G&G Micro-World

Editor: Nathan Renfro
Contributing Editors: Elise A. Skalwold and John I. Koivula

Three-Phase Inclusion in Alexandrite

Natural gemstones form under very intense conditions that allow for a wide range of interesting phenomena and inclusions to occur within them. Environmental conditions within the earth's crust influence the types and amounts of inclusions that occur. Various categories of inclusions, such as crystals or structural defects, for example, are widespread among almost all gem species. On the other hand, there are less frequent types of inclusions that form only under specific geological conditions and are found only in certain gem species. Although less common, it is possible to observe up to three phases of matter within a single inclusion suite.

At conditions slightly above room temperature (i.e., in the well light of a gemological microscope), the largest jagged cavity pictured here contains multiple separate crystals and a transparent colorless fluid (figure 1). At a temperature below 31.2°C, the fluid separates into liquid and multiple bubbles of carbon dioxide gas are released (figure 2). Differences in environmental conditions during formation influence the amount of static pressure within the stone, which explains why some three-phase inclusions are visible at room temperature while others are only visible at lower temperatures (see J.I. Koivula, "Carbon dioxide fluid inclusions as proof of natural-colored corundum," Fall 1986 *G&G*, pp. 152–155). Despite the shape and the relief of the

About the banner: Acicular inclusions of the blue mineral dumortierite are present throughout this quartz crystal from Brazil. Photomicrograph by Nathan Renfro; field of view 5.68 mm.

Gems & Gemology, Vol. 59, No. 1, pp. 84–91.

Figure 1. Top: Negative crystal in an alexandrite containing a fluid and crystals at room temperature. Bottom: Below 31.2°C, multiple gas bubbles appear. Photomicrographs by Jamie Price; field of view 1.99 mm.

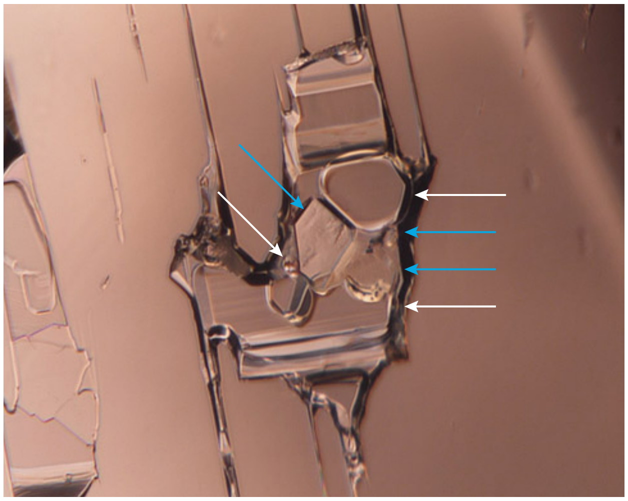


Figure 2. Close-up view distinctively pointing out the locations of the crystals (blue arrows) and gas bubbles (white arrows). Photomicrograph by Jamie Price.

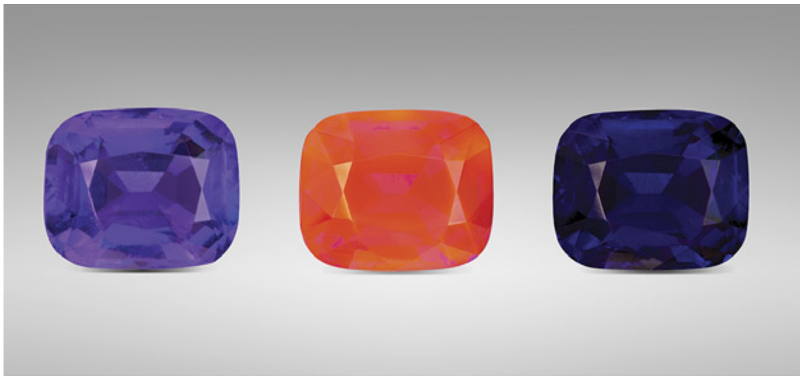


Figure 3. A hackmanite with a faded purple color after storage in the dark (left), illuminated with long-wave UV light (center), and after removal from a few seconds of exposure to the long-wave UV light (right). The color has deepened after exposure to UV light. Photos by Ronnakorn Manorotkul.

crystals present, the overall appearance of this alexandrite's multiphase inclusion is comparable to the typical jagged three-phase inclusions that are distinctive for Colombian emerald.

