G&G

Micro-World

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Ametrine Optical Dishes: Windows into the Effects of Crystal Structure

During exploration of a gem's interior, it is important to understand how crystal structure affects the incorporation and orientation of inclusions, how an inclusion can affect its host, how interpretation of observations can depend on point of view, and the nature of light as it passes through a crystal—host or inclusion. As proposed earlier in this column (Spring 2016, p. 81), polished inclusion study blocks are ideal for showcasing, studying, and reviewing basic concepts relating to the micro-world. Here we take a look at light and crystal structure.

Of all the varieties of quartz, ametrine is perhaps the most fascinating to observe. While its stunning color zoning makes it a popular designer gemstone, it also encompasses several optical properties unique to different quartz varieties that can all be explored in one specimen. Almost unrecognizable as quartz, ametrine crystals are deeply etched (figure 1, left) and have abundant healed fractures. The only clues to the trigonal symmetry typical of quartz are occasional rhombohedral faces and, very rarely, an enigmatic flat termination manifesting a three-armed figure (figure 1, right). Only when a basal section is made by cutting a slice perpendicular to the c-axis is the improbable yet beautiful combination of citrine and amethyst revealed.

Figure 1. Left: An 85 × 25 mm ametrine crystal from Bolivia's Anahí mine exhibits the deeply etched prism faces typical of this quartz variety. Right: The crystal's termination, viewed in the direction of its c-axis, displays a rare "Y"-shaped manifestation of the crystal's trigonal symmetry. Slices made perpendicular to this direction will reveal this symmetry with alternating amethyst and citrine sectors. Since the optic axis parallels the c-axis located at the intersection of the "Y" arms, all paths of light found across this termination face will be along the optic axis. Photos by Elise A. Skalwold.

Beauty and function are married in an ametrine study block oriented so that the view through its two largest faces is directly along the optic axis of a crystal, as seen in figure 1. The innovation of adding a set of concave dishes for sampling each color zone, as well as the borders between them, reveals truly remarkable optical phenomena (figures 2 and 3). These optical dishes allow the viewer to see light passing

About the banner: In this scene, pyrite inclusions have dissolved, leaving behind hematite and goethite, both of which react dramatically to polarized light. Photomicrograph by John Koivula; field of view 10 mm.

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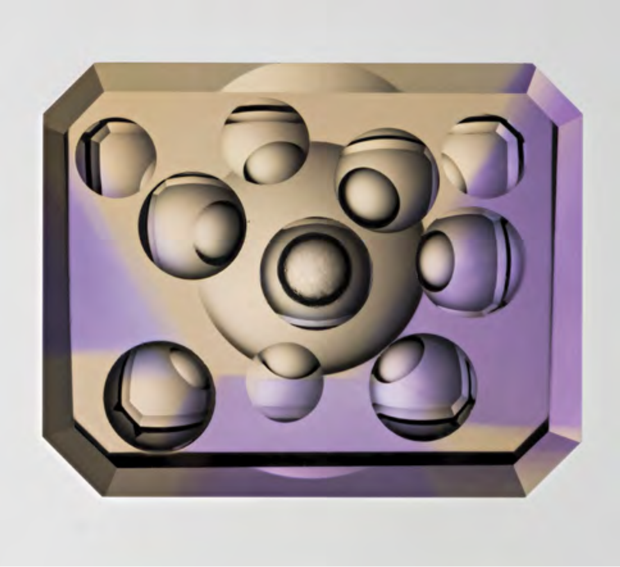


Figure 2. An ametrine study block with concave dishes cut and polished into its surface, including one on the opposite side. Viewed in transmitted light along the optic axis direction (i.e., all paths parallel to the c-axis), as in figure 1 (right), the trigonal symmetry of the crystal defines the citrine and amethyst sectoral zoning and allows observation of the effects of the optic axis on light. This specimen was fashioned by Nathan Renfro. Photo by Kevin Schumacher.

