NOTES · AND · NEW TECHNIQUES

AN EXTRAORDINARY CALCITE GEMSTONE

By C. S. Hurlbut, Jr. and Carl A. Francis

A 1,156-ct calcite gemstone cut from a twin crystal presents an unusual phenomenon when the interior is viewed through the table. One observes a multitude of colored images of the lower pavilion facets that change position and color with change in the viewing angle. This kaleidoscopic effect results in part from dispersion and the high birefringence of calcite, but the large number of facet images is caused by the twinning. As a single light ray enters the table, it is broken into two rays, O and E. On crossing the twin plane, each of these rays is divided into O and E rays, resulting in four rays that are reflected across the pavilion to be reflected toward the table. On this upward path, the rays again cross the twin plane and once more are divided into new O and E rays. Thus a single entering light ray emerges as four O and four E rays.

Several varieties of calcite are used for ornamental purposes but, because of its low hardness and easy cleavage (it has three perfect cleavage directions), calcite is rarely cut into faceted stones. The gemstone described here is an exception. Not only is it an unusually large faceted calcite (1,156 ct, 75 mm long × 44 mm wide × 48 mm high), but a most remarkable feature is seen when the interior of the stone is viewed through the table (figure 1). Considering the strong birefringence of calcite (0.172), one would expect a pronounced doubling of the back facets. In this stone, however, a multitude of colored images of the back facets also appear, changing color and position in a kaleidoscopic manner as the viewing angle is shifted slightly.

CRYSTALLOGRAPHIC POSITIONING OF THE FACETS

This gem was loaned by Professor Sidney Ross of Troy, New York, to the Harvard Mineralogical Museum for exhibition and study. It was faceted by Mr. Arthur Grant of Hannibal, New York, from flawless, optical-quality calcite from the Faraday Mine, Faraday Township, Hastings Co., Ontario, Canada. Specifically, the gemstone was cut from a twin crystal composed of two individuals twinned on the negative rhombohedron $\{01\bar{1}2\}$. In the following discussion, these individuals will be designated as crystal 1 and crystal 2. In this type of twinning, two of the three cleavages are common to both individuals; the third cleavage directions of crystals 1 and 2 make an angle 143° with each other (figure 2). This stone has been cut so that its length is parallel to the direction of intersection of these third cleavages. Since this direction is parallel to the twin plane, the twin plane is also parallel to the length. Although the twin plane divides the stone into two roughly equal parts, the table lies in only one individual and makes an angle with the twin plane of approximately 67° (see figure 3). This

ABOUT THE AUTHORS

Dr. Hurlbut is professor of mineralogy emeritus, and Dr. Francis is curator of the Mineralogical Museum, at Harvard University, Cambridge, Massachusetts.

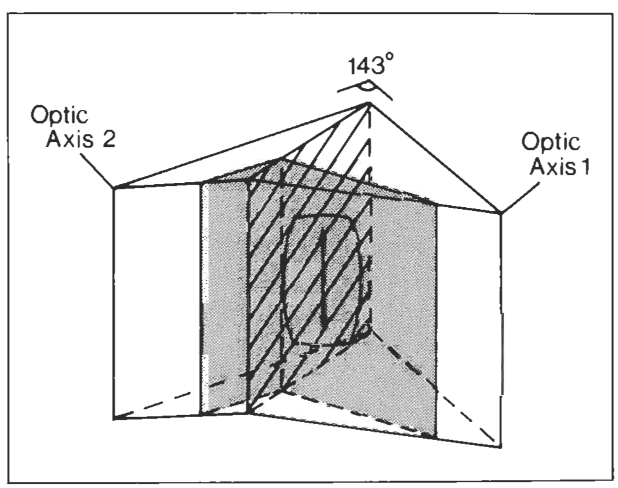
Figure 1. The Ross calcite displaying the kaleidoscopic effect. The gem is 75 mm × 44 mm × 48 mm and weighs 1,156 cts. Photo © 1984 Tino Hammid.

orientation of the table with respect to the twin plane is responsible for the intriguing kaleidoscopic appearance of the faceted stone.

The pavilion facets are arranged in six courses parallel to the girdle. The facets of the top row make angles of about 75° with the table, those of the bottom row about 37°. Light entering through the table is reflected from the upper three rows of pavilion facets to the opposite side of the pavilion, striking facets there at angles less than the critical angle, and then passes out of the stone. However, light striking the lower three rows is reflected across the stone to strike opposing facets at angles greater than the critical angle and is totally reflected upward through the crown facets.

This movement of light is essentially the same as in any properly proportioned gemstone but only partially explains the unusual feature of this particular stone. To understand the observed phenomenon, a review of some of the principles of crystal optics that apply to calcite may be helpful.

