Sapphire has been mined in the western U.S. state of Montana for more than a century and a half. Historically, gem-quality sapphires have been mined commercially in four main areas in southwestern Montana, shown in figure 1: the upper Missouri River gravel bars (1865), Dry Cottonwood Creek (1889), Rock Creek (1892), and Yogo Gulch (1895). Today, the first two areas remain quite active, while operations in Yogo Gulch and Dry Cottonwood Creek have been suspended for many years. To better understand the characteristics of Montana sapphire and record current mining and commercial activities, GIA sent a team to visit the placer deposits at the upper Missouri River and Rock Creek areas in August 2015.

Since the latter half of the 19th century, Montana’s history has been intertwined with gold, silver, and copper mining. Corundum was discovered during the course of gold mining activities in southwestern Montana. Before the 1940s, the state’s alluvial sapphire deposits were exploited mainly to supply the watch industry, but production fell dramatically with the use of synthetic sapphire in watch bearings (Emmett and Douthit, 1993). Among Montana’s secondary deposits, Rock Creek (figure 2) is the only area mined specifically for sapphire from its discovery in 1892 until World War II (Clabaugh, 1952).

While Yogo Gulch is a primary deposit, the placer deposits at Rock Creek, Dry Cottonwood Creek, and the upper Missouri River near Helena have been a matter of speculation among researchers trying to work out the origin of these sapphire crystals. Research indicates that they were carried to the surface by volcanic activity, but their ultimate origin is still an open question, even after about 125 years of searching (e.g., Pratt, 1906; Clabaugh, 1952; Garland, 2002; Berg and Dahy, 2002; Berg, 2014; Zwaan et al., 2015). Due to the lack of significant sapphire-bearing host rock outcrops in these areas, the search and discussion continue. The glamour of the sapphires, the mysteries of their origin, the area's mining history, and the natural beauty of Big Sky country are an intriguing combination (figure 3).

**MISSOURI RIVER**

Gold miners first discovered Montana sapphire crystals in 1865, in the gravel bars along the upper Missouri River, about 15 miles northeast of Helena. Kunz (1894) reported that the sapphires were found by an “earnest and reliable prospector” named Ed R. Collins in 1865. Collins had some of the Eldorado Bar sapphires cut in New York by Tiffany & Co. and M. Fox & Co., as well as overseas, as part of an effort to locate a potential market. The first scientific reference to these stones was in 1873, when Dr. J. Lawrence Smith described them in the *American Journal of Science*. Smith had some of the sapphires faceted and stated “my opinion is that this locality is a far more reliable source for this gem variety of corundum than any other in the United States that I have yet examined.” Today, seven different small-scale commercial operations are active in the Missouri River area, some of which mainly cater to
Among all of Montana’s secondary sapphire deposits, Rock Creek has been the most productive. Potentate Mining is actively operating on its property in this area. Photo courtesy of Potentate Mining.

Tourists. Some of the finer rough is sold to jewelers, gem dealers, and hobbyists who facet these gems. In addition, there are several other areas along the Missouri River where sapphires are mined by hobbyists, including McCune Bar and Gruell’s Bar.

Figure 2. Among all of Montana’s secondary sapphire deposits, Rock Creek has been the most productive. Potentate Mining is actively operating on its property in this area. Photo courtesy of Potentate Mining.

On October 8, 1942, President Roosevelt issued War Production Order L-208, which closed all gold mines in the United States. The order was designed to shift gold miners to commodities that were essential to the war effort, such as copper, and to allow the shipment of mining equipment to U.S. allies, including the Soviet Union (Hammett, 1966).

The Perry-Schroeder Mining Co. was given special permission to continue dredging gold on Eldorado Bar throughout the war, because its significant sapphire by-product had military applications (Ball, 1943). The various non-gem uses included bearings for bombsights and torpedoes, as well as abrasives in grinding wheels. From 1940 to 1944, the Perry-Schroeder gold dredge on Eldorado Bar recovered approximately seven million carats of sapphires of all qualities, most of which were sold for industrial purposes (Clabaugh, 1952).

During this trip, we visited the Eldorado Bar (figure 4) and Spokane Bar deposits, which are active sapphire mining sites. Cass Thompson, owner of the Spokane Bar deposit and one of the six independently owned mines at Eldorado Bar, took the team on a boat tour of Hauser Lake, a reservoir on the Missouri River near Helena. The Missouri River flows from southeast to northwest in this portion of Montana. In addition to

Figure 3. A selection of heat-treated Rock Creek sapphires produced by Potentate Mining shows various shades of blue and green. The majority of alluvial sapphires from Montana have bluish and greenish pastel colors prior to heat treatment. Photo by Jeff Scovil, courtesy of Potentate Mining.
other occurrences of known sapphire-bearing gravel, there are at least nine historical sapphire bars (geologically known as strath terraces). These gravel bars, shown in figure 5, have long been known as American Bar, Eldorado Bar, Dana’s Bar, McCune Bar, Metropolitan Bar, Spokane Bar, French Bar, Gruell’s Bar, and Emerald Bar. Many of these deposits were exploited in the late 1800s and early 1900s, and remnants of the old mining activities can still be found. All of the sapphire deposits are distributed along this approximately

Figure 4. Eldorado Bar is one of the sapphire-bearing gravel bars that have been mined for over 150 years. The operation is visible from the Missouri River. The small gravel mound in the foreground is a tailings pile left by previous miners. Due to the higher river level caused by the 1910 reconstruction of Hauser Dam, the lower part of the tailings pile is submerged. Photo by Andrew Lucas.

Figure 5. Sapphires have been discovered in gravels in many areas—some very recently—along this northwest-flowing section of the upper Missouri River. This map shows nine of the historic mining areas, seven of which are distributed between the Canyon Ferry Dam and the Hauser Dam. All nine occurrences of sapphire-bearing gravel on this section of the river have also been mined for gold. Sapphires are very rarely found downstream from American Bar. Modified by R. Kane from Berg (2015), with permission, courtesy of the Montana Bureau of Mines and Geology.
14-mile section of the original river. The deposits extend downriver to the northwest from Canyon Ferry Dam to Hauser Dam—essentially all of Hauser Lake—in gravel bars on both sides of the river channel, as well as the riverbed itself. Sapphires are very rarely found northwest of American Bar. When each dam was built, the river level rose dramatically, so the lower layers of many previously exposed gravel bars have been submerged ever since.

Rocks in this area include argillites of the Precambrian Belt series, Paleozoic sedimentary rocks, Tertiary lake sediments and volcanic materials, and Cretaceous or Tertiary intrusives (Clabaugh, 1952). Gravel layers sit directly above the Precambrian Belt series metasedimentary rocks (figure 6). The thickness of the gravel layers varies and at some localities is more than 40 feet. According to Thompson, some gravel bars have a very thick sapphire-bearing layer but are expensive to operate due to extremely thick overburden, as is the case at Dana’s Bar and some portions of Eldorado Bar.

At Eldorado Bar, a mine run was prepared for GIA’s corundum collection. The team witnessed the entire day’s operation as approximately 100 cubic yards of gem-bearing gravel were run through the mechanized processing plant. This process started with gravel extraction in the morning, during which a complete rock profile was exposed (figure 7). Topsoil, overburden sediments, a volcanic ash layer, a gravel layer, and metasedimentary bedrock were observed from top to bottom in the mining pit. The overburden in this particular area is about six feet deep, which makes it relatively easy to remove. Other parts of Eldorado Bar have more than 100 feet of overburden, making these areas uneconomic to mine.

Extracted gravels are then transported by front-end loader to a nearby screen separator to get rid of the larger rocks that might break the onsite washing facilities. Materials are fed on a conveyor belt to a rotating trommel (figure 8). The trommel separates the gravel into different size fractions, diverting material over a certain size to the waste piles. At this point the remaining gravels are more likely to contain sapphires. The heavy minerals in the ore, including sapphires, are further concentrated using water, gravity
separation, and a series of screens and jigs, and sluices are used to process the remaining ore.

Many of the sapphires are first removed by hand from the bottom of the mechanized processing plant jigs. All of the concentrate is combed through a second time, either on a light table or by hand jigging in water, and then flipped over onto a table. If this is expertly done, the minerals with the highest specific gravity—sapphires have an SG of 4.00—are concentrated on top in the center of the pile. The authors were informed that currently a small quantity of gold is found with the sapphire. Vast amounts of gold were sometimes recovered in the late 1800s when miners used the highly destructive method of hydraulicking, and in the early 1900s when the Perry-Schroeder dredge was operating [Lyden, 1948]. Present-day miners will extract the gold to pay for a portion of the mining costs.

Sapphire crystals from the mines at Eldorado Bar generally have different shades of pastel colors, particularly bluish green and greenish blue. Pink, purple, yellow, deep green, and the rare ruby are found sporadically at this location. Some rather large stones have been recovered. One of the authors (RK) has examined a gem-quality hexagonal tabular crystal weighing nearly 50 ct—it was mounted in a pendant, so the exact weight is unknown.

At the end of our day at Eldorado, a total of 1,045 carats of sapphire were recovered from the mine run, with the largest stone weighing 16.78 ct (figure 9). Also of note was a pink stone weighing 7.86 ct. All of these sapphires are now in the GIA corundum collection in Carlsbad, California.

Today, many of the sapphires mined at the Missouri River deposits are sold—rough and cut—in their natural state. If the transparency is greatly decreased due to dense concentrations of exsolved rutile, they can be heated to change both their transparency and color (figures 10 and 11). Beautiful heat-treated faceted sapphires are produced from Missouri River material.

The origin of sapphires found in the Missouri River gravel bars has been discussed since their discovery in the late 1800s. Pratt (1906) reported a dike containing greenish sapphires about three miles below the Canyon Ferry at French Bar in 1900. A similar rock had been described by Kunz (1890). This rock, called “trachyte rock” by Kunz, came from a dike near the river and above Eldorado Bar. Later, Clabaugh (1952) checked the reported dike location at French Bar and found a similar dike but no sapphires. These reported dikes are still the only source rocks that have ever been proposed. Experts agree that a small outcropping above French Bar containing sap-

Figure 8. At Eldorado Bar, the washing plant is set up on the gravel bar. Sapphire-bearing gravels are fed through an oversized screen and a trommel, then sorted by a set of jigs and a sluice box for gold and very small sapphire recovery. The operation lies next to the river and some beautiful grassland. Photo by Andrew Lucas.

Figure 9. Four of the best bluish and greenish sapphires mined from Eldorado Bar on the day of the authors’ visit. All four show the material’s characteristic pastel color, and some clearly display a hexagonal crystal habit even though the surface is worn. The second sapphire from the left, the largest recovered that day, weighs 16.78 ct. Photo by Kevin Schumacher.
ROCK CREEK
Sapphires were discovered at Rock Creek, popularly known as Gem Mountain, along its tributaries in 1892. The American Gem Mining Syndicate was incorporated in 1901 in the town of Philipsburg, with headquarters in St. Louis, Missouri. The company’s top priority was to mine and market sapphires from several different gulches at the huge Rock Creek deposit. While they also maintained sapphire cutting facilities, the bulk of their Rock Creek rough was shipped to the company’s factory in Geneva, Switzerland. Most of it was consumed by the watch industry for bearings, with smaller amounts used as industrial bearings and as faceted stones set in jewelry. Large-scale mining took place at Rock Creek between 1906 and 1923.

Mining resumed for a brief time before World War II, until synthetic sapphire took over the watch component market. Since then, Rock Creek sapphires have been extracted solely for jewelry making and mining tourism, with most of the stones undergoing heat treatment. Large-scale mechanized mining and processing facilities have recently been installed, marking the start of a new era of Montana sapphire mining.

Historically, sapphires were mined from Anaconda Gulch and Sapphire Gulch, although many other gulches were also worked (figure 12). Similar to the upper Missouri River area, bedrock in this district is argillite of the Mesoproterozoic Belt Supergroup, overlain by Eocene volcanic rocks from different eruptive events (Berg, 2014). According to Clabaugh (1952), intrusions of either Cretaceous or Tertiary age also occur in this area. The sapphires are found in loose sediments. Currently, two operations are active at Rock Creek: Potentate Mining and Gem Mountain Sapphire Mine. For this trip, the GIA team visited Potentate’s mining and washing operations and Gem Mountain’s sapphire tourism and heat treatment facilities.

Figure 10. Various colors of heated Missouri River sapphires, ranging from 0.16 to 1.65 ct. Courtesy of American Sapphire Company, © Robert E. Kane.