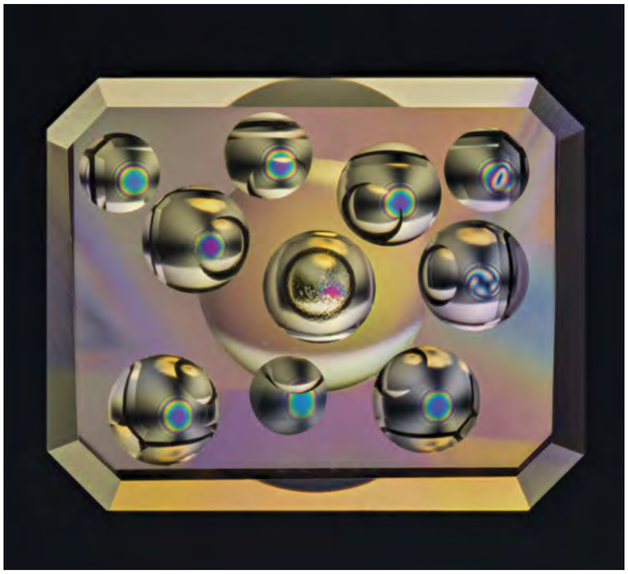
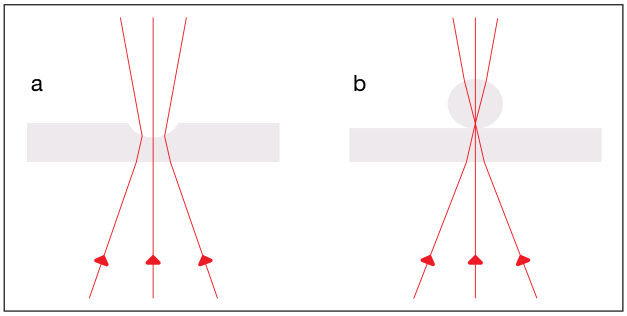


*Figure 3. Placing the study block between crossed polarizing filters in transmitted light results in a variety of bull's-eye optic figures that form in the divergent light produced by the concave dishes. The citrine sectors under the minor rhombohedral faces (*z*) are free of twinning and show a classic bull's-eye optic figure with varying colors due to slightly different thicknesses. The amethyst sectors display an Airy's spiral (middle row, right dish) produced by the alternating layers of left- and right-handed quartz of the Brazil-law twinning that formed under the crystal's major rhombohedral faces (*r*); broadly angled colors in these latter areas are also indicative of this twinning. The dish on the upper right is a distorted figure on the border of the sectors. Photo by Kevin Schumacher.*

through the specimen in many directions, as does the strain-free glass sphere familiar to gemologists for use with a polariscope (figure 4). When viewed between crossed polarizing filters, these dishes dramatically display the different uniaxial optic figures unique to quartz, which vary depending on thickness and placement in the sectors: the classic "bull's-eye" optic figure seen in the untwinned citrine sectors, an Airy's spiral in the amethyst sectors, and a distorted figure produced in a border region. All of these observed phenomena are produced by optical activity (i.e., the rotatory dispersion of light as it travels along the optic axis direction within the quartz crystal). By analyzing these figures, we can determine handedness and the effects of thickness, while observations of the amethyst's Brazil-law twinning may help distinguish natural versus synthetic origin.

Figure 4. Left: A section through part of the study block. The dish serves as a concave (negative) lens that causes the light rays to diverge. Right: A gemologist's strain-free glass sphere is used to observe an interference figure. Although the rays first converge at the base of the sphere, they ultimately diverge just like the rays in the figure on the left. Illustration by William A. Bassett.



For an in-depth analysis of the phenomenon of optical activity and the origin of quartz's optic figure, see E.A. Skalwold and W.A. Bassett, *Quartz: A Bull's Eye on Optical Activity*, Mineralogical Society of America, 2016, www.minsocam.org/msa/OpenAccess_publications/Skalwold/Quartz_Bullseye_on_Optical_Activity.pdf.

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Figure 5. This 6.92 mm bastnäsite-(Ce) from Pakistan contains numerous straight and curving acicular inclusions of astrophyllite. Photo by Kevin Schumacher.