Jamie Price
GIA, Carlsbad

Apatite in Hackmanite

Hackmanite, $Na_8Al_6Si_6O_{24}(Cl_2,S)$, is a variety of sodalite notable for its tenebrescence. When kept in darkness, samples can fade to pale purple and even gray or translucent to opaque white. When exposed to long-wave ultraviolet illumination, they can display a strong orange fluorescence reaction. After exposure to sunlight or artificial light with a UV component, samples can quickly develop a much stronger color. One hackmanite sample recently examined by the author (figure 3) showed this phenomenon.

Another hackmanite was submitted that displayed an interesting elongated white inclusion (figure 4, left) that was identified by micro-Raman as apatite. As we examined the sample in the microscope, we tried exposing it to a 6-watt long-wave UV light for approximately one second. Almost immediately, a change was observed. The hackmanite developed a more vibrant purple color that is clearly displayed in figure 4 (right).

E. Billie Hughes
Lotus Gemology, Bangkok

Figure 4. Left: In darkfield illumination, a white apatite crystal is visible in the hackmanite. Right: After exposure to long-wave UV light for approximately one second, a dramatic change can be seen. The overall color of the hackmanite is now a more vivid shade of purple. Photomicrographs by E. Billie Hughes; field of view approximately 5 mm.

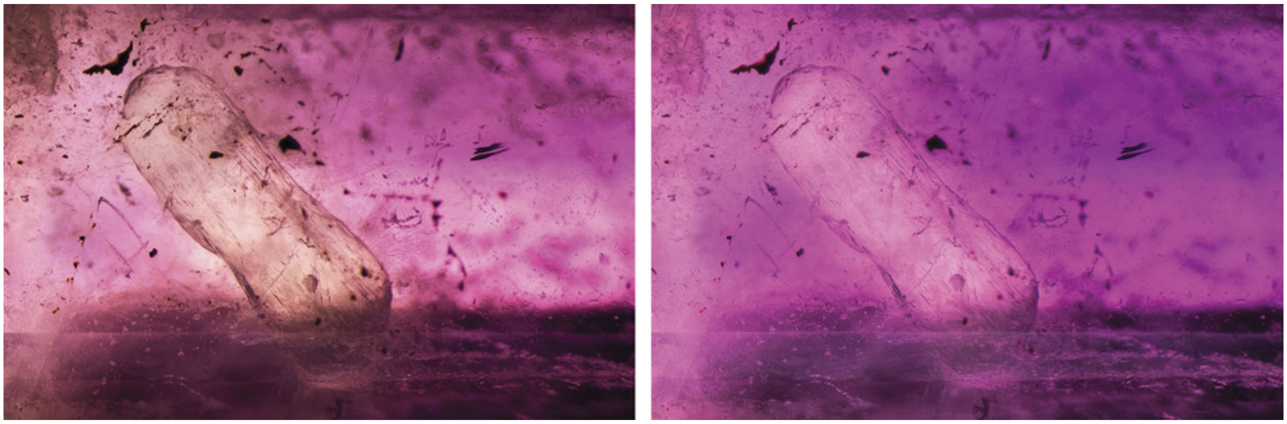


Figure 5. This 4.63 ct chondrodite contained irregular multiphase and reflective iridescent platelets with a bright orangy yellow color. Photo by Adriana Gudino; courtesy of Bill Vance.

Inclusions in Chondrodite

The authors recently examined a 4.63 ct orangy yellow pear modified brilliant (figure 5). The gemological properties as well as infrared and Raman spectroscopy identified the stone as chondrodite.

Microscopic observation revealed a lively inclusion scene with colorless reflective and iridescent platy inclusions (figure 6). Dark, highly reflective platelets of graphite, which can be associated with low-relief colorless crystals of various minerals (figure 7), were also confirmed by Raman analysis.

Chondrodite, $Mg_5(SiO_4)_2(F,OH)_2$ is a member of the humite group. This rare mineral occurs primarily in metamorphosed limestones and dolomites (W.L. Roberts et al., *Encyclopedia of Minerals*, 2nd ed., Van Nostrand Reinhold, New York, 1990, p. 170). If contact metamorphism occurs in an area with sufficient magnesium, chondrodite and other associated magnesium-bearing minerals such as spinel, phlogopite, and tremolite may form.