Figure 11. This 32.02 ct crystal is one of the largest high-quality Montana gem sapphires ever recorded. It was discovered at Bruce Scharf’s Montana Blue Jewel mine at Eldorado Bar. The stone was heated to intensify its color. It shows strong pleochroism when viewed down the c-axis (left) and at a right angle to the c-axis (right). This consideration is especially important for gem cutters. Courtesy of American Sapphire Company, © Robert E. Kane.
At Eureka Gulch, Dr. Keith Barron, geologist and owner of Potentate Mining, described the nature of the sapphire-bearing deposits. Unlike the river gravel layers at the upper Missouri River area, these sapphire-bearing sediments lack the well-defined layering pattern formed by river flows. Instead, gravels and boulders of different sizes are randomly mixed (figure 13). Barron concluded that sapphires are buried in mudflows instead of riverbeds in the Gem Mountain area (Barron and Boyd, 2015). Since mudflow is a rapid mass-wasting process, emplacement can cover both topographic lows and highs. After mudflow emplacement, the local topography is often shaped again by weathering and erosion to form gül-

**Figure 12.** A detailed map shows the main sapphire mining gulches and placers in the Gem Mountain area along the west fork of Rock Creek and its tributaries. From Berg (2014).**

**Figure 13.** Dr. Keith Barron, geologist and owner of Potentate Mining, shows the sapphire- and gold-bearing mudflow at Eureka Gulch. Compared to the well-sorted alluvial gravel layer at Eldorado Bar, the ore zones contain much finer-grained soils along with coarser gravel and boulders. Photo by Andrew Lucas.
lies and ridges. Today, sapphire-bearing mudflow deposits are found both in gulches and hilltops in Potentate’s mining sites. For instance, Potentate set up their dry screening/concentrating operation on a hilltop [bench], and the bulk sampling pit has turned out to be quite productive (figure 14).

Although sapphires have not yet been observed in situ in this area, aeromagnetic surveys of the Potentate property also reveal potentially sapphire-bearing igneous bodies beneath the surface. Potentate is mainly working on the Eureka Gulch deposit and bulk sampling the Sapphire Gulch deposit. The former is primarily for gold mining, with sapphire as a by-product, while the latter is focused on sapphire.

Sapphire Gulch material with a size range of 1/8 inch to 1 inch also goes through the washing plant at Eureka Gulch (figure 15). Sapphire concentrates extracted from the jigs are then sorted by hand. The washing plant’s capacity is about 50–60 cubic yards [38–46 cubic meters] per hour. After observing the washing process, our team hand-picked sapphire from the jig. About 13–15% of the production had attractive natural colors of blue, greenish blue, yellow, or pink. Most of the remaining sapphires have green and brownish colors that react very well to heat treatment.

Potentate’s first mining season at Rock Creek was in 2015, and was very successful. The 2016 mining season near Sapphire Gulch recovered about 220 kilograms of rough sapphire larger than 3.5 mm. According to Potentate marketing director Warren Boyd, the mining operation recovered about 150 kilograms of rough sapphire under 3.5 mm, suitable for very small faceted gemstones and beads. Boyd added that Potentate’s objective is to become a major international rough sapphire supplier in the next few years.

Gemstone cutters are important buyers of the rough sapphires mined by Potentate, with stones ranging from 2.5 to 6.0 mm best suited for precision cutting. In today’s market, these sapphires will command a premium price if they are custom-faceted or sold in their natural, unheated state. Jeffrey Hapeman of Earth’s Treasury [Westtown, Pennsylvania] has faceted many Rock Creek sapphires, applying special cut styles such as “Helena Oval,” named after Montana’s capital [figure 16]. Rachel Abel of Americut Gems is working on heat treating and precision cutting sapphires purchased from Potentate. She uses robotic cutting systems to precisely facet stones ranging from 2.5 to 4.5 mm. The stones are faceted as modified round brilliants and to display the “hearts and arrows” effect seen in some diamonds.

Gem Mountain Sapphire Mine is a diversified business, with a mining site at Rock Creek, a heat treatment facility, a gravel washing site for tourists, and a jewelry store in Philipsburg. The mining at this site is quite different from Potentate’s large-scale mechanized operation in the same area. Sapphire-bearing gravels are extracted and transported to the tourist washing site and to the jewelry store for sale.
Figure 16. These sapphires (0.49–4.19 ct) were mined by Potentate in 2015 and faceted by Jeffrey Hapeman of Earth’s Treasury. The 0.57 ct pink stone in the front row (second from left) has outstanding brightness and saturation for this deposit. Some of the stones have the “Helena Oval” cut specially designed for Montana sapphire. All of these sapphires are unheated. Photo by Jeffrey Hapeman, courtesy of Earth’s Treasury and Potentate Mining.

As the authors witnessed, untreated rough sapphires from Rock Creek generally have more saturated colors than those from the upper Missouri River, but pastel colors are still the most prevalent. Many of the heated stones have color zoning and a brightly colored center that corresponds to lighter or nearly colorless zones in the untreated crystals (figure 17). Local miners call this bright center “yolk.” Kunz (1901) noted that Rock Creek sapphires are notable for small colored spots, which when properly cut and positioned can color the entire stone when looking down the table. He also observed that many fancy colors from this area are quite distinct compared to other sources, and that the pink stones in particular can be intensely brilliant. These descriptions matched our own observations (again, see figure 16). Many Rock Creek sapphire crystals show a clear hexagonal habit, similar to those from the Missouri River gravel bars.

The origin of Rock Creek sapphires has drawn the attention of researchers, yet as of this writing, no in situ sapphires have been found. In the most recent study on Rock Creek sapphires [Zwaan et al., 2015], the inclusion studies and chemical composition analysis pointed to a plumsatic/metamorphic origin. Palke et al. [2015] performed a study on the glassy melt inclusions in sapphires from both Rock Creek and the Missouri River. The study showed abnormal two-phase inclusions consisting of a glassy solid and a gas. Chemical study indicates that the glassy solid phase is of dacitic to trachydacitic composition. This ongoing study could provide more information on the crystallization of these alluvial sapphires. Previous research by Berg and Cooney (2006) on stones from the same area revealed two characteristic materials attached to the surface: felsite and kaolinite.

The study speculated that surface features such as grooves and flats underneath the adhering felsite were from resorption (solution) of the sapphires when they were transported in the felsic magma. Attached kaolinite formed from alteration of feldspars in the volcanic ash also indicates that the sapphires were derived from felsic volcanic rocks.

HEAT TREATMENT OF ROCK CREEK SAPPHIRES

While gemstones have been heated to enhance their quality for thousands of years, a well-controlled high-
Figure 18. Two scoops of sapphires picked from the jig at Potentate’s washing plant. Most of the stones have pale green and bluish hues. Heat treatment can enhance the color of many stones and increase their market value. Photo by Andrew Lucas.

Figure 19. Chris Cooney of Gem Mountain Sapphire Mine operates the electrical furnace used to heat sapphires. The metallic blue cylinder to the right of the control panel houses the sapphire-containing crucibles. Photo by Andrew Lucas.

temperature heating environment has only existed for the past 30–40 years. The authors were offered the opportunity to record the entire process of heat treatment of Rock Creek sapphires at the Gem Mountain facility nearby.

Rock Creek has had considerably higher sapphire production than the other alluvial deposits in Montana over the years, and many people consider it the only alluvial deposit that can be economically mined on a large scale for sapphire alone. Emmett and Douthit [1993] reported that about 8% of Rock Creek sapphires can be marketed as gems, while 65–70% of the production is of pale greenish and bluish colors that are acceptable to the jewelry market (figure 18). Since color is the most important value factor for sapphires, enhancing the stones’ color became a priority.

The electrical furnace (figure 19) and the method used are the same as those published in Emmett and Douthit [1993]. Today, rough sapphires submitted to Gem Mountain for heat treatment are carefully documented and go through two rounds of heating (figure 20). The first round, called the “fancy burn,” is done under an oxidizing environment. After the fancy burn, the stones’ color is evaluated; the ones that did not gain satisfactory fancy colors such as yellow, orange, and pink will go to the second round of heating. The second round is the “blue burn,” done under a reducing environment. When both rounds of treatment are complete, the stones are reevaluated. Cutting and manufacturing decisions can then be made.

According to Chris Cooney, owner of Gem Mountain Sapphire Mine, about 30–40% of the stones gain a marketable bluish color after the “blue burn” (figure 21). While heating itself risks damage to the stone, the most tedious but most critical step in heat treatment at Gem Mountain is the evaluation of the stones after each round (C. Cooney, pers. comm., 2015). Color zoning and color concentration at the center of many stones further complicate the evaluation process.

Figure 20. Rough sapphires from Rock Creek before and after two rounds of heating. Left: The material before heating. Center: The same sapphires after the oxidizing “fancy burn.” Right: The same sapphires after the reducing “blue burn.” Photos courtesy of Gem Mountain Sapphire Mine.
Rough that was treated in an oxidizing environment (producing darker yellow, orange, and pink colors) will often have a dark central color concentration, while many of the stones heated in a reducing environment will have a colorless or very light yellow spot in the center. The concentrated color spots can brighten the entire stone, but sometimes they combine with the bodycolor of the stone, producing unpleasant results. Since many stones are also cut by contractors of Gem Mountain, this evaluation also plays an important role in the process.

Cooney compares the heat treatment of sapphire to cooking, in that procedures are adjusted based on intuition and years of experience. Not all Montana sapphire yields predictable or desirable results from heat treatment; the nature and chemical composition of the stone are critical, as are temperature-time profiles and the conditions inside the furnace [Kane, 2008].

The heating service is not just for the tourists who extract their stones at Gem Mountain. Sapphires sourced elsewhere are also submitted for treatment. Over the years, Cooney has found that sapphires from certain sources achieve better results, while others hardly change color.

MONTANA SAPPHIRE TOURISM

Gem tourism is an essential component, in some cases the only one, of sapphire-related businesses in Montana [figure 22]. The authors observed the tourist activities at both Gem Mountain and one of the upper Missouri River operations.

The tourist bucket mining facility at Gem Mountain is about 16 miles southwest of Philipsburg. Gravels removed from the neighboring mining claim by mechanized mining methods are transported to this site, where domestic and international tourists can purchase sapphire-containing “gravel bags” of various sizes. They can either wash their gravels on-site (again, see figure 22) or take them home. Most of the sapphire mines, including Gem Mountain, will mail gravel bags to people who cannot visit in person. Sapphires found can also be evaluated by staff with years of experience. Visitors can choose to keep the stones as they are or have them heat-treated, faceted, or even mounted in jewelry by Gem Mountain’s staff. They are encouraged to have larger stones cut and mounted locally to help the local economy. The heat treatment and cutting and manufacturing services set this business apart. Tourists have fun treasure hunting, but also see the whole mine-to-market story happening for themselves.

Figure 21. After the second round (the “blue burn” heating), about 40% of the stones acquire an attractive blue color. Some stones do not change significantly after two rounds of heating. Photo by Andrew Lucas.

Figure 22. Visitors of all ages can be found sorting washed and concentrated gravel at Gem Mountain. This boy is carefully putting his just-found sapphire into a tube provided by the operator. Photo by Andrew Lucas.
The authors asked several visitors at the washing site about their experiences at Gem Mountain. We were surprised to see them wearing jewelry mounted with sapphires found there over the years (figure 23). Through our conversations, we learned that many of the tourists have returned repeatedly over the last 10–15 years. They come with family and friends in what has become an annual ritual for some. It is not uncommon to see a couple showing off an engagement ring with their own handpicked sapphire on social media.

At the upper Missouri River operations run by Spokane Bar Sapphire Mine, tourists can purchase gravel bags at the store and wash them on- or off-site. Besides gravel washing, mine owner Cass Thompson and other Montana sapphire miner operators also offer a special mine run service (figure 24). With advance reservations, clients—who range from gemstone wholesalers, to interested clients from outside the gem and jewelry industry—can purchase a certain number of dump truck loads (measured in cubic yards). These will be run through the commercial mechanized mining plant—which can take as long as eight hours for an 80-yard run—which concentrates the gem-bearing gravels along with non-sapphire accessory minerals such as hematite and garnet. These customers come to see the mining process, and at the end of the day they pick up their concentrates from the jig and take them home to sort for fun.

**SUMMARY**

As one of the “Big Three” colored gemstones, sapphire has always been a focus of exploration and gemological education. The related history, geology, and business models are all of interest to those who trade in sapphire. Montana is one of the few major gemstone sources in the United States. Over the past 150 years, countless people have devoted themselves to prospecting and mining these sapphire sources. The success of these operations has often been difficult to achieve, but the passion for these sapphires has persisted.

Today, the alluvial sapphire deposits are still actively mined. Although small-scale mining still pre-
vails in these areas, Potentate Mining’s large mecha-
nized operations with heavy investment could change the dynamic of sapphire mining in the Rock
Creek area [figure 25]. Meanwhile, sapphire tourism is quite important to the local economy.

One thing the different operators have in common is their commitment to protecting the environment. The sapphire mining happens in harmony right next to agriculture land, and we were encouraged to see them taking responsibility for restoring the land. The miners follow state guidelines regarding water and land reclamation. For example, the Eldorado Bar and Potentate Mining pits are refilled after mining. Potentate also plants trees after operations have ceased; water from their washing plants is filtered and restored to potable levels.