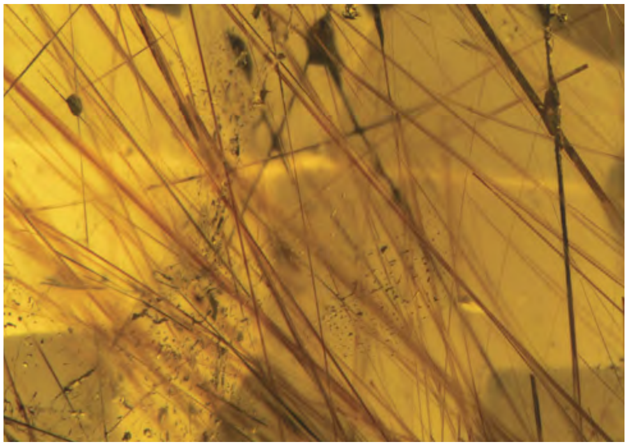

Figure 6. Magnification affords a more detailed view of the bastnäsite-(Ce) inclusions. Photomicrograph by Nathan Renfro; field of view 2.85 mm.

Astrophyllite in Bastnäsite-(Ce)

Pakistan's Zagi Mountains are known as a source for both astrophyllite and bastnäsite-(Ce). The two minerals often grow together, with bastnäsite-(Ce) overgrowing stalks and fibers of astrophyllite; the latter is then sometimes incorporated as inclusions in the bastnäsite-(Ce). We refer to these types of inclusions as "protogenetic."

The author recently had the opportunity to examine the brownish orange bastnäsite-(Ce) seen in figure 5. The 1.40 ct oval modified brilliant, provided by Luciana Barbosa (Gemological Center, Asheville, North Carolina), hosted an abundance of eye-visible inclusions of astrophyllite (figure 6), both straight and curved, that were identified by Raman analysis. Some of the included fibers and stalks appear to have been partially altered or coated with iron compounds.

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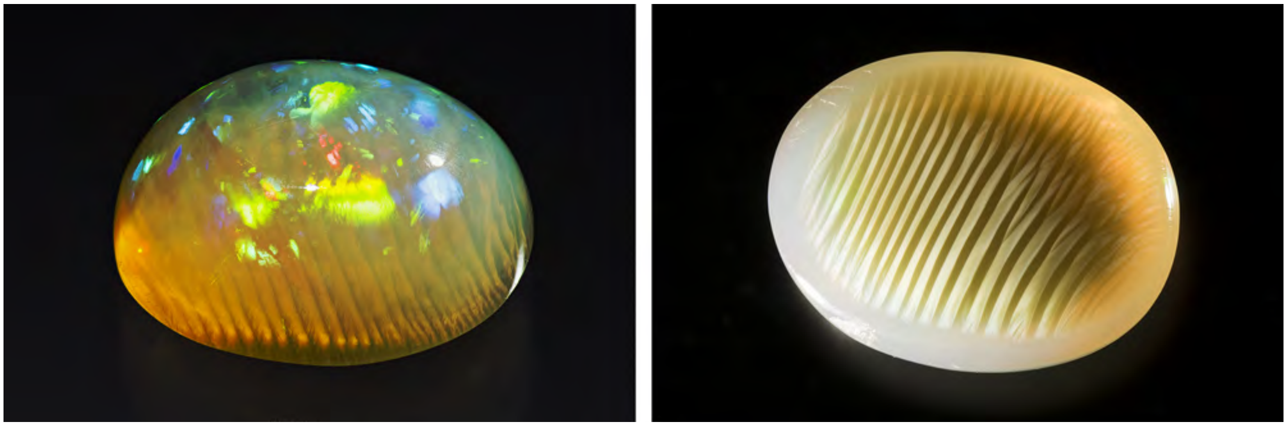
Flashes and Flames in Ethiopian Opal

The relatively new source for precious opal located in Ethiopia's Wollo Province produces material with vibrant play-of-color and occasionally with interesting inclusions.

Figure 7. This 2.68 ct opal displayed play-of-color when viewed face-up (left) and flame-like chatoyancy on its slightly domed base (right). A more pronounced dome might have had the effect of sharpening the sheen into a cat's eye. Photos by Kevin Schumacher.



A recently examined 2.68 ct cabochon contained a scattering of octahedral metal sulfide inclusions (relatively common in Ethiopian opal) along with an unusual combination of optical phenomena: play-of-color and chatoyancy. Face-up, the stone showed the typical flashes of colors one would expect in precious opal (figure 7, left). However, the back of this cabochon contained an interesting structure that produced a sheen-like chatoyancy over its slightly rounded surface (figure 7, right). This chatoyant zone was strikingly similar to the flame structure seen in some non-nacreous pearls, which is produced by an intricate structure of aragonite crystal laths (figure 8). In the case of this opal, the flame-like structure's cause remains an enigma, though it could be due to the structural influence of a pre-existing fibrous mineral replaced by opal. Unfortunately, Raman analysis was unable to detect any presence of another mineral phase in the chatoyant area, so the exact cause of chatoyancy is still unknown.