Figure 2. Drawing of calcite twinned on {01$\bar{1}$2} and bounded by cleavage surfaces. The ruled area is the twin plane. The stippled area shows the position of the plane of the table with the outline of the table superimposed. The double arrow indicates the direction of the length of the stone.



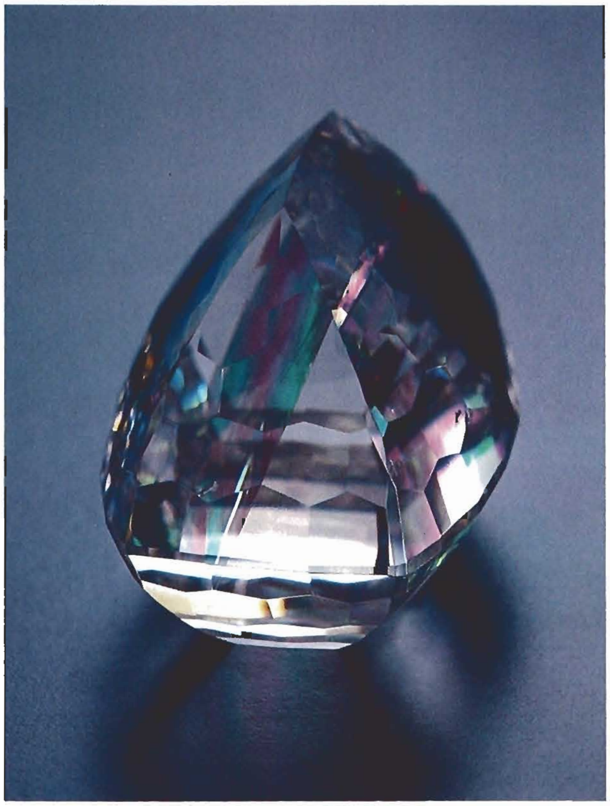


Figure 3. The twin plane that almost bisects the Ross calcite is clearly evident in this photo. Note how the table lies entirely in one individual. Photo © 1984 Tino Hammid.

CRYSTAL OPTICS OF CALCITE

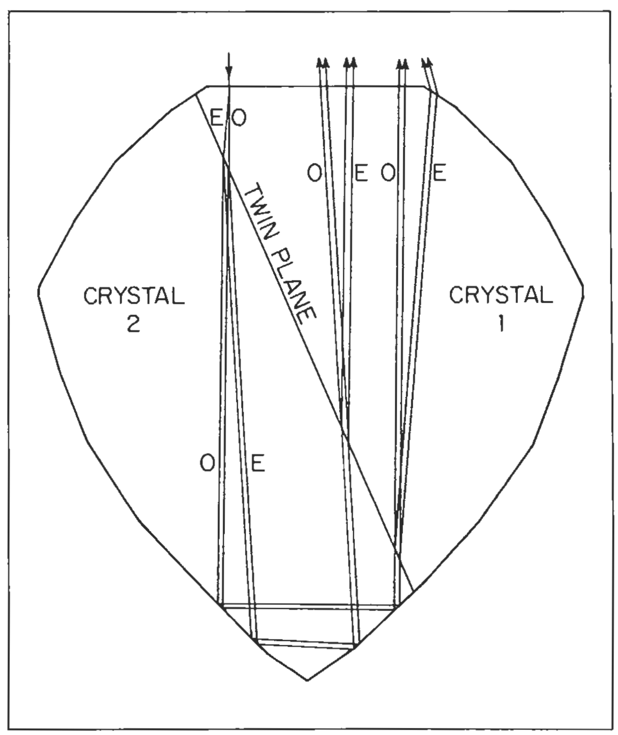
A beam of light entering calcite (or any uniaxial crystal) is broken into two polarized rays, the ordinary (O) ray and the extraordinary (E) ray, which vibrate at right angles to both the direction of movement and to each other. The O ray vibrates at right angles to the optic axis and the E ray in the principal section, that is, in a plane that includes the optic axis. Except when light moves parallel to the optic axis, the two rays, traveling at different velocities, follow different paths. The familiar illustration of the double image of a dot viewed through a calcite cleavage piece shows the divergence of the two rays (Hurlbut and Switzer, 1979). The doubling of back facets also illustrates the divergence: one image is produced by the O ray, the other by the E ray. (See Bloss, 1961, p. 73, or Wahlstrom, 1969, p. 220, for a more complete discussion of the crystal optics of calcite.)

The plane in which the optic axes of the two twin individuals lie is at right angles to the twin plane and in this gemstone makes a low angle with the table. The optic axis of crystal 1 (the individual containing the table) makes an angle of 20° with the table. Knowing this angle, the divergence of the two rays resulting from light entering perpendicular to the table was calculated to be 4°.