Chondrodite has been found to originate from Tanzanian localities at Mahenge (Winter 2011 Gem News Inter-

Figure 6. Platy inclusions were observed throughout the chondrodite. Photomicrograph by Nathan Renfro; field of view 4.11 mm.

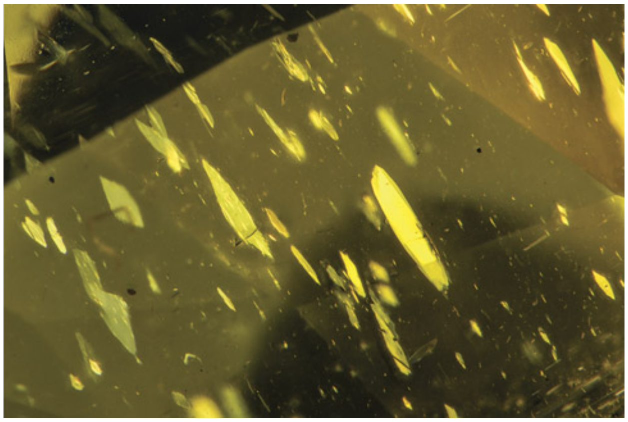
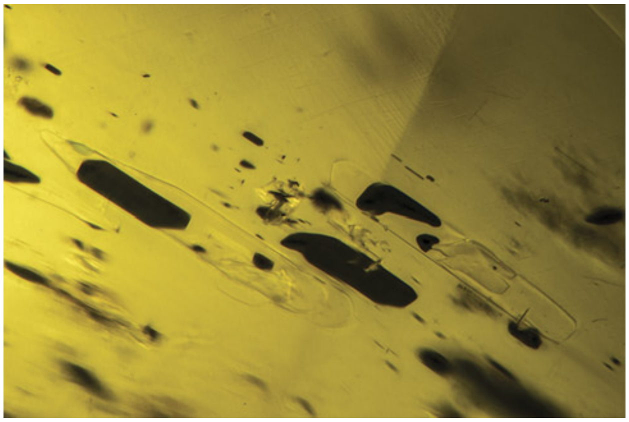


Figure 7. Dark, highly reflective platelets of graphite as well as unidentified low-relief colorless inclusions of multiple minerals were also observed in the chondrodite. Photomicrograph by Nathan Renfro; field of view 0.91 mm.



national, p. 316), Sumbawanga (Winter 2007 Gem News International, pp. 377–379), and Tanga (B. Clark, "Chondrodite reportedly from Tanga, Tanzania," *Journal of Gemmology*, Vol. 34, No. 8, p. 655). It has also been identified as an inclusion in a spinel from Mogok, Myanmar (Winter 2021 *G&G* Micro-World, p. 383). The gemological properties of this stone were consistent with material from Mahenge, but the origin could not be confirmed.

Chondrodite is an uncommon mineral and even more rare as a gemstone. This exceptional example of a bright orangy yellow color, faceted by Bill Vance of Vance Gems, showcases the types of inclusions that can be found in this gemstone.