Chatoyancy is not unheard of in opal, though it is quite rare in precious material. Cat's-eye common opal from Tanzania owes its optical effect to arrays of parallel needles, while the asterism and chatoyancy unique to the precious opal of Spencer, Idaho, are due to the arrangement of the same silica micro-spherules responsible for its play-of-color. At least one cat's-eye precious opal was observed to even "wink" at the viewer when viewed with opposing lighting (Summer 2003 Lab Notes, p. 148). This Ethiopian opal cabochon joins the rarefied group of chatoyant precious opal with its unusual phenomenal display of flashes and flames.

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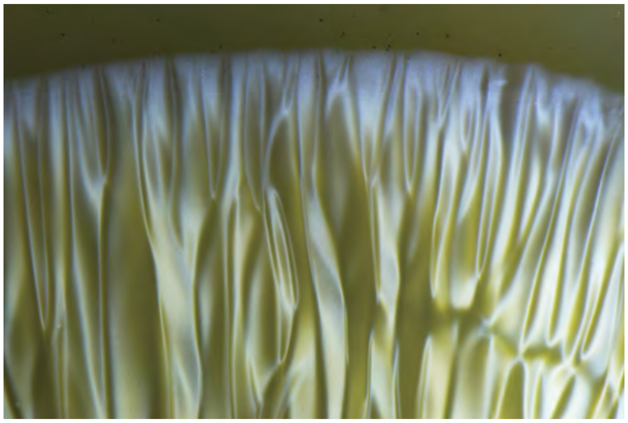
Figure 8. The fibrous nature of the opal's unusual chatoyant zone is clearly revealed, along with the numerous minute octahedral black metal sulfide crystals that are a common inclusion in opal from Wollo. Oblique fiber-optic illumination. Photomicrograph by Nathan Renfro; field of view 2.73 mm.



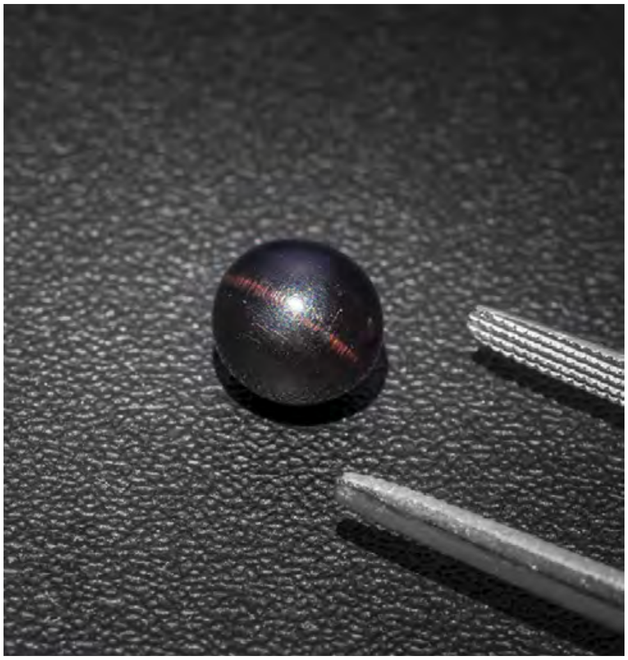


Figure 9. With fiber-optic illumination, a sharp, bright pink chatoyant band extends across the surface of a 1.89 ct dark brown button-shaped imitation pearl perpendicular to its internal fibrous structure. Photo by Robert Weldon/GIA.

Imitation Cat's-Eye Pen "Pearls"

Chatoyancy is an optical phenomenon commonly seen in gemstones that have an abundance of parallel solid or hollow long acicular inclusions in which an eye-like band is produced when viewed in strong light. Fine cat's-eye gemstones of various mineral species are prized; however, natural chatoyancy in pen pearls would be an extraordinary occurrence. During a recent study on reportedly non-nacreous pearls from the Dr. Eduard J. Gübelin Collection, the author found three dark brown button-shaped samples stated to be from a *Pinna* species mollusk. All three samples displayed an attractive cat's-eye effect when illuminated under a fiber-optic light or any single white light (figure 9). In each specimen, the chatoyant band manifested as a single bright pink line extending across the surface in a direction perpendicular to the internal fibrous structure.