As stakeholders in the local economy, the mines maintain good relationships with neighboring farms and businesses. Many miners are from the area and have worked on the sapphire fields for years, so they have an emotional connection to the land and the stones being extracted. Montana sapphire is a gemstone that Americans are proud of. As Cass Thompson put it, “They love the idea of keeping the state of Montana just as beautiful as the sapphires they pull out.”

ABOUT THE AUTHORS
Dr. Hsu is technical editor of Gems & Gemology, Mr. Lucas is manager of field gemology education, Mr. McClure is global director of colored stone services, and Mr. Renfro is the gemological manager of the gem identification department and analytical microscopist in the inclusion research department at GIA in Carlsbad, California. Mr. Kane is president and CEO of Fine Gems International and American Sapphire Company in Helena, Montana.

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REFERENCES
DIAMOND
With Concentric Inclusions
As a diamond grows, layer by layer, it may incorporate small pieces of the surrounding mantle rocks as mineral inclusions. The three-dimensional arrangement of inclusions in most diamonds has the appearance of being somewhat random, with no discernible pattern. However, GIA’s New York laboratory recently examined a noteworthy exception.

A 2.34 ct Fancy Intense yellow-green type IaAB diamond was found to have abundant silicate inclusions with a more systematic pattern delineating growth layers (figure 1). Collectively, the inclusions outline concentric octahedral layers. The growth layers are made even more noticeable by a sort of optical graining that could be caused by layered distortions in the diamond crystal from variations in nitrogen concentration. Many of the individual inclusions have an elongate or flattened oblate shape that conforms to the growth layering (figure 1, bottom). Thus, both the shape of individual inclusions and the collective distribution of multiple inclusions imitate the geometry of concentric octahedral diamond growth. This kind of symmetrical, growth-outlining texture is rarely observed in diamond.

Evan M. Smith and Wuyi Wang

With Unusual Fluorescence Distribution
The New York lab recently encountered a round brilliant diamond, weighing just over 2 ct, that displayed little if any reaction to long-wave UV except for a small spot confined to the area around the culet (figure 2, left). This small area appeared to have medium fluorescence intensity. While the laboratory determination of fluorescence strength and color is

Editors’ note: All items were written by staff members of GIA laboratories.

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performed in the table-down position, we noticed a very different appearance when the diamond was observed through the crown (figure 2, right). Because of the location of the fluorescent area, it reflected evenly throughout the face-up position and appeared to have higher intensity, at approximately the strong/very strong boundary. DiamondView imaging revealed that the diamond was cut with its growth zonation parallel to the girdle. We speculate that the area of fluorescence in the rough was larger and more centrally located, indicating that the earlier growth showed more blue fluorescence than the later growth, which was basically inert to UV radiation. With the given orientation and placement of the finished stone in the rough, a part of this fluorescent area remained at the culet in the cut stone, leading to this unusual feature.

Absorption spectra in the infrared region confirmed this to be a type Ia diamond with a high concentration of aggregated nitrogen and spectral features typical of a natural diamond. The N3 defect was detected by the presence of moderate-intensity absorption in the UV-Vis absorption spectrum, which is consistent with this type of diamond. The N3 defect is a well-known cause of blue fluorescence in natural diamonds. Based on past experience, it should be pointed out that the area at the culet with medium-strength blue fluorescence does not necessarily have higher concentrations of the N3 defect. The occurrence of other impurities or lattice distortion could affect fluorescence intensity from the N3 defect as well.

The effect of blue fluorescence on the appearance of D-to-Z diamonds has been debated for more than 25 years. GIA conducted a study on this subject in the 1990s [see T.M. Moses et al., “A contribution to understanding the effect of blue fluorescence on the appearance of diamonds,” Winter 1997 GeoG, pp. 244–259]. The study showed that blue fluorescence had little to no impact on color appearance or transparency except in extremely rare examples of “overblues.” With this in mind, the 2 ct round brilliant offered an interesting opportunity to revisit the earlier experiment’s face-up observations. We compared the diamond, which was graded “H” color, with nonfluorescent diamonds—GIA color master stones—of similar color. As seen in figure 3, no visual difference was observed in the standard color-grading environment. This example supports the conclusion from the 1997 article that the industry would be better served by considering each diamond on its own visual merits.

John King and Wuyi Wang

Cat’s-Eye KORNERUPINE

A dark, translucent, yellowish green oval cabochon (figure 4) was recently submitted to the New York lab for identification. The 1.44 ct stone displayed an intense chatoyancy. With a spot refractive index (RI) reading of 1.67 and a hydrostatic specific gravity (SG) of 3.32, the stone was identified as kornerupine, a rare borosilicate mineral found in boron-rich volcanic and sedimentary rocks that have undergone metamorphism (http://rruff.info). Raman spectroscopy confirmed the identification.

Cat’s-eye kornerupine is an extremely rare gemstone. Its chatoyancy...
Natural Conch “Rosebud” PEARLS

Non-nacreous conch pearls from Strombus gigas are known mainly for their very attractive pink color and distinctive shimmering appeal due to the characteristic flame structures on their surfaces. Although conch pearls are found in various tones of yellow, brown, and white, the most desirable hue is undeniably pink with an intense saturation. The flame structures are due to “crosswise arrays of bundles of aragonite laths or fibers that may reflect or absorb the light that falls on the structure, letting it appear bright or dull” (H.A. Hänni, “Explaining the flame structure of non-nacreous pearls,” The Australian Gemmologist, Vol. 24, No. 4, 2010, pp. 85–88).

In late 2016, GIA's New York lab staff had the opportunity to study part of Susan Hendrickson's conch pearl collection. Among the assortment of conch pearls of various sizes, colors, and shapes, a few “rosebud” specimens caught our attention (figure 6). The term “rosebud” is most commonly used to describe characteristically shaped freshwater nacreous pearls, but this is the first time GIA has examined conch pearls with such shapes (figure 7). The nine pink specimens had roundish outlines with a button-like appearance. But in keeping with the rosebud pearl form, they exhibited differences in the bumps or ridges on their surfaces. Some bumps were rounded and spread out, while others were jagged and tightly grouped. The authors could not locate any reports of rosebud conch pearls in the literature, and the cause of these distinctive surface structures is unknown. One possible explanation is that when a pearl forms in a pearl sac positioned in a region of muscular activity rather than the mantle, it will not form in a smooth symmetrical shape (E. Fritsch and E.B. Misiorowski, “The history and gemology of Queen conch ‘pearls,’” Winter 1987 G&G, pp. 208–221).

All nine samples displayed typical flame structures under magnification (figure 8). Some of them did not exhibit the flames on the bumpy surface, but only within the smoother areas. Microradiography revealed a tight internal structure with uneven outlines corresponding to the bumpy surfaces. The Raman spectra were characteristic of aragonite and clearly showed additional natural polyenic...
pigment peaks, both as expected for pearls formed in *Strombus gigas* mollusks.

There are records of attempts to cultivate conch pearls [H. Acosta-Salmón and M. Davis, “Inducing relaxation in the queen conch *Strombus gigas* [L.] for cultured pearl production,” *Aquaculture*, Vol. 262, No. 1, 2007, pp. 73–77; N. Sturman et al., “Cultured Queen conch pearls—A comparison to natural Queen conch pearls,” 32nd *International Gemmological Conference*, Interlaken, Switzerland, 2011; Summer 2015 GNI, pp. 201–202]. No further news about the commercial production of cultured conch pearls has reached the market, however. As a result, conch pearls are still highly desirable and valued by the trade and specialty collectors. The opportunity to study such unique and exciting examples of rosebud conch pearls allowed GIA to expand its understanding of rosebud conch pearls for future reference.

*Joyce WingYan Ho and Emiko Yazawa*

**Partially Hollow Tridacna Blister Pearls with Shells Attached**

GIA sees pearls of all types submitted to its global laboratories. Almost all of them are either loose or mounted in jewelry pieces; however, exceptions are occasionally encountered. The submission of a blister pearl or blister still attached to its shell is such an example [Winter 2015 Lab Notes, pp. 432–434]. In January 2017, the Bangkok laboratory received an intact shell with a pearl attached near the adductor muscle area (figure 9, top). The item weighed 2.36 kg. The shell measured 32.0 × 21.0 × 11.5 cm, while the pearl measured 52.0 × 47.5 mm. At the same time and by sheer coincidence, another shell with a similar appearance and a pearl attached to the same area (figure 9, bottom) was submitted to the New York laboratory. This item weighed 806.40 g and the shell measured 20.0 × 13.5 × 9.5 cm, while the pearl measured 80.0 × 50.0 mm.

The exterior of the shell submitted to Bangkok exhibited a light brownish color and appeared roughly triangular in outline with a wavy pattern of thin ridges in rows, while the interior was white to cream with a porcelain-like surface. According to the client, the shell was found in 2014 by fishermen off the coast of Kood Island, a district of Trat Province in eastern Thailand. The shell’s features are characteristic of *Tridacna* species mollusks, of which there are a number of varieties [U.E. Hernawan, “Taxonomy of Indonesian giant clams (Cardiidae, Tridacninae),” *Biodiversitas*, Vol. 13, No. 3, 2012, pp. 118–123)](http://example.com).

As figure 9 (top right) shows, a blister pearl of similar color is prominently attached to the surface. Observation with a loupe and microscope confirmed that it was naturally attached and untreated. Microscopic examination using a fiber-optic light source confirmed the presence of flame structure on some surface areas.
of the shell and pearl, confirming their non-nacreous or porcelaneous nature. The pearl’s flame structure was short and patchy, while that seen on the shell was sharper and more defined. While the pearl’s nomenclature may be the source of some debate, we considered it to be a blister pearl, rather than a blister, based on its external appearance, position on the shell, and size [E. Strack, Pearls, Ruhle-Diebener-Verlag, Stuttgart, Germany, 2006, pp. 115–127]. The shell and pearl were exposed to long-wave UV, with the shell showing a moderate to strong chalky blue reaction with yellowish orange patches near the lip area (figure 10, left), while the blister pearl exhibited a weak to moderate yellowish green color (figure 10, right). This demonstrates how fluorescence in samples may vary from area to area.

However, the most noteworthy feature of the Bangkok specimen was that when the shell was tilted or gently rocked from side to side, a liquid clearly moved within the blister pearl (figure 11, left). The liquid was not viscous and so was most likely water, rather than a thicker liquid such as oil. It is possible that seawater was trapped during the blister pearl’s formation or found its way into the “hollow” pearl at a later date. When fiber-optic light was used to illumi-
Void-like structures in whole or blister pearls from *Tridacna* species mollusks are not unusual [S. Singhamroong et al., “Microradiographic structures of natural non-nacreous pearls reportedly from *Tridacna* [clam] species,” *Proceedings of the 5th GIT International Gem and Jewelry Conference*, Pattaya, Thailand, pp. 200–222], and GIA has examined many voids in other non-nacreous pearls. The RTX results proved that the specimen described was a natural blister pearl attached to its shell.

The shell submitted to GIA’s New York laboratory is also noteworthy, not only for the coincidental submission, but also because the pearl was larger relative to its host’s size than the one examined in Bangkok. The baroque natural blister pearl attached to this rather more colorful shell was also partially hollow, although not to the degree of the Bangkok sample. As the RTX results in figure 12 [right] revealed, the partially hollow blister pearl had a complex internal structure and was less homogenous than the specimen submitted in Bangkok. Unfortunately, no provenance was supplied with the New York sample, so there is no record of where it was found.

Both GIA reports stated that the naturally attached feature on each shell was a natural blister pearl. Many such specimens examined at GIA’s labs are submitted as loose examples that have already been removed from their hosts, so it was a welcome change to handle these two shells. In addition, a comment was included on each report informing the clients of the pearl’s partially hollow nature and, in the case of the Bangkok submission, the presence of a liquid. The size and appearance of the shells submitted proved they were not *Tridacna gigas* (giant clam), and the report referred to the hosts as *Tridacna* species only.

Nanthaporn Somsa-ard, Areeya Manustrong, and Joyce WingYan Ho

**Atypical BEAD-CULTURED PEARLS With Unusual Nacre Growth**

Atypical bead-cultured pearls are, by definition, cultured with unconventional beads as opposed to the typical round, predominantly freshwater shell beads. Examples of such atypical bead nuclei are irregularly shaped pieces of shell, ceramic, plastic, wax, coral beads, or even cultured or natural pearls.

Recently, GIA’s New York laboratory received 10 loose undrilled pearls for identification. These samples exhibited a brownish bodycolor and measured from 7.17 × 6.92 × 6.42 mm to 12.25 × 9.72 × 9.28 mm [figure 13]. Many were unusually lightweight for their size. Microradiographic examination of seven of the pearls revealed atypical bead nuclei [figure 14]. The X-ray transparencies of the bead nuclei allowed us to observe faint demarcations and drill holes with varying degrees of clarity in the nuclei.