Kendra Carty and Amy Cooper
GIA, Carlsbad

A "Flying Insect" in Diamond

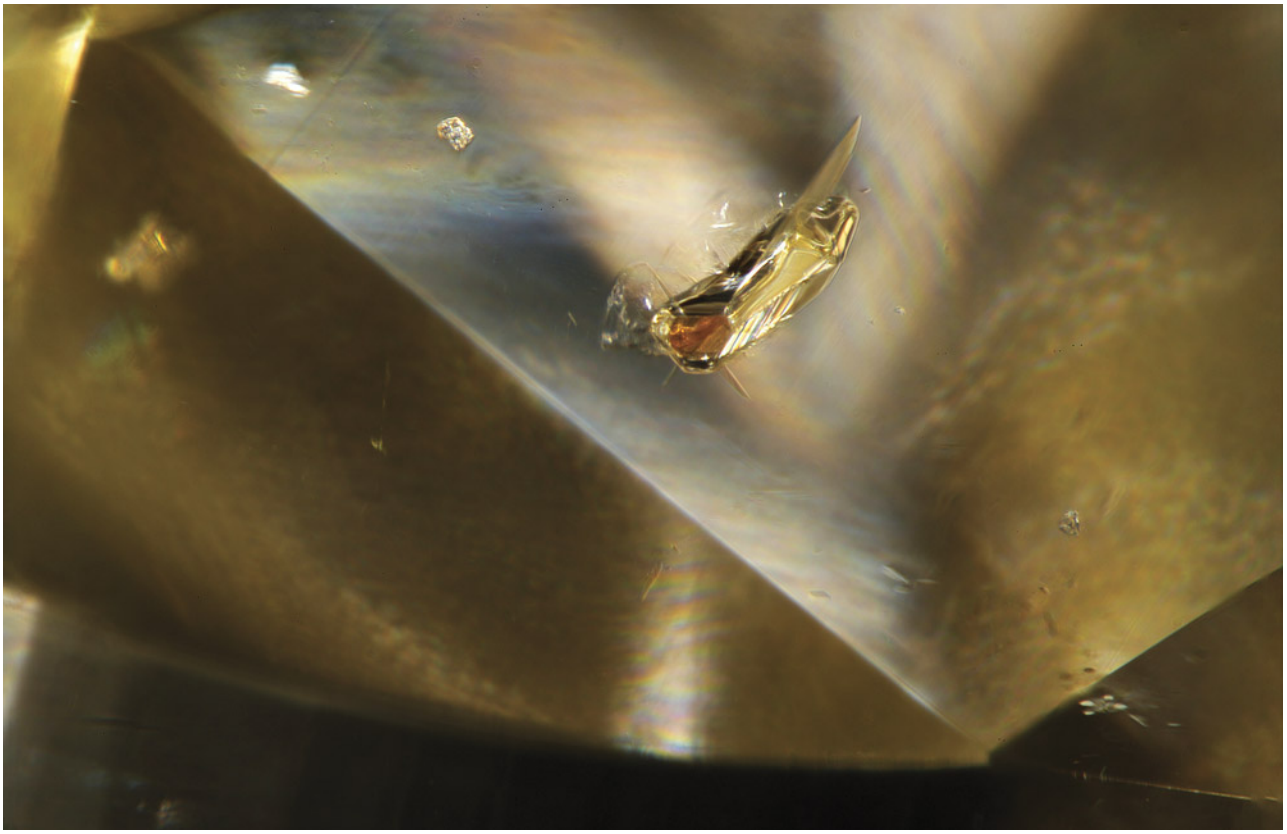
The authors recently examined a 0.75 ct type IaA Fancy Light brownish yellow diamond. This diamond, with a clarity grade of I_1, contained at least 10 orange inclusions, the largest one ~500 µm in its longest dimension. A partially exposed orange inclusion resembled a flying insect, with "flapping wings" and "antennae" caused by fractures around the inclusion (figure 8). Raman spectroscopy revealed the inclusion to be pyrope-almandine-grossular garnet, $(Mg,Fe,Ca)_3Al_2(SiO_4)_3$, a major constituent mineral of eclogite.

Eclogite and peridotite are the major diamond host rocks in the lithospheric mantle. Worldwide, the ratio of diamonds with eclogitic mineral inclusions to those with peridotitic inclusions is ~1:2 (T. Stachel and J.W. Harris, "The origin of cratonic diamonds – constraints from mineral inclusions," *Ore Geology Reviews*, Vol. 34, No. 1-2, 2008, pp. 5–32).

Although the presence of inclusions generally reduces a diamond's clarity grade, diamonds containing visually identifiable mineral inclusions are uncommon. Studies of some smaller diamonds (~2 mm) from South Africa and Botswana revealed a low abundance of inclusion-bearing diamonds (about 1% in a total of one million diamonds examined; Stachel and Harris, 2008). For a gem-quality diamond to contain more than 10 mineral inclusions is therefore notable.

Mei Yan Lai and Taryn Linzmeyer
GIA, Carlsbad

Figure 8. This partially exposed orange garnet inclusion with surrounding fractures in a brownish yellow diamond resembled a flying insect. Photomicrograph by Mei Yan Lai; field of view 1.58 mm.



