in an objective used with transmitted light, we look for a deformation of the interference figure as the objective is rotated. We take a specimen of common type such as mica or quartz and set up the microscope to obtain the normal position interference figure (centered black cross) of that crystal. Then the objective is rotated and if there is any deformation of the interference figure we know that strain is present in some part of the objective. The degree of deformation of the interference figure indicates the amount of strain which may be present. It is reasonable to assume that the same procedure would work with vertical illumination provided no strain is present in the optical elements between the polarizer and analyzer."

G. T. Hammond suggested that the optical figure obtained from pyrite with an unstrained objective should theoretically be a type I figure rather than the type III figure consistently obtained. Accordingly the rotating adapter was sent on loan for the purpose of determining if the objectives used were strain free. The test was first made on opaque minerals using vertical illumination; totally unsuspected results were obtained. At this time a test with transmitted light had not been made on the objectives in question; on learning of the perplexing results which had been obtained, G. T. Hammond was kind enough to send an objective guaranteed to be strain free.

The objectives used in this investigation, numbered for reference, are No. 1—a Spencer 4 mm. short-mounted objective, No. 2—a B & L 4 mm. short-mounted objective, No. 3—B & L 4 mm. long-mounted objective No. 72140 (manufacturer's serial number), No. 4—B & L 4 mm. long-mounted objective No. BD8659 (on loan from Bausch & Lomb), and No. 5—a Leitz 4 mm. long-mounted objective.

Observations

Using transmitted light and the Bx_a interference figure from a basal section of muscovite, the following results were obtained in the strain test: objective No. 1—a very slight amount of strain in the exact center of the field of view; objective No. 2—same results as for objective No. 1, but the amount of strain is even less; objective No. 3—a barely perceptible and slight amount of strain is evident near the edge of the field of view; objective No. 4—no detectable strain; and objective No. 5—the test was not performed on this objective. It is unfortunate that the tests made in this instance and elsewhere are not complete, but as the instruments on loan have been returned to Bausch & Lomb, this oversight has not been corrected.

The effects of rotation of the adapter with vertical illumination are described below as they were seen on the minerals pyrite, stibnite, and covellite.

A. Pyrite. On a (001) face of pyrite, all objectives so far used in this investigation and elsewsere (16 in number) yield a type III figure, having an "optic angle" of approximately 20°. True, the "optic angle" varies slightly, but otherwise there is no difference. All the objectives used in this investigation show the same behavior on rotation. As the objective is rotated with the mineral in a stationary position, the isogyres behave in somewhat the same way as does a centered Bx_a interference figure during rotation of the mineral; that is, they come together and they separate into alternate pairs of quadrants four times during rotation of the objective (Fig. 1). Rotation of the mineral, when the objective is

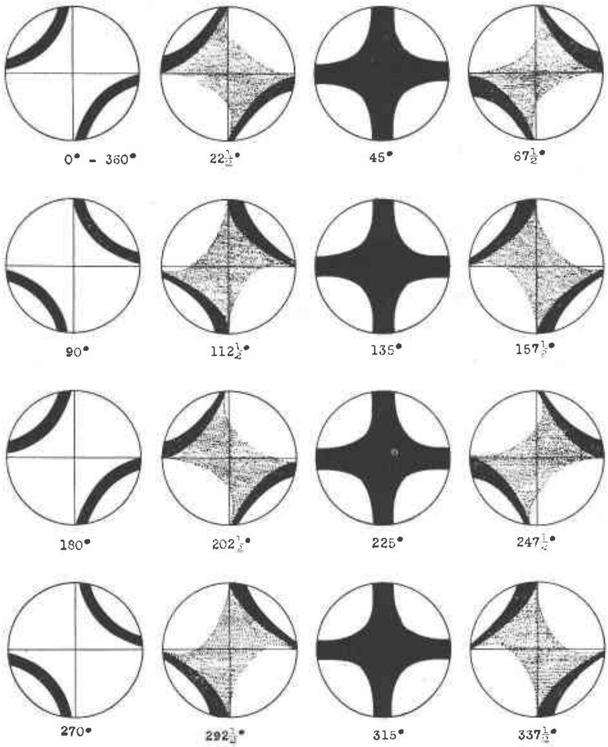

FIG. 1. Effect of rotation of the objective on the type III figure of pyrite (001). The 0° and 180° positions shown above correspond to the type III figure. The gray areas appear only between 0° and 45°.

stationary, does not alter the configuration of the optical figure determined by the position of the objective. It is of interest to note that all objectives show exactly the same configuration without the adapter.

B. Stibnite (010 cl.). Only objectives No. 1 and No. 4 were used in this case. Rotation of objective No. 1 produces the same general effect as on pyrite, but superimposed on the type IV figure of stibnite. The distance between the isogyres, as determined by the orientation of the mineral with respect to the planes of polarization, is a maximum in each case, which is not exceeded in that orientation, during rotation of the objective; this is also true of covellite. Here again, 16 different objectives, without the adapter, yield the same figure on stibnite (type IV).

With objective No. 4, the results differ slightly from those obtained with objective No. 1. Between the minimum angle position and approximately halfway to the maximum angle position, rotation of the objective causes the same change as does rotation of objective No. 1. Between this position and the maximum angle position, rotation of the objective has little effect, acting only to slightly distort the isogyres.

C. Covellite. (Polished section near (0001)—Subtype II*b*). As with stibnite, only objectives No. 1 and No. 4 were used. Rotation of objective No. 1 causes the same qualitative effect as on pyrite, but superimposed on the subtype II*b* figure; this is true only between the crossed and 45° positions. At the 45° position only the color pattern is affected, roughly in the same sense as when the mineral is rotated with the objective stationary.

The effect on the optical figure of rotating objective No. 4 was masked by myriad internal reflections. Apparently there was little, if any, change in the figure.

With covellite and stibnite, the behavior of the isogyres on rotation of the mineral, with the objective stationary, apparently is the same as that normally seen when the microscope is used without the adapter.

The results obtained with pyrite were communicated to Dr. George Tunell, who suggested the following explanation (3): "Your approach to the problem of the behaviour of the pyrite interference figure by rotating a number of different objectives strikes me as good. Since everything else remained stationary the effect must be due to lack of rotational symmetry of the objectives. The phenomena you are dealing with involve elliptical polarization and it may be that this is one reason why they are so sensitive to lack of rotational symmetry in the objective."

The question then arose; if this were true, would the phenomenon be confined to the opaque mineral optical figures. If not, should not a similar set of results be obtained with those other optical properties of reflecting surfaces, which owe their origin in part to elliptical polarization? Accordingly, the effect of rotating the objective was investigated with respect to rotation colors and reflected pleochroism. As these phenomena are better seen with objectives of lower magnification a Leitz 14 mm. objective was used. The results obtained were checked with objectives of higher magnification. The phenomenon was determined in a qualitative sense only.

A. Rotation Colors. The effects obtained on covellite and stibnite, the two minerals examined, are similar. The effect of rotation of the objective with the mineral stationary is qualitatively the same as rotation of the mineral with the objective stationary. The actual colors observed with rotation of the objective depends on the orientation of the mineral in relation to the planes of polarization of the microscope, and vice versa. The colors obtained in different positions of either mineral or objective, on rotation of the other are the same as those obtained with different settings of the polarizer; i.e. different angles between the planes of polarization of the polarizer and the analyzer. The same phenomenon was noted with objectives of higher magnification.

B. Reflected Pleochroism. On covellite, rotation of the 14 mm. objective produces no, or a very slight, perceptible change in the reflected pleochroic colors. The changes that take place are best seen with objectives of higher magnification. It appears that changes produced on rotation of the objective are similar to those changes produced in the rotation colors.

Summary

The phenomenon described here presents an interesting and important problem. It has been demonstrated that this phenomenon is not confined to opaque mineral optical figures. This observation lends further support to Tunell's suggestion that the phenomenon is due to lack of rotational symmetry in the objective, accentuated by elliptical polarization. The lack of agreement among different workers in the determination of certain optical features of opaque minerals in polarized light can conceivably find its explanation in this phenomenon. Yet, there is remarkable agreement in these determinations in light of the phenomenon described above.

It seems doubtful that the use of the rotating adapter should cause this phenomenon, as the only way in which it modifies the optics of the equipment used is to increase the tube length of the microscope. Furthermore, the use of the adapter has no effect on interference figures obtained with transmitted light, and it seems unlikely that this should not also be the case with opaque mineral optical figures obtained with reflected light. The effects of rotating the objective and the use of the rotating adapter on thin section pleochroism and birefringence were not investigated, but it seems probable that these properties, like the interference figures, would suffer no change.

However, the rotating adapter, by changing the tube length of the microscope, does have an effect as it changes the size of the "optic angle." The changes caused are not consistent; with some objectives the "optic angle" is increased by a large amount and with other objectives by only a small amount, if at all. Since similar changes are noted when examining the same optical figure with different objectives without the adapter, this

effect of the rotating adapter seems of little importance in an explanation of the phenomenon under discussion.

The different "optic angles" obtained with different objectives without the adapter vary in a narrow range of 0–10° from the mean value for each mineral. As the variations noted are not consistent with an increase or decrease in tube length of the microscope, it may be that they are due in part to differences in the converging powers of the objectives.

Of 16 objectives used in examining the optical figures from six standard opaque mineral crystals, showing types II, III, and IV, all but two gave consistent results. These objectives range in date of manufacture from the 19th century to 1947, and include the products of Bausch & Lomb, Leitz Wetzlar, and Spencer. The two exceptions, both old objectives, showed the optical figures exactly inverted, or rotated 90° from the optical figures obtained with the other objectives. This may be due to the phenomenon described above, or, perhaps, it may be due to the optics of the objectives.

Other than the major problem of the phenomenon itself, there are three related minor problems. The first of these is the observation that most objectives yield the same kind of figure for each mineral, which has been examined with more than one objective. Allied to this observation is the unusual, though not perfect, agreement in the determinations of such features as rotation colors by different workers. No comment is offered at present toward a solution of this problem.

The second problem is the observation that all objectives, when rotated show the same phenomenon on pyrite, but differ from this in the changes caused on covellite and stibnite. Apparently the changes caused on covellite and stibnite are, to some extent, governed by the nature of the figure; the changes are not exactly equivalent to a superposition of the pyrite reaction on the figures of these minerals. This seems a likely conclusion, when it is considered that covellite and stibnite are anisotropic, while pyrite is isotropic; the different optical constants of anisotropic minerals are of varying importance according to the orientation of the optical directions with respect to the planes of polarization of the polarizer and analyzer. This explanation suffers from the observation that different objectives, when rotated, do not cause the same changes in the optical figures on covellite and stibnite. This problem requires further investigation.

With types II and IV figures the separation of the isogyres for any particular orientation of the mineral is a maximum separation for that orientation, which is not exceeded on rotating the objective through 360°. No explanation of this observation is offered. Obviously this phenomenon is related to the type of figure, and is governed by the orientation of the mineral. Here, again, because this was noted on types II and IV figures, and because the different objectives, when rotated, did not cause the same effect, further investigation is necessary. In fact this difference in behavior of different objectives on types II and IV figures has a direct bearing on the solution of the major problem at hand, and, in itself, poses a problem of no minor importance.

Other than these statements, no explanations are offered for these phenomena. In fact this article is presented for publication primarily to bring these observations to the attention of mineralogists, to indicate some of the interesting and noteworthy results of an investigation into opaque mineral optical figures, and to invite discussion of this phenomenon.

The author wishes to express his appreciation for the kind help and suggestions given him by Bausch & Lamb Optical Company and Mr. G. T. Hammond. Dr. George Tunell's interest and suggestions are gratefully acknowledged.

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