These atypical bead nuclei permitted some unusual nacre growth to develop within the drill holes, as shown in figure 14C, where the nacre secretion flows into the drill hole. This interesting observation concerning nacre viscosity was also described in recent work on atypical bead culturing experiments [K. Scarratt et al., “Atypical ‘beading’ in the production of cultured pearls from Australian *Pinctada maxima,*” GIA Research & News, Feb. 13, 2017].
Figure 13. The 10 loose pearls submitted for identification. Samples 1, 4, and 5 are conventional bead-cultured pearls, while the rest were cultured with atypical nuclei. Photo courtesy of Aloha Pearls.

To better visualize the unusual nacre growth within the drill hole of the bead in one of the pearls, we used computed X-ray microtomography (μ-CT) and subsequently reconstructed the pearl using computer software (figure 15). The reconstructed image displayed a surface indentation aligned with the bead's drill hole (shown in orange in figure 15, left). Additional nacre growth (shown in green, figure 15, right) filled about half of the drill hole. The yellowish outer region in figure 15 (left) represents the outer nacre of the pearl.

Although this is not the first time GIA has received pearls cultured using X-ray transparent bead nuclei [Fall 2011 Lab Notes, pp. 229–230], the unusual nacre growth pattern within some of the drill holes in this sample group is worthy of note. Three-dimensional rendering using computer software and μ-CT data sets also proved very useful in visualizing the internal structure, further demonstrating the technique’s worth as a powerful tool in pearl identification.

Chunhui Zhou and Emiko Yazawa

Punsiri Heat Treatment on Basalt-Related Blue SAPPHIRE

Heat treatment is often applied to sapphire to modify color or improve clarity. One known heat-treatment technique is the Punsiri method, typically applied to metamorphic or low-Fe blue sapphires. This treatment lightens the blue color by heating the stones in an oxidizing atmosphere to diffuse holes and aluminum vacancies into stones with low Ti levels [J.L. Emmett, lectures on corundum at GIA Bangkok, Aug. 28 and Dec. 4, 2010]. The main characteristic of Punsiri heat treatment is distinct color zoning observable when the stone is immersed in methylene iodide. The stone will display a pale blue to near-colorless layer corresponding to the girdle outline that surrounds a deep blue core.

Recently, GIA’s Bangkok laboratory examined a 1.63 ct blue sapphire, identified by standard gemological testing (RI of 1.760–1.769 and an inert reaction under long- and short-wave UV radiation). Microscopic observation revealed only a few inclusions, consisting of stringers and small healed fractures. We then immersed the stone in methylene iodide and observed Punsiri-type color zoning (figure 16). Fourier-transform infrared (FTIR) spectroscopy is a common technique used in advanced gemological laboratories to determine whether a stone is heated or unheated. When the FTIR spectrum shows Punsiri fea-

Figure 14. Microradiographs of seven pearls revealed atypical beads that were transparent to X-rays. The beads showed faint demarcations and drill holes of varying clarity. Unusual nacre growth that partially filled the drill hole of the bead of one pearl is seen in image C.

A

B

C

D
Figure 15. Left: A computed 3-D reconstruction of one of the atypical bead-cultured pearls. The orange area represents the transparent bead revealed by X-rays, with a drill hole partially filled by nacre growth shown by the whitish area (indicated by the arrow). A surface indentation toward the top also corresponds to the orientation of the bead’s drill hole. Right: Reconstruction of the internal bead only. The central pink area is the drill hole inside the bead nucleus. The green area represents the nacre growth that formed inside the drill hole.

CVD SYNTHETIC DIAMOND
Mimicking Natural Stone

A 0.51 ct round brilliant (figure 17) was recently submitted to GIA’s Hong Kong laboratory for update service to verify the results from a diamond grading report issued in 2014. Investigation showed that its properties were much different from the diamond in the original report and that it was actually a CVD synthetic diamond.

The round brilliant submitted [5.18–5.20 × 3.11 mm] had H-equivalent color grade, much lower than the D color of the diamond submitted in 2014 [5.07–5.09 × 3.15 mm]. Its IF-equivalent clarity was better than the VVS, clarity of the original stone, however. Only pinpoints and blemishes observable with greater than 10× magnification were found in this specimen. A GIA report number inscribed on the girdle was easily identified as a fake (figure 18). A minor difference in weight was also observed: an “increase” from 0.50335 ct to 0.51444 ct.

Infrared absorption spectroscopy identified the synthetic as type IIa and led to further spectroscopic testing. Photoluminescence (PL) spectroscopy was performed at liquid nitrogen temperature, and spectra

Figure 17. This 0.51 ct CVD synthetic diamond, submitted to GIA for update service, yielded some surprising results.

Figure 16. The 1.63 ct blue sapphire treated by the Punsiri method. Different views show a typical light blue to near-colorless outer layer when the stone is immersed in methylene iodide.
were collected with various excitation wavelengths. A very strong SiV-doublet observed at 736.6 and 736.9 nm indicated a synthetic diamond. Under the short-wave UV radiation of the DiamondView, the sample showed green fluorescence but, interestingly, none of the obvious layered growth structures that CVD synthetics usually display. All geological and spectroscopic features confirmed that the stone was CVD synthetic with post-growth HPHT annealing. This is another example of the importance of using a combination of tests and data to identify a stone. GIA's laboratories continue to develop and implement various measures to identify possible fraud.

**Billie Law**

**Melee Diamond Parcel Containing Nearly One-Third CVD Synthetics**

In February 2017, a parcel containing 323 colorless to near-colorless diamond melee was submitted to the Mumbai laboratory for screening and color sorting. The average weight of each round brilliant was 0.015 ct, with an average diameter of 1.5 mm. Of this parcel, GIA's fully automated screening and sorting system confirmed that 219 samples were natural, with the remaining 104 samples referred for further testing. Detailed analysis determined that three of the referred stones were natural, and the remaining 101 stones (31.3%) were CVD synthetics (figure 19).

This result is especially remarkable due to the type of synthetic observed. While the undisclosed mixing of HPHT synthetic diamonds in melee has become a primary concern of the diamond trade, CVD synthetics have been very rare in this size group (Fall 2016 Lab Notes, p. 307). The synthetics were color graded using the GIA melee sorting device for research purposes. The majority of the CVD synthetics were G/H [74.3%] in color, though the D–F (20.8%) and I/J (4.9%) color ranges were also represented.

Further analysis was conducted on these synthetics using FTIR and PL spectroscopy [the latter at liquid nitrogen temperature] and DiamondView imaging. Interestingly, the group included both as-grown (10.9%) and treated synthetics [89.1%], indicating that they may have been produced by different laboratories. The treated diamonds showed evidence of annealing at high temperatures for color improvement, probably under HPHT conditions. FTIR revealed that they were all type IIa, with only two samples [1.9%] showing the CVD-specific NVH absorption peak at 3123 cm⁻¹. Several impurity complexes common in CVD synthetic diamonds were detected by PL spectroscopy, including NV⁺⁺ [575 and 637 nm, 100%], the 596/597 nm center [4.0%], SiV⁺⁺ [736/737 nm, 100%], the 883/884 nm Ni-related center [13.9%; see J.P. Goss et al., “The lattice location of Ni in diamond: A theoretical study,” *Journal of Physics: Condensed Matter*, Vol. 16, No. 25, 2004, pp. 4567–4578], SiV⁺ [946 nm, 29.7%], and H₂ [986 nm, 17.8%]. The presence of SiV⁺⁺ and the 596/597 nm center were particularly indicative of CVD origin, as SiV⁺⁺ centers are routinely found in CVD synthetics yet are comparatively rare in other diamond materials. The 596/597 nm center has been observed only in CVD synthetics.

DiamondView imaging further emphasized the variety of CVD synthetics included in this parcel. The fluorescence of the as-grown CVD synthetics ranged from orange to red to pink, as seen in figure 20 [top left], due to emissions from NV⁺⁺ centers. The other samples showed the typical blue–green fluorescence associated with high-temperature annealed CVD synthetics (figure 20, top right). In an unusual finding, layered structures suggesting abrupt changes in growth conditions—which may include stopping and restarting growth—were seen in 35.6% of the CVD synthetic melee. These abrupt changes resulted in alterations to the impurity uptakes of the material, producing the layered structures. Layer thicknesses varied...
Figure 20. DiamondView images of the 101 CVD synthetic diamonds showed a wide range of patterns and colors, indicative of their different growth and treatment histories. As-grown synthetics showed orange, pink, or red fluorescence (top left), while those treated by high-temperature annealing fluoresced blue or green (top right). Slightly over a third (35.6%) of the synthetics showed layers indicative of changes in growth conditions (bottom left). Those with very high Si content were dominated by blue dislocation bundles (bottom right).

but were generally about 200-500 μm, with samples often showing two or more layers intersecting their table facets (figure 20, bottom left). Such layers are regularly seen in large CVD synthetics [Winter 2015 Lab Notes, pp. 437–439], though they have not been reported for melee-sized goods. Striations and blue dislocation bundles (the latter visible in figure 20, bottom right) were common [45.5% and 19.8%, respectively]; certain high-Si synthetic diamonds were dominated by these bundles. Green or blue phosphorescence was observed for 84.2% of the CVD samples.

The substantial undisclosed mixing of CVD synthetic diamonds in this parcel, approaching one-third of the stones, emphasizes the importance of routine testing of melee to identify HPHT and CVD synthetics. GIA’s automated melee screening and sorting device was able to successfully separate the natural and CVD synthetic material, providing confidence in the stones’ origin and supporting transparency in the industry.

Manisha Bhoir, Priyanka Dhawale, and Ulrika D’Haenens-Johansson

CVD Synthetic Diamond Overgrowth on a Natural Diamond

Nitrogen is the most abundant defect in natural diamonds. It can be observed as single substitutional atoms or in aggregate forms. Boron, on the other hand, is a rare impurity in natural diamonds. It is very unusual to see both nitrogen and boron defects in a single diamond. GIA’s New York laboratory recently encountered this in a 0.33 ct diamond graded Fancy blue (figure 21).

The infrared spectrum revealed something very unusual: a mixed type Ia and IIb diamond (figure 22). It also showed a platelet peak at 1367 cm⁻¹ and a hydrogen peak at 3107 cm⁻¹. Mixed type Ia and IIb diamond occurs very rarely in nature; one was previously reported in Gems & Gemology [Spring 2009 Lab Notes, pp. 55–57]. Nitrogen aggregation in this diamond was much higher, however. DiamondView images showed bluish green fluorescence in the face-up view and blue fluorescence in the face-down view (again, see figure 22). Detailed analysis using the DiamondView revealed a yellowish green fluorescence zone at the top of the crown with a sharp boundary in the crown facets (figure 22). PL spectra collected from the table and at the boundary in the crown facets showed emissions from SiV defects at 736.3 and 736.9 nm.

Although SiV defects can be observed in a natural diamond, the combination of SiV defects, a sharp boundary, yellowish green fluorescence, and phosphorescence sug-
Figure 22. The mid-IR spectrum on the left revealed peaks for nitrogen aggregates and boron defects, along with a platelet peak at 1367 cm⁻¹ and hydrogen peak at 3107 cm⁻¹. DiamondView imaging showed bluish green fluorescence in the face-up view (top right) and blue fluorescence in the face-down view (center right). The yellowish green fluorescent top layer was visible in a DiamondView image (bottom right).

Figure 23. Left: A distinct boundary line indicating an interface (marked with arrows) was seen under the microscope. A dark needle inclusion is located at or near the interface (near the center of the image). Field of view 1.95 mm. Center: An electron microscope image combining secondary electron and cathodoluminescence emissions reveals the presence of an overgrowth layer. Right: The CVD synthetic layer is approximately 80 microns thick.
scopical analysis did not show boron and SiV defects.

Based on the growth pattern of the natural diamond, it is clear that the type IIb CVD diamond was produced in or very close to [100] orientation. The natural diamond substrate showed no observable inclusions except for a very small stress halo. The thickness of the CVD overgrowth layer was approximately 80 microns (again, see figure 23). FTIR spectroscopy is a bulk analysis, making it very hard to measure and separate IR spectra between a thin CVD layer on top and a thick diamond substrate. However, the fluorescence and phosphorescence reactions suggest that the top synthetic layer contained boron [e.g., boron-doped CVD synthetic] and the bottom diamond contained nitrogen aggregates. The thin layer of type IIb CVD synthetic diamond on the top of this stone effectively introduced Fancy blue color when viewed from its table.

This synthetic overgrowth on a natural diamond with a Fancy color grade is the first GIA has seen. Identification of colored diamonds should be performed very carefully by looking for unusual characteristics, such as a straight boundary line associated with an interface plane, and fluorescence zones with sharp edges in DiamondView images. Examination of this fancy-color composite diamond indicated that similar challenges could exist for colorless and near-colorless diamonds.

Kyaw Soe Moe, Paul Johnson, Ulrika D’Haenens-Johansson, and Wuyi Wang

**HPHT SYNTHETIC DIAMOND**
**Melee Found in Mounted Jewelry**

Separation of treated and synthetic diamond melee from natural diamond is challenging work. Diamond melee, which weigh less than 0.2 ct, are often submitted to gemological laboratories in parcels containing hundreds (or more) loose stones. GIA’s automatic screening device, introduced in 2016, can separate synthetic and treated diamond melee from natural diamond melee. Identification becomes more challenging when the melee are mounted, due to their small size and the difficulty of accessing them.