THE EFFECT OF TWINNING

Figure 4, a cross section of the Ross calcite at right angles to its length, shows schematically the manner in which light entering as a single ray at right angles to the table passes through the stone. The resulting diverging rays move into the stone only a short distance before they encounter the twin plane. As they pass through the twin plane, the rays are constrained to vibrate in conformity with the optical orientation of crystal 2; that is, as O rays vibrating perpendicular to its optic axis and as E rays vibrating at right angles to the O rays in

Figure 4. Cross section of the Ross calcite gemstone at right angles to the twin plane and the table. The lines crossing the figure show the manner in which a single light ray, entering perpendicular to the table, is divided and subdivided into O and E rays as it passes through the stone.



the principal section. Thus the O ray and E ray of crystal 1 each breaks into an O and E ray of crystal 2 (again, see figure 4). This results in four separate rays that pass to the lower pavilion facets to be reflected across the stone. On striking the opposing facets, at angles greater than the critical angle, the rays are totally reflected upward toward the table. But before they reach the table, the reflected light rays must again pass through the twin plane. As in the first crossing of the twin plane, each separate O and E ray is broken into O and E rays with vibration directions conforming to the optical orientation of crystal 1. Thus the light that entered the table as a single ray emerges from the stone as four O rays and four E rays.

In order to trace the passage of light, we have considered a single entering ray. But of course, when the table is bathed in light, beams of parallel rays enter the stone from all directions. Each set of parallel rays is divided in the same manner as the single ray described above, and each subdivision carries with it the images of the first facets from which it is reflected. The result is a multiplicity of overlapping facet images—and the distinctive kaleidoscopic appearance.

DISPERSION

Yet an additional factor contributes much to the charm of this stone: dispersion. In calcite, the dispersion of the refractive index of the O ray is 0.024 and of the R.I. of the E ray, 0.012. Although these values are low compared to the dispersion of diamond (0.444), they are significant, particularly in a large gemstone. Not only is a beam of white light entering the stone broken into O and E rays, but each of these rays is also composed of all wavelengths of the visible spectrum and every wavelength (color) takes a slightly different path through the stone. Because of this, the images of the facets are colored. With a slight change in the line of sight or a degree or two rotation of the stone, a facet image changes color.

Because facet images overlap and overlie one another, only rarely does an entire facet present a pure spectral color. In most instances, the color that reaches the eye is a combination of colors coming from two or more superimposed images. Some of these colored images leave the stone with vibration directions of the O ray, others as the E ray. By viewing the interior of the stone through a polarizing filter and then rotating the filter (less than 90°), one will find a position that eliminates completely some of the facet images; a 90° rotation of the filter from this position will eliminate others. In one position all the overlying images emerge as the O ray, in the other they emerge as the E ray. However, some facets, or portions of facets, are visible in all positions of the filter, which demonstrates that the image and its color are a combination of O and E rays. When one ray is eliminated by the filter, the color resulting from the other is seen. Each of these colors is purer and deeper than the composite color.

CONCLUDING THOUGHTS

The phenomenon observed in this gemstone is probably unique to calcite, because no other mineral found in large gem-quality crystals has the same high birefringence, clarity, and twinning. Calcite is almost commonly twinned on $\{01\bar{1}2\}$, as in the gemstone described. Although such instances are rare, calcite may be twinned on another negative rhombohedron, $\{02\bar{2}1\}$, and on the positive rhombohedron $\{10\bar{1}1\}$ (the cleavage rhombohedron). A gemstone cut from either of these twins, with proper regard to positioning the table with respect to the twin planes, would also show the same effect. Calcite is also commonly twinned on the base, $\{0001\}$, but because in this case the two individuals have parallel optic axes, the vibration direction of a light ray would not be changed on passing from one individual to the other. Thus, gemstones cut from this twin would not display the optical effect described here.

We congratulate Mr. Grant for his skillful and imaginative cutting of this gem. The Ross calcite is no longer unique. Several smaller gems displaying the kaleidoscopic effect have since been cut by Mr. Grant and by Mr. Michael Gray of Midpines, California, including a 70-ct stone on exhibit at the Los Angeles County Museum of Natural History, Los Angeles, California.

REFERENCES

Bloss F.D. (1961) *Introduction to the Methods of Optical Crystallography*. Holt, Reinhart and Winston, New York, NY.

Hurlbut C.S. Jr., Switzer G.S. (1979) *Gemology*. John Wiley & Sons, New York, NY.

Wahlstrom E.E. (1969) *Optical Crystallography*, 4th ed. John Wiley & Sons, New York, NY.