Evidence of human manipulation includes fine linear features present in random directions across cellular structures; these are proof of work carried out during the fashioning of the samples into cabochons. Microscopic examination revealed the fibrous structure as numerous well-formed, minute parallel acicular crystals. Infrared spectroscopy subsequently confirmed the crystals to be calcite. The calcite was arranged in a vertical columnar orientation rather than in a radial and concentric structure characteristic of non-nacreous *Pinna* (pen) pearls, which led to further doubts concerning the "pearl" identity of the samples.

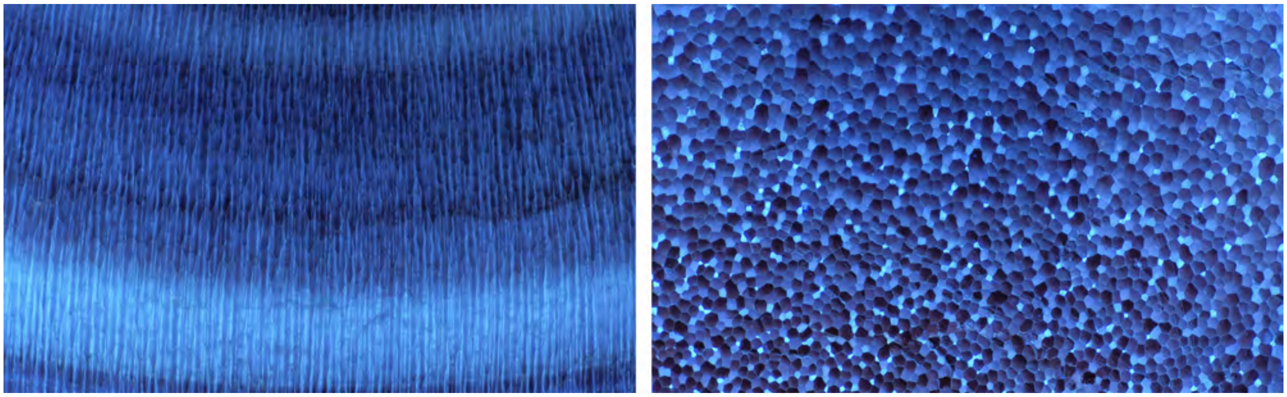


Figure 10. Fluorescence images reveal banded features, typical of shell, at right angles to the vertical columnar structure of the calcite crystals (left). A mosaic pattern (right) is apparent looking down the hexagonal cross-section of the calcite columns. Photomicrographs by Artitaya Homkrajae; fields of view 2.88 mm and 1.44 mm, respectively.

Microradiography of all three samples revealed tight internal structures. The obvious radial structures that would be expected in pen pearls were not observed (N. Sturman et al., "Observations on pearls reportedly from the Pinnidae family (pen pearls)," Fall 2014 *G&G*, pp. 202–215). Based on its external and internal features, this material was almost certainly the same type of imitation pearl previously reported in *G&G* (Winter 2011 GNI, pp. 330–332).

Fluorescence images taken of one specimen using a polarizing microscope and an ultraviolet excitation filter with a wavelength range of 330–380 nm (figure 10, left) reveal a prominent banded structure at right angles to the calcite columns. When viewed at right angles to their lengths under the same conditions, the long, thin calcite crystals reveal a hexagonal cross-section, creating a striking mosaic or cellular pattern (figure 10, right). The cells varied in form, and their approximate diameters ranged from 15.50 to 38.00 microns.

These samples were appealing for the magnificent kaleidoscopic colors that were seen using fiber-optic illumination (figure 11). The semitranslucent to translucent nature of the crystals allowed light to pass through and produce vibrant, colorful scenes owing to the interference of the light rays that were reflected and refracted when interacting with the crystals. As one can see, exploration of the micro-world is not only important to forensics—it can also be quite beautiful.

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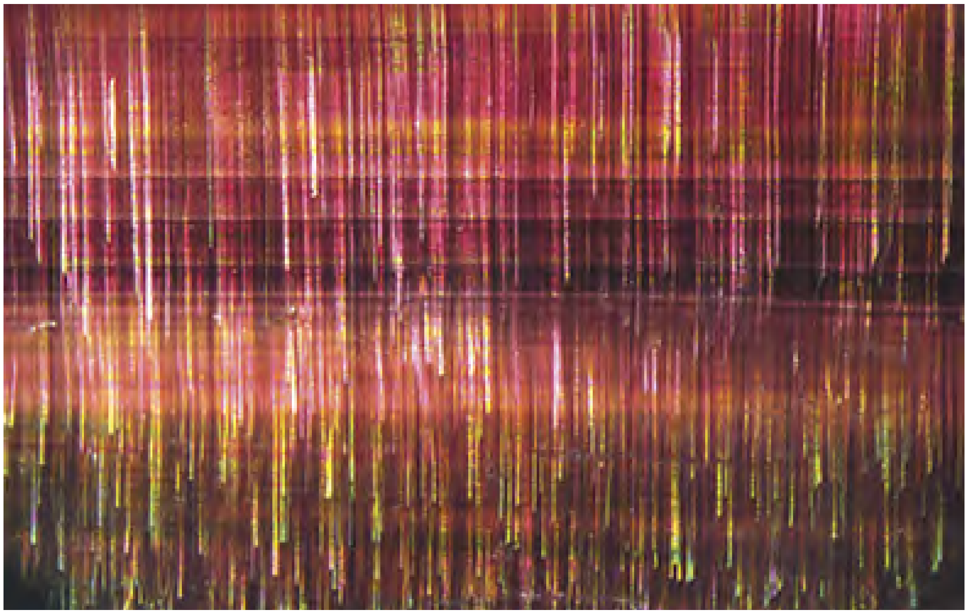

Figure 11. Under fiber-optic light, magnificent reflective kaleidoscopic colors of pink, yellow, and green are revealed from the well-formed acicular calcite crystals after mineral oil is applied to the sample's surface. Photomicrograph by Artitaya Homkrajae; field of view 3.57 mm.

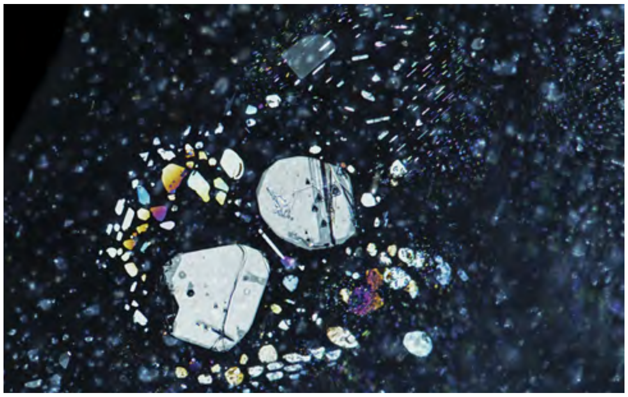

Figure 12. A beautiful iridescent rosette pattern made up of flattened negative crystals appears around the primary negative crystals when illuminated by oblique fiber-optic lighting. Photomicrograph by Victoria Raynaud; field of view 1.07 mm.

Figure 13. These two large primary fluid inclusions containing a black solid phase are associated with fingerprints that have a variable orientation. The photo was taken along the c-axis in darkfield illumination. Photomicrograph by Victoria Raynaud; field of view 1.07 mm.

Negative Crystals in Sapphires

Negative crystals, or cavities within a crystal, and fluid inclusions occur in almost every mineral. They are generally too small to notice without high magnification, but these modest features hold great beauty and scientific value. These microscopic features are valuable to understanding the growth of continents, the rise of mountains, and the formation of gems. The following photos show beautiful examples of such inclusions in sapphires from the Baw Mar mining area in Mogok, Myanmar. Some of these fluid inclusions are arranged in a "rosette" pattern consisting of a large flattened negative crystal surrounded by smaller ones. This structure is always seen perpendicular to the c-axis (figure 12). The larger primary inclusions like those seen in figure 13 are characterized by their high relief and may display triangular growth markings as well as beautiful iridescence under oblique fiber-optic illumination. Other negative crystals associated with healed fissures are observed in random orientation. The smaller, more delicate fluid inclusions in these structures have a smoother outline, while the fingerprints themselves are often associated with the primary negative crystals.