In late February 2017, GIA’s Hong Kong laboratory received a ring containing 70 melee in addition to a marquise-cut diamond center stone (figure 24). Using a prototype of GIA’s new screening device for mounted gems, 69 of the melee passed the test for natural diamond, and one was referred as possible treated or synthetic diamond. The stone in question, which was set next to the center marquise diamond (figure 25, left), had no apparent inclusions. Infrared absorption spectroscopy identified it as a type IIb diamond with an absorption band at 2800 cm⁻¹, indicating the presence of boron as a defect, forming a local vibration mode. Using PL spectroscopy, a very strong doublet peak at 882/884 nm related to nickel impurity was recorded under laser excitation and low temperature. The NV⁻ center was more prominent than the NV⁺ center. Strong blue phosphorescence was also detected (figure 25). These observations confirmed that this was an HPHT synthetic diamond, very similar to melee we have previously tested that were manufactured in China.

How to screen jewelry items with mounted diamonds for quality control is a concern in the industry. GIA’s robust instrument for rapid and accurate screening of small diamonds set in mountings will be available in late 2017.

Terry Poon and Wuyi Wang

**PHOTO CREDITS**

Evan Smith—1; Jian Xie (Jae) Liao—2 and 3; Sood Oil (Judy) Chia—4, 6, 13, and 21; Daniel Girma—5; Tino Hammid—7 (top left); Joyce Wing Yin Ho—7, 8, and 9 (bottom); Nuttapol Kildae—9 (top); Promkrit Kessrapong—10; Kwanrun Lawarwong—10; Emiko Yazawa—15; Sudarat Saeasaew—16; Johnny Leung—17, 24, and 25 (left); Tony Leung—17; Bille Law—18; Roxane Bhot—19; Priyanka Dhawale—20; Jemini Nak—20; Kyaw Soe Moe—22 and 23 (left); Ulrika D’Haenens-Johansson—23 (center); Terry Poon—25 (center and right).
Mysterious Iridescence in Aquamarine

Iridescence is a common interference phenomenon seen in many minerals and gems. It occurs when light travels through a stone and interacts with a thin film that has a different refractive index (RI) than the host material, producing a rainbow effect. Iridescence caused by a layered structure occurs on or near the surface of many gems, including iris agate, “rainbow moonstone,” and the fossilized ammonite gem known as Ammolite. Iridescence can also indicate the presence of a fracture or cleavage (see Fall 2016 Micro-World, pp. 312–313).

An appealing 40.27 ct aquamarine crystal on calcite matrix owned by Lucas Fassari (Costa Mesa, California) featured eye-visible, cloud-like stringer inclusions that extended from the base of the crystal parallel to the c-axis (figure 1). Inexplicably, examining the stone down through the c-axis with oblique fiber-optic illumination revealed a concealed iridescent, slightly three-dimensional “shimmer” that shifted colors as the light source moved (figure 2; see video at http://www.gia.edu/gems-gemology/iridescence-aquamarine). What was puzzling was that in the iridescent regions there seemed to be no evidence of a break, thin film, liquid inclusion, or other discernible feature that would cause these interference colors. We hypothesize that the cloud-like stringers could be creating dislocations, producing a structure capable of generating interference colors in the localized region just above the stringers.

Figure 1. This 40.27 ct aquamarine contains eye-visible parallel stringers that could be responsible for interference colors seen when the crystal is viewed along the c-axis with a fiber-optic light. Photo by Kevin Schumacher.
Figure 2. The surface of the aquamarine crystal contains a hidden iridescence that is only visible when the light source is at certain angles relative to the surface of the stone. The angle of the oblique fiber-optic illumination in the photo on the left does not make the iridescence visible. As this light is swept across the surface, changing the angle of illumination, colorful iridescent colors appear (center). The appearance of the phenomenon alters along with the angle of illumination (right). The large dark area in the right portion of each image is a reflective void. Photomicrographs by Nathan Renfro; field of view 4.8 mm.

This aquamarine crystal is one of the most interesting the authors have encountered because of its unusual and unexplained iridescence.

Nicole Ahline and Maryam Mastery Salimi
GIA, Carlsbad

Chlorapatite in Quartz

We recently examined a 57.56 ct rock crystal quartz [figure 3] that came from Luciana Barbosa (Gemological Center, Asheville, North Carolina). Said to be from Bahia, Brazil, the transparent and colorless rectangular step-cut gem measured 31.91 × 19.01 × 11.83 mm and hosted two relatively large translucent euhedral crystals. When examined under magnification, these inclusions appeared to be hexagonal prisms, the larger one measuring approximately 7.0 mm in length. Rotation of the microscope’s analyzer clearly displayed the crystals’ dichroism, which changed from blue to pale yellow (figure 4). Laser Raman microspectrometry was used to identify the inclusions as chlorapatite. This is

Figure 3. This 57.56 ct rock crystal quartz hosts two large euhedral chlorapatite crystals. Photo by Kevin Schumacher.

Figure 4. The blue and pale yellow dichroic colors of a chlorapatite inclusion in quartz are clearly seen in these microscopic views. Photomicrographs by Nathan Renfro; field of view 14.16 mm.
Christmas Tree–Shaped Internal Feature In Diamond

A 3.32 ct Fancy yellow marquise diamond recently submitted to GIA’s Carlsbad laboratory for color origin determination was of particular interest for its large, eye-visible laser manufacturing remnant (LMR). This LMR extended along a relatively straight path from a star facet through the pavilion and featured lily pad stress fractures stacked in parallel along its length, a composition reminiscent of a Christmas tree preserved within the diamond. With its resulting “green foliage” against a dark blue night, the use of Rheinberg color contrast illumination technique (N. Renfro, “Digital photomicrography for gemologists,” Summer 2015 GeoG, pp. 144–159; Fall 2015 Micro-World, pp. 328–329) dramatically accentuated this already evocative scene (figure 5).

Unlike the remnants of laser drilling used to remove small inclusions, LMRs are an unintended consequence of either carelessness or unpredictable laser optics. As such, they are graded as clarity characteristics that can reduce the overall quality and value of a diamond. LMRs can occur during the laser cutting of a diamond. They appear in a variety of shapes but often resemble the remnants of internal laser drilling (Fall 2013 Lab Notes, p. 174).

Ironically, an accidental feature that might otherwise downgrade a diamond’s value can have a positive outcome. This unique and aesthetically pleasing internal feature has created an interesting collector’s gemstone, a perfect gift for the Christmas season!

Cosalite in Quartz

A search of the gemological literature shows that rock crystal quartz contains a wide variety of unusual and interesting inclusions. Many of those inclusions look alike, so careful analysis is necessary for a positive identification. We recently examined a 16.20 ct cushion-shaped rectangular modified step-cut rock crystal from Kara-Oba, Betpak-dala Plateau, Kazakhstan (figure 6), that was fashioned by Michael E. Gray [Coast-to-Coast Rare Stones, Mendocino, California]. Measuring 18.15 × 13.24 × 10.60 mm, it hosted several opaque silvery gray stalks and needles that appeared to have an orthorhombic morphology (figure 7). A fragment cut from the original rough crystal was analyzed by laser Raman microspectrometry and yielded a possible identification as cosalite, a rare orthorhombic lead bismuth sulfide. This was subsequently confirmed by X-ray powder diffraction analysis.

Figure 5. Left: A 3.32 ct fancy-color diamond hosts a laser manufacturing remnant of unusual shape; here, it is seen with diffused fiber-optic illumination. Right: Rheinberg illumination accentuates the LMR’s resemblance to an evergreen tree. Photomicrographs by Jonathan Muyal; field of view 2.90 mm.

Figure 6. This 16.20 ct quartz contains an abundance of inclusions. Photo by Kevin Schumacher.
Diffraction. The discovery of such a rare mineral as an inclusion in this stone was a pleasant surprise.

**John I. Koivula**

**Kyanite: A Rare Blue Guest in Diamond**

Few landscapes in the micro-world of minerals are as exciting as those encountered within diamonds, which can tell us much about the world from which this most precious of gems originates: the otherwise inaccessible deep earth (J.I. Koivula and E.A. Skalwold, “The microworld of diamonds: Images from the earth’s mantle,” *Rocks & Minerals*, Vol. 89, No. 1, 2014, pp. 46–51). Of the minerals found as inclusions in diamonds, a few are very deeply colored, due to their strong saturation at any dimension (e.g., red chromium-containing pyrope or a vivid green diopside) or their relatively large size (e.g., olivine crystals that are less saturated with diminishing size, ultimately becoming colorless). While ruby is considered one of the rarest inclusions encountered in diamond, inclusions that are vivid blue hold a similar rank. When discovered in routine examination of a diamond gemstone, they elicit not just breathless appreciation for their exquisite hue, but also anticipation of what they might turn out to be.

So it was with great interest that we examined an intensely saturated rounded blue inclusion within a 2.23 ct diamond (figure 8), a rarity greatly exceeding that of a flawless diamond gemstone. In this case, Raman analysis was used to non-destructively identify the crystal as kyanite, a mineral that occurs only in diamonds of eclogitic origin. This crystal is remarkable for its size (about 0.60 mm long), which in part accounts for its deep color; smaller crystals range from pale blue to colorless. Such colored mineral inclusions in diamonds should not be regarded as imperfections, but rather as hallmarks of beauty and as windows into our planet’s deepest secrets. At the very least, they are a compelling invitation from the micro-world to embark on a fascinating scientific adventure.

**Elise A. Skalwold**

**Ithaca, New York**

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**GIA, Carlsbad**

**Figure 7. Displaying an orthorhombic morphology, these inclusions were identified as cosalite. Photomicrograph by Nathan Renfro; field of view 4.11 mm.**

**Figure 8. A deep blue kyanite crystal inside a 2.23 ct diamond identifies its host as being of eclogitic origin. Photomicrograph by Nathan Renfro; field of view 2.18 mm.**
Oiled Ruby: A Remarkable Visual

As laboratory gemologists working in Bangkok, we often encounter gems that have been treated with oil to minimize the appearance of fissures. Most of these stones come from Myanmar, where many vendors consider oiling an accepted standard procedure to enhance their goods, particularly ruby and spinel. Furthermore, red oil is commonly used not only to improve clarity, but also to enhance the color of the stone (in Chanthaburi, Thailand, it is sold under the brand name “King Ruby Red Oil”). Often this treatment can be identified by flattened gas bubbles in the fissures or by droplets of oil seeping out of the fissures on the surface when the stone is gently warmed by microscope light or hot point.

Figure 9 shows a small surface-reaching cavity filled with oil in an unheated 1.75 ct ruby from Myanmar. Unlike other examples we have seen, this remarkable gem contained enough of the filler to easily photograph the striking red color of the oil itself within the cavity. With oblique fiber-optic lighting, a stunning image of this enhancement in situ was made possible, turning even another commonplace forensic determination into an aesthetic exploration of the micro-world.

E. Billie Hughes
Lotus Gemology Laboratory
Bangkok

Sapphires With Unusual Radial “Eye” Structure

The Luc Yen district in northern Vietnam produces some remarkable stone varieties, including ruby and red cobalt-blue spinel. Recently, Geir Atle Gussiås of BalderGems in Luc Yen procured some interesting sapphires from local gem traders. These stones exhibited a radial pattern often accompanied by concentric color zoning. This pattern is commonly seen in minerals that precipitate from fluids such as carbonates and cryptocrystalline silica varieties, but to our knowledge it has never been observed in...
The patterns exhibited different forms and sizes but were always a combination of blue and white, with a lower polish quality in the white areas. Raman spectroscopy confirmed that both the white and blue areas were corundum, but the presence of diaspora was detected only in the whiter areas. Some areas also showed a mottled texture and small unidentified black inclusions (figure 11). Laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) analysis of the sapphire in figure 10 revealed a low iron content, which excludes a basalt-related origin. Epigenetic yellow goethite was found in several fractures on the top of the cabochon. The presence of this mineral was evidence that the stone had not been heat treated (figure 12): Goethite, an iron hydroxide mineral, alters to rust-colored hematite at relatively low temperatures (J.I. Koivula, “Useful visual clue indicating corundum heat treatment,” Fall 2013 GemGems, pp. 160–161). Corundum heat treatments have been performed for centuries and are widely accepted in the trade, but this stone needed no extra enhancement beyond cutting and polishing to reveal its anomalous beauty.

While the cause of this unusual radial aggregate structure remains unknown, it is certainly a welcome novelty in the collector gem market.