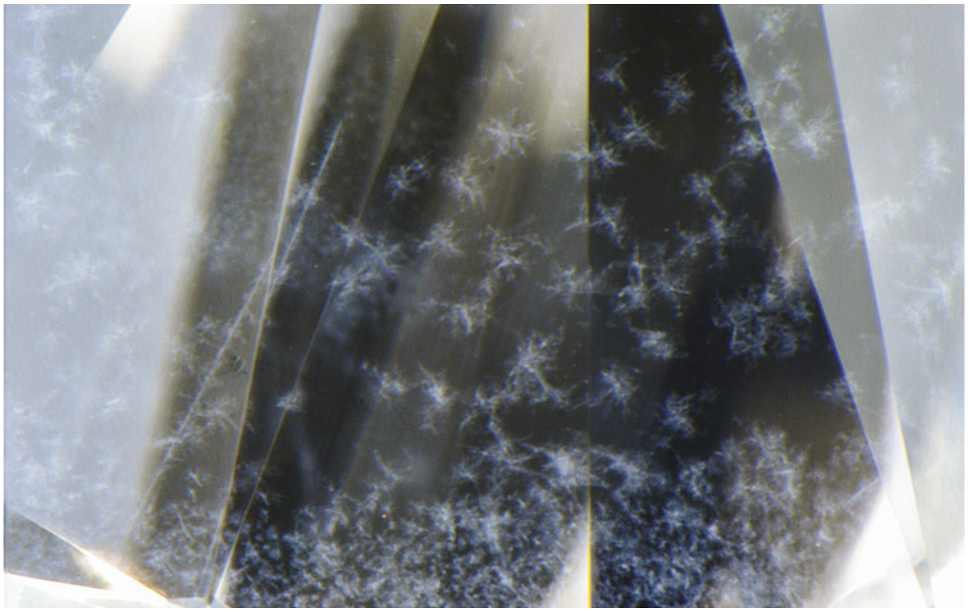


Figure 9. Rare cloud inclusions were observed in a 0.53 ct D-color diamond. Photomicrograph by Nathan Renfro; field of view 2.39 mm.

Starry Night in Diamond

In astronomy, a star cloud is defined as a group of many stars. A diamond recently submitted to GIA's Surat lab contained cloud inclusions resembling a starry night (figure 9). This diamond was a 0.53 ct D-color natural round brilliant with SI_2 clarity. Fourier-transform infrared absorption spectroscopy indicated a type IaAB diamond with low nitrogen content of about 5 ppm. Each of the cloud inclusions had apparently randomly placed dendrites. The star field in this stone appeared comparable to a diamond described previously (Fall 2017 *G&G* Micro-World, p. 369); however, the individual clouds in that diamond resembled crosses of uniform orientation that corresponded with the cube face.

Photoluminescence (PL) mapping using 455, 532, and 633 nm excitations was used to determine whether optical features could be detected within the cloud inclusions, as that analysis method has proven useful with cloud features in other diamonds (Fall 2020 Lab Notes, pp. 416–419). However, the PL maps were inconclusive, as no distinctive features were detected within the star-shaped inclusions. In deep ultraviolet fluorescence imaging, they appeared to be contained within the same growth zone (figure 10).

The inclusion suite was an interesting collection of cloud formations and a delightful discovery in this unusual diamond.

Sally Eaton-Magaña and Stephanie Shaw
GIA, Carlsbad

Alpesh Vavadiya
GIA, Surat

Xenomorphic Garnet in Diamond

Garnet is a nesosilicate mineral belonging to the cubic crystal system. The crystal habit most commonly assumed by this mineral is a dodecahedron. A garnet crystal with rare octahedral morphology was recently encountered in the form of a xenomorphic inclusion within diamond. Xenomorphism is the process by which a growing mineral forces a syngenetic mineral inclusion to adopt a crystal habit familiar to the host (J.I. Koivula, *The MicroWorld of Diamonds*, Gemworld International, Northbrook, Illinois, 2000). Xenomorphic crystals may also be referred to as "anhedral" since they lack their own characteristic crystal shape in favor of the host's. However, it should be noted that not all anhedral included mineral crystals are xenomorphic. As an octahedron is the most common diamond habit, the garnet inclusion grew into this form, complete with triangular growth marks visible on one of the octahedral faces (figure 11). Xenomorphism in diamond can also occur with mineral inclusions that do not belong to the

Figure 10. This deep ultraviolet fluorescence DiamondView image shows that the cloud inclusion features appear to be contained within a single growth zone. Image by Sally Eaton-Magaña.

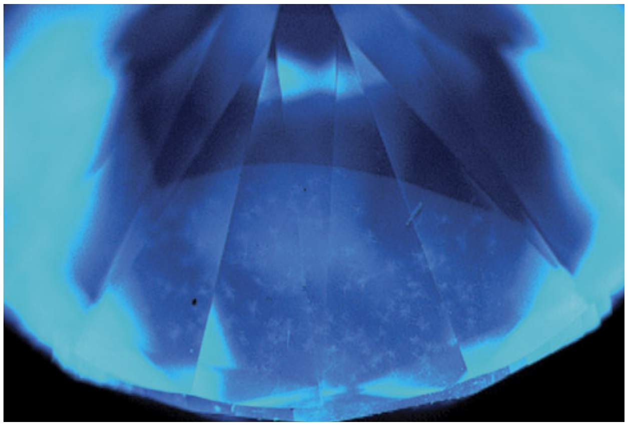


Figure 11. A purplish pink xenomorphic octahedral garnet crystal seen in a diamond. Note the trigons on the upper right octahedral face and stress fractures around the intersections of the crystal faces. Photomicrograph by Britni LeCroy; field of view 1.26 mm.

cubic crystal system, and these can be forced into other diamond habits. For example, a monoclinic crystal of diopside may be forced into a cuboctahedral habit. Xenomorphic crystals are just one of many unique inclusion types possible within diamond.

Britni LeCroy and Virginia Schwartz
GIA, Carlsbad

Arrow-Patterned Negative Crystals in Sapphire

Negative crystals are a common inclusion in corundum and often rupture upon exposure to moderate heat treatment. The author recently analyzed a sapphire containing a series of negative crystals arranged in an arrow-like pattern (figure 12). Careful examination revealed a partially healed fissure intersecting one of the negative crystals, indicating the stone had been subjected to heat treatment.

Fortunately, this spectacular pattern of negative crystals endured the heat treatment process, decorating the internal micro-world of this sapphire.

Piradee Siritheerakul and Tao Shiu Hei
GIA, Bangkok

Unusual Solid Inclusions in Flame-Fusion Ruby

The author recently examined unusual dark red solid inclusions in a flame-fusion laboratory-grown ruby. Standard gemological testing yielded a refractive index of 1.760–

Figure 12. Negative crystals arrayed in an arrow-like pattern. Photomicrograph by Suwasan Wongchacree; field of view 1.07 mm.

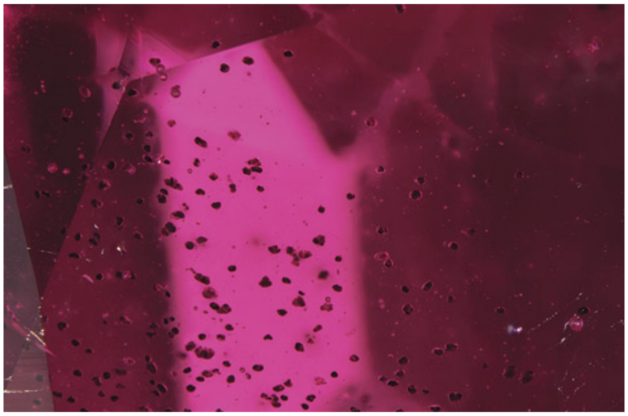


Figure 13. Numerous natural-looking dark red solid inclusions were observed in a flame-fusion laboratory-grown ruby. Photomicrograph by Ezgi Kiyak; field of view 2.9 mm.

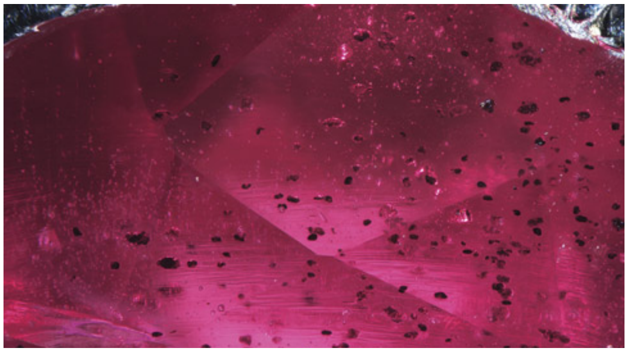


Figure 14. Strong curved growth lines and numerous gas bubbles and dark solid inclusions were present in the flame-fusion ruby. Photomicrograph by Ezgi Kiyak; field of view 2.9 mm.

1.768, a chromium emission line in red using a handheld spectroscope, medium red fluorescence under long-wave UV, and weak red fluorescence under short-wave UV. These properties were consistent with ruby. Microscopic examination using brightfield illumination revealed numerous dark red inclusions (figure 13) that resembled crystals commonly seen within natural corundum.

Furthermore, magnification showed characteristic internal features of flame-fusion ruby such as curved striae and gas bubbles. The strong curved growth lines and numerous gas bubbles (figure 14) suggested that this was an early type of flame-fusion ruby. Although flame-fusion corundum is widely available in the marketplace, it is unusual to encounter a specimen containing natural-looking dark red solid inclusions. These inclusions are possibly unmelted alumina powder, and the fact that Raman was unable to identify something other than alumina supports this (E.J. Gübelin and J.I. Koivula, *Photoatlas of Inclusions in Gemstones, Volume 3*, Opinio Publishers, Basel, Switzerland, 2008).

Identification of the natural or laboratory-grown origin of a stone with this type of natural-looking inclusion can be difficult. Careful observation is needed to correctly identify such a specimen's origin.

Ezgi Kiyak
GIA, New York

Quarterly Crystal: Columbite(?) in Beryl

Those in the gem and mineral community can appreciate the near-perfection of a beautifully crystallized mineral specimen or a well-cut gemstone. But these surfaces are only the exterior, covering a complex, multilayered story within. These internal contents often remain unknown unless we choose to explore below the surface. Somewhat like trees and their rings, minerals and gems form as concentric, typically crystallized layers, recording the developmental details within each layer through changes in temperature, pressure, and chemistry. While some of these growth details are submicroscopic and remain hidden during microscopic observation, other features such as mineral inclusions and encapsulated fluids are waiting to be discovered. In a very real sense, inclusions and their developmental sequencing in their host gems and minerals are descriptions of mineralogical genetics.

Researchers focused specifically on inclusions usually cannot outbid serious gem and mineral collectors for crystals and fashioned gems with interesting internal targets. As a result, many such "gems" end up in private collections, and their inclusions are rarely, if ever, fully documented. This is a tremendous missed opportunity, because inclusions contain geological information that tells a story about themselves and their host.

For this issue's Quarterly Crystal, we recently had the opportunity to document a well-formed gem-quality, transparent, very light greenish blue terminated hexagonal crystal of aquamarine, with a small amount of light brown matrix at the base and a clearly visible inclusion cluster at the near center (figure 15). The aquamarine was obtained from Muntazir Mehdi of Shad Fine Minerals International in Gilgit-Baltistan, Pakistan. The geographic source was reportedly the Kharguluk mine in Baltistan Province.

At 56.00 ct with corresponding measurements of 26.36 × 16.09 × 15.02 mm, this aquamarine played host to an easily eye-visible tight cluster of randomly arranged dark reddish brown to black bladed crystals (figure 16) that resembled the mineral columbite-(Mn), $Mn^{2+}Nb_2O_6$, as shown by E.J. Gübelin and J.I. Koivula (*Photoatlas of Inclusions in Gemstones*, Volume 2, Opinio Verlag, Basel, Switzerland, 2005, pp. 263, 319).

Micro-Raman has significantly reduced the time required to instrumentally identify many inclusions. Some inclusion identifications that once took hours can now be made in a matter of minutes using this technique. The Raman instrument can also analyze some subsurface inclusions at depths of more than a millimeter in certain fa-

Figure 15. Measuring 26.36 mm in length and weighing 56.00 ct, this Pakistani aquamarine crystal is host to an eye-visible 7.20 mm mineral inclusion cluster. Photo by Annie Haynes.

vorable instances, which means inclusions do not need to be exposed to the surface.

After several Raman attempts from different directions, we realized that destructive analysis would be needed to clearly identify the inclusion cluster deep within this stone. Due to the value of this inclusion specimen, we opted to forgo destructive analysis and keep the beryl crystal intact for future gemological exploration.

John I. Koivula and Nathan Renfro
GIA, Carlsbad

Figure 16. None of the analytical techniques at our disposal were able to conclusively identify the mineral making up the 7.20 mm inclusion cluster. The distinctive morphology shown by these inclusions strongly suggests that the cluster is composed of columbite-(Mn) crystals. Photomicrograph by Nathan Renfro; field of view 10.28 mm.