The multiphase inclusion in figure 14 contains a gas, a liquid, and at least one solid. When the specimen was gently heated by the microscope's well light, the gas and the liquid homogenized. Raman spectroscopy identified the gas phase as pure CO_2 and the opaque solid as marcasite. Using the same method, we also identified diaspore fibers, seen as faint lines in the inclusions, and a miniscule siderite crystal. Although fluid inclusions are common in most blue sapphires, the examples from Baw Mar reveal these fascinating inclusions in an appealing way.

Figure 14. Left: A large fluid inclusion containing a CO_2 gas bubble and a marcasite crystal. The primary inclusion is surrounded by smaller inclusions that make up a healed fissure. Right: When the sample was gently heated, the gas bubble disappeared as the gas and liquid homogenized. The sample is illuminated using diffused backlighting. Photomicrographs by Victoria Raynaud; field of view 1.20 mm.

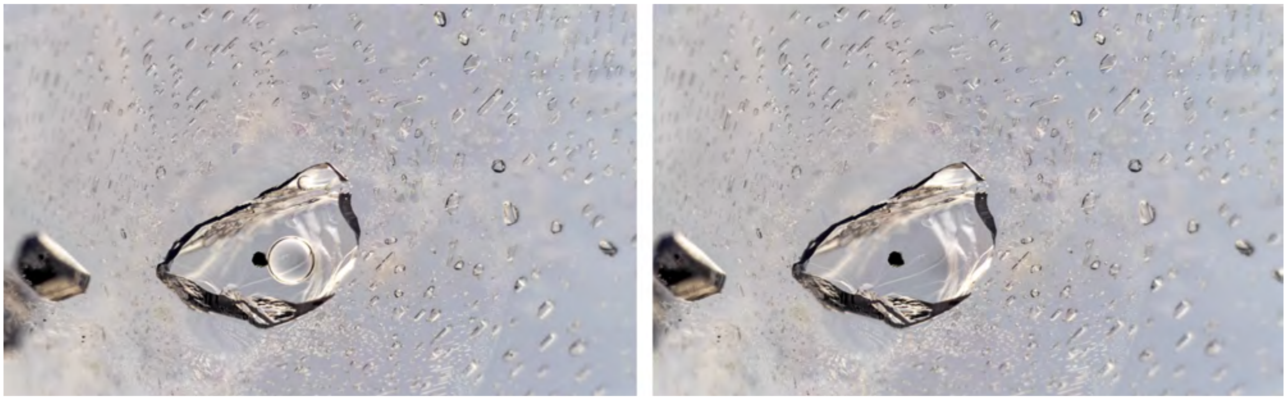

Figure 15. The interior of this 5.10 ct Sri Lankan topaz is dominated by a dramatic inclusion scene. Photo by Kevin Schumacher.

These photos were taken as part of a research project to document the blue sapphires from the Baw Mar mine. The complete report of this study can be found at https://www.gia.edu/gia-news-research/blue-sapphires-baw-mar-mine-mogok-myanmar.

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Quarterly Crystal: Mystery in Topaz

Occasionally we run into an inclusion identification problem we just can't solve. Such was the case with the 5.10 ct topaz from Elahera, Sri Lanka, shown in figure 15. This transparent colorless crystal, acquired from Kusum S. Naotunne (Colombo, Sri Lanka), hosts a prominent translucent light green crystal and a flowery cluster of hexagonal opaque silvery black plates (figure 16). The bodycolor and characteristic form of the green inclusion suggest fluorite; this was confirmed by laser Raman micro-spectrometry.

Analysis of the opaque black plates was a more difficult matter. GIA's Carlsbad lab staff employed Raman to identify the plates, but the inclusion was too deep to get any signal other than the spectral lines of the topaz host. Energy-dispersive X-ray fluorescence (EDXRF) was attempted to pick up any hints of the plates' chemical composition, but useful information continued to elude such efforts. It became clear that destructive analysis would be needed to clearly identify the black plates. Since this was an inclusion combination, we decided that this topaz should be preserved unaltered for future exploration. Surely one day technological advances will allow the identification of this mystery inclusion, but for now it is enough to enjoy the aesthetics of such a beautiful included crystal and the fascinating exploration of its inner world.

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Figure 16. While the light green crystal was identified as fluorite by Raman analysis, the opaque platy inclusions were too deep to be identified. Photomicrograph by Nathan Renfro; field of view 5.87 mm.