Wim Vertriest and Victoria Raynaud
GIA, Bangkok
Hollie McBride
GIA, Carlsbad

Quarterly Crystal: Molybdenite Phantoms in Quartz

Quartz is the most abundant mineral found in the earth’s crust. When it forms as solid single crystals, it can serve as a transparent and durable host for a wide variety of mineral inclusions. The two crystals seen in figure 13...
came from collector Terry Szenics (Massapequa, New York), who found them in 2004 as part of a very small discovery at the Confianza mine in the Coquimbo region of Chile.

At a glance, the inclusions in the two crystals looked as though they might be hematite, a common iron oxide. However, laser Raman microspectrometry identified them as molybdenite (figure 14), a hexagonal molybdenum sulfide and a much more unusual inclusion than hematite. The inclusions were situated in the quartz crystals in the form of phantoms that developed through the deposition of the molybdenite on the surface of the quartz. The host then continued to grow, enveloping the molybdenite as inclusion planes tracing the form of the original quartz host.

John I. Koivula

For More on Micro-World

To watch the iridescent “shimmer” of the aquamarine featured in this section, visit https://www.gia.edu/gems-gemology/iridescence-aquamarine, or scan the QR code to the right.
COLORED STONES AND ORGANIC MATERIALS

Sapphires from northern Ethiopia. Since February 2017, rumors of a newly discovered sapphire deposit in northern Ethiopia have been circulating in the trade. In June, one of the authors (SB-L) visited the mining area, located in the country’s Tigray region. The city of Aksum (or Axum), about 35 km south of the Eritrean border, is used as a base for gem merchants. Mining and trading is concentrated around the town of Chila, about 25 km northwest of Aksum. Based on the literature, the alkali basalt field that produces the sapphire stretches into Eritrea, although no sapphires from that area have reached the market. Several sites are active, and about 5,000 miners were working the deposits. All of the deposits are secondary in nature and have yielded rounded crystals. The majority of the rough (figure 1) weighs 2–3 grams, but crystals over 50 g have been reported, the larger ones are usually cracked. Heat treatment experiments are being conducted in Chanthaburi [Thailand] and Beruwala [Sri Lanka] to see how the material reacts. It is estimated that 5–10% of the sapphires do not require heat treatment.

At the end of April, the first parcels started to arrive in Bangkok, and GIA was able to study selected samples donated by author SB-L. The color of the crystals ranged from dark to light blue, and many contained fine rutile particles. Some stones had a trapiche-like pattern. The stones occasionally exhibited a green or yellow color, sometimes combined with blue in bicolor sapphires. All of the sapphires studied by GIA showed strong blue-green pleochroism. The main inclusions were intersecting twinning planes (figure 2), along with crystals, fingerprints, tubules, and bands of rutile particles (figure 3).

Trace-element analysis using laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) was performed on two samples. On each stone we measured 12 spots: six in a clean area and six in a particle-rich area. The clean areas from both stones showed very similar chemical composition, and the same was observed for the particle-rich areas. The compositional ranges of both stones, presented in table 1, clearly show that the chemical concentrations are different between the clean and particle-rich areas. None of the areas contained enough natural Be or Cr to detect with LA-ICP-MS. All samples showed a high Fe concentration. While Ti content was higher than Mg concentration in both areas, the particle-rich areas showed elevated levels of titanium (table 1). The UV-Vis-NIR spectrum shows a broad band around 860 nm, which is typical of basalt-related sapphires (figure 4).

Figure 1. Rough sapphires from a new deposit near Chila, Ethiopia. Photo by Simon Bruce-Lockhart.
TABLE 1. Chemical composition (ppma) of Ethiopian sapphire, obtained by LA-ICP-MS.

<table>
<thead>
<tr>
<th>Element</th>
<th>Clean area</th>
<th>Particle-rich area</th>
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<tr>
<td>²⁴Mg</td>
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</tr>
<tr>
<td>⁴⁷Ti</td>
<td>10–12</td>
<td>15–43</td>
</tr>
<tr>
<td>⁵¹V</td>
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<td>0.6–0.8</td>
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<tr>
<td>⁵⁷Fe</td>
<td>1362–1450</td>
<td>1365–1588</td>
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<tr>
<td>⁶⁹Ga</td>
<td>58–66</td>
<td>57–64</td>
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</table>

*a In total, 12 spots in clean areas and 12 in particle-rich areas were analyzed. Be and Cr were both below detection limit (0.2 and 0.4 ppma, respectively).

Starting in May, many Sri Lankan dealers have traveled to Ethiopia to buy this material, causing steep price increases in local gem markets. All of the mining around Chila is artisanal, but large volumes of sapphire have been mined in a short time span. Time, and the results of the heat treatments, will show the viability of this deposit.

Wim Verriest, Vararut Weeramonkhonlert, and Victoria Raynaud
GIA, Bangkok
Simon Bruce-Lockhart
Chanthaburi, Thailand

New deposits of gem-quality common opal from Michoacán, Mexico. The principal gemological characteristic of precious opal is the play-of-color produced by the diffraction of white light from three-dimensionally stacked layers of microscopic spheres of silica. In comparison, so-called common opal does not show play-of-color but may be valued for its attractive bodycolors. Most play-of-color opals are opal-A (e.g., Australian and Brazilian sedimentary opal), which is amorphous in X-ray diffraction (XRD). Less-studied Mexican volcanic opals, both precious and common, are by contrast opal-CT (for “cristobalite-tridymite”). In these specimens, XRD shows diffraction peaks for highly disordered cristobalite with abundant tridymite stacking [M. Ostrooumov et al., “Spectres Raman des opales: aspect diagnostique et aide a la classification,” European Journal of Mineralogy, Vol. 11, No. 5, 1999, pp. 899–908]. Yet there have been few studies of gemological interest on the microstructure of common opals.

Recently, the author discovered new deposits of common gem opal (figure 5) in the hills near Lake Cuitzeo, in Mexico’s Michoacán State. These opals were embedded in volcanic andesitic rocks. They were generally characterized by a medium to light orange to brown color, with no visible inclusions. While these new deposits are considered “common opal” since the material does not show play-of-color, some gemologists may also consider the specimens to be fire opal due to the orangy bodycolor. The samples were studied at the Institute of Earth Sciences at the University of Michoacán in Morelia.

Standard gemological testing yielded refractive indices between 1.440 and 1.457 and hydrostatic specific gravities (SGs) ranging from 2.11 to 2.14. The material was inert to both long- and short-wave UV radiation. These properties suggested common opal, which we later confirmed with scanning electron microscopy (SEM), transmission electron microscopy (TEM), and Raman spectroscopy.

Figure 2. An Ethiopian sapphire wafer with two polished windows perpendicular to the c-axis under crossed polarizers shows two sets of twinning planes. Photo by Victoria Raynaud; field of view 13.4 mm.

Figure 3. Left: An unidentified crystal surrounded by a fingerprint. Many particles and fine wispy fingerprints can be seen throughout the stone in darkfield lighting. Center: Intersection tubules associated with different types of fingerprints, shown here in fiber-optic lighting, were always found in the twinning planes of the Ethiopian sapphires. Right: Bands of particles seen with fiber-optic lighting. Photomicrographs by Victoria Raynaud; fields of view 1.20 mm (left), 3.60 mm (center), and 1.44 mm (right).
microscopy (TEM), atomic force microscopy (AFM), Raman microprobe, and infrared spectroscopy.

Previous research [E. Fritsch et al., “Mexican gem opals: Nano-and micro-structure, origin of colour, comparison with other common opals of gemmological significance,” Australian Gemmologist, Vol. 21, No. 6, 2002, pp. 230–233] has shown that Mexican opals with play-of-color exhibit a higher degree of organization. In these specimens, nanoparticles measuring about 10–50 nm in diameter form pseudospheres (lepispheres) of appropriate size to diffract visible light (about 200 nm) in a matrix of less acid-soluble silica particles. When examined with a scanning electron microscope, fresh broken surfaces show no particular organiza-

Figure 5. Gem-quality common opal was recently discovered in Michoacán State in western central Mexico. The approximate size of this sample is 15.04 × 7.68 × 5.57 cm. Photo by M. Ostrooumov.

tion, but after etching with diluted hydrofluoric acid (10% vol. HF), the microscopic arrangement of spheres is revealed. There is a continuum of structures between opals with and without play-of-color. In addition to the role of particle size, rounder spheres with a more organized structure display a more noticeable play-of-color with a wider range of colors.

From SEM and AFM images, it is clear that these newly discovered common opals from Michoacán are built from a random aggregation of small, near-spherical grains, averaging 60 to 100 nm in size. (The software we used was ImageJ, an open-source image processing program designed to generate scientific multidimensional images.) The apparent diameter of some grains actually ranges from about 120 to 130 nm (figures 6 and 7). The nanostructure of this common opal explains the absence of play-of-color. In this case, we can consider the following general explanations for the lack of play-of-color:

1. The spheres do not have the same size (heterogeneous structure).
2. The spheres are not perfectly spherical.
3. The spheres are the same size but not well organized.
4. The spheres are too small (<150 nm) or too large (>300 nm) to diffract light.

In some cases two or more of these conditions occur in the same sample.

All Mexican volcanic CT-opals have similar Raman spectra characterized by a very strong general band (apparent maximum toward 325 cm⁻¹) that shows a complex structure with lines of weak to medium intensity (M. Ostrooumov et al., “Spectres Raman des opales: aspect diagnostique et aide a la classification,” European Journal of Mineralogy, Vol. 11, No. 5, 1999, pp. 899–908). According to theoretical calculations, the normal modes in the 300–350 cm⁻¹ range consist mainly of Si-O-Si bending vibrations...
of ring atoms. Other principal bands in the Raman spectra of opal from these new deposits are found at about 800 and 960 cm\(^{-1}\), 1069–1086 cm\(^{-1}\), and 1600 and 3200 cm\(^{-1}\). These bands belong to \(\alpha\)-tridymite, \(\alpha\)-cristobalite, \(\alpha\)-quartz, and groups of \(\text{H}_2\text{O}\) and \(\text{OH}\). Infrared absorption bands were observed between 4000 and 400 cm\(^{-1}\), which is typical for all varieties of micro- and non-crystalline opals (C, CT, and A). The three strong bands near 1100, 790, and 480 cm\(^{-1}\) are common to all silicates with tetrahedrally coordinated silicon (M. Ostrooumov, “A Raman, infrared and XRD analysis of the instability in volcanic opal from Mexico,” Spectrochimica Acta, Part A, Vol. 68, No. 4, 2007, pp. 1070–1076). Broadly speaking, in opal-CT only localized Si-O-Si stretching and bending vibrations remain. The distinction between opal-CT and opal-A requires careful inspection of the frequencies of the three strong Si-O bands. In particular, the band at 790 cm\(^{-1}\) is always at higher frequency in opal-A than in opal-CT. Broad absorption bands between 3700 and 2700 cm\(^{-1}\) are due to fundamental O-H stretching vibrations. For example, a very broad band is present at around 3448–3458 cm\(^{-1}\), with a shoulder at about 3250 cm\(^{-1}\) that is generally considered to be related to hydrogen-bonded molecules of water.

Based on TEM results, we have been able to prove that the orange to brown bodycolor of Mexican common opal is due to nano-inclusions of an iron-containing material. It is probably related to hematite, which is often found associated with common opal in nodules. It typically appears as needles measuring 10 to 20 nm wide by 100 to 200 nm long, seen only with TEM.

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Morelia, Michoacán, Mexico

Raspberry-red garnet with black core. Raspberry-red grossular garnet mineral specimens have been popular in the collector market since their discovery in 1994 in the Sierra de Cruces range in the State of Coahuila, Mexico. V.W. Lueth and R. Jones (“Red grossular from the Sierra de Cruces, Coahuila, Mexico,” Mineralogical Record, Vol. 34, No. 6, 2003, p. 73) described the geological environment where the garnet was discovered and the petrological composition of the garnet and matrix (figure 8). An interesting internal characteristic of this type of grossular crystal is its raspberry-red rim and black core with sharp color transition at the core-rim boundary. Lueth and Jones reported that the raspberry-red rim is composed mainly of grossular and the black core contains up to 4.5 wt.% titanium that can be used to calculate additional morimotoite and schorlomite garnet end-member species (table 2). No detailed chemical analysis of the black core was presented, however. To better understand the composition of this type of garnet, we prepared a thin section sliced from the middle of one garnet crystal (see the color-zoned image in

![Figure 7. Distribution of particle sphere diameters in the nanostructure of the newly discovered Mexican volcanic opal. Most of the spheres are 60–100 nm, a size too small to diffract light.](image)

<table>
<thead>
<tr>
<th>Table 2. Cation site occupancies for garnet end members.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>End members</strong></td>
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<tr>
<td>Schorlomite</td>
</tr>
<tr>
<td>Schorlomite-Al</td>
</tr>
<tr>
<td>Morimotoite</td>
</tr>
<tr>
<td>Morimotoite-Mg</td>
</tr>
<tr>
<td>Morimotoite-Fe</td>
</tr>
<tr>
<td>Grandite</td>
</tr>
<tr>
<td>Andradite</td>
</tr>
<tr>
<td>Kimzeyite</td>
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<td>Kimzeyite-Fe</td>
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</table>
the middle of figure 9) for detailed chemical analysis at GIA’s Carlsbad laboratory.

