Gems&Gemology

Gems & Gemology

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ABOUT THE COVER: During the 1600s the Spanish conquerors of the New World shipped tons of gold, silver, and copper back to their mother country. They also sent back thousands of carats of rough and jewel-set emeralds. This rosary was one of the many emerald treasurers brought up from the sunken Nuestra Señora de Atocha during the past decade. It had been in its underwater tomb for over 350 years. Staff at the GIA Gem Trade Laboratory and their colleagues have examined several of the emerald and gold treasures recovered from the shipwreck; they report their gemological discoveries and observations on the goldwork in this issue. Photo by Shane F. McClure, GIA Gem Trade Laboratory, Santa Monica, CA.

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Gems & Gemology welcomes the submission of articles on all aspects of the field. Please see the Suggestions for Authors in the Spring 1989 issue of the journal, or contact the editor for a copy. Letters on articles published in *Gems & Gemology* and other relevant matters are also welcome.

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Reflections on the 1980s

The past decade has been one of significant changes in the diamond and colored stone industry, with a potential impact that is perhaps unparalleled in modern gemology. We began this decade with major upheavals in the diamond market and are ending it with that market stronger than ever. We have seen colored stones reach new heights in availability and consumer awareness. New localities have been found, as have several unusual varieties of old favorites (witness the new Paraíba tourmalines). Perhaps most challenging of all have been the technological advances: The broader use of heat treatment and irradiation, the application of a process that actually fills cleavages in diamond, the appearance of new synthetic emeralds and corundum, and the unprecedented commercial availability of gem-quality synthetic diamonds have brought new demands in gem identification and evaluation. They have also spurred the introduction of new techniques (infrared spectroscopy, for one) into the gemology laboratory.

We at *Gems & Gemology* are proud to have published the first in-depth reports on many of these new localities, new treatments, new synthetics, and new identification techniques. The 1980s also marked the introduction of the larger format, full-color *G&G*, with a mandate to supply the most thorough and current gemological information to the international gem community. To close the 1980s and look forward to the final decade of the second millenium, we have asked a number of prominent gemologists and researchers to summarize the key developments of the last 10 years in gem localities, treatments, synthetics, technology, and jewelry manufacturing and design, as well as provide a preview of the '90s. These articles will be presented in a special, expanded Spring 1990 issue and will serve as the springboard with which we plan to "face the future" at the June 1991 International Gemological Symposium. In the future, as we have in the past, *Gems & Gemology* will continue to keep you informed of the latest and most significant events in this exciting field.

Richard T. Liddicoat
Editor-in-Chief

EMERALD AND GOLD TREASURES OF THE SPANISH GALLEON NUESTRA SEÑORA DE ATOCHA

By Robert E. Kane, Robert C. Kammerling, Rhyna Moldes, John I. Koivula, Shane F. McClure, and Christopher P. Smith

During the 1970s and 1980s, treasure hunters discovered the centuries-old remains of the sunken Spanish galleons Nuestra Señora de Atocha *and* Santa Margarita. *Not only did they find massive amounts of silver and gold in coins, bars, and chains, but they also uncovered a number of rough emeralds and several pieces of emerald-set jewelry. Recently, some of the treasures recovered from the* Atocha *were examined at the Santa Monica office of the GIA Gem Trade Laboratory. Gemological testing of the emeralds revealed inclusions typical of stones mined in Colombia as well as possible evidence of extended submersion in seawater. Study of the jewelry revealed a high-karat gold content and fine workmanship that represented methods typical of the era.*

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During the Spanish conquest of the New World in the 1500s, *conquistadores* discovered vast amounts of valuable commodities such as gold, silver, copper, indigo, pearls, and emeralds. The last of these, emeralds, was one of the rarest items — with only the exhausted Egyptian deposits then known to the Western world. Gold and silver were mined in Upper Peru (now Bolivia), Mexico, and the area that was eventually known as New Granada (Colombia, parts of Venezuela, Ecuador, and Panama). In 1537, Gonzalo Jiménez de Quesada was pursuing his conquest of the interior of Colombia when his men located emerald deposits in an area then called Somondoco and later named Chivor. Subsequently, emerald deposits were also found at Muzo, with its even larger (and, many consider, finer) crystals. The Spaniards quickly enslaved the local tribes and forced them to work the mines, as they had done elsewhere (Keller, 1981). Many emeralds, both set in jewelry and as rough crystals (figure 1), were subsequently sent to Spain.

Spain set up a sophisticated system of delivery and pickup to and from the New World and Asia using fleets of cargo vessels guarded by warships (Lyon, 1982; Mathewson, 1987). On September 4, 1622, the cargo vessels and galleons of the *Tierra Firme* fleet set sail from Havana, Cuba, carrying many noblemen and their families, as well as soldiers, slaves, and priests. Besides the personal effects of the passengers, the cargo of the heavily armed rear galleon *Nuestra Señora de Atocha* included 901 silver bars, 161 gold bars or disks, and about 255,000 silver coins (Lyon, 1976), along with copper ingots and, although not entered into its manifest, emeralds. Soon after leaving port, a

Figure 1. These rough emeralds and emerald-set and gold jewelry, found in the main body of the wrecked 17th-century Spanish warship Nuestra Señora de Atocha, *are the subject of this investigation. Photo by Shane F. McClure.*

ferocious hurricane ravaged the convoy; the *Atocha* and another galleon, the *Santa Margarita*, also heavy with cargo, were two of eight ships dashed against the reefs of the Florida Keys (figure 2). Over the next few years, Spanish salvors enlisted the help of local native pearl divers, with their rudimentary diving techniques, to search for the ships and recover their cargo (Christie's, 1988); they had some success with the *Santa Margarita*, but very little with the *Atocha* (Lyon, 1976, 1982). In all, only 380 silver ingots, 67,000 silver coins, and eight bronze cannons were recovered (Mathewson, 1986). Eventually, the remains of the ships were swept farther out to sea and forgotten.

MODERN RECOVERY OF THE TREASURES

In the early 1960s, almost 350 years after the sinking of the galleons, treasure hunter Mel Fisher and a group of collaborators arrived in Florida determined to find Spanish shipwrecks in the seas off the peninsula. After considerable success with other recoveries, the group decided in the late 1960s to search for the *Atocha* and the *Santa Margarita*. R. Duncan Mathewson, the operation's archaeologist, detailed the recovery efforts extensively in his book, *Treasure of the Atocha* (1987).

While studying the history of Spanish Florida in Spain's Archives of the Indies, Dr. Eugene Lyon came across Francisco Nuñez Melián's 17th-century account of the salvage of the *Santa Margarita* (Lyon, 1976). This document specified that the ships had gone down near the *Cayos del Marquez* (Keys of the Marquis), a group of islands situated between Key West and Dry Tortugas. Recovery efforts started in earnest.

In June 1971, divers found the anchor of the *Atocha* and a lead musketball (Lyon, 1976, 1982). Days later, professional underwater photographer Don Kincaid discovered a gold chain 8½ feet (259 cm) long. Not until 1973, however, did the Fisher group recover any significant treasure: approximately 4,000 silver coins and other objects (including swords, some gold coins, and a rare navigation instrument known as an astrolabe) found in an area called the "Bank of Spain" (Mathewson, 1986). They still did not know if they had found either the *Atocha* or the *Santa Margarita*; only when they encountered the main hulls and compared their contents with those listed in the ships' manifests would they be able to establish proof of the source.

In July 1975, Fisher's son Dirk found five cannons very near the "Bank of Spain"; later, the crew found four more cannons close to the first group. Some of these bore recognizable marks, which matched those indicated in the *Atocha's* documents. Only a few days later, though, diving came to a tragic halt after Dirk, his wife, and another member of the crew perished when their vessel sank.

The search eventually resumed and a variety of artifacts were recovered over the next five years, but not the actual hulls with the bulk of the cargo. "Mailboxes" (huge metal conduits designed by Fisher to pump clear water to the bottom of the ocean to increase visibility and remove sand from the wreck site) aided their efforts. Finally, in June 1980, the searchers located six silver ingots, copper ingots, and thousands of silver coins surrounded by ballast and shipwreck debris. From the manifest, the crew determined that they had found the hull of the *Santa Margarita*. During the next two years they recovered 43 gold chains with a total length of 180 feet and a concentration of gold bars worth an estimated $40 million (Mathewson, 1987). Yet the treasures of the *Atocha* remained elusive.

In 1985, however, two divers came across what they thought was a coral reef; it turned out to be silver bars and coins. Then they noticed the wooden beams in the area: They had finally found the main hull of the *Atocha*. The searchers eventually brought up seven chests filled with 2,000 silver pieces each and an eighth filled with gold bars (Starr et al., 1985). An added bonus, not on the manifest, were hundreds of rough emeralds—over 2,300 according to a 1986 article in the *Los Angeles Times*.

Many gold artifacts and jewels set with gems, including emeralds, also were found in the wreck (figure 3). One emerald ring, an engraved piece that still retains part of the black enameling in the shank, was sold at Christie's New York in June 1988 for $79,200. Many of the emeralds and other artifacts are on exhibit at the museum of the Mel Fisher Maritime Heritage Society in Key West, Florida.

THE EMERALDS AND GOLD TREASURES STUDIED

Several of the items recovered from the *Atocha* were recently submitted to the GIA Gem Trade Laboratory for examination. These included (again, see figure 1): seven rough emerald crystals

Figure 2. The 28 ships of the Tierra Firme *fleet* were laden with goods obtained on the summer trade circuit through the Caribbean colonies as well as those brought from Manila. Weeks behind schedule, they left Havana during hurricane season, and were caught in a violent storm on only the second day out of port. The Santa Margarita *and the* Atocha *went down in sight of each other, with six other ships lost over a course of 50 miles (Lyon, 1982). Painting by Richard Schlecht; calligraphy by Julian Waters; compiled by John R. Treiber; courtesy of the National Geographic Art division.*
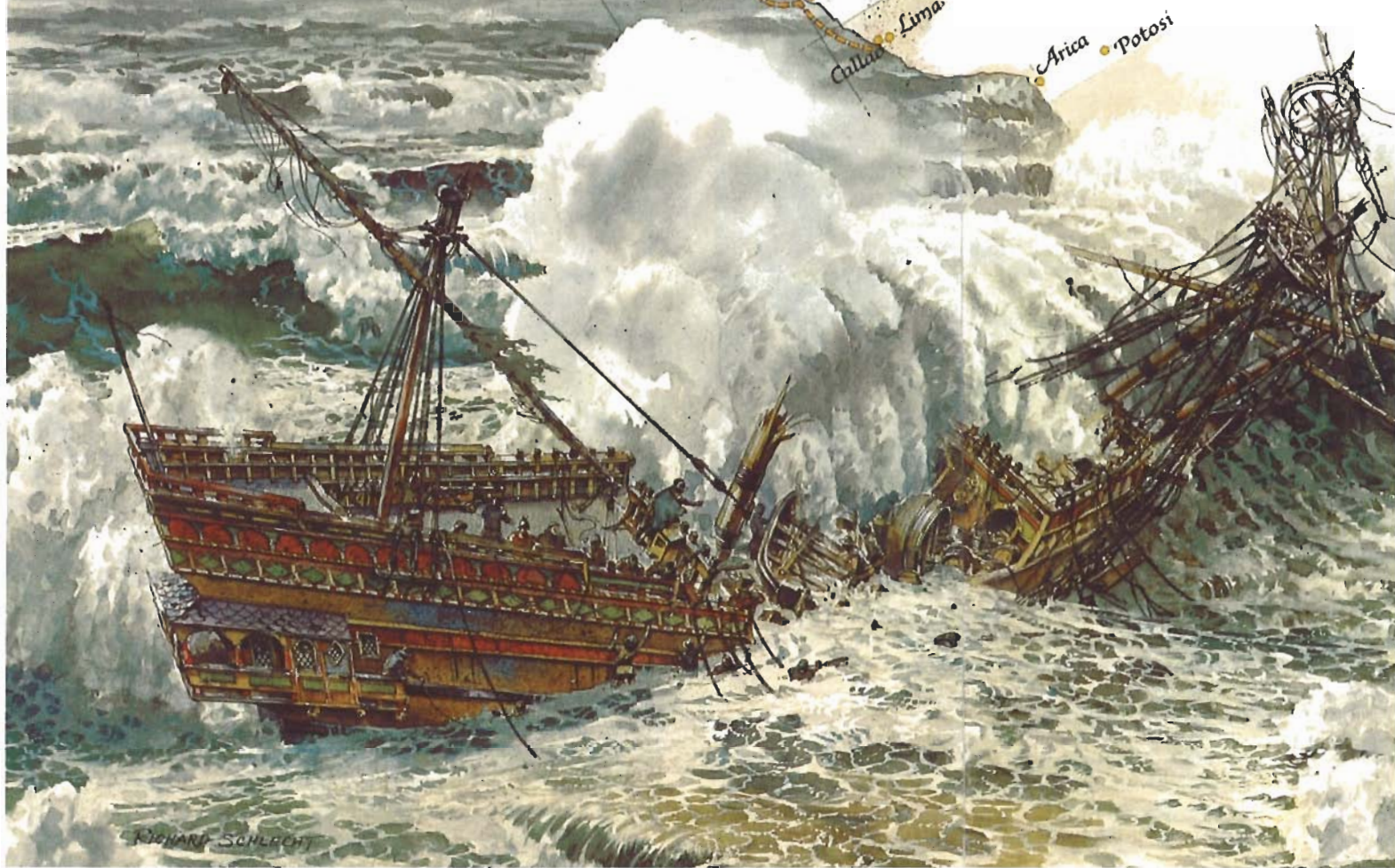
ranging from 3.69 to 64.46 ct; one gold rosary and crucifix set with nine cabochon emeralds (the largest is an 8.9-mm round cabochon); two gold rings each set with a single emerald (6.7 × 7.3 mm and 8.6 × 8.9 mm, respectively); one gold brooch set with a large (9.9 × 14.9 mm) rectangular step-cut emerald; and one gold chain. Also examined

was an engraved gold spoon with minor remaining inlay (figure 4).

GEMOLOGICAL DESCRIPTION OF THE EMERALDS

A gemological investigation of all the emeralds, both rough and fashioned, was carried out in order

Figure 3. The crucifix depicted on the cover of this issue and in figure 1 was recovered by divers in 1986, approximately 100 feet (35 m) from the main wreck site of the Atocha. Photo © Don Kincaid.

to document the properties of these historically significant stones as well as to determine if there was any evidence of their long submersion in the sea.

Visual Appearance. The seven emerald crystals ranged from transparent to translucent and from medium to dark tones of green to slightly bluish green (figure 5). We observed scattered white patches on the surfaces of most of the crystals; these were especially prominent on the 30.34-ct and 64.46-ct pieces.

The crystals were all first-order hexagonal prisms, the most common form of beryl crystallization (Sinkankas, 1981). Five were terminated at one end with pinacoidal faces; one displayed pinacoidal terminations at both ends, with only a small broken surface where it had been attached to the matrix; and one exhibited only hexagonal prism faces, with both ends broken.

Most of the emeralds set in jewelry, with the exception of two cabochons suspended from the crucifix, were bezel set in closed-back mountings, limiting visual examination. The two square step-cut stones mounted in gold rings were both moderately included, with one a medium green and the other a medium-dark green. The nine cabochons set in the crucifix were very well matched for color and transparency: medium to medium-dark green and lightly to moderately included. Six of these cabochons had small polished concave surfaces on their exposed areas.

The largest faceted stone (9.9 × 14.9 mm) was set in a brooch (figure 6). The stone revealed no inclusions to the unaided eye and appeared to be very dark green (almost black) with virtually no brilliance. The reasons for the exceptional darkness and lack of internal reflection were discovered during the microscopic examination (see below).

Refractive Indices and Birefringence. We obtained R.I.'s using a Duplex II refractometer in conjunction with white light for the rough crystals and the cabochons and a sodium-equivalent light source for the faceted stones. Because of irregularities on the unpolished surfaces, including surface etching, we could only obtain a very vague shadow reading of 1.58 on the seven crystals. Clearer spot readings of 1.57 or 1.58 were obtained on all nine of the cabochons set in the crucifix. The faceted emerald in the brooch and the larger ring-set emerald were determined to have refractive indices of $\epsilon = 1.570$ and $\omega = 1.578$, with a birefringence of 0.008. The faceted stone in the other ring read slightly higher, $\epsilon = 1.572$ and $\omega = 1.580$. These refractive indices are consistent with those reported in the literature for emeralds originating in Colombia (Sinkankas, 1981). While the birefringence determined for the three faceted stones is higher than that reported for Colombian emeralds, in the authors' experience this value is in fact quite common for stones from this country. Although birefringence could not be determined on the rough crystals or the cabochons, their doubly refractive nature was confirmed with a polariscope and/or dichroscope.

Figure 4. These emerald crystals from the Atocha are sitting in a large gold spoon that was also among the items recovered from the galleon. The ornate handle still shows remnants of some type of inlay. Photo by Shane F. McClure.

Pleochroism. Using a calcite dichroscope, we observed dichroism in strongly distinct colors of bluish green parallel to the c-axis and yellowish green perpendicular to the c-axis in all seven crystals. These results are typical of many natural emeralds (Webster, 1983).

Chelsea Filter Reaction. When viewed through a Chelsea filter, all seven crystals displayed a spectacular saturated dark red, a reaction consistent with that described in the literature for Colombian emeralds (Webster, 1983). The mounted emeralds exhibited a red reaction of varying intensity.

Figure 5. The seven emerald crystals examined (3.69–64.46 ct) ranged from transparent to translucent and from green to slightly bluish green. The chain surrounding the crystals is one of many from the Atocha wreck site. It has been suggested that the chains were worn as jewelry to try to escape taxation; individual links could be removed and used as coinage (Lyon, 1982). Note the draw lines on the links, evidence of the relatively crude technique used. Photo by Shane F. McClure.

Figure 6. This brooch contained the largest faceted stone examined, measuring 9.9 × 14.9 mm. The dark appearance of this otherwise fine emerald is caused by the combination of a relatively shallow pavilion, seawater trapped in the setting, and corroded remnants of the backing. Photo by Shane F. McClure.

Absorption Spectra. The visible-light absorption spectra of the seven crystals, examined with a Beck prism spectroscope, appeared to be essentially the same as those for emeralds described by Liddicoat (1989, p. 135). When looking down the optic axis direction, we observed a vague general absorption from 400 nm to approximately 480 nm, a sharp line at 477 nm, a broad band of absorption between 580 and 615 nm, and lines in the red at 637, 646, 662, 680, and 683 nm. We observed a similar spectrum perpendicular to the optic axis, but the sharp line at 477 nm was absent. The saturated color and thickness of some of the crystals caused a very strong dark, nearly black absorption in many areas of the visible-light spectrum, which tended to mask the 477-nm line even when the spectrum was viewed parallel to the c-axis.

The same basic absorption pattern, although weaker, was observed in all of the mounted emeralds. Limitations imposed by the mountings made it impossible to examine the stones both parallel and perpendicular to the c-axis. Using a polarizing filter, however, we did observe the 477-nm line associated with the ordinary ray.

Reaction to Ultraviolet Radiation. The crystals themselves appeared inert to long-wave U.V. radiation. However, there was an extremely weak to moderate chalky yellow-green fluorescence in some surface-reaching fractures and cavities. All but one of the crystals had a similar, but much weaker, reaction to short-wave U.V. The exception, the largest crystal (64.46 ct), fluoresced an extremely weak, patchy orange, possibly due to the presence of carbonaceous inclusions. Looking down the c-axis of all of the crystals while they were exposed to long-wave U.V. radiation, we also noted that the weak fluorescence seemed to be confined to less than 1 mm of the periphery of the crystals.

All of the fashioned stones were essentially inert to both long- and short-wave U.V radiation, although a few exhibited a very weak chalky yellow-green fluorescence to long-wave U.V. in small surface-reaching fractures. Furthermore, the large faceted emerald in the pendant appeared to fluoresce a weak chalky yellow-green from within, rather than from irregularities in the exposed surfaces.

The chalky yellow-green fluorescence in some of the fractures was surprising, since it is usually associated with emeralds that have had surface-breaking fractures oiled to make them less apparent. Microscopic examination showed that there was no liquid of any kind in most of the fractures. While two of the rough crystals did exhibit some form of liquid in a few fractures (figure 7), subse-

Figure 7. This fracture system in one of the emerald crystals contained a liquid that did not react like the oils commonly used to treat emeralds today. Photomicrograph by John I. Koivula: darkfield illumination, magnified 10×.

quent testing indicated that it was not an oil like those commonly used to treat emeralds. Specifically, when a thermal reaction tester (hot point), was applied the liquid flowed more rapidly within the fractures than do the typical oils. The liquid also did not "sweat out" of the fractures and bead up on the surface, as will oils used in emerald treatment; it did "sweat out" but most of it then quickly evaporated.

It is possibile that the fluorescence reaction was caused by the residue from an oil that had seeped out and/or had been flushed out by the action of water during the approximately 350 years the pieces sat on the ocean floor. Another alternative is that the crystals were stored in oil after recovery. Or the reaction might be due to something naturally present in the seawater environment. A number of additional observations supported this last theory.

According to expedition diver R. D. LeClaire, a number of the emeralds that appeared very transparent when found underwater and when first brought to the surface subsequently became much less transparent. This observation would be consistent with water-filled fractures drying out on extended exposure to air. In addition, as mentioned above, the weak chalky yellow-green fluorescence of the brooch-set emerald appeared to come from within and not from the exposed upper surfaces. Microscopic examination (covered in more detail below) revealed a liquid (seawater?) trapped beneath the emerald within the bezel setting. Examination of this stone with magnification and while exposed to long-wave U.V. radiation revealed that this trapped liquid fluoresced a chalky yellow-green; the fluorescence could actually be made to "flow" as the pendant was rocked back and forth, allowing the gas bubble to move.

The authors feel that the chalky yellow-green fluorescence exhibited in areas of some of the emeralds is probably due to some fine precipitate of seawater that has entered surface breaks.

Luminescence to Visible Light. Some gems appear red when illuminated with intense transmitted light. This reaction is typical of many chromium-colored materials, including various synthetic emeralds. It is also seen, infrequently, in some natural emeralds, such as fine-quality stones from Chivor and some medium- to light-toned emeralds from another Colombian locality, Gachalá (Kane and Liddicoat, 1985). Of the study group, only the
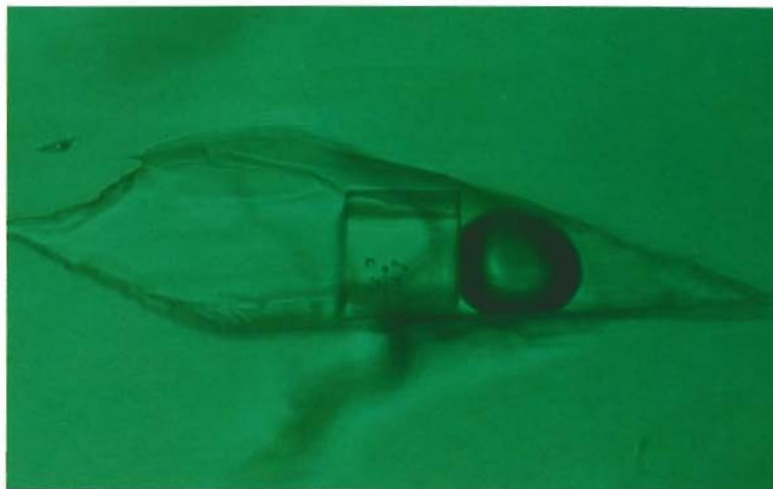

Figure 8. High magnification (200×) revealed minute fluid inclusions in the solid phase of this three-phase inclusion in one of the Atocha emeralds. Photomicrograph by John I. Koivula; transmitted light.

faceted stone in the brooch exhibited a red transmission luminescence; the reaction was very strong.

Specific Gravity. Using a Mettler AM100 electronic scale equipped with the appropriate attachments, we made at least three hydrostatic weighings for each of the crystals. Specific gravity values of 2.67 to 2.71 were determined. We attributed the relatively low values for several of the crystals to bubbles trapped in large surface-breaking cavities as well as to gaseous phases in multi-phase fluid inclusions within these stones (see the Microscopic Examination section below). Significant quantities of trapped gaseous inclusions can decrease specific gravity in emeralds just as, for example, pyrite inclusions (S.G. 4.95 to 5.10) can significantly increase it. The S.G. range determined is consistent with that reported in the literature for Colombian emeralds (Sinkankas, 1981).

Microscopic Examination. All of the emeralds exhibited classic three-phase inclusions of the type associated with Colombian localities. These inclusions ranged from less than 0.1 mm to slightly over 1 mm in the long direction. All had a jagged outline and contained a gas bubble and one or more cubic crystals (figure 8). In addition, all were oriented parallel to the prism faces, indicating that they were primary (i.e., they did not result from the

Figure 9. Dolomite crystals were exposed on the fracture surface of this 15.12-ct Atocha emerald crystal. Photomicrograph by Robert E. Kane; oblique illumination, magnified 10×.

Figure 10. Surface etching was noted on all of the emerald crystals examined. Photomicrograph by John I. Koivula; oblique illumination, magnified 6×.

healing of fractures). In some instances, relatively high magnification (200×) revealed primary fluid inclusions within the solid phases of the three-phase inclusions (again, see figure 8).

Several translucent crystals were exposed on a fracture surface of the 15.12-ct crystal (figure 9). These were first tested with a minute drop of dilute (10%) hydrochloric acid solution which produced an effervescence characteristic of carbonate minerals. X-ray diffraction analysis showed an exact match with dolomite.

All of the rough crystals showed surface etching (figure 10). Some, most notably the two largest, showed a considerable amount of what appeared to be very deep etching on the prism faces. Microscopy revealed that this was caused by superficial etching that had broken into near-surface fluid inclusions which apparently subsequently drained. Even on those faces that appeared relatively smooth to the unaided eye, magnification revealed very fine etch figures. Emerald, like other

hydrothermally grown natural crystals, frequently shows surface etching caused by dissolution (Sinkankas, 1981).

One of the most interesting discoveries during the microscopic examination was the cause of the very dark, dull appearance of the faceted brooch-set emerald. We knew that the relatively shallow pavilion would create a "window" effect, the result of unplanned light leakage, that would seriously diminish brilliance. However, closer examination revealed that the fairly large space between the pavilion facets of the stone and the back of the mounting contained a liquid (thought to be seawater) that had probably been forced in by the pressure exerted on the piece during burial at sea over three and a half centuries. This liquid, which contained a large movable air bubble (figure 11), caused a partial immersion effect that undoubtedly contributed significantly to the stone's lack of brilliance. Finally, what appeared to be the remains of a reflective backing were trapped in the space and floated about as the liquid was agitated. The authors speculate that this backing may have been silver that corroded over time, further contributing to the dark appearance of the emerald.

SOME OBSERVATIONS ON THE GOLD WORK

Most of the jewelry we examined appeared to be cast, except for the two chains and some components of the brooch and rosary. The casting process was probably an early form of the modern-day lost-wax casting technique, which uses a wax carving encased in a thick, porous clay mixed with coarsely ground charcoal (Mitchell, 1985). Al-

Figure 11. Close examination of the brooch revealed liquid and a large gas bubble between the pavilion facets of the emerald and the back of the bezel setting. The black residue trapped between the emerald and the mounting in the pendant may have been the remains of a silver coating on either the pavilion facets of the stone or on the inner surface of the bezel itself. Slight movement of the brooch caused the bubble and the residue to move freely. Photomicrograph by Robert E. Kane; oblique illumination, magnified 10×.

though sand casting (i.e., casting from a negative impression made in sand; Hayward, 1976) was also popular in Europe at this time, the detail on the jewelry examined makes it unlikely that this coarser technique was used.

The metal was soft and appeared to be of high karat gold. Thornton Mann, of the GIA Jewelry Manufacturing Arts Department, performed an acid test oh a portion of the rosary and determined it to be slightly less than 24K. All of the pieces were a deep yellow color except for one gold chain (46 in. long, 15.8 troy oz.) that was slightly greener and less saturated. XRF analysis of this piece by the GIA Research Department determined the primary elements to be gold, platinum, silver, and titanium, with trace amounts of iron and copper. As would be expected of a chain from this era, the surface of the metal was very uneven, with features characteristic of a rudimentary drawing process (see figure 5).

The emerald brooch was a particularly fine example of New World goldsmithing (figure 6). The bezel setting was burnished with such accuracy that the stone was held by pressure applied at the girdle, with very little metal actually extending onto the crown; in fact, at one corner a small portion of the upper girdle plane was exposed, with the gold bezel firmly against the girdle edge. The metal folded onto the crown was burnished to a paper thin edge for a perfectly flush seal. This was carried out with such precision that magnification revealed tiny gold remnants pressed into shallow abrasions in the emerald where the bezel and facet met, leaving the metal at a relief no higher than that of the facet. The plate on the back of the emerald was initially held in place by a series of raised pegs that were subsequently soldered for a more permanent seal. A pair of square arches had

also been soldered to opposite sides of the backing, probably so that the piece could be used with a pin.

The rosary necklace presented an intriguing mystery: All of the beads were missing, with only a series of opposing bell caps remaining (figure 1). Although one theory is that the beads might have been pearls (M. Fisher, pers. comm., 1989), this is unlikely given the relatively large size of the spaces and the fact that no remnants remained. Although badly corroded, recognizable pearls were recovered from the wreckage of the Atocha (Mathewson, 1987). It is more likely that these were wooden beads, which were commonly used in rosaries, and which would have deteriorated rapidly in seawater (D. Kincaid, pers. comm., 1989).

The emerald-set crucifix hanging from the necklace was ornately carved. It is typical of those worn by high church officials and European nobility during this era (Muller, 1972). The several bezels were actually cast as a single piece, not as individual bezels soldered together. They were firmly attached to the main body of the crucifix by several raised metal pegs, with no solder present.

The gold spoon (11.3 cm long, 1.91 troy oz.) consisted of a large basin and an intricately carved handle (figure 4). These were held together by only two crimped pegs; again, no solder was used. The pegs appear to have worn with time, so that there is now movement between the two pieces and the joint is very fragile.

Both the back of the crucifix and the handle and back of the spoon were intricately engraved (figure 12), with deep figures and channels that were rough in texture, typical of engraving used for enameling (C. Weber, pers. comm., 1989). David Callaghan, of the Gemmological Association of Great Britain, suggested to the authors that niello, another material also popular during this period,

Figure 12. Note the intricate engraving on the back of the spoon and the crucifix. The rough nature of the engraving suggests that it was all inlaid at one time. Photo by Shane F. McClure.

may have been used instead of enamel. Niello is an opaque dark gray to black metallic mixture of sulphur, silver, copper, and lead that is ground into small grains, not powdered; enamel is a semitransparent to opaque glass of varying composition that is ground to a fine powder (Ashbee, 1967). Both materials are applied and finished by similar techniques. The delicate artistry on the back of the cross suggests that enameling was probably used here to better display the engraver's workmanship while adding color to the intricate scenes depicted. Channels on the handle of the spoon, however, still contained severely etched, slightly granular remains of what could have been the coarser niello. The crudeness of the engraving on the back of the spoon basin suggests the use of either niello or a more opaque enamel, although the subject matter — birds — is more compatible with colors possible only with enamel.

SUMMARY

The gemological properties of the emeralds examined for this article are consistent with those reported in the literature and noted in the experience of the authors for emeralds from Colombia. Some features could be attributed to the immersion of the stones in seawater for an extended period of time.

The jewelry represents superb craftsmanship, using several techniques popular in the early 17th-century. These include early forms of lost-wax casting and chain drawing, as well as examples of stone setting and engraving that rival any seen today.

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ZIRCON FROM THE HARTS RANGE, NORTHERN TERRITORY, AUSTRALIA

By Maxwell J. Faulkner and James E. Shigley

Gem-quality zircon from a relatively un-derdeveloped locality in the Harts Range of central Australia is described. While exhibiting many properties of other gem zircons, this material is unusual in its almost total lack of radioactive trace elements. Thus, there is little or no radia-tion-related structural damage as is the case with some other gem zircons. The Harts Range material occurs in a size, quality, and color range suitable for faceting.

A long-known but underdeveloped locality in Austra-lia's Harts Range is now producing some magnificent gem zircons in an attractive variety of yellow, brown, pink, and purple colors (figure 1) in sizes typically of several carats. Occasionally, even near-colorless crystals are found. Of particular significance is the fact that these zircons contain little or no detectable amounts of radioac-tive trace elements. Thus they display no evidence of the structural damage that is common in some gem zircons from other localities. This article briefly describes the geologic occurrence and gemological properties of these interesting zircons.

WHAT IS ZIRCON?

Zircon is a widely distributed accessory mineral in ig-neous rocks, particularly granites and syenites (Deer et al., 1982; Webster, 1983). It is a fairly common detrital mineral in some sediments due to its resistance to chemical attack. Zircon also occurs in certain metamorphic rocks such as marbles, gneisses, and schists. While often found as small, rounded grains, zircon can occur as large, well-formed prismatic crystals. Because of its relatively high refractive index, dispersion, and hardness, zircon has long been used as a gemstone.

Chemically, zircon is zirconium silicate ($ZrSiO_4$); how-ever, there is always a small amount (usually about 1%) of the element hafnium present (Deer et al., 1982). A number of trace elements can also occur in zircon, including uranium and thorium. When present, these two trace elements undergo radioactive decay, thereby giving off energetic alpha particles that can cause extensive struc-tural damage. As a result of this internal radiation bom-bardment, the initially crystalline zircon (referred to as *high zircon*) progressively changes into an amorphous, noncrystalline (or metamict) state (*low zircon*; see Holland and Gottfried, 1955). Transition to the metamict condition

Figure 1. These faceted zircons from the Harts Range illustrate some of the attractive colors in which this material occurs. They range up to 5 ct in weight. Photo by Robert Weldon.

is accompanied by changes in physical and chemical properties (such as a decrease in density, refractive index, and transparency, and an increase in water content). Thus, gemological properties such as refractive index or specific gravity can lie anywhere between the values for high and low zircons (see table 1).

While crystalline zircons occur in a range of colors, metamict zircons are typically green or brown. Some low and intermediate zircons can be transformed back into high zircons by heating them to 1450°C for six hours (Chuboda and Stackelberg, 1936), which heals the radiation-induced structural

damage. Like most gem zircons, stones from the Harts Range belong to the high type.

LOCATION AND ACCESS

The Harts Range lies in the south-central portion of the Northern Territory, toward the center of Australia (see figure 2). The zircon occurs at a site aptly called Zircon Hill, which can be reached from the town of Alice Springs by driving 69 km (43 mi.) north on Stuart Highway, and then 77 km (48 mi.) east on Plenty Highway. The turnoff from Plenty Highway to the zircon deposit is marked by a large windmill and several concrete storage containers at a livestock watering station called Mud Tank Bore. From this turnoff, the last 9 km (5.6 mi.) south to Zircon Hill is a gravel road, suitable for passenger cars. The digging area for zircons is in open savannah country crossed by a few dry stream beds.

GEOLOGY

The low-lying hills of the Harts Range extend east-west for approximately 150 km (93 mi.). They are composed of schists, gneisses, and other strongly metamorphosed sediments and volcanic rocks which have been intruded by occasional pegmatites (for details of the local geology, see Joklik, 1955). The area has long been known as a source of mica, but it also contains numerous separate small deposits of gem minerals such as ruby, aquamarine, garnet, and amethyst that have been mined sporadically in the past (see McColl and Warren, 1980). In addition, gem-quality iolite, epidote, sunstone feldspar (called "rainbow lattice" sunstone in the trade), as well as kornerupine

TABLE 1. The three types of zircon.[a]

Property	Normal (High)	Intermediate	Metamict (Low)
Color	Colorless, brown, green, yellow, red-brown, orange, blue (heat treatment)	Brownish green, brownish red	Green, orange, brown
Structural state	Crystalline, undamaged	Slightly damaged	Amorphous, damaged
Refractive indices			
ω	1.92–1.94	1.83–1.93	1.78–1.87
ϵ	1.97–2.01	1.84–1.97	
Birefringence	0.036–0.059	0.017–0.043	—
Specific gravity	4.6–4.8	4.2–4.6	3.9–4.2
Radioactivity	Low	Medium	High

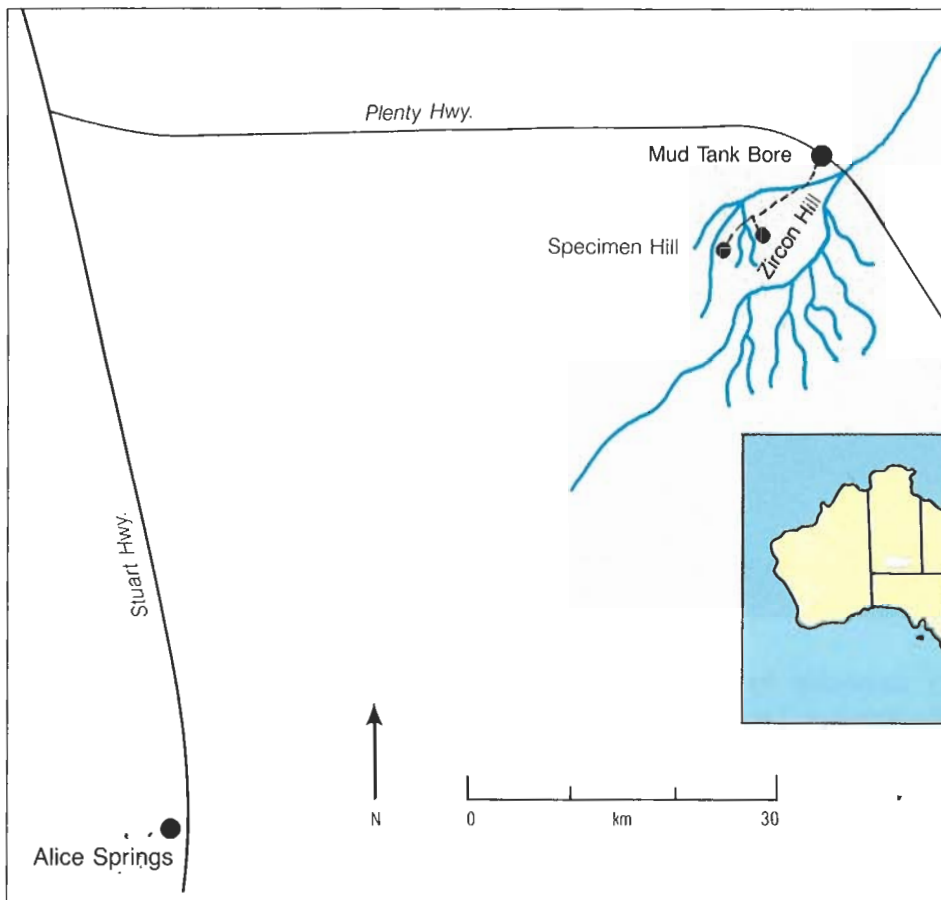[a]Properties compiled from Anderson (1941), Webster (1983), Liddicoat (1987).

and sapphirine (McColl and Warren, 1984) are found in small amounts. A guidebook to localities in this area has been published by the Northern Territory Department of Mines and Energy (Thompson, 1984).

Brown et al. (1989) briefly describe the gem-quality zircons that are found at Zircon Hill both as large crystals and crystal fragments. The entire crest of the hill, a slight, brush-covered prominence that rises some 50 m above the surrounding plateau (which is 1,500 m above sea level), is covered by small diggings (figure 3). Zircon is also found at a nearby location called Specimen Hill, but these crystals, although better developed than those from Zircon Hill, are generally unsuitable for faceting because of internal fracturing. Both locations have been known by local miners and mineral collectors for about 40 years.

At these two localities, the zircon occurs in carbonatite, a carbonate-rich magmatic igneous rock that intruded the country rock to form a series of low hills. The carbonatite is late Proterozoic, and has been age-dated between 1.50 and 1.78 billion years. In addition to calcite and zircon,

phlogopite, magnetite altered to martite, and apatite are present.

While there are many sites in Australia where sediments rich in fine-grained zircons occur, the area around Zircon Hill produces the mineral in large crystals. Zircons up to 2.5 kg (5.5 lbs.) have been recovered from the decomposed carbonatite. Although these large crystals are invariably cracked and flawed, they may contain small areas of material suitable for faceting. Much more common are crystals or crystal fragments that range up to several carats in weight. Only recently has the gem potential of this material begun to be recognized (Brown et al., 1989).

MINING

According to guidelines issued by the Department of Mines and Energy, digging at these deposits can only be done with hand tools, and only after one has obtained a prospecting license. Use of explosives or mechanical equipment is prohibited. Hence, there has not been any large-scale mining in this area.

On Zircon Hill and along a nearby creek bed,

Figure 3. This view of Zircon Hill shows a number of diggings. A sieve used in the process of separating zircon from other mineral and rock fragments stands in the center of the photograph.

crystals and fragments are recovered by hand digging and dry sieving of the weathered soil that covers the carbonatite. Because of zircon's subadamantine luster, the glistening but often highly fractured crystals and fragments are easily recognized. After six hours of easy digging, about 0.5 kg (1 lb.) of mine-run zircons can usually be recovered. Pick-and-shovel mining of the underlying weathered but still intact carbonatite can yield zircon matrix specimens.

As is usual for many gem mineral deposits, less than 5% of the mine-run material is facet grade.

Figure 4. These four of the eight rough zircons examined for this study are representative of the material found at the Harts Range. The largest specimen shown here weighs 19.1 ct. Photo by Robert Weldon.

Some of this material may be enhanced by heat treatment. No accurate figures are available for the quantity of zircon that has been recovered from this deposit thus far, nor has any estimate been made of possible reserves. However, the potential seems quite good.

CHARACTERIZATION OF HARTS RANGE ZIRCON

For this study, we examined eight rough zircons and two faceted stones. The rough pieces weighed between 6.6 and 37.1 ct (figure 4). With the exception of the largest sample, the rough pieces were rounded crystals or fragments. The largest sample exhibited some crystal faces and a recognizable tetragonal habit. Most of these specimens are light brownish purple, but orange-brown, yellow-brown, and near-colorless zircons are also represented. In the authors' experience, purple zircons are the most sought after from this locality (figure 5). The two cut stones examined for this study, one near colorless and the other a light orangy brown, weighed 8.03 and 4.44 ct, respectively (figure 6). Both the rough and faceted near-colorless samples had been heat treated. The gemological properties of these 10 samples are summarized in table 2 and discussed below (for comparison to gem zircons from other localities, see Webster, 1983, and Liddicoat, 1987).

Physical Properties. Using immersion oils and the Becke line method, we found the refractive index to be above 1.81, a value consistent with that of intermediate or high zircons.

Figure 5. This brownish purple zircon from the Harts Range represents some of the best material from this area. The 35-ct stone was faceted by Jennifer Try. Photo by Robert Weldon.

Figure 6. The study also included these two faceted zircons, which weigh 8.93 and 4.44 ct, respectively. The near-colorless stone has been heat treated. Photo by Robert Weldon.

Hydrostatic measurement of the specific gravity of four of the zircons yielded values between 4.62 and 4.72, which are also typical for high zircon. Brown et al. (1989) report the hardness of the material to be 7–7½.

Absorption Spectrum. Many gem zircons exhibit a characteristic absorption spectrum that consists of numerous sharp bands of varying intensity. Anderson (1956) lists more than 40 bands observed in high-type gem zircons, noting that the number, intensity, and sharpness of the bands decreases in the spectra of low-type zircons (see also Webster, 1983, pp. 155–156).

When viewed with a hand-held spectroscope, the Harts Range zircons exhibited a relatively small number of sharp absorption bands (all of which, however, are included in Anderson's list). The 653-nm band was the most prominent, but additional weak bands were seen at 535, 590, 657, and 689 nm in one or more of the samples. We found that the intensity of all these bands was greater in zircons of lighter color, and greatest in the near-colorless, heat-treated material. This confirms the observations by Brown et al. (1989).

We recorded room-temperature absorption spectra for all the zircons using a Pye-Unicam 8800 UV/VIS spectrophotometer. There was little variation among spectra except for the relative intensities of the features that can be correlated qualitatively with the depth of the body color and size of the specimen.

Representative spectra of a light brownish pur-

ple zircon are illustrated in figure 7. These two spectra, recorded in orientations both parallel and perpendicular to the optic axis, can be considered as having four components:

TABLE 2. Gemological properties of Harts Range zircon.

Color	Pink, purple, yellow-brown, orangy brown, near colorless, (produced by heating in a reducing atmosphere)
Transparency	Transparent
Refractive index	Above 1.81 ($\omega = 1.923$, $\epsilon = 1.982$; see Brown et al., 1989)
Specific gravity	4.62–4.72; average 4.65
Absorption spectrum (as seen with a hand spectroscope)	Increasing absorption below 500 nm; possibly a weak, broad band at 535 nm; a weak but sharp band at 590 nm; a strong, sharp band at 653 nm (or a broad band from 650 to 653 nm); and weak, sharp bands at 657 and 689 nm
U.V. fluorescence	
Long wave	Yellowish, brownish yellow, yellowish orange; weak to strong in intensity; cloudy appearance; no phosphorescence
Short wave	Yellow, brownish yellow, yellowish orange, often with zones that are bluish white; moderate to very strong in intensity; cloudy appearance; no phosphorescence
Inclusions	Tiny pinpoint inclusions; needle-like inclusions of an unknown mineral; partially healed fractures and occasional cleavages

1. Increasing absorption toward the ultraviolet, giving rise to the brown component of the color, which we believe results from a color center that produces a very broad absorption band in the ultraviolet with an absorption "tail" that extends into the visible.

2. A broad region of absorption centered at about 540 nm, giving rise to the pink-to-purple coloration, and which we believe is due to a radiation-induced color center, possibly involving rare-earth elements. The shape of this broad band is different in the spectrum taken parallel to the optic axis as compared to the one taken perpendicular to it, which is consistent with the slight brownish purple to purple dichroism observed in this sample.

3. A series of weak but sharp bands that have no influence on the color (since they are found even in near-colorless samples), and are attributed to trace amounts of uranium (as U^{4+}). Fielding (1970) illustrated a spectrum with these same sharp bands for a synthetic zircon doped only with about 10 ppm U^{4+}.

4. A weak broad band centered at 760 nm present only in the spectrum recorded parallel to the optic axis.

Spectra (recorded in a random optical orientation) of the darker purple, yellow, brown, and near-colorless zircons exhibited various combinations of these same features. The weak sharp bands attributed to uranium were present in each spectrum but with slight variations in intensity. In an orange-brown sample, only the broad band in the ultraviolet was present; the absence of the purple color coincided with the absence of the 540-nm broad band. A yellow zircon also displayed the broad band in the ultraviolet, but was missing the 540-nm broad band. Finally, a near-colorless sample had a very flat spectrum that nonetheless exhibit a few of the same sharp bands caused by uranium.

Ultraviolet Fluorescence. Zircon is known to vary widely in both the color and intensity of its reaction to U.V. radiation (Webster, 1983). This is also the case for the Harts Range material. The purple samples fluoresced a weak to moderate brownish yellow to both long- and short-wave U.V. radiation; the yellow-brown, orange-brown, and
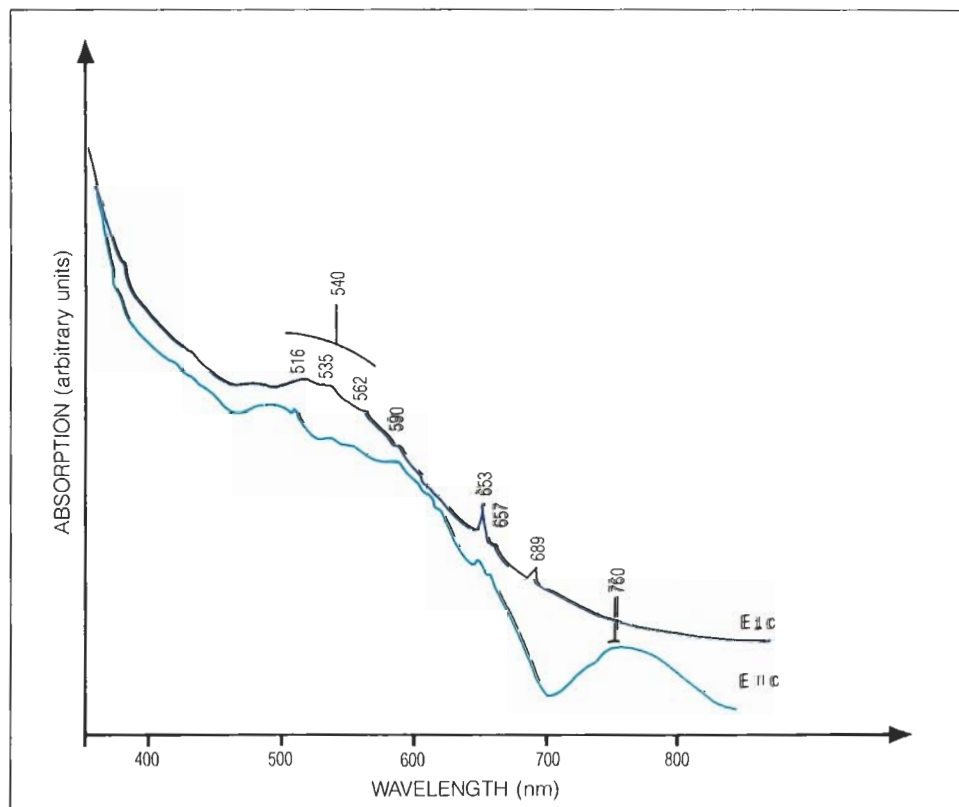

Figure 7. These absorption spectra were recorded both perpendicular (top) and parallel (bottom) to the optic axis of a 37.1-ct brownish purple zircon crystal from the Harts Range.

TABLE 3. Microprobe chemical analyses of eight Harts Range zircons.[a]

Wt. % Oxides[b]	Light purple	Yellow	Near colorless	Light purple	Light purple	Orange brown	Light purple	Light purple
SiO_2	33.03	33.04	32.44	32.41	32.45	32.57	32.56	32.36
CaO	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.02
ZrO_2	66.70	66.27	66.58	66.58	66.29	66.45	66.58	66.14
Er_2O_3	0.10	0.03	0.03	ND	0.01	0.03	0.05	0.03
Tm_2O_3	0.10	0.08	0.03	BDL	ND	ND	0.04	BDL
Lu_2O_3	ND	0.10	ND	0.06	ND	0.02	0.03	BDL
HfO_2	1.31	1.41	1.48	1.48	1.50	1.44	1.37	1.49
TOTAL	101.25	100.94	100.58	100.55	100.26	100.52	100.64	100.04

[a]Figures based on an average of five point analyses
ND = Not detected
BDL = Measurement obtained at or below the reliable detection limits (approximately 10 ppm) of the equipment and operating conditions. Cameca MBX microprobe run at 15 KeV and about 40 nanoamps; 100 second counting time; standards—Si, Zr (zircon), rare-earth elements (Drake Weill REE glass), Fe (hematite), Ca (wollastonite), U (davidite), Th (ThO_2), Ce (CeO_2), Gd (gadolinium gallium garnet), Y (yttrium aluminum garnet), Hf (pure metal)
Complete analyses and further details of operating conditions are available on request to the authors.
Analyst: Paul F. Hlava
[b]Other elements measured: Fe, Y, La, Ce, Th, U = ND – BDL; Pr $\leq$ 100 ppm, Nd $\leq$ 200 ppm, Sm $\leq$ 350 ppm, Eu $\leq$ 200 ppm, Gd $\leq$ 250 ppm, Tb $\leq$ 200 ppm, Dy $\leq$ 250 ppm, Ho $\leq$ 150 ppm, Pb $\leq$ 100 ppm.

near-colorless zircons fluoresced a more intense yellow or yellowish orange color. No phosphorescence was noted for either long- or short-wave conditions. In all cases, the fluorescence was cloudy. In addition, zones (sometimes very conspicuous) of blue-to-white fluorescence could be seen in several of the samples during exposure to short-wave U.V. radiation.

Chemical and X-ray Data. Qualitative chemical analyses using wavelength-dispersive X-ray fluorescence were performed on samples of each color. The presence of zirconium, hafnium, and iron was indicated, while the following elements were checked for but not detected: uranium, thorium, yttrium, tin, arsenic, gallium, technetium, lead, niobium, and tantalum.

The samples were also analyzed quantitatively using a Cameca MBX electron microprobe (table 3). These results confirm the almost complete absence of uranium and thorium. The concentration levels of uranium, which is indicated by the presence of sharp U^{4+}-related absorption bands in the spectrum, are too low to be detected by microprobe analysis. It is interesting that no iron was detected during this analysis, which contrasts with the X-ray fluorescence data.

An X-ray diffraction pattern was prepared for samples of each of the four colors using a Rigaku powder diffractometer. The resulting patterns are consistent with the pattern of zircon illustrated in the 1986 JCPDS Powder Diffraction File (pattern no. 6266). Least-squares refinement of 20 mea-

sured reflections (for the brownish purple zircon that produced the absorption spectra shown in figure 7) yielded unit-cell dimensions of $\underline{a}$ = 6.603(4)Å and $\underline{c}$ =´ 5.983(5)Å. These values are nearly identical to those for an idealized zircon crystal structure (see Deer et al., 1982).

Documentation of Radiation Level. Some gem zircons can be slightly radioactive due to their contents of uranium and thorium. Using a portable Geiger-Muller detector (Technical Associates Model 6A) attached to a scaler/counter, we checked the radiation levels of each of the eight rough samples. To isolate the samples from background radiation in the surrounding environment, we positioned both the sample and the detector inside a container of lead bricks. In each instance, the measured level was identical to the level of natural background radiation. Under these same testing conditions, several gem zircons from the GIA collection display radiation levels slightly above background. Our results further substantiate the very low uranium and thorium contents of these zircons.

Microscopy. The zircon samples we examined were transparent with no hint of cloudiness except for a few local areas that contained small inclusions. In each sample, the color of the material appeared to be evenly distributed.

The two faceted stones did contain planes of tiny inclusions along partially rehealed fractures (fig-

FACETING OF HARTS RANGE ZIRCON

To take best advantage of the optical properties of zircon, the style and method of faceting is important. For the initial dopping, the senior author uses a wax developed by Heath Sabadina that is both tough and allows time for accurate centering. Sabadina wax is made by mixing green Samson or Jewelers' Special wax with an equal volume of flake orange shellac, heating the mixture to just below the boiling point, and then pouring it into a large volume of cold water. The stone is usually oriented on the dop for maximum weight recovery, since the pleochroism of these zircons is weak. However, some cutters do orient it on an optic axis of the crystal to minimize the double images of the pavilion facet junctions caused by birefringence.

The senior author roughly shapes the zircons by hand on a 180-grit diamond-bonded lap (all of his laps are either Crystalite Maja or glass). Then he dops the stone with the Sabadina wax and locks the dop in the chuck of his Gemax faceting machine. After setting the protractor angle to 90°, he lowers the dopped stone to a 260-grit lap and in free wheel (if a standard brilliant or a round stone) proceeds to cut the outside to the desired diameter. The table is cut and polished at 0° or at 45° using a 45° dop.

All cutting is done first on a 1200-grit, then a 3000-grit, lap; all polish is with either a ceramic or a tin lap. After the table is polished, the protractor is set to a 40° angle to cut the eight main facets of the crown; then the eight star facets are cut at 24°. The author rechecks the accuracy of the main and star facets before proceeding to cut the 16 girdle facets. These facets are then polished and the stone transferred to a second dop using epoxy putty as an adhesive. After the epoxy putty is set hard (approximately 20 minutes in sunlight), the first dop is removed either by heating the wax with an alcohol lamp or by means of blacksmith's pincers.

The author then proceeds to facet the pavilion with the common zircon-cut facets, making the main facets 43°. After the crown has been completed, he sets the protractor to 88° and in free wheel polishes the area needed for the girdle.

ure 8). One of these stones also displayed a small needle-like solid inclusion of unknown identity. Finally, when the faceted stones were examined with magnification, the expected doubling of facet junctions was characteristically quite pronounced. Brown et al. (1989) also reported (and illustrated) small needle-like crystals thought to be apatite, brownish lath-like crystals of an unknown mineral, and rounded unknown crystals surrounded by a halo of tiny cracks.

Figure 8. At 5× magnification, small inclusions were observed lying along partially rehealed fractures in the faceted zircons studied. Photomicrograph by John I. Koivula.

Effects of Heating. Heat treatment has long been used to transform reddish brown zircon into more marketable colorless, blue, or red material (for further details, see Webster, 1983, pp. 156–158; Nassau, 1984, pp. 172–173; Brown et al., 1989). Experiments performed over the last several years to study the reaction of Harts Range zircons to heat treatment have demonstrated that these zircons can be decolorized by heating to several hundred degrees Celsius in a reducing atmosphere for several hours. In fact, heat treatment of the Harts Range material can only produce near-colorless stones. The color in all Harts Range zircons can be restored by radiation treatment. Unless exposed to radiation, the near-colorless material produced by heat treatment is stable.

CONCLUSION

An area of the Harts Range, Australia, is producing gem zircons in a range of attractive colors. Perhaps the most unusual feature of these zircons is that they contain very low quantities of radioactive trace elements. Thus, they exhibit no evidence of being or becoming metamict and, more importantly, are not detectably radioactive. This locality is likely to be a commercial source of gem zircon as well as other gem materials in the future.

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BLUE PECTOLITE FROM THE DOMINICAN REPUBLIC

By Robert E. Woodruff and Emmanuel Fritsch

Blue pectolite from the Dominican Republic, also known by the trade name Larimar, has recently entered the U.S. market. Large quantities of this attractive ornamental stone have been found in cavities and veins of altered basalt. Most of the gemological properties are consistent with those previously reported for pectolite; the cause of color in this material is believed to be related to the presence of small amounts of Cu^{2+}. The color appears to be stable to light, but does react to irradiation and to the heat of a jeweler's torch. It is easily separated from similar-appearing materials.

The Dominican Republic is perhaps best known to gemologists as an important source of amber and conch "pearls." Since 1986, however, it has gained recognition as the source of a relatively new gem material, blue pectolite. Although actively mined since about 1974, blue pectolite has recently benefited from greater availability and broader distribution (Koivula and Misiorowski, 1986a). Previously, gem pectolite occurred only in an unattractive white to gray color and was considered rare because of its scarcity in pieces suitable for cutting (Webster, 1983; Liddicoat, 1976). The new and more plentiful supply of blue, and less commonly green, pectolite has helped it achieve recognition as an excellent lapidary material (figure 1); carvings are now on display in the Smithsonian Institution and the Lizzadro Museum (Lizzadro, 1987).

The first mention of this material in the gemological literature was by Arem (1977). Although he does not list blue under the possible colors of pectolite, he includes a photograph of some Larimar cabochons. More recently, two articles have appeared in the lapidary and consumer literature (Woodruff, 1986, 1987). The present article reviews the deposit where this material is found, its history, location, and geology. Also examined are the gemological properties of pectolite, including chemistry, cause of color, and reaction to treatment.

LOCATION AND ACCESS

The Dominican Republic occupies the eastern portion of the island of Hispaniola (figure 2). The blue pectolite is found approximately 170 km southwest of the capital, Santo Domingo (Ciudad Trujillo), just west of Baoruco, a small village south-southwest of Barahona in the province of the same name. The climate is tropical and the vegetation luxuriant. Waterworn fragments of pectolite were first found in the alluvials of the Río Baoruco and later traced to their in-situ source upstream.

Figure 1. The 26 × 14 mm-cabochon of fine blue pectolite in this silver ring is from the Dominican Republic. Behind it is an excellent example of some of the best rough material. Photo by Kris Illenberger; courtesy of Mountain-Mark Trading Ltd.

The actual deposit is located on the road to Filipinas in an area known as Los Checheses (two localities so small that they do not appear on local maps). The entrance to this road is about 3 km north of Baoruco. Dirt roads lead to the mine, but four-wheel drive vehicles are needed to negotiate the last few kilometers of the journey. The area is accessible all year round.

The pectolite is found in various portions of a single volcanic deposit approximately 0.15 km² in surface area. The Río Sitio, a small stream that drains into the Río Baoruco, was probably the carrier of those tumbled pieces first found at Baoruco.

HISTORY

In 1974, Norman Rilling, a Peace Corps volunteer, reportedly found some blue stones at Baoruco that were later identified as pectolite (Woodruff, 1986). By 1975, specimens had already appeared in jewelry shops in Santo Domingo. Many unverified stories exist about the find and subsequent developments (Woodruff, 1986), but it is known that Miguel Mendez, a local resident, originally was

the sole supplier to the domestic trade. According to Luis Augusto Gonzales Vega, lawyer and owner of property on which a portion of the deposit occurs, he and Mendez formed a corporation to mine and market pectolite. The original documents of this venture give the trade name Travelina, but this was later changed to Larimar, coined by Mendez from his daughter's nickname *Lari* combined with the Spanish word for sea, *mar*. This trade name has been used consistently since 1975, although neither Gonzales Vega nor Mendez is currently involved in the marketing of this material.

All mineral rights in the Dominican Republic belong to the government, and pectolite mining is permitted only by concession from the Minería, the Dominican Bureau of Mines. By 1985, nearly 100 miners were working the deposit. To avoid confusion, overlapping claims, and disputes, the Minería suggested that the miners form a cooperative and sell Larimar only from a small outlet in the town of Baoruco. After the cooperative was formed, Ramón Ortíz of Puerto Plata purchased the eastern part of the deposit and obtained a 10-
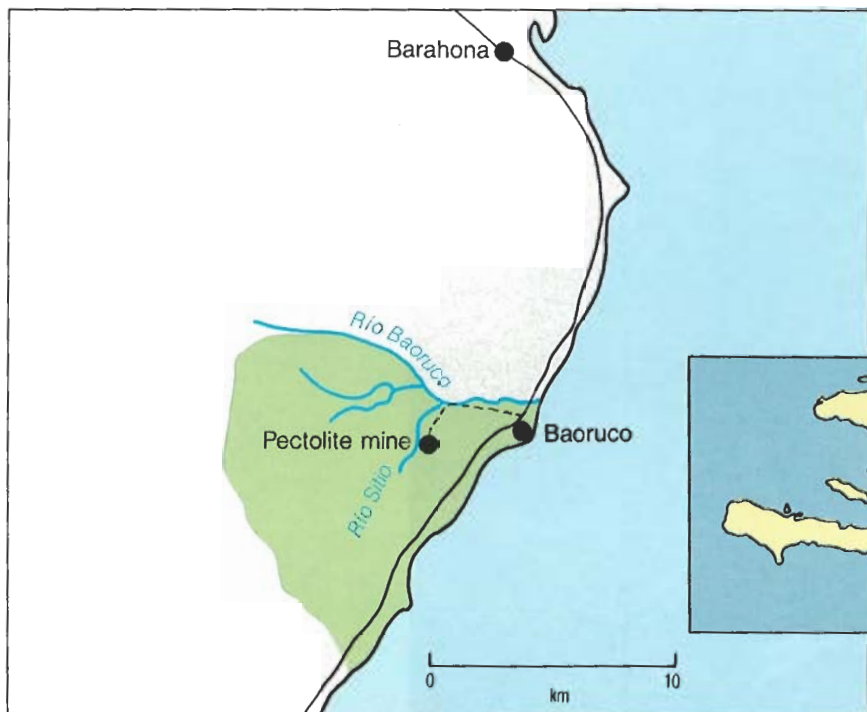
Figure 2. Blue pectolite is found in a basalt intrusion (green area) that extends inward from the village of Baoruco, in the province of Barahona, Dominican Republic. Artwork by Jan Newell.

year mining concession. His miners and those of the cooperative work side-by-side. Currently, as many as 150 miners are involved on an irregular basis. Pectolite may be purchased either at the mine – from the cooperative or from Ortíz – or at the cooperative building in the village of Baoruco.

GEOLOGY AND OCCURRENCE

The commercial quantities of blue pectolite available today are all mined at the primary deposit in the mountains above Baoruco. The few stones collected in the bed of the Río Baoruco, where it was originally discovered, are mostly small, tumbled pieces, although some are of excellent quality.

The Barahona peninsula extends south of a major west-east depression containing Lake Enriquillo (approximately 40 m below sea level). This peninsula is composed of Tertiary limestones (Oligocene to Miocene), with a few enclaves of Upper Cretaceous volcanic rocks described as basalts and andesites (Zoppis de Sena, 1969). The main basalt intrusion, in which the pectolite is

Figure 3. This exceptionally large (about 20 cm) slice of a pectolite vein shows the mineral and color zonation typical of this gem material. Natrolite (light gray) and chalcocite (black) crystallize, for the most part, on the walls of the vein. In this sample, they are followed by red sprays ("plumes") of hematite crystals intergrown with several generations of blue pectolite of different color intensity and transparency. Fibrous colorless pectolite and white calcite fill the center. Photo by Robert Weldon.

found, extends from the coast inward at the latitude of the village of Baoruco (again, see figure 2). The volcanic rocks have been intensely weathered and for the most part are altered to fine-grained serpentine. The only recognizable mineral visible in thin sections of the basalt matrix is clinopyroxene in small twinned crystals.

Indications of copper, especially chalcocite, have been reported in these basalts (Vaughan et al., 1921). Blue pectolite occurs as a hydrothermal mineral in cavities and veins in the altered basalt. This is the typical occurrence for the white to gray material, as already noted for pectolite deposits in Italy, Scotland, and the United States (Webster, 1983). Sprays of elongated natrolite crystals are sometimes present on the walls along which pectolite crystallizes in finely fibrous spherulites (figure 3). No other zeolites have yet been found in this deposit. Colorless calcite is also commonly associated with the blue pectolite in these veins. Rarely, peridot crystals and small amounts of white pumice are found as well.

The blue pectolite does not occur systematically; generally the veins are found under an uppermost layer of altered basalt that contains red hematite. These veins may disappear or enlarge very suddenly (unlike the system of fractures associated with pegmatite veins, for example).

Petrified, carbonized logs are found embedded in the altered basalt. Rarely, some logs even exhibit a filling of blue pectolite in fractures between the rings of the wood (figure 4).

Figure 4. This 17-cm slab of fossilized wood found at the mine shows blue pectolite between the rings.

MINING

Most mining is open pit, with miners using only pick, shovel, and hammer to break the weathered basalt in search of pectolite. Until recently, the pits averaged 1 m across and were no deeper than 10 m. The heavy rainfall common to this area floods the pits periodically, so mining is intermittent. The recent acquisition of a scraper and a pump has resulted in a number of pits that are larger (as much as 10 m in diameter) and deeper (as much as 25 m) than average (figure 5). This acquisition coincided with the development of the western area of the deposit. The fine blue of the gem-quality material found in this newer area contrasts

Figure 5. Although much of the area is marked by small pits dug by hand, the newly developed part of the mine uses more sophisticated equipment and techniques to excavate deeper, larger pits in the weathered basalt that hosts the blue pectolite. Photo by Richard Barrett; courtesy of Mountain-Mark Trading Ltd.

Figure 6. A striking contrast is seen between this fine blue pectolite (15 × 21 mm) found in 1987 and a green cabochon (18 × 25 mm) with considerable matrix and natrolite inclusions found in 1975. The stone on the left is representative of the finest color found to date. Photo by Robert Weldon.

markedly with the poorer quality green stones (figure 6) originally found in the mouth of the Río Baoruco. Many miners work only when they are not picking coffee—which is harvested from November to February—or fishing.

GEMOLOGICAL PROPERTIES

Six samples of Larimar were tested by X-ray powder diffraction to confirm their identity as pectolite, $NaCa_2Si_3O_8(OH)$. While pectolite is decomposed and gelatinized by HCl (Deer et al., 1978), it does not effervesce to the standard 10% solution commonly used in testing (Liddicoat, 1988); if effervescence occurs, it is due to the presence of calcite inclusions.

Visually, blue pectolite displays finely fibrous spheroidal aggregates in polished slabs or cabochons; some pieces show patches of what appears to be chatoyancy. The range of color is similar to that of turquoise (figure 7), although most valued are the few darker specimens that resemble chrysocolla. White calcite veinlets between the spherules are common, and hematite inclusions form fern-like patterns in some pieces that are referred to as "red plume." Homogeneous pieces of rough seldom exceed 10 cm.

Index of Refraction. We measured R.I. on a flat, well-polished surface of each of 12 samples of blue and green pectolite, and determined a range of 1.59–1.63 for this polycrystalline material. This corresponds to that reported for pure pectolite (Deer et al., 1978). Less accurate measurements by the spot method ranged from 1.57 to 1.63, with the variations due to different contents of iron and manganese (Arem, 1977; Schmetzer, 1984).

Specific Gravity. Measurements obtained by the hydrostatic method on five of the sample stones varied from 2.62 for the green material to 2.87 for a fine, homogeneous blue cabochon. A specimen with numerous chalcocite inclusions showed an S.G. of 2.90. These values are consistent with measurements of 2.84–2.90 reported by Deer et al. (1978) and 2.74–2.90 by Schmetzer (1984). Note that the green pectolite with the lowest S.G., 2.62, in our sample group contained numerous natrolite inclusions (S.G. of 2.20–2.25).

Hardness and Toughness. Scratch tests on freshly mined material suggest a Mohs hardness of somewhat over 5 to as much as 6 for finely fibrous, compact material. Although the book value for pectolite is 4½–5 (Roberts et al., 1974; Deer et al., 1978), fibrous types may be expected to have a higher value as well as greater toughness than their monocrystalline counterparts, because each grain boundary forms a barrier to the propagation of microfractures induced by the scratch (Fritsch and Misiorowski, 1987; M. Gardos, pers. comm., 1989). The toughness of blue pectolite is excellent, although pieces less than 2 mm in thickness may tend to flake. Carvers report that they work this material using methods and agents similar to those used to carve jadeite. Like jadeite, pectolite also takes an excellent polish.

Fluorescence. More than 20 specimens of blue and green, rough and cut, pectolite were examined for their reaction to long- and short-wave radiation. The blue pectolite exhibited a moderate, zoned fluorescence to long-wave U.V. A very chalky green usually predominated, with some zones more yellow and others almost blue. Fluorescence was weaker in areas of very deep blue as compared to those with the fibrous whitish material. The green pectolite fluoresced yellow to long-wave U.V.

Fluorescence to short-wave U.V. of both colors of pectolite was much more homogeneous and slightly more intense; the color was a very turbid green. Sinkankas (1964) reported that pectolite fluoresces orange to short-wave U.V.; we presume

Figure 7. The different colors of Larimar are similar to that of turquoise. These reference stones, all about 16 × 11 mm, illustrate the general grading system used for the various qualities of pectolite: good blue (top left) to green (bottom, middle) and "red plume" (middle right). Stones courtesy of Mountain-Mark trading Ltd.; photo by Robert Weldon.

that this is due to the high manganese content of the gray to white varieties then known.

Inclusions. Red dendrites, identified by X-ray diffraction as hematite, create distinctive fern-like patterns in the so-called "red plume" variety; most such dendrites appear in outer portions of the pectolite veins (again, see figure 3). The carver of the elephant in figure 8 took advantage of such patterns to create a drapery effect on the back of the beast. Hematite is abundant in the altered basalt just above the pectolite-bearing veins.

More common are white to gray squarish patches of calcite that may be as large as 2 mm in maximum dimension (figure 9). Calcite also occurs as submicroscopic crystals between the ends of the pectolite fibers. Natrolite, another common inclusion, appears as transparent light gray sprays of elongated square crystals in the pectolite. When a cabochon is cut perpendicular to the main orientation of a natrolite spray, the surface is marked by shallow undercut pits of square or lozenge shape.

Chalcocite forms clusters of microscopic black flakes (again see figure 9) and sometimes adopts euhedral form (figure 10); material that is heavily included with chalcocite is not used for gem purposes. Rarely, native copper may be present, usually fairly close to the wall of the vein.

CHEMISTRY AND CAUSE OF COLOR

The chemical composition of three samples of blue

pectolite was determined with an electron microprobe (Joel 733 Superprobe). The results, shown in table 1, are similar to those published previously for pectolite from other localities (Deer et al., 1978). The presence of manganese is not surprising, as it is known to substitute easily for calcium

Figure 8. In these two blue pectolite carvings produced in Thailand, the carver has used the "red plume" layer to mimic a drapery on the elephant's back and the sheen of the fibrous pectolite to suggest the cat's fur. The elephant is approximately 5 cm high × 5 cm along its base. Photo by Robert Weldon.
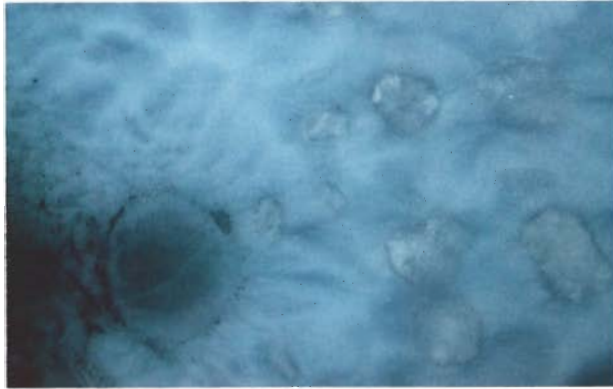
Figure 9. These squarish, slightly fibrous light gray inclusions are calcite crystals. Microscopic flakes of black chalcocite sometimes form "black eyes" (bottom left) in blue pectolite. Photomicrograph by John I. Koivula; magnified 10×.

Figure 10. Rarely, minute euhedral monoclinic crystals of chalcocite are scattered in the blue pectolite. The presence of this copper sulphide strongly suggests that the color is related to traces of Cu. Photomicrograph by John I. Koivula; magnified 2×.

in the crystal structure (in fact, pectolite forms an isostructural series with serandite, the manganese analogue of pectolite; see Deer et al., 1978).

The copper content, too low to be determined accurately with the electron microprobe, was obtained by means of wavelength-dispersive X-ray fluorescence (WDXRF) using a Rigaku spectrometer. Three measurements, in different areas of a single sample of good color, gave a remarkably homogeneous concentration of 46 to 47 ppm copper.

TABLE 1. Chemical composition of light blue and dark blue pectolite from the Dominican Republic.[a]

Oxide	Light blue	Dark blue
MnO	0.06	nd[b]
FeO	nd	nd
SiO_2	53.74	52.36
Al_2O_3	0.07	0.04
CaO	35.50	36.27
MgO	nd	nd
CuO	0.01	0.03
TiO_2	nd	nd
Cr_2O_3	nd	nd
Na_2O	8.10	8.13
P_2O_5	0.11	0.11
K_2O	0.02	0.02
Total	97.61	96.95

[a]Microprobe analyses performed at the Center for Materials Research, Stanford University, by Dr. Julie Paque. The total composition does not equal 100% because water, a component of pectolite, cannot be measured with an electron microprobe. The range of water concentration measured in pectolite is 2.25% to 4.08% (Deer et al., 1978).
[b]nd = not detected.

Similar features were observed in the optical absorption spectra of all six blue pectolite slices examined using a Pye Unicam 8800 spectrophotometer (figure 11). A strong absorption in the ultraviolet decreases toward the red end of the visible spectrum, except for a very broad, asymmetric absorption band centered at approximately 630 to 650 nm in the red. This creates a transmission "window" in the blue at around 480 nm, from which the blue color of the pectolite is derived.

The spectrum of the rarer green variety (two specimens studied) is similar to that of the blue specimens (again, see figure 11). However, the absorption centered in the ultraviolet expands about 80 nm further into the visible. A weak, very broad band centered at around 470–475 nm is present on its slope. Both features are apparently responsible for shifting the transmission window from 480 to approximately 510 nm, which explains the green color of this material. More detailed chemical and spectroscopic data are necessary to interpret those relatively minor variations.

These pectolite spectra are reminiscent of those of turquoise, which might suggest that the two materials have the same coloring agent (Koivula and Misiorowski, 1986b). However, turquoise contains copper as a major constituent, while it is present only as traces in pectolite. The occurrence of copper in silicate minerals is rather unusual, and there is little research available on this coloring mechanism (Gordon Brown, pers. comm., 1986).

We do know that the absorption coefficient of the main copper absorption in the red is 373 to 691 mol^{-1} cm^{-1}, assuming a homogeneous copper concentration of 50 ppm. This contrasts sharply with values of 6 to 40 mol^{-1} cm^{-1} for coloration due to isolated Cu^{2+} ions (Lehmann, 1978; Rossman 1988). This, along with other technical arguments, suggests that the absorption might be due to processes involving multiple atoms, probably within small clusters of Cu^{2+} ions. Even for a small overall concentration, such processes may absorb light efficiently enough to produce the depth of color seen in fine blue pectolite. However, the details of the electronic transitions involved are not known at present.

COLOR STABILITY

To test for color stability, we cut a specimen of blue pectolite into two parts and exposed one to light at the end of a FiberLite for more than 50 hours. No noticeable difference in color was observed when this specimen was compared to the unexposed control.

Figure 11. The optical absorption spectra of blue and green pectolite show an increasing absorption toward the ultraviolet and a broad, asymmetrical band centered at around 645 nm, which is attributed to trace amounts of copper. The position of the resulting transmission window (480 nm for the blue and 510 nm for the green) accounts for the color. Artwork by Jan Newell.
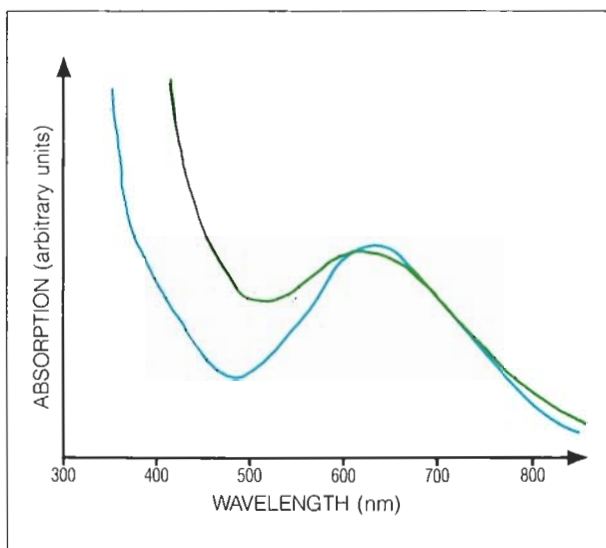
Figure 12. The left part of this pectolite slice was submitted to a jeweler's torch for a few seconds, while the right section remained untouched. The heated section shows a loss of color and transparency that is due in part to the development of small fractures which also reduce the toughness of the specimen. Photo by Robert Weldon.

TREATMENT

We do not know of any effort to commercially enhance blue pectolite. Rumors in the Dominican Republic about dyeing low-quality material with a copper sulphate could not be substantiated, and we have no direct evidence that such a treatment has been performed.

We submitted a slab of blue pectolite to a dose of 16 Mrads using Cs-137 gamma rays. Irradiated in this fashion, the specimen turned mostly violet, although small blue spots remained and the white areas (calcite) turned brown. The violet coloration is thought to be due to the formation of Mn^{3+} by irradiation of Mn^{2+}, which is present in trace amounts in blue pectolite (again, see table 1). For further discussion of Mn^{3+} as a coloring agent, see Fritsch and Rossman (1988).

When exposed to the flame of a jeweler's torch, pectolite tends to get whiter as a result of the propagation of small cracks (see figure 12). Also, some transparency is lost in the process. However, no noticeable change in color or transparency was observed in a thin slab of blue pectolite that was heated in an oven to approximately 300°C for 10 hours.

Figure 13. Blue pectolite is used in virtually any type of jewelry as well as in carvings. Photo by Jeff Lotz.

SEPARATION FROM OTHER MATERIALS

Because of blue pectolite's distinctive appearance, only a few materials are likely to be mistaken for it. "Victoria stone," a devitrified man-made glass, shows a fibrous structure similar to that observed in high-quality pectolite. However, the fibrous aggregates in pectolite are much smaller and more irregular, and none of the colors in which "Victoria stone" is produced actually matches those of Dominican pectolite. Recently, GIA's Technical Development Department noted the similarity of Larimar to "Imori stone," a partially devitrified glass (manufactured in Japan) into which fibrous inclusions are induced to give it an overall fibrous appearance. However, the vividness and homogeneity of "Imori stone's" color, as well as the perfection of its fiber bundles, makes its separation from pectolite relatively easy.

Although the best blue pectolite (figure 6) may resemble chrysocolla-stained chalcedony, fine pectolite has a higher R.I. (1.59–1.63 versus 1.46–1.57) and S.G. (2.87 versus 2.24 or lower).

PRODUCTION AND DISTRIBUTION

Since this deposit of blue pectolite was first discovered, production has been extremely erratic. No exact figures are available, although Ramón Ortíz estimates that 2,500 kg were removed in 1975, and 300–500 kg per week in early 1987. Unfortunately, no records have been kept, so it is difficult to estimate the volume and quality of the material produced between 1975 and 1987. In 1988, Ortíz reports, he had almost no production, and he believes that the cooperative also encountered little material. In mid-December 1989, however, four major veins of good-quality material were found in the western part of the deposit, which is being worked by the cooperative (C. Mark, pers. comm., 1989). There are no firm estimates of future reserves.

The material produced varies greatly in quality. Buying rough is considered a *lotería* (lottery) because the pectolite is difficult to grade without cutting. Ortíz estimates that about 20% is cuttable, but only 5% is truly gem quality. The presence of matrix and fractures further limits the usefulness of the material.

A simple grading system has been developed by one entrepreneur to help communicate with his customers (again, see figure 6). It is based on the relative proportion of blue, white, and green (in

order of decreasing value) in a particular piece and the presence or absence of "red plume." Although a large lapidary market has yet to develop because of the limited availability of raw material, several dealers were selling the material at the 1989 Tucson Gem and Mineral Show. Larimar is also one of the few gemstones to be trademarked in the U.S., with the moniker "Gemstone of the Caribbean."

Blue pectolite is used in many types of jewelry, from rings and necklaces to bola ties (figure 13). One style typical of pectolite jewelry manufactured in the Dominican Republic is a silver necklace combining Larimar cabochons with white boar's tusk ivory ("Amber . . .," 1978). A market has also developed with "New Age" initiates, who appreciate blue pectolite in various nonstandard products, such as meditation wands and even as pebbles.

CONCLUSION

Although relatively little has been written on blue pectolite from the Dominican Republic, this new gem material has become a familiar item on the U.S. colored stone market. Production remains, however, unpredictable, and much of what we see on the market today was cut from material found some years ago. An organized effort is needed to understand the geology of the deposit and the distribution of the pectolite veins so that the commercial potential of this material can be better evaluated.

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NOTES
· AND ·
NEW TECHNIQUES

REFLECTANCE INFRARED SPECTROSCOPY IN GEMOLOGY

By F. Martin, H. Mérigoux, and P. Zecchini

External reflectance infrared spectroscopy permits a very rapid and nondestructive determination of the species of a mineral. It is particularly useful with polished gems in that it requires no more than placing the stone, loose or mounted, on a reflection device in the infrared spectrometer and observing the recorded spectrum. Therefore, compared to the classical methods of physical measurement such as refractive index, specific gravity, and the like, reflectance spectroscopy provides a much faster means of establishing the species of the gem and, in some cases, whether it is natural or synthetic.

Gem identification requires broad knowledge built on a number of observations. Generally, the identity of a gem material can be easily determined on the basis of physical and optical properties such as specific gravity, refractive index, and visible-light absorption spectrum. In some cases, however, such as the separation of scapolite from quartz (figure 1), more sophisticated methods may be required. X-ray diffraction and microprobe analyses have been used for this purpose, but they require very special equipment and sample preparation (which may be destructive).

External reflection infrared spectroscopy (commonly referred to as reflectance spectroscopy) provides an intermediate solution for these problem cases. It has been used in mineralogy for many years to measure optical constants such as refractive index (Simon, 1951) and to determine fundamental vibrations of crystals (Simon, 1953). Ba-

sically, reflectance spectroscopy measures the vibration energy of the atoms inside the crystals. Inasmuch as these energies vary from one gem material to another, the reflectance spectrum serves as a "fingerprint" of the stone. This allows identification of the mineral species and, in some cases, determination as to whether the stone is natural or synthetic.

The measurements for reflectance spectroscopy are much easier than for most other sophisticated techniques. Because a gem — whether mounted or loose — generally has at least one polished face, it need only be placed on the reflectance device in the spectrometer to obtain the spectrum. No elaborate sample preparation is required, and the method is completely nondestructive. Results can be obtained in a few minutes.*

This article presents a general application of reflectance infrared spectroscopy to identify a cut stone, with sample spectra provided for more than 60 natural gemstones, synthetics, and simulants

(some of which were first reported by Leung et al., 1982; Ramirez et al., 1983, 1985; Zecchini, 1986; Zecchini et al., 1986, 1987).

INSTRUMENTATION AND EXPERIMENTAL PROCEDURES

For this study, we used Perkin-Elmer instrumentation: two conventional grating infrared spectrometers, PE 580 B and PE 983, connected to PE 3600 data stations (which enabled us to record the spectra and provide graphic representation of the data) and the reflectance accessory illustrated in figure 2. This accessory is readily available from most infrared spectrometer accessory manufacturers.

For a given crystal, two types of infrared spectra can be recorded: a transmission spectrum (from which, if the sample is "transparent" to the infrared beam, an absorption spectrum can be derived) and a "mirror-like" (or specular) reflection spectrum correlated to the lattice vibrations of the crystal. According to observations made on the infrared spectra of gem crystals, the fundamental vibration energies of atoms in crystals are situated in the infrared domain, typically between 1500 cm^{-1} (6600 nm) and 100 cm^{-1} (100,000 nm), so reflection spectra can be observed only in this region.

The transmission method would be very powerful if it were feasible to cut the stone; observations through a thin (few microns thick) slab give, directly, very accurate results on real lattice vibration absorption positions. Such exact positions, which are not necessary for our purpose, can be calculated from the reflection spectrum (Laroussi, 1984). Although direct observation through a faceted stone is sometimes possible, the transmission spectrum from such thicker materials does not show the fundamental crystal lattice vibrations (i.e., there is almost total absorption in that range), but rather only reveals the typical impurities such as water, carbon dioxide, nitrogen, hydroxide, and the like. Moreover, the stone must be placed in front of the incident beam in such a way that light-

Time varies according to the spectrometer used and the observable surface of the sample. With a conventional grating spectrometer and an observable surface larger than about 2 mm^2, it takes no longer than five minutes. If an FTIR spectrometer is used, even less time should be needed. For smaller samples, additional time is often required for placement of the sample on the reflection device in the right position to obtain sufficient intensity.

Figure 1. The separation of scapolite (right and bottom) and quartz (top and left), may be difficult to perform using standard gemological testing but is accomplished in a matter of minutes with reflectance infrared spectroscopy. Photo © Tino Hammid.

scattering dispersion is minimized, which is very difficult with most dispersive infrared spectrometers.

Reflectance is much easier to perform: Simply place a facet of the polished gem on the reflection device. Because the observed bands are very specific to a given crystal, the identification is easily made by comparing the spectrum obtained with prerecorded spectra for various gem materials.

TESTING AND RESULTS

To determine the usefulness of this technique for gem identification, we obtained infrared spectra, using reflectance spectroscopy, on more than 60 natural and synthetic gem materials. We studied at least five samples of each gem, and found that within the same mineral species, the variations between spectra for different varieties or from different localities are very small.

The reflectance spectrum of a pyrope garnet is shown in figure 3 both in a conventional manner, a continuous line that rises and falls with the reflectance of the sample, and converted to a set of parallel bars with height and thickness correlated to the reflective power. This latter format facili-
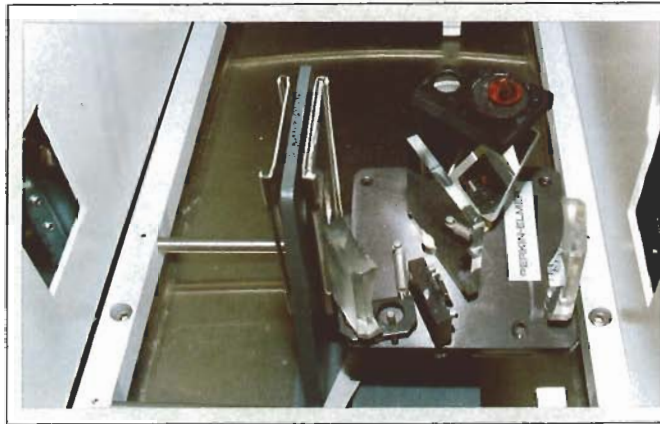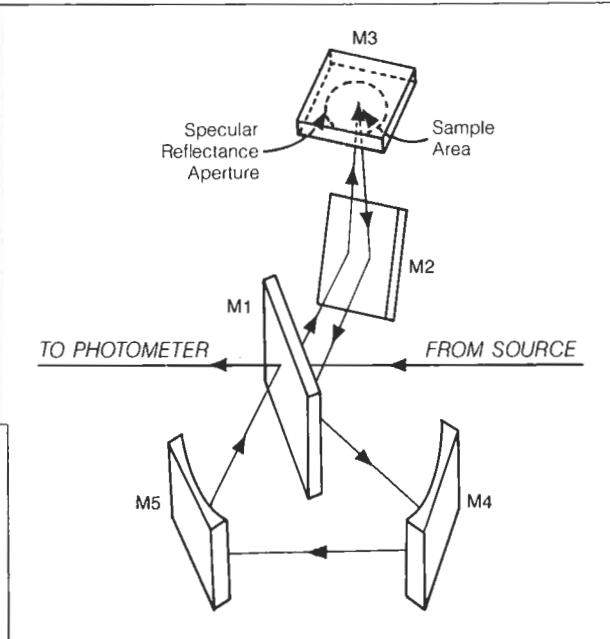
Figure 2. This optical scheme shows how the sample interacts with the source of infrared light and the photometer through a series of mirrors (M1–M5) in the reflection accessory to produce the reflectance spectrum.

tates presentation of the data and comparison from one gem material to another. The ability to present the results for many stones on a single piece of paper (figure 4) allows for a very rapid and effective identification of, for example, corundum from spinel, calcite from aragonite, cubic zirconia (djevalite) from strontium titanate (fabulite), and grossular garnet from pyrope garnet. Only type IIa diamond, which is transparent to the infrared beam in the 100–1500 cm^{-1} range, cannot be determined, although all of its common simulants can be readily characterized by this method.

This technique is particularly useful for the separation of some synthetics from their natural counterparts. This is the case for alexandrite (figure 5) and for spinel (again, see figure 4). The different sites occupied by the atoms in natural as compared to synthetic stones can be observed as a difference in the lattice vibration spectra.

As part of our study, we also investigated the effects of polarization. That is, on crystals that have one or two optic axes, the incident beam is partially polarized and the spectrum observed depends on the orientation of the facet used and its
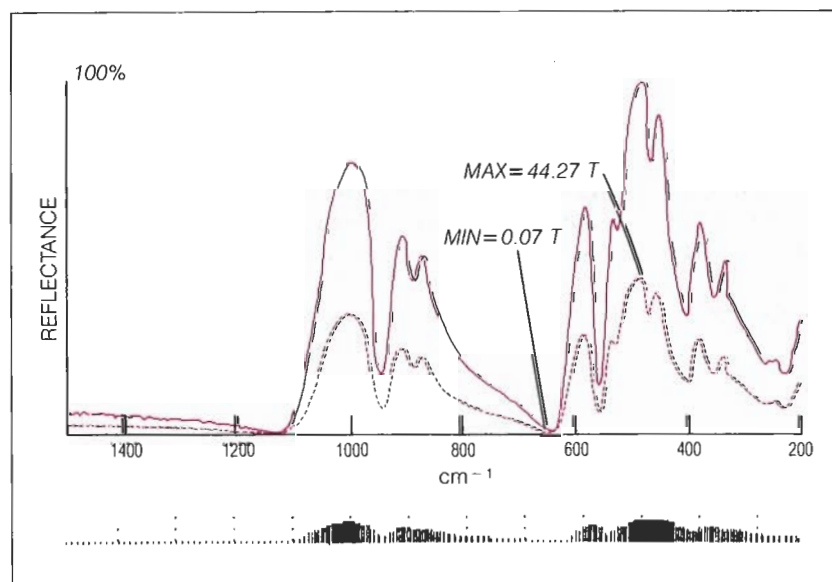
Figure 3. The reflectance spectrum of a pyrope garnet as it normally appears (upper part) and as converted (lower part) for this study. For the conversion, the recorded infrared spectrum (broken line) is expanded between 0 and 100% (continuous line). In this expanded spectrum, a point represents each 10 cm^{-1}. The height of the bar at each point represents variations in reflection intensity. That is, the bar is counted as nine units if the reflection intensity varies between 90% and 100%, as eight units if between 80% and 89%, and so on. The black regions show where the largest reflective power is located; to achieve this, one correlates the thickness of the bar to its height.
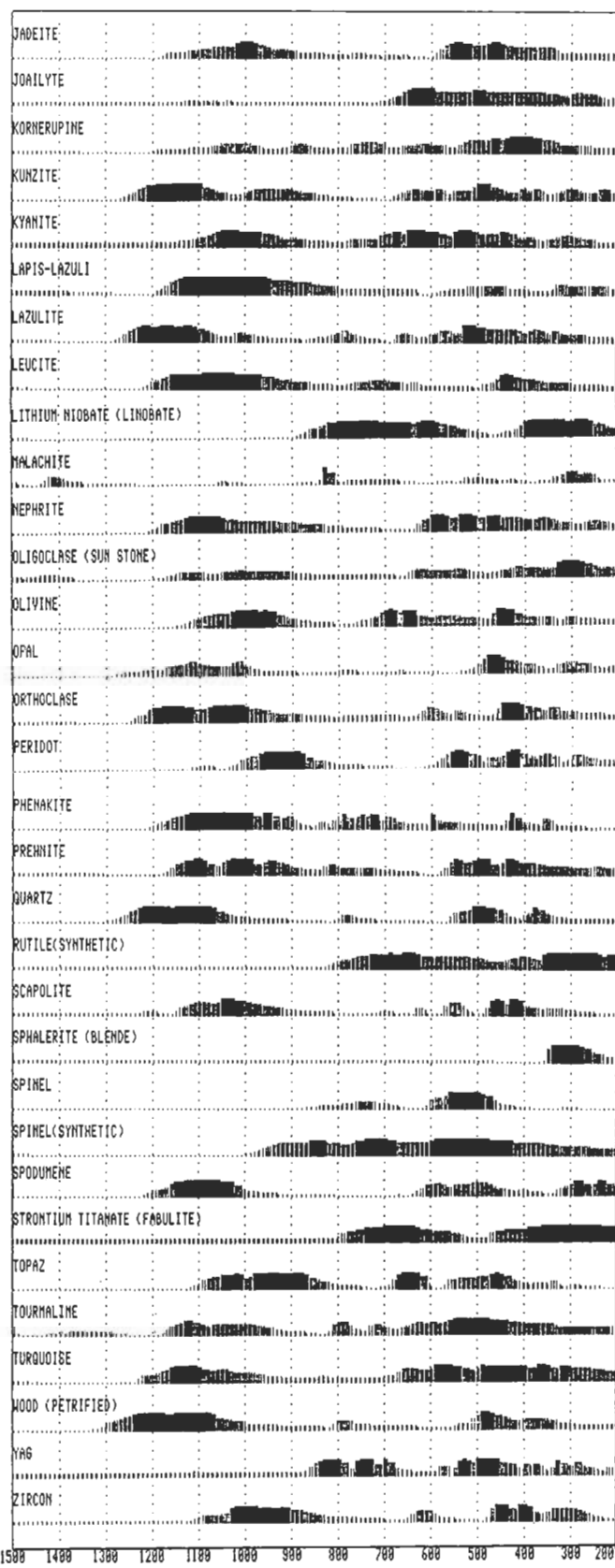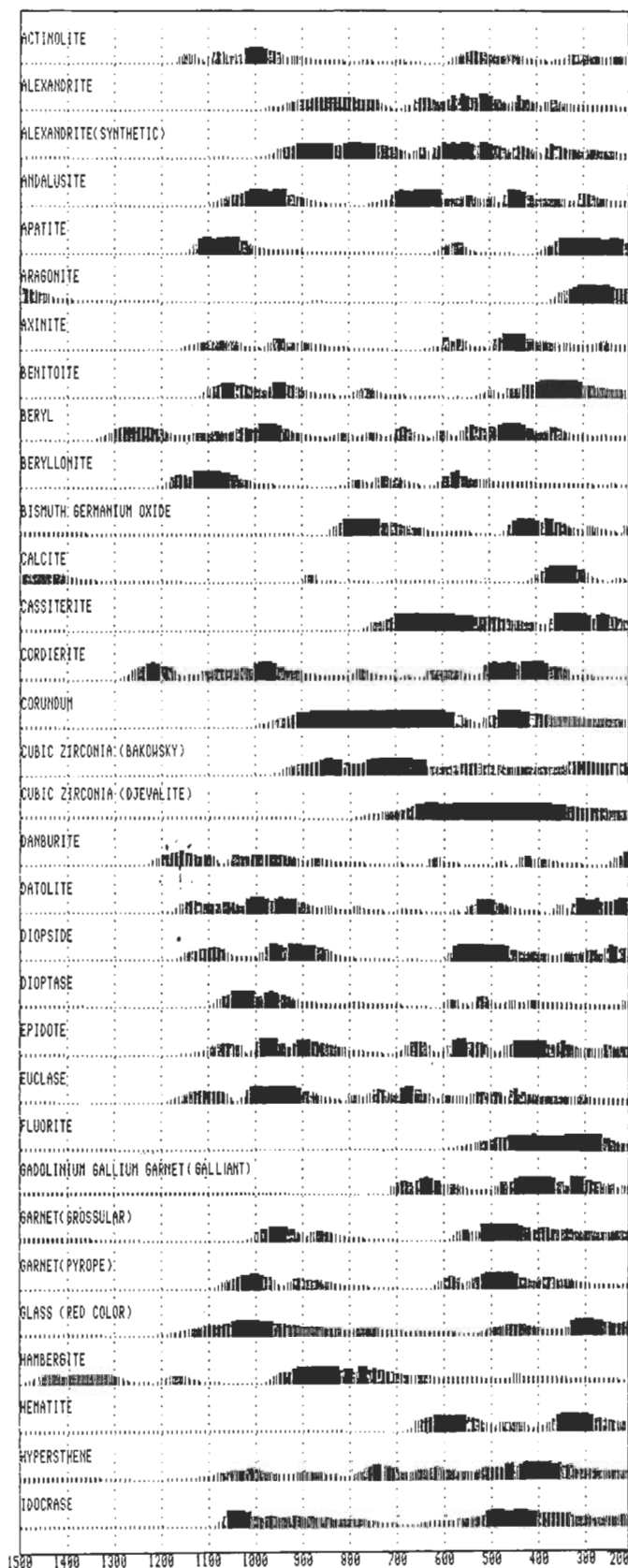
Figure 4. The authors recorded the reflectance spectra of at least five samples each of more than 60 gems, synthetic gems, and simulants, and then converted their results to these simple bar graphs for easy comparison. The authors found no significant variability within a species for the materials they tested.
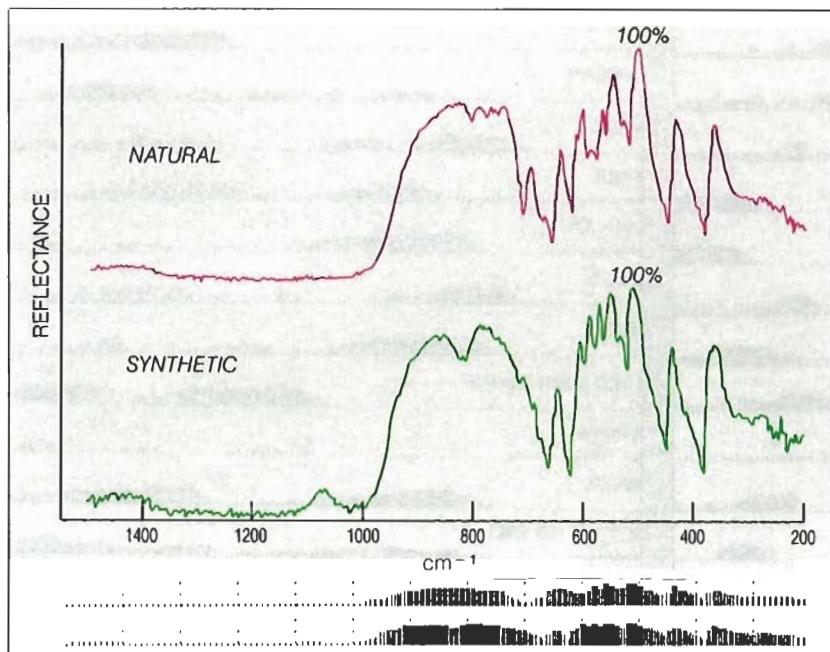
Figure 5. Natural and synthetic alexandrite (here manufactured by Created Crystals) are easily separated by the reflectance method. Note, however, that because the bargraphs are simplified representations, the difference between the two spectra—that is, an additional weak reflection observed between 1050 and 1100 cm^{-1} in the man-made stone—is better seen with the conventional spectra.
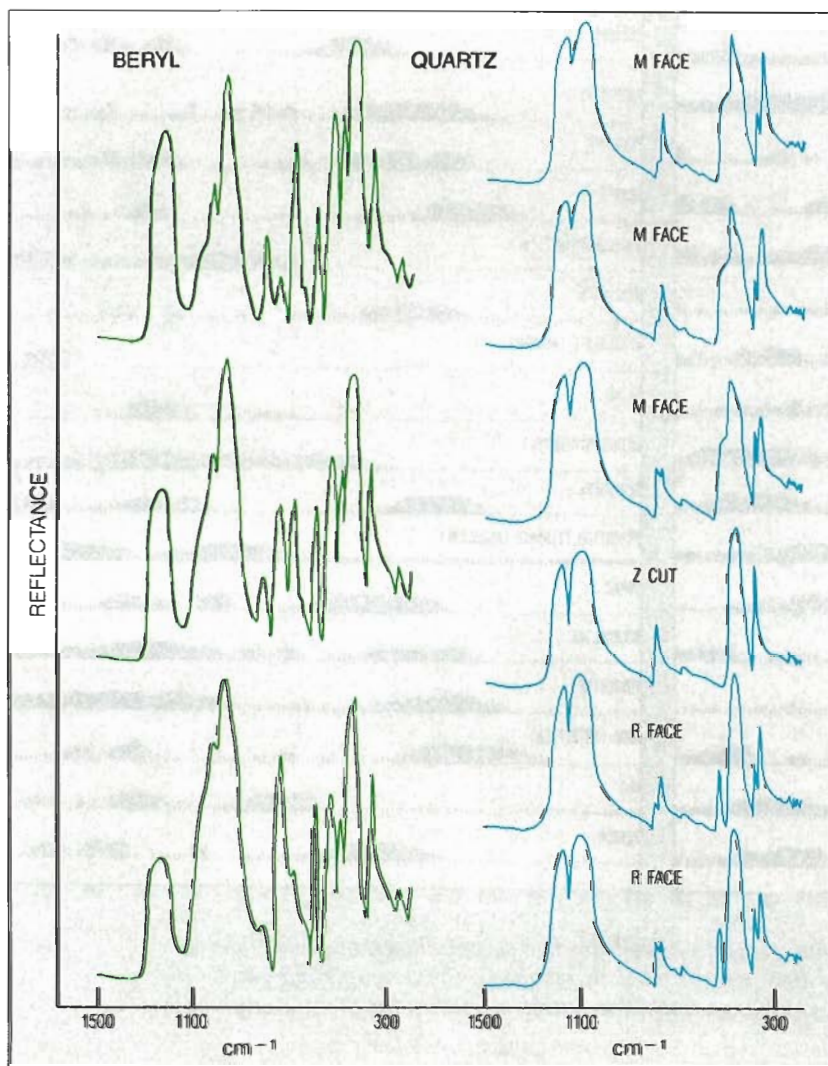
Figure 6. Although the position in which the sample is run does have some effect on the reflectance infrared spectrum, all of the spectra are within the range for that gem material, thus allowing its identification. In the left-hand column, rotations (at 30° steps) about the axis normal to the table of this faceted beryl induce these spectra, all of which are characteristic of this gem species. In the right-hand column, rotations (again, at 30° steps) about the axis normal to the M (minor rhombohedron) and R (major rhombohedron) faces of a natural quartz show only small differences from one spectrum to another. For a Z cut—the observed plate was cut perpendicular to the Z (or optic axis) of the crystal; the same spectrum is obtained for any rotation about this axis (isotropic direction).

position on the reflectance accessory. We found that while the spectra do differ slightly according to the position of the sample, overall they are still within the spectral range of that particular species (figure 6).

CONCLUSION

External reflection infrared spectroscopy provides a nondestructive method for identifying the mineral species of most gem materials, whether loose or mounted in jewelry. Our results were obtained with faceted stones, but they may also be obtained with uncut crystals that have at least one polished face. In some cases, such as chrysoberyl (including alexandrite) and spinel, this technique can be used to determine the natural or synthetic origin of the stone as well.

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MILDLY RADIOACTIVE RHINESTONES AND SYNTHETIC SPINEL-AND-GLASS TRIPLETS

By Kurt Nassau and Edward A. Lewand

Low levels of radioactivity were found in some greenish yellow to yellow-green (peridot-like) synthetic spinel-and-glass triplets, mirror-backed glass rhinestone chatons, and fully fashioned glass rhinestones. Uranium was detected in the radioactive stones. Although individual stones in jewelry carry virtually no risk, it is recommended that parcels of such stones not be carried on one's person for prolonged periods.

Knowing that a broad variety of gemstones are candidates for irradiation treatment, many gem dealers routinely check all stones with a Geiger counter for radioactivity. This can often lead to surprising results, as was the case a few months ago, when a parcel of stones that should *not* have registered on the Geiger counter did just that. The dealer brought the stones to the authors' attention and, as a result, we have located three types of commercially available gem materials that show low, but not negligible, radioactivity.

Comprising the first type are triplets that consist of two layers of colorless synthetic spinel fused together with a thin layer of colored glass. Webster and Anderson (1983, p. 463) refer to these as *soudé sur spinelles*. According to trade sources, such spinel triplets are currently manufactured in Europe in a wide range of colors for use in birthstone jewelry, class rings, and the like. Only greenish yellow to yellow-green peridot-like material showed radioactivity, although not all material of this color did. Comprising the second type are peridot-colored rhinestones that consist of a crown with a flat, silvered (mirror) back. Known as *chatons*, these also are currently made in Europe and are usually sewn or glued onto clothing. Third, we found radioactivity in some fully faceted glass rhinestones, again of the same yellow-green color.

The use of lead oxide in glass to give it high dispersion, so-called flint glass, is well known (Webster, 1983, p. 437), as is the use of uranium compounds to produce a yellow-to-green color (Nassau, 1983; Webster 1983, p. 441). In fact, Webster (1952) reported examining a yellow doub-

let that consisted of a crown of rock crystal with a glass base containing uranium; he also noted the strong yellow-green fluorescence and "discrete (banded or fluted)" fluorescence spectrum that is characteristic of uranium. Unfortunately, the piece was not tested for radioactivity, as this was not considered a significant issue at that time.

To confirm the source and determine the levels of radioactivity in these three types of gem simulants, we examined several samples of each for both key gemological and chemical properties and for radiation activity (figures 1 and 2).

MATERIALS AND METHODS

We obtained a wide variety of synthetic spinel-and-glass triplets and glass rhinestones from several Manhattan stone dealers, from a mail-order finding catalog, and from the authors' collections. We ultimately focused on greenish yellow and yellow-green peridot-like material since our initial survey of dozens of stones of all available colors showed radioactivity only in these two hues. Some of the mirror-backed rhinestones tested also had an iridescent interference coating on the crown.

All 17 of the radioactive, as well as a selection of some of the nonradioactive, samples tested are described in table 1. Included as well are two pieces of rough: SC_2, a slab of triplet material of dimensions suitable for faceting small stones; and NA_5, one of several pieces of unfaceted uranium glass obtained a few years ago at the Tucson Gem and Mineral Show.

Conventional gemological testing was used to

Figure 1. Some of the radioactive stones tested include, from left to right: back— LE_5 (a rhinestone), GR_1 and LE_2 (synthetic spinel–glass triplets); front— GO_1 and GR_2 (synthetic spinel–glass triplets), SW_2 (a chaton). Photo by Robert Weldon.

determine the optical constants and fluorescence for all of the radioactive samples and some of the nonradioactive specimens as well. The color descriptions are also given in ISSC-NBS Centroid color numbers (Kelly and Judd, 1976). Qualitative chemical analysis for five representative specimens (in the case of the triplets, for the glass exposed at the girdle) was performed on an X-ray fluorescence unit using a chrome target and a solid-state energy-dispersive detector with a PGT System 4 analyzer. Note that under these conditions one cannot detect chromium, vanadium, or elements below aluminum in the periodic table.

A Solar Electronics Radiation Alert Monitor 4 Geiger counter (thin-window type) was used to screen the stones for radioactivity. With a stone placed against the probe area, we averaged several one-minute counts for each specimen; the smallest stones were measured three at a time. The results are given in table 1 as radiation levels in terms of multiples of background, which is 12 counts per minute for this instrument in the test location used. We considered any reading lower than 1.5 times background to indicate absence of radioactivity by this test. More detailed radioactivity and elemental measurements were performed on three of the stones with a gamma-ray spectrometer, using a lithium-drifted germanium detector with a Canberra Series 80 multi-channel analyzer and two-hour counting periods.

RESULTS AND DISCUSSION

Gemological Data. All of the triplets in table 1 showed a refractive index of 1.729 to 1.730, which is consistent with synthetic spinel; some stones also showed a weaker indication of 1.69, derived from the glass. These results, as well as the anomalous double refraction typical of synthetic

Figure 2. Some of the nonradioactive stones tested include, from left to right: back— GO_3 and LE_1 (synthetic spinel–glass triplets), LE_3 (a rhinestone); front–SW_1 and NA_1 (chatons), NA_4 (a rhinestone). Photo by Robert Weldon.

spinel, are consistent with those reported by Kane (1986) for synthetic spinel-and-glass triplets. The glass layers ranged from 0.3 to 0.5 mm thick, contained gas bubbles, and were reasonably well centered at the girdle. The rhinestones in table 1 showed an R.I. of 1.57 to 1.58, with strain visible in the polariscope, gas bubbles and flow lines, and conchoidal fractures; all of these results are consistent with lead-containing glass.

All of the radioactive triplets showed medium to strong greenish yellow fluorescence to short-wave radiation and were inert to long wave. The nonradioactive glass chaton SW_1 had a similar fluorescence reaction, but radioactive SW_2 fluoresced a greenish yellow that was very weak to short-wave

TABLE 1. Glasses and synthetic spinel-and-glass triplets surveyed for radioactivity.

Sample no.	Color[a]	Color no.[b]	Size (mm)	Shape	Weight (ct)	Radio-activity[c]
Synthetic Spinel-and-Glass Triplets						
LE$_1$	Yellow-green	115	12 × 10	Oval	5.39	—
GO$_3$	"Emerald" green	139	9 × 7	Oval	2.02	—
RI$_1$	Yellow-green	117	8 × 6	Oval	1.53	—
GR$_3$	Yellow-green	117	8 × 6	Emerald	1.67	—
LE$_2$	Greenish yellow	98	12 × 10	Pear	4.93	1.5
GR$_1$	Greenish yellow	101	9 × 7	Oval	2.01	1.5
GR$_2$	Yellow-green	116	9 × 7	Oval	2.00	1.5
GO$_1$	Yellow-green	115	10 × 8	Oval	2.70	2
GO$_2$	Greenish yellow	97	10 × 8	Oval	2.90	2
GO$_4$	Greenish yellow	101	9 × 7	Oval	2.05	2
GO$_6$[d]	Yellow-green	116	3.5	Round	0.54	2
SC$_1$[d]	Yellow-green	115	5 × 3	Pear	0.81	4
SC$_2$	Yellow-green	120	24 × 3	Slab	21.32	1.5, 4
Glass, Faceted and Rough						
LE$_3$	Yellow-green	115	11 × 6	Pear	1.52	—
NA$_1$	Colorless B	263	9	Chaton	1.97	—
NA$_3$	Green BC	—	7	Round	1.43	—
NA$_4$	Blue BC	—	7	Round	1.37	—
SW$_1$	Greenish yellow B	104	9	Chaton	1.97	—
SW$_2$	Yellow-green B	117	9	Chaton	2.17	4
LE$_4$	Greenish yellow	104	10 × 8	Oval	2.07	4.5
LE$_5$	Greenish yellow	101	12 × 10	Oval	3.83	5
NA$_5$	Greenish yellow	97	26	Rough	40.20	13

[a]B indicates a mirror back; C, an iridescent surface coating.
[b]Color number from the ISSC-NBS Centroid Color Chart (Kelly and Judd, 1976).
[c]Activity as number of times background; — indicates less than 1.5 times background; background was 12 counts per minute; the activity of 13 for NA$_5$ corresponds to a reading of 0.14 mR/hr.
[d]Consists of three stones; weight and radioactivity level are the totals for all three.

U.V. but strong to long wave. Moreover, the triplet fluorescence observed here differs from that reported on similar material by Kane (1986). Accordingly, fluorescence cannot be considered diagnostic for radioactivity.

Elemental Composition. X-ray fluorescence confirmed that the synthetic spinels did not contain any significant amounts of metallic elements other than the expected Mg and Al (again, note that Cr, V, and elements lighter than Al could not be detected). Partial analyses of the glass for representative yellow-green and greenish yellow samples, both with and without radioactivity, are shown in table 2. All of the radioactive samples tested by elemental analyses or gamma-ray spectroscopy were found to contain uranium, which was clearly the coloring agent.

Radioactivity. Table 1 shows a range of radioactivity up to five times background in the faceted material and up to 13 times background in a piece of rough uranium glass. Different counts were

TABLE 2. Elemental analyses (as determined by X-ray fluorescence) of the glass in some of the stones in table 1.

Sample no.	Color and type	Radio-activity[a]	Elements detected[b] High to medium	Low
LE$_2$	Greenish yellow triplet	1.5	Pb, Si, K, Zn	U, Cu
SW$_2$	Yellow-green glass chaton	4	Pb, K, Zn	U, Cu
LE$_1$	Yellow-green triplet	—	Pb, Si, Ca, K	Fe, Cu
LE$_3$	Yellow-green glass rhinestone	—	Pb, Si, K, Bi	Cu
SW$_1$	Greenish yellow glass chaton	—	Pb, Si, K, Ti	—

[a]Times background, as in table 1.
[b]Elements not detectable under the analysis conditions used, but that could be present, include B, Li, Na, Cr, and V.

observed on the two sides of the triplet slab, since there is less absorption of the gamma rays from the uranium in the glass on the thinner synthetic spinel side intended to be the crown of the triplet.

Gamma-ray spectroscopy of three samples showed that the observed radioactivity was derived from natural (nondepleted) uranium and its daughter products. The measured radioactivity in nanocuries per gram (nCi/gm) is given in table 3. Although acceptable limits for radioactivity established in the U.S.A. vary considerably depending on a number of factors, 0.4 nCi/gm (NRC) and 2 nCi/gm (DOT) have been reported for certain gem applications by Ashbaugh (1988). Some of the stones are clearly above the lower of these acceptability limits.

CONCLUSIONS

Three types of greenish yellow to yellow-green (peridot-like) materials have been found to be radioactive: some synthetic spinel-glass triplets (in which the glass layer contains uranium as the colorant), some uranium-glass rhinestones in the form of silver-backed chatons, and some fully fashioned uranium-glass rhinestones. Although the radioactivity in some of these stones exceeds

TABLE 3. Gamma-ray spectroscopy of three radioactive stones from table 1.

Sample no.	Color and type	Radio-activity[a]	Radio-activity[b] (nCi/gm)
GR$_1$	Greenish yellow spinel triplet	1.5	0.44
GR$_2$	Yellow-green spinel triplet	1.5	0.38
SW$_2$	Yellow-green glass chaton	4	4.0

[a]Times background, as in table 1.
[b]As determined by gamma-ray spectroscopy; error ±20%.

U.S. government limits, they probably present no hazard under normal wearing conditions. The dealer who carries a large parcel of such materials in a pocket for a prolonged period of time may, however, be at some risk. Since similar colors can be produced in glass without the use of uranium, it is difficult to understand why uranium-containing glass is still being used in jewelry today.

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Gem Trade
LAB NOTES

AMBER, Plastic Imitation

A large translucent-to-opaque orange, white, yellow, and brown piece of rough was submitted to the West Coast laboratory for identification. The piece measured approximately 28.7 × 20.5 × 28.0 cm. Our client reported that it had been represented as amber when he purchased it in Tahiti; he was told that it had been found floating offshore there.

The appearance of the piece was rather unusual. One side had a thin white coating over a brown area where a few broken sections revealed a third layer that was orangy brown. The other side (figure 1) had some of the white coating plus what appeared to be stamped impressions. In addition to numerous gas bubbles, this side also had a broken portion that revealed a dark yellow interior.

In general, the piece resembled slag material from a plastics factory. Because of its size and the rough surface, we could not get either a specific gravity (although the "heft" test indicated it was very low) or a refractive index. However, a thermal reaction tester produced the slightly acrid odor that is typical of many plastics. An infrared spectral analysis performed by the GIA Research Department confirmed that the material was indeed plastic. The IR

Figure 1. This 28.7 × 20.5 × 28.0 cm plastic imitation amber shows numerous gas bubbles and unnatural stamped depressions.

spectral curve closely matched a standard curve for polyvinyl chloride. *RK*

DIAMOND

With an Almandine-Pyrope Garnet Inclusion

While grading a 1.25-ct diamond recently in the West Coast laboratory, we noticed the unusual appearance of a transparent crystal inclusion. As evident in figure 2, when the diamond is viewed face-up, the crystal appears to be half black and half orange. Because of the high refractive index of diamond, the color of included crystals may sometimes be masked, either partially or entirely. In this case, when the diamond is tilted, one can see that the entire crystal is actually orange (figure 3).

This inclusion, approximately

0.55 mm at its longest point, appears to be a reddish orange almandine-pyrope garnet, similar to published descriptions (see, e.g., *Photoatlas of Inclusions in Gemstones*, by E. J. Gübelin and J. I. Koivula) of compara-

Figure 2. When the host diamond is viewed face up, this included crystal appears to be half black and half orange. Note also the dodecahedral face. Magnified 35×.

Figure 3. When the diamond in figure 2 is tipped slightly, the true orange color of the entire included crystal becomes visible. Magnified 27×.
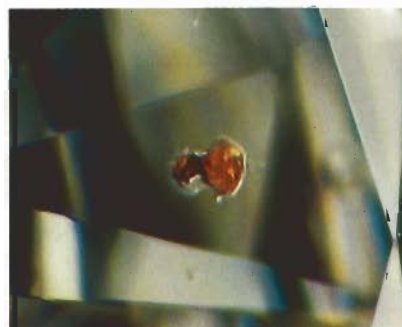
Figure 4. The light yellow tips and near-color-less center give this 0.69-ct marquise-shaped diamond the distinctive appearance of a true bicolor.
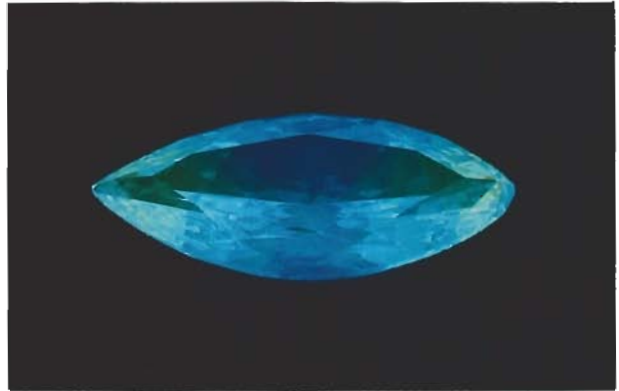

Figure 5. When exposed to long-wave U.V. radiation, the light yellow tips fluoresce a very strong chalky yellow, while the near-colorless center fluoresces a very strong blue.

ble stones, which would place the origin of this diamond in the eclogitic suite of kimberlites. Of course, since the inclusion does not break the surface of the diamond, it is impossible to prove the composition conclusively without damaging the host.

Typically, diamond imposes its own crystal structure on inclusions. Consequently, the faces visible on an included crystal are actually negative diamond faces, not those characteristic of the included mineral. (The term *xenohedral* is used to describe a crystal inclusion bounded by faces of its host mineral.) In this case, however, we cannot tell if the dodecahedral face visible in figure 2 belongs to the garnet or is imposed by the diamond's structure, because both belong to the cubic system.

The study of included crystals in diamond enables scientists to determine what elements are present deep within the earth where the diamonds crystallized. If there are no breaks between the surface of the diamond and the inclusion, then scientists know that the inclusion has remained compositionally unchanged since its creation more than 150 km deep in the earth's crust.

Holly Baxter

Bicolored

The West Coast laboratory recently studied a most unusual 0.69-ct mar-

quise-shape brilliant-cut diamond that was truly a bicolor (figure 4). The center portion was near colorless (approximately an H on the GIA color-grading scale), and both tips were light yellow (in approximately the T to U range on the same scale).

When the diamond was exposed to long-wave U.V. radiation, we observed a distinctly zoned fluorescence: the center portion a very strong blue, with both tips a very strong chalky yellow (figure 5). The zoned fluorescence appeared to correspond directly to the near-colorless and light yellow portions seen in visible light. When the long-wave lamp was turned off, the entire diamond exhibited a very weak chalky yellow phosphorescence that lasted approximately 10 seconds. Interestingly, the phosphorescence did not appear to be zoned. The fluorescence to short-wave U.V. radiation was essentially the same as to long-wave, except that the intensity was moderate rather than very strong. Although the diamond did phosphoresce after exposure to short-wave U.V. radiation, the phosphorescence was extremely weak and very short lived.

The absorption spectrum of this stone was examined at room temperature using a spectroscope unit equipped with a Beck "hand-held" type of prism spectroscope. The near-colorless portion exhibited a

strong, sharp 415-nm line, but the rest of the "Cape series" lines at 423, 435, 452, 465, and 478 nm were very weak. The light yellow tips of the marquise cut did not show any absorption lines or bands. When the diamond was placed over the strong light source from the opening of the iris diaphragm on the spectroscope unit, the near-colorless center portion showed a strong blue transmission luminescence. However, the light yellow areas did not show any transmission luminescence.

When the diamond was examined under the microscope with diffused lighting, both in air and while immersed in methylene iodide, no line of demarcation was observed between the light yellow and near-colorless areas.

Although we occasionally see diamonds that are strongly and irregularly zoned yellow and near colorless, this is the first one that possessed a symmetrical bicolor appearance to the unaided eye. *RK*

With a Color-Change Garnet Inclusion

The West Coast laboratory recently received a 0.58-ct diamond for quality analysis. This diamond was found to contain a very unusual inclusion, a color-change garnet, which was red-purple in incandescent light (fig-

ure 6, left) and saturated green in fluorescent light (figure 6, right).

The included crystal, approximately 0.25 × 0.30 mm, was partially exposed on the surface of the pavilion. Using X-ray fluorescence analysis, Dr. Emmanuel Fritsch of the GIA Research Department determined that magnesium, aluminum, and silicon were present, with a trace of iron and chromium, but found no indication of any manganese. This suggests that the crystal is a color-change pyrope garnet.

The diamond contained other wholly included crystals; one near the table showed a very faint change of color. One should always examine colored inclusions in diamond with both incandescent and fluorescent light to see if there is a color change.

Soheila Jalali

Radium Treated

The East Coast laboratory recently encountered a green pear-shaped diamond (approximately 9.70 × 8.00 × 3.70 mm) that was bezel set as an accent stone to a 6-ct fancy light yellow round diamond (figure 7). When examining green diamonds to determine origin of color, we routinely use a Geiger counter to test for radioactivity. This stone turned out to be radioactive, probably as a result of having been treated with radium salts earlier in this century.

Although encountered infrequently today, artificial coloration of gemstones by treatment with radium was first reported in 1909. In 1916, Sir William Crookes, reportedly the first to experiment with laboratory irradiation of diamonds, presented a small blue-green octahedron to the British Museum that he had treated with radium salts in 1914 (see *Gems & Gemology,* Summer 1950, p. 317).

The pear-shaped diamond we examined was medium dark green in color and showed no luminescence when exposed to either long- or short-wave U.V. radiation. Although the setting restricted our observations with the hand spectroscope, we did see a pair of lines at 498 and 504
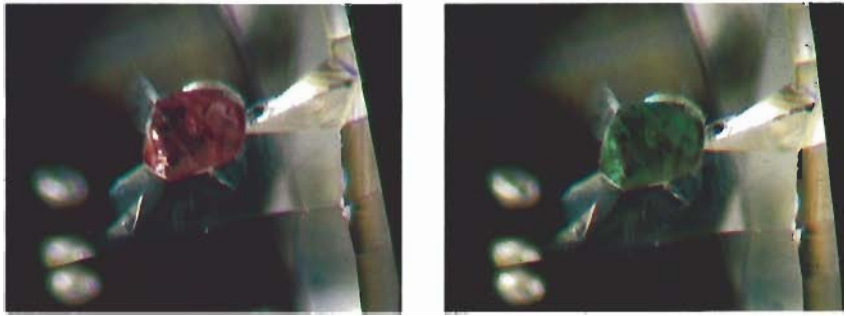

Figure 6. This inclusion in diamond appears red-purple in incandescent light (left) and green in fluorescent light (right). Magnified 25×.

nm. Because the stone was dark and the heavy gold setting covered an unusually large portion of it, we could not see the tell-tale green "mossy" patches that result from radium treatment until we illuminated the diamond with a FiberLite. We then noted a few very subtle green stains on the pavilion (see p. 164 of the Fall 1987 issue of *Gems & Gemology* for a photo of such stains). Mr. John Haynes, who has treated diamonds with another type of radioactive salt, americium, reports that green diamonds treated by his method do not show these mossy patches (pers. comm., 1989).

To rule out the possibility that the reading from the Geiger counter of

Figure 7. The green pear-shaped diamond seen here as a side stone to the 6-ct fancy yellow diamond at the bottom was found to be radioactive.

two millirems per hour was from the setting, we wrapped the green diamond with lead foil and again checked the entire ring with the radiation detector. The significant reduction in detectable radiation proved that the source of the original reading was the green diamond.

Although this stone did not have as high a level of residual radiation as has been reported in other radium-treated diamonds, we would not advise using it in jewelry.

Tom Moses

Treated Crystal

In recent months, the laboratories on both coasts have received a greater-than-normal number of fancy color diamonds for examination. With this trend, we have also encountered more treated diamonds. Particularly rare is an irradiated rough diamond crystal submitted for examination to the East Coast laboratory. Although we have seen two such crystals in the past, this is the first we have had an opportunity to photograph and report.

This 2.95-ct well-formed bluish green octahedron was low in clarity and lacked the natural green irradiation stains usually seen on the surface of natural-color green diamond crystals. More significantly, as is evident in figure 8, the coloration was very superficial and was concentrated along the crystal edges. This was most likely the result of electron or alpha-particle treatment.

The diamond did not luminesce to either long- or short-wave ultraviolet

radiation. The absorption spectrum, observed with a GIA spectroscope unit, showed a line at 415.5 nm, a pair of lines at 498–504 nm, and a weak, but sharp, line at 594 nm, a spectrum that is commonly observed in treated diamonds.   *Tom Moses*

Figure 8. A magnified view (10×) of this treated diamond crystal shows that the color has very shallow penetration and is concentrated along the edges of the crystal.
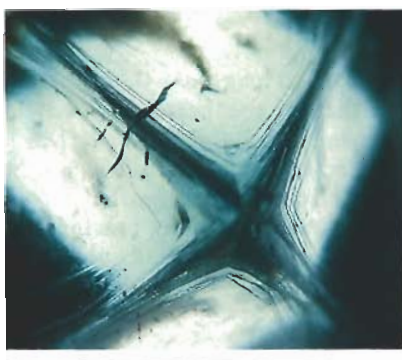
Impregnated JADEITE JADE

Our West Coast laboratory learned that a new type of treatment was being used in the Orient to improve the appearance of some jadeite jade. Four sample beads, each measuring approximately 9 mm in diameter, were loaned to us for examination. As can be seen in figure 9, the center pair of beads looks quite different from the outer two. We were told that the center two slightly yellowish green beads are representative of the material after treatment, whereas the outer two darker brownish green beads represent the untreated material.

With magnification we noticed that the "treated" material appeared to be more homogeneous in structure; few of the tiny cracks that are usually present in jadeite jade were visible. The "untreated" beads showed numerous cracks that seemed to be filled with iron stains, thus giving the beads their brownish appearance. However, the area

Figure 9. Although all four of these 9-mm jadeite beads were impregnated with plastic, the treatment was more successful on the inner pair than on the outer two.

within and around the drill holes of both types of beads showed a foreign colorless material. When touched lightly with the hot needle of the thermal reaction tester, the very soft material started to flow and give off an acrid odor. This indicated that both types of beads had actually been impregnated with a plastic. We concluded that the lighter colored beads had been treated more successfully, with the iron-stained cracks masked to improve the overall color appearance of the material.

Using a Nicolet 60SX-FTIR spectrometer, Dr. Emmanuel Fritsch was able to record the infrared spectrum of the treated beads (figure 10). The peaks in the area of approximately 6200 to 5500 wavenumbers are those of jadeite jade; all others can be attributed to a plastic. Bob Rosen-

Figure 10. Only the peaks in the 6200–5500 wavenumber range of this infrared absorption spectrum of one of the beads in figure 9 can be attributed to jadeite; all of the others represent a plastic.
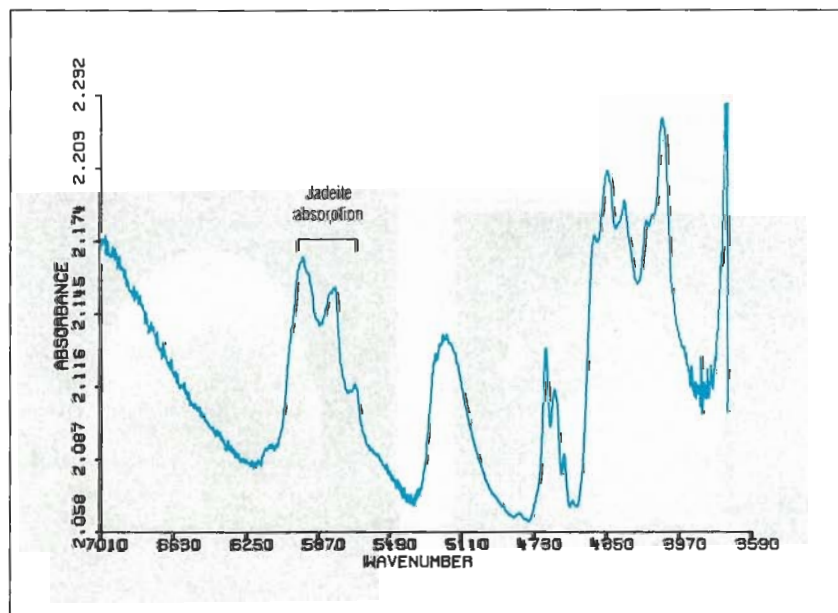
thal, of Nicolet Instrument Corporation, reported that the plastic is probably a mixture of different polyacrylates, although a definite conclusion is not possible without destructive testing. *KH*

Assembled PEARL

In most cases, identification of mounted pearls does not present a problem. The X-radiograph in figure 11, taken at the East Coast laboratory, shows a large (approximately 18.75 × 17.30 mm) half-drilled slightly baroque pear-shaped pearl that was set in a yellow metal ring. Although this X-radiograph seemed to indicate natural origin, it was not conclusive. After several more X-radiographs were taken, all with unsatisfactory results, we asked the client to remove the pearl so that we could examine it unmounted.

We were surprised to find that the unmounted pearl actually was assembled (figure 12), a fact that had been carefully concealed in the gallery work of the setting. Neither section fluoresced to X-rays, and a subsequent X-radiograph proved that both sections were of saltwater natural origin. The fact that both pearls had slightly flared outlines near the

Figure 11. This X-radiograph of a large (18.75 × 17.30 mm) mounted pearl suggests, but does not conclusively prove, natural origin.
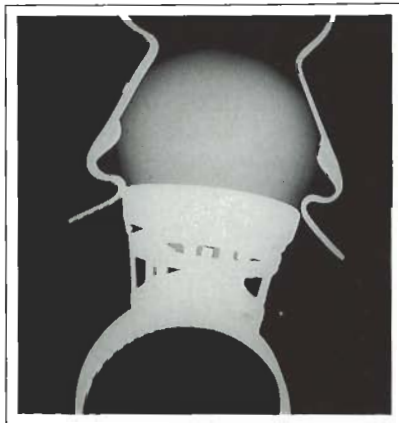
union suggests that they were worked from blister pearls. If it went undetected, such an assemblage would appear to be an important pearl because of its large size. Our report concluded: "Assembled pearl consisting of two sections of natural pearl or blister pearls cemented together." *Tom Moses*

CULTURED PEARL, Treated Black

The West Coast laboratory had the rare opportunity to see the interior of a cultured pearl that had been treated to give it a black color. A jeweler from Texas discovered that a triple strand of cultured black pearls, which had been represented to him as being of natural color, were actually artificially enhanced. He sent us a few loose brownish black pearls from the necklace together with one that he had cut in half for research purposes.

Figure 13 shows one of the loose pearls, which measured approximately 9 mm in diameter, next to half of the cut pearl. The striated grayish bead nucleus and a brownish black nacreous layer approximately 2-mm thick are readily visible. When

Figure 12. When the pearl shown in figure 11 was unmounted, it became readily apparent that it had been assembled, possibly from two blister pearls.

Figure 13. When a companion to the 9-mm treated black cultured pearl at the left was sawed in half, it revealed a rim of black nacre, evidence that the pearl had been dyed.

exposed to long-wave U.V. radiation, neither of the pearls showed the brownish red fluorescence that is characteristic of natural-color Tahitian black cultured pearls; instead, both remained inert, proving that they had been artificially enhanced.

The GIA Research Department has been studying the chemistry of the nacreous layers in black pearls by means of X-ray fluorescence. XRF analysis of these two pearls showed the presence of a high amount of silver in both, indicating that they had been dyed, probably with a silver nitrate solution. Comparative analyses have shown that natural-color black pearls do not show any traces of silver. *KH*

Damaged "Burma" RUBY

Recently the East Coast laboratory had the pleasure of identifying an attractive untreated ruby that was mounted in an older yellow and white metal lady's ring set with old-mine-cut brilliants, single cuts, and Swiss cuts. The stone displayed the patches of short rutile needles and irregular "treacle" color zoning that are characteristic of Burma rubies. In addition, it luminesced strongly to both long- and short-wave U.V. radiation. The stone appeared to be in exceptionally fine condition.

Several weeks later the stone and ring, which we recognized imme-

diately, were returned to us for a damage report. The ruby was now so badly fractured (figure 14) that it could not be repaired.

We examined the fractures in question using an overhead light source and a high-magnification contrast-interference microscope. The fractures lacked undercutting and polishing drag lines where they reached the surface, thus proving that they had occurred after the stone was last polished and, therefore, were not inherent. The nature and extent of the fractures indicated that the damage was probably the result of a rapid temperature change.

While examining the mounting, we noticed new metal at the end of a pitted prong next to one of the diamonds, a sign that it had been re-tipped. This was probably the cause of the damage. Why the ruby was subjected to the heat of retipping the prongs and not removed from the setting first is the real mystery.

DH

Figure 14. The numerous fractures in this natural ruby (8.60 × 6.20 × 3.80) probably resulted when the stone was heated during a retipping of the prongs. Magnified 10×.

Large Purple SCAPOLITE

Although scapolite occurs most frequently in colorless to yellow transparent crystals, it is also found in other colors; purple is one of the most popular. An unusually large (17.61 × 16.36 × 15.20 mm) transparent purple oