edged. The work was conducted during the tenure of fellowships given by the National Science Foundation and Harvard University.

The writer would also like to express his thanks to Bear Creek Mining Company for permission to publish this paper.

REFERENCES

BROSGÉ, W. F. (1960) Metasedimentary rocks in the south-central Brooks Range, Alaska. *U. S. Geol. Survey Prof. Paper* **400-B,** 351–352.

CHADWICK, R. H. W. (1960) Copper deposits of the Ruby Creek area, Ambler River Quadrangle, Alaska. *Paper presented, Fifth Ann. Alaskan AIME Conf., College, Alaska,* April 11–13.

HERREID, GORDON (1961) Geology and ore deposits of Alaska. *Min. Eng.* **13,** 1316–1325.

KELLER, W. D., J. H. SPOTTS AND D. L. BIGGS. (1952) Infrared spectra of some rock-forming minerals. *Am. Jour. Sci.* **250,** 453–471.

RUNNELLS, D. D. (1963) The copper deposits of Ruby Creek, Cosmos Hills, Alaska. Ph.D. thesis, Harvard University.

SMITH, P. S. (1913) The Noatak-Kobuk region, Alaska. *U. S. Geol. Survey Bull.* **536,** 147–150.

SMITH, W. C., F. A. BANNISTER AND M. H. HEY. (1949) Cymrite, a new barium mineral from the Benallt manganese mine, Rhiw, Carnarvonshire, *Mineral. Mag.* **28,** 676–681.

WOODLAND, A. W. (1956) The manganese deposits of Great Britain. *Cong. Geol. Intern., Symposium Sobre Yacimientos de Manganeso,* **Vol. 5,** 197–218.

THE AMERICAN MINERALOGIST, VOL. 49, JANUARY-FEBRUARY, 1964

AZIMUTHALLY DISPERSED POLARIZED LIGHT

K. S. DEFFEYES,[1] *Shell Development Company, Exploration and Production Research Division, Houston, Texas.*

In a thin section being observed between crossed polarizers, the probability of adjacent grains having identical interference colors is high for any single position of the rotating stage. The usefulness of the rotating stage, when one is studying rock textures comes from the much lower probability that two adjacent grains have identical extinction directions. It is almost always possible to find one position of the rotating stage in which the two grains are visually distinguishable.

In limestone and dolomite sections of standard thickness, the interference "colors" are mostly light gray shades in the seventh to ninth orders and the only visual contrast between grains is based on the difference in intensity as the grain is turned from its extinction position. By rotating the stage to those azimuths near the extinction position where the light transmission varies rapidly with azimuth, it is possible

[1] Present address: Department of Geology and Geophysics, University of Minnesota, Minneapolis, Minnesota.

to distinguish positively most of the grain boundaries. This procedure has several disadvantages:

1) Memory storage of the results of a number of rotations are inherent in visualizing the rock texture.
2) A single photograph taken with crossed polarizers shows only some of the grain boundaries clearly.
3) On the photograph, pore spaces are not distinguishable from grains that happen to be at extinction.

Since grains in limestones and dolomites are distinguishable largely by their different extinction directions, it is desirable to display this information in an effective way. One way of achieving such a display is to keep the polarizer and analyzer crossed, but to have a different azimuth of the polarizer and analyzer for each visible wavelength. The strong wavelength dependence of the rotation of the plane of polarization of light traveling perpendicular to the *c* axis in quartz furnishes a means of

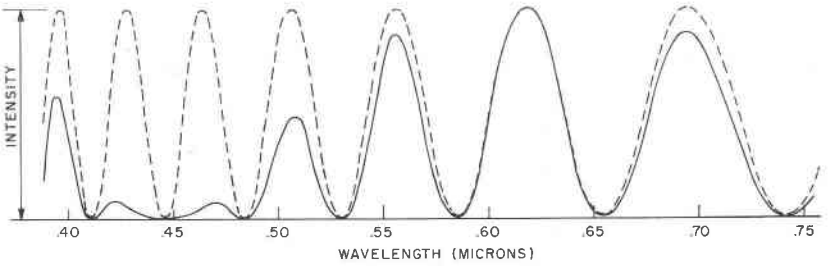

FIG. 1. Light transmission computed for systems containing a birefringent crystal plate having a 5.29 micron retardation and negligible dispersion of birefringence. The dashed curve is the light transmission of the crystal plate at 45° between crossed polarizers and the solid curve is the combination of the 2.27 mm quartz plates discussed in the text with the same crystal oriented parallel to the polarizers.

azimuthally dispersing the light after it passes through the polarizer. A second quartz plate, of opposite handedness from the first, placed after the thin section reassembles the light in the plane of the analyzer. If the visible spectrum is dispersed through 90° the wavelength that corresponds to the extinction position of the crystal will be removed completely and wavelengths near the extinction direction will be reduced in intensity. To the viewer, each grain has a bright "minus" color which is different for grains having even slightly different extinction directions (Fig. 1). Rotation of the stage causes each grain to sweep through a range of colors. Pore spaces and isotropic crystals remain black.

The optimum thickness for the quartz plates is one which gives the most sensitive visual changes at all azimuths. Because there is an extinc-

tion position every 90° in the crystal, we wish to spread the visible spectrum over roughly 90°. Maximum visual discrimination will be obtained by having red, blue and green wavelengths at about 30° from one another. Table 1 shows the dispersion in azimuth for a quartz plate of 2.27 mm thickness. This thickness spreads the limits of the visible spectrum (taken where the relative visibility has fallen to .001 × the visibility of the most visible wavelength, .555 microns) over nearly 90° and places the red and blue colors 60° from one another.

Plates of quartz can be constructed from suitable right- and left-handed crystals by lapping down sawed slices. Matching of the two

TABLE 1. ROTATION OF THE PLANE OF POLARIZATION OF LIGHT TRAVELING ALONG THE *c* AXIS OF QUARTZ

	Wavelength (microns)	Rotation in degrees per mm thickness	Rotation for 2.27 mm
Lower threshold	.388	52.2	118.4
Blue	.435	41.6	94.5
Green	.546	25.5	58.0
Red	.700	15.1	34.3
Upper threshold	.755	12.7	28.8

plates is much more important than having both of them at the ideal thickness. In order to return the shortest wavelengths to within one degree of the plane of the analyzer, the plates must be matched to within 1 per cent of their thickness. This tolerance is roughly 0.001 inch and a micrometer is quite adequate for controlling the final lapping. The plates should be polished, and since the upper plate affects the optical performance of the microscope, its flatness and its polish are important. Both plates should be in the optical train in nearly parallel light, because the birefringence of the two quartz plates becomes increasingly noticeable away from the *c* axis. Tilting of the *c* axis of the plates away from the optical axis of the microscope must also be avoided, the tolerance being about 1°. Misalignment or strongly divergent light is most noticeable in the pore spaces, which become light gray instead of black. Alignment can be made readily by removing the thin section and adjusting the isogyres of the quartz plates to the center of the field. The upper quartz plate works quite well in the accessory slot of the petrographic microscope. The lower quartz plate can be placed anywhere above the polarizer, and in some microscopes (such as the Zeiss research microscopes) an accessory slot is available below the stage and the author has found that certain combinations of condenser lenses give reasonably

parallel light at this position. It may often be easier to remove the lower polarizer and to substitute an external polarizer and the quartz plate somewhere in the light train where the light can be nearly parallel.

For photomicrography, an equivalent display on color film can be obtained without the quartz plates by making a triple exposure, with the polarizer and analyzer rotated together through 30° between exposures and with one tricolor filter in place during each exposure. The only difficulty is finding an analyzer that can be rotated without shifting the image out of register. Several models of microscopes with rotatable analyzers have been examined, and varying degrees of image shift were found. A large rotatable sheet of Polaroid immediately in front of the film contributes very little shift in the image positions. Figure 2 is a photomicrograph taken using this technique.

THE AMERICAN MINERALOGIST, VOL. 49, JANUARY-FEBRUARY, 1964

AN *X*-RAY STUDY OF SURSASSITE FROM NEW BRUNSWICK[1]

R. L. FREED, *Department of Geology and Mineralogy, The University of Michigan, Ann Arbor, Michigan.*

INTRODUCTION

The geology and mineralogy of sursassite from New Brunswick have been described by Heinrich (1962). Sursassite from the only other known locality, Oberhalbstein, Graubünden, Switzerland, has been analyzed chemically by Müller (1916), Jakob (1926, 1931, 1933), and de Quervain (Jakob: 1931, 1933). Various chemical formulae have been proposed for sursassite and these are listed in Table 1. Heinrich (1962) presents *x*-ray powder-diffraction data of both the New Brunswick and Swiss materials, and a chemical analysis of the sursassite from New Brunswick. Geiger (1948) gives *x*-ray powder-diffraction data of the Swiss material. He also determined a value of 3.2 Å for the fiber, or *b*-axis, translation.

TABLE 1. PROPOSED SURSASSITE FORMULAE

1. $5SiO_2 \cdot 2Al_2O_3 \cdot 5MnO \cdot 3H_2O$+ca. 1.80 mol. % excess SiO_2	(Jakob, 1926)
2. $21SiO_2 \cdot 8Al_2O_3 \cdot 20MnO \cdot 12H_2O$	(Jakob, 1931)
3. $(Si, Al)_3(Al, Mg, Fe, Mn)_3(Ca, Mn, Na, K)_2(O, OH)_{13.5}$	(Geiger, 1948)
4. $MgMn_4Al_4Si_5O_{20}(OH)_2 2H_2O$?	(Winchell & Winchell, 1951)
5. $Mn_5Al_4Si_5O_{21} \cdot 3H_2O$	(Hey, 1955)
6. $(Mn \ldots)_3Al_2(SiO_4)_3 \cdot 2H_2O$	(Strunz, 1957)
7. $Mn_9Al_4(Si, Al)_{12}O_{39} \cdot 6H_2O$	(Heinrich, 1962)

[1] Contribution No. 257, from the Mineralogical Laboratory, Dept. of Geology and Mineralogy, The University of Michigan.