The section’s chemical composition was obtained with a Thermo Fisher iCAP Q ICP-MS coupled with a New Wave Research UP-213 laser ablation unit. 29Si was used as the internal standard. GSD-1G and GSE-1G were used as external standards. A line of 33 ablation spots was selected to cross the whole section from one outer rim to the opposite outer rim. The black core contained up to 27.91 mol.% morimotoite and up to 4.07 mol.% schorlomite (figure 9). The detailed composition of the black core of spot 7 to spot 15 (the light blue vertical zone in figure 9) is listed in table 3. The black core contained 4.10–5.04 wt.% TiO2, confirming the analytical results reported by Lueth and Jones, and 4.42–5.49 wt.% FeOtot. It also contained 0.26–0.84 wt.% ZrO2 that could be used to calculate a distinct kimzeyite garnet end-member species (tables 2 and 3, table 2 gives the composition and site occupancy of the end members). It is the first time a detailed chemical analysis of the black core of this type of raspberry-red garnet has been documented.

Ziyin Sun and Nathan D. Renfro
GIA, Carlsbad

“Sango pearl” from Japan. A type of pink Japanese akoya cultured pearl, introduced about a decade ago and known as “Sango” pearl (figure 10), uses a pink coral nucleus and a Pinctada fucata mollusk. It is produced by Matsumoto Pearls, a Japanese pearl farming company based in Uwajima, Ehime Prefecture. Sango is the Japanese word for coral, and the species of pink coral used as the nucleus is likely a Corallium species, one of the precious corals harvested off the Pacific coast of Japan, especially around southern Kochi Prefecture (N. Iwasaki et al., “Biology of Japanese Corallium and Paracorallium,” Proceedings of the First International Workshop on Corallium Science, Management, and Trade, 2009, pp. 68–70). Matsumoto Pearls has successfully combined two beautiful organic gem materials to produce these attractive pink-colored pearls.

The coral nuclei in this study exhibited a pinkish orange color and measured 5.60–5.90 mm in diameter. Under microscopic examination, white layer-like structures and banding as well as polyp-related cavities have sometimes been
observed. The nuclei also exhibit a weak whitish and stronger whitish fluorescence under short-wave and long-wave UV, respectively. The coral bead’s Raman spectrum (figure 11, top) shows strong pigment peaks at 1129 and 1517 cm⁻¹ and calcite peaks [e.g., 280 and 713 cm⁻¹], identifying them as *Corallium* species, as in S. Karampelas et al. (“Identification of the endangered pink-to-red *Stylaster* corals by Raman spectroscopy,” Spring 2009 GeG, pp. 48–52). The full-range photoluminescence spectra closely match that of natural pink coral with natural pigment-related peaks, similar to those in C.P. Smith et al. (“Pink-to-red coral: A guide to determining origin of color,” Spring 2007 GeG, pp. 4–15). Visible-range reflectance spectra [figure 11, middle] reveal peaks at 468, 482, 590, and 666 nm, like those observed in the spectra of natural coral by C.P. Smith et al. [2007]....

**Figure 10. Sango pearls (left and center) and a coral bead nucleus (right), each approximately 6 mm in diameter. Photo by Y. Katsurada.**

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**TABLE 3. Chemical composition of grandite-morimotoite garnet spots by LA-ICP-MS.**

<table>
<thead>
<tr>
<th>Number of spots</th>
<th>spot 7</th>
<th>spot 8</th>
<th>spot 9</th>
<th>spot 10</th>
<th>spot 11</th>
<th>spot 12</th>
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†The “remainder” in the end-member components is what is left over after assigning all the atoms to stoichiometric garnet formula. This value is related to analytical error in the chemical measurements.
RAMAN SPECTRA

<table>
<thead>
<tr>
<th>WAVELENGTH (nm)</th>
<th>VISIBLE RANGE REFLECTANCE SPECTRA</th>
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<tr>
<td>482</td>
<td>Sango pearl</td>
</tr>
<tr>
<td>400-800</td>
<td>Coral bead</td>
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<tr>
<td>400-800</td>
<td>Nacre thickness (µm)</td>
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<td>0-50</td>
<td>Plot of the relationship between nacre thickness and the differential reflectance of Sango pearls at 482 nm based on the average reflectance of the coral beads (differential reflectance = R_{Sango pearl} - R_{coral bead}).</td>
</tr>
</tbody>
</table>

**Figure 11.** Top: Raman spectra of a coral bead (black trace) and a Sango cultured pearl (pink trace) with pigment-related peaks at 1129 and 1517 cm\(^{-1}\). The bead's peaks are stronger at those wavelengths. Middle: Visible-NIR spectra of a coral bead (black trace) and two Sango cultured pearls showing the different reflectance values obtained. The dark pink trace represents thinner nacre (120 µm thick); the light pink trace is from nacre that is 400 µm thick. Bottom: Plot of the relationship between nacre thickness and the differential reflectance of Sango pearls at 482 nm based on the average reflectance of the coral beads (differential reflectance = R_{Sango pearl} - R_{coral bead}).

**Figure 12.** RTX images of Sango cultured pearls showing clear demarcations between the larger coral bead nucleus and thinner nacre overgrowth. The pearl on the left has a thinner nacre than the one on the right.

The different nacre thicknesses were also visible in real-time X-ray (RTX) images (figure 12). The pearls exhibited excellent luster, with almost no overtone and very weak orient, and showed a weak yellow to greenish yellow fluorescence under long-wave and short-wave UV radiation, respectively. These observations indicated that the 10 samples' pink coloration was natural, though it remained to be seen whether the pink color originated from the pearls' nacre or the underlying coral beads.

Chemical analysis using an energy-dispersive X-ray fluorescence (EDXRF) spectrometer revealed manganese levels of 0 to 28 ppmw and strontium levels of 1077 to 1719 ppmw, indicating that the pearls formed in a saltwater environment. A useful observation was that pearl color seemed to be related to nacre thicknesses: Thin nacre overgrowth produced a more obvious pink tint, while thicker nacre resulted in a less saturated pink. Likewise, the Raman and visible-range reflectance spectra were also related to the nacre thickness. Raman spectra for pearls with thin nacre showed stronger pigment peaks at approximately 1129 and 1517 cm\(^{-1}\), similar in strength to those noted in the coral beads; only the aragonite-related peaks—and no pigment peaks—were noted in pearls with thicker nacre (see figure 11, top). The visible-range spectra of the pearls possessing thin nacre also matched the coral beads more closely, albeit with a lower reflectance (figure 11, middle), while pearls with thicker nacre had higher reflectance, as would be expected for lighter-colored pearls. By correlating the coral pigments with the maximum visible reflectance spectrum at 482 nm, the point of least reflectance (see figure 11, bottom), the relationship between nacre thickness and the visible spectra of the pearls could be gauged. The intensity at 482 nm indicates that the pink color of Sango pearls most likely originates from their coral nuclei.

While Sango pearls are not the first cultured pearls to use atypical bead nuclei in the form of other gem materials (see K. Scarrott et al., “Atypical ‘beading’ in the production of cultured pearls from Australian Pinctada maxima,” GIA Research News, 2017, https://www.gia.edu/gia-news-research/atypical-beading-production-cultured-pearls-australian-pinctada-maxima), this is the first time the author has analyzed the detailed color origin of Sango pearls with
*Pinctada fucata* mollusks as the host. The pearls are known to possess relatively thin nacre overgrowth, which has enabled the creation of the commercial type of akoya cultured pearl using a natural coral nucleus. GIA would classify Sango pearls as atypical bead-cultured pearls.

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**Tektite with a large fluid inclusion.** Tektites are a form of natural glass related to extraterrestrial impact. When a meteorite hits Earth’s surface, the impact site is subjected to tremendous heat and pressure. This causes the rocks to instantly melt and quickly cool, creating a glass with a bulk composition similar to that of the original host rock. Only the most volatile elements will be removed, because their gaseous phases escape easily. This is the case for fluids and gases such as water and carbon dioxide, as well as certain metals. This melting and cooling results in a silica-dominated glass called tektite that is often very dark green to black.

Tektites are common in many parts of the world. The most famous type is probably moldavite, related to an impact in southern Germany. The world’s largest tektite area is the Australasian field, which covers Australia (australites), southeast Asia (indochinites), and most of the Indian Ocean. It is related to a single impact 790,000 years ago, although the impact crater has not been identified.

The gem mines in northern Vietnam around Thac Ba Lake, which are famous for ruby and spinel, also yield tektite from secondary deposits. Local dealer Geir Atle Gusås (BalderGems) procured a large tektite weighing 230.9 g (figure 13) with a very large fluid inclusion. The inclusion contained a mix of gas and liquid, which could be seen under strong illumination (figure 14; see video at http://www.gia.edu/gems-gemology/tektite-inclusion). GIA's Bangkok lab examined this unique piece by comparing it to six tektite samples collected in the mines during several field expeditions to Vietnam.

We examined the specimen and performed density measurements as well as chemical analysis to determine whether it was a real tektite. The surface features and overall shape of the large piece were very similar to the reference samples, although the reference samples were much smaller. The overall color was black, but when strong light was transmitted through the sample, a brown color was observed. The SG of the reference samples ranged from 2.01 to 2.42. This range can be explained by differences in chemical composition, mainly iron concentration, and the amount of gas bubbles in the matrix, which lowers the SG. The SG of the Vietnamese sample was 1.84, indicating an unusual abundance of fluid and/or gaseous inclusions in the sample. Because this tektite was too large to analyze using LA-ICP-MS, its chemical composition, along with those of the reference samples, was revealed with EDXRF. The large tektite had Fe, Sr, Rb, and Zr contents that are comparable to the other Vietnamese tektites.

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We then imaged the internal structure using real-time X-ray microradiography (RTX), a technique commonly used in pearl analysis. Because the device has a small detector, we could not view the whole tektite in one image. The maximum resolution of 4 μm should have been sufficient to pick up any artificial structures such as drill holes. The RTX images show the irregular outline of the tektite’s surface and a large bubble with a smooth outline (figure 15). Several smaller negative inclusions are also visible as dark ovals. When the sample was moved under the RTX, the liquid-gas inclusion was clearly seen because of the motion of the liquid.

Since we did not find a drill hole or any signs of man-made glass, we assume that the liquid in the negative inclusion is a natural phenomenon. Since glass is not porous, it seems most likely that the liquid was included during the tektite’s formation. Although this could not be proven, this tektite remains a unique specimen.

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SYNTHETICS AND SIMULANTS

Dyed yellow beaded freshwater cultured pearls imitating South Sea cultured pearls. In the spring of 2017, the Gübelin Gem Lab received a yellow pearl necklace for testing. The size and color of the specimens implied that they were South Sea cultured pearls. The high insurance value appeared to confirm this; however, there were some suspicious color patches that suggested the material had been dyed.

Only a few months earlier, author LK visited the Hong Kong office of Grace Pearls, a large producer with a pearl farm and factory in China, to see their latest batch of freshwater cultured pearls. Grace Pearls developed a proprietary method to grow large freshwater pearls with bead, marketed as “Edison” pearls. These occur in all the known colors of traditional freshwater pearls, typically white, orange, pink, and purple. To complement their color range, they also offer yellow and black treated pearls ranging from approximately 12 to 18 mm.

The goods we saw at Grace Pearls had a wide range of qualities and prices. The lowest price for a strand of Edison pearls was approximately US$100, while the highest-quality yellow dyed pearls go for as much as US$2,000. Prices for top-quality white and pink natural-color pearls may reach up to US$40,000 per strand.

The Gübelin Gem Lab acquired from Grace Pearls a necklace of yellow dyed freshwater bead-cultured pearls to complement our extensive reference collection. The largest of these pearls measured nearly 17 mm. For study purposes, we deliberately chose a low-quality necklace showing color concentrations, slightly irregular colors from pearl to pearl, and slight blemishes on the surface (figure 16).

The grafting process, which Grace Pearls considers a proprietary method, appears to be similar to that of “Kasumigaura pearls” from Japan and “Ming pearls” from China, where the bead is drilled first and a tissue is partly inserted into the drill hole in order to introduce both tissue and bead at the same time during the implantation procedure [H.A. Hänni, “Ming pearls: A new type of cultured pearl from China,” Journal of the Gemmological Association of Hong Kong, Vol. 32, 2011, pp. 23–24]. X-ray images clearly show drill holes in the beads of several of these cultured pearls, mostly in the smaller beads (figure 17), while larger beads, like the one in the center of figure 16, have only one drill hole. This may be due to a possible re-implantation into the pearl sac once the first pearl has been harvested. X-ray fluorescence (XRF) analysis gave Mn and Sr values consistent with those of freshwater pearls.

Upon testing, the necklace submitted by the client showed identical properties: dark yellow color concentrations around drill holes and in cavities, uneven surfaces with various shades of yellow (figure 18, left; see also C. Figure 17. X-ray image of yellow dyed freshwater cultured pearls. The beads range from approximately 10 to 15 mm in diameter, while nacre thickness varies from <0.2 to >5 mm. Some of the beads show an additional drill hole. Image by Pierre Hardy.
Zhou et al., “Update on the identification of dye treatment in yellow or ‘golden’ cultured pearls,” Winter 2012 GemG, pp. 284–291. X-rays showing an additional drill hole through the bead in some of the pearls (figure 18, right), and the chemical composition of freshwater pearls (figure 19). This demonstrates the importance of staying informed on new developments in the market.

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Figure 18. Left: Blemishes and dark color concentrations in cavities on the surface of dyed cultured freshwater pearls in a client-submitted necklace. Photo by Lore Kiefert. Right: An X-ray image of two pearls from the client necklace showing a clear bead. The left pearl displays an additional drill hole in the bead. Image by Pierre Hardy.

Figure 19. A plot showing the theoretical distribution of MnO vs. SrO in freshwater and saltwater pearls (after W. Gutmannsbauer and H.A. Hänni, “Structural and chemical investigations on shells and pearls of nacre forming salt- and fresh-water bivalve molluscs,” Journal of Gemmology, Vol. 24, No. 4, 1994, pp. 241–252). The red dots represent values for our reference collection necklace, the yellow dots the values for the client-submitted necklace.

Colorful chatoyant glass. This year at the Tucson gem shows, this author encountered an interesting new product of chatoyant devitrified glass (glass that has converted to a crystalline material) marketed as “Starburst Stone.” This material (figure 20) closely resembles the chatoyant glass known as Victoria Stone, which was developed in Japan by Dr. Satoyasu Iimori in the 1950s and produced for almost 40 years (http://victoriastone.sakura.ne.jp/JP-30-88-B.pdf). John Bennett, in partnership with Artur Birkner (both based in Perth, Western Australia), began developing Starburst Stone in 2013, and this is the first year of commer-

Figure 20. Starburst Stone is a colorful new devitrified glass, reminiscent of the product once marketed as Victoria Stone. Photo by Kevin Schumacher, courtesy of Australian Rough and Tumble.
cially available production (approximately 100 kilograms). This devitrified glass is made from a chemical mixture that is cooled at a rate to facilitate nucleation and growth of dense networks of elongate lath-like crystals, and each batch of glass is colored by the addition of certain metals. Darker blues are achieved by adding cobalt, lighter blue by adding copper, and green by adding chromium to the glass mixture.

Standard gemological testing revealed properties consistent with manufactured glass. The RI was between 1.51 and 1.52 and varied slightly between the different colors tested. The average SG, measured hydrostatically, was 2.62. Raman analysis identified the devitrification product responsible for the chatoyancy as apatite, which was also responsible for the chatoyancy in the devitrified glass product known as Victoria stone.

Dark and light blue, green, and golden Starburst Stones are being manufactured, with additional colors in development. This new ornamental glass showing chatoyancy is a welcome addition to the gem trade. Those interested in the material once sold as Victoria Stone will certainly appreciate this very similar phenomenal glass product.

Nathan Renfro

TREATMENTS

Chalcedony beads coated with titanium nitride. Recently, RAG Gemological Laboratory in Turin received a necklace of unusual metallic appearance [figure 21]. The beads showed irregular surfaces that were actually small geodes with shiny and well-shaped crystals. The cavities in the beads (figure 22) were reminiscent of the small quartz-lined holes that are often formed in agates and chalcedony. The necklace consisted of 29 beads ranging from 12.0 to 12.5 mm in diameter, with a total weight of 84 g.

Some loose opaque beads provided by the necklace’s owner allowed us to measure the material’s density. The value of 2.60 g/cm³ was in agreement with chalcedony. RI was not measurable on the beads due to their rough surface. No fluorescence reaction was observed under long- or short-wave UV. A sawed bead revealed that the inner part consisted of light gray chalcedony without zonation [figure 23]. Observation of the area near the drill holes showed discoloration and the true color of the underlying material. The coating on these grayish gold chalcedony beads in this necklace had an unusual composition. The unusual color and reflectivity of the external surface, clearly not inherent to chalcedony, warranted investigation.

The chemical composition of the bead was confirmed by energy-dispersive spectroscopy (EDS) using a Cambridge Stereoscan 360 scanning electron microscope equipped with an Oxford Inca Energy 200 EDS and a Pentafet detector for the determination of elements from boron to uranium. The results showed homogeneous composition on the sample surface, with titanium, oxygen, and silicon as major elements. No known compound of Ti and Si could explain the nature of the bead’s surface or the goldish gray metallic tinge.

Low-acceleration voltage conditions in EDS analysis (4 kV) allowed us to enhance the X-ray emission yield of lighter elements and reduce the penetration depth of the electron beam at around 100 nm into the bead’s surface. The EDS spectra at low acceleration voltage showed the presence of nitrogen and titanium, suggesting a coating of titanium nitride (TiN) on the beads. At low potential the electron beam could pass through the thin layer of TiN, so the oxygen and silicon peaks from the underlying silica were still visible in the spectra. We calculated the thickness of the coating by acquiring several EDS spectra at dif-

Figure 21. The beads in this necklace, ranging in diameter from 12.0 to 12.5 mm, have a submetallic luster and a gray tinge with goldish reflection. Small vugs lined with sparkling crystals are clearly visible in most of the beads. Photos by Raffaella Navone.

Figure 22. SEM imaging shows the small, well-shaped quartz crystals within the cavities. The crystal in the lower middle clearly displays the classic “flute” termination typical of quartz. Image by Emanuele Costa; field of view 1 mm.
Figure 24. Raman spectrum of the TiN film in the 100–800 cm$^{-1}$ region. The Raman bands are related to transverse acoustic (at 260 cm$^{-1}$), longitudinal acoustic (330 cm$^{-1}$), second-order acoustic (418 cm$^{-1}$), and transverse optical (584 cm$^{-1}$) modes of TiN, respectively (Cheng et al., 2002). The poor quality of the spectrum, despite a long collection time and enhanced sensitivity, is due to the faint response of TiN to Raman investigation (as well as to the extreme thinness of the coating); it is comparable to the reported spectra available in the literature.

TiN deposition is widely used for the coating of small mechanical parts or tools, giving them a higher resistance to corrosion and scratching. Therefore, TiN films are essential for applications such as wear-resistant coatings, diffusion barriers, and optical coatings. The coating typically produces a golden hue, but other colors are also possible. Even though TiN films are common in industrial applications, this may be the first time such a coating has been reported in gemology.

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Figure 23. This sawed cross-section clearly demonstrates the homogeneity and light gray color of the chalcedony that constitutes most of the bead. Photo by Emanuele Costa.
Tri-color-change holmium-doped synthetic CZ. Colored yttria-stabilized synthetic cubic zirconia (CZ) has been an attractive diamond substitute since the late 1970s (R.T. Liddicoat and J.I. Koivula, “Synthetic cubic stabilized zirconia,” Summer 1978 Ge&G, pp. 58–60). The different colors seen in synthetic CZ are caused by the introduction of specific transition metal elements and rare earth elements [K. Nassau, “Cubic zirconia: an update,” Spring 1981 Ge&G, pp. 9–19]. At this year’s Tucson Gem and Mineral Show, the authors obtained an interesting synthetic CZ rough that exhibited an unusual color-change behavior (figure 25). Unlike traditional color-change stones such as alexandrite, color-change corundum, and color-change garnet, this material did not exhibit different colors when illumination alternated between incandescent light and daylight conditions [approximated by CIE standard illuminants A and D65, respectively]. Surprisingly, it showed three distinct hues in daylight/incandescent light (yellowish green), in fluorescent lighting corresponding to CIE standard illuminant F9 (green-blue), and in CIE standard illuminant F10 (purplish violet). One wafer with 3.32 mm thickness was polished and analyzed to understand this color-change phenomenon.

The wafer’s chemical composition was obtained using a Thermo Fisher iCAP Q ICP-MS coupled with a New Wave Research UP-213 laser ablation unit. LA-ICP-MS analyses were performed in the same spot where the spectroscopic data was collected. Based on its calculated chemical formula of $\text{Zr}_{0.92}\text{Y}_{0.06}\text{Ho}_{0.02}\text{O}_{1.97}$ (the formula is nonstoichiometric and calculated by forcing cations to 1 atom per formula), the wafer was a holmium-doped yttria-stabilized CZ (S. Gutzov et al., “High temperature optical spectroscopy of cubic holmium doped zirconia, Zr$_{0.76}$Y$_{0.23}$Ho$_{0.01}$O$_{1.99}$,” Physical Chemistry Chemical Physics, Vol. 9, No. 4, 2007, pp. 491–496). Holmium was the only detected chromophore, at a concentration of about 7780 ppm.

Visible spectra were collected with a Hitachi U-2910 spectrometer with a 1 nm spectral resolution at a scan speed of 400 nm/min. The wafer’s spectrum matched the holmium-doped CZ spectrum reported by Gutzov et al. [2007]. The unusual color change under different illuminants can be qualitatively understood by examining figure 26. The violet and orange emission peaks of the F10 illuminant are not absorbed by Ho-doped CZ; however, there is significant absorption by holmium of the green emission peak for the F10 illuminant. This selective absorption of the F10 emissions creates a purplish violet color (figure 26, top). The F9 illuminant has more of a broadband emission,
which is unaffected by the strong but narrow absorption by holmium of green light at 540 nm. This results in a blue-green color under F9 illumination (figure 26, middle). The D65 illuminant is essentially a broadband emission roughly corresponding to a black body irradiator at 6500 K. Under D65 illumination, a yellowish green color is produced because of the strong absorption of blue light by holmium (figure 26, bottom).

The wafer’s visible absorption spectrum was reflection-corrected by subtracting the absorbance value at 850 nm, where no chromophoric absorption is expected, from values for every other data point along the rest of the spectrum. The reflection-loss-corrected visible spectrum can then be used to quantitatively calculate the color of this material at a wide range of path lengths and under different lighting conditions [Z. Sun et al., “Vanadium- and chromium-bearing pink pyrope garnet: Characterization and quantitative colorimetric analysis,” Winter 2015 Ge&G, pp. 348–369]. There are large differences in the CIE L*, a*, b* color coordinates between D65, F10, and F9 (figure 27). One way to judge the quality of a color-change stone is to plot the color pair in the CIE 1976 color circle. Well-defined color-change pairings show a large hue angle difference, a small chroma difference, and high chroma values. The color coordinates of the material with a 10 mm light path length in D65, F9, and F10 were plotted in the CIE 1976 color circle shown in figure 27; calculated color panels for the illuminants were also placed alongside the faceted material (see online at http://www.gia.edu/gemology/summer-2017-gemnews-holmium-synthetic-cz]. The fact that the material shows three distinct hues in three different white lights makes it unique.

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ERRATA

1. The cover description on the Spring 2017 masthead page was incorrect. The cover photo actually shows a rose-cut diamond brooch, or “stomacher,” from France that contains over 10 carats of diamonds set in silver over gold. It has a 1.90 ct center stone and three side stones totaling 5.05 ct. The photo is by Robert Weldon, courtesy of Lang Antique & Estate Jewelry (San Francisco, California).

2. In the Spring 2017 Gem News International section, the cultured pearl market update (pp. 124–126) showed a necklace featuring baroque South Sea cultured pearls (figure 23), which the caption described as “keshi.” We would like to clarify that these are baroque, beaded (bead-cultured) pearls and cannot be true keshi pearls, which are pearls produced by a loose tissue piece, or in a pearl sac that previously held a bead or cultured pearl. We are grateful to Prof. Henry A. Hänni for this observation.
This chart contains a selection of photomicrographs of natural, synthetic, and treated sapphires. It is by no means comprehensive. The images show the visual appearance of numerous features a gemologist might observe when viewing sapphires with a microscope.

**Treated**

- A synthetic crystal, filled with colorants and synthetic inclusions, as observed through a microscope. Field of view 1.58 mm.
- A synthetic crystal, filled with colorants and synthetic inclusions, as observed through a microscope. Field of view 1.58 mm.
- A synthetic crystal, filled with colorants and synthetic inclusions, as observed through a microscope. Field of view 1.58 mm.

**Natural**

- A natural crystal, showing typical features of a natural sapphire, as observed through a microscope. Field of view 1.58 mm.
- A natural crystal, showing typical features of a natural sapphire, as observed through a microscope. Field of view 1.58 mm.
- A natural crystal, showing typical features of a natural sapphire, as observed through a microscope. Field of view 1.58 mm.

**Synthetic**

- A synthetic crystal, showing typical features of a synthetic sapphire, as observed through a microscope. Field of view 1.58 mm.
- A synthetic crystal, showing typical features of a synthetic sapphire, as observed through a microscope. Field of view 1.58 mm.
- A synthetic crystal, showing typical features of a synthetic sapphire, as observed through a microscope. Field of view 1.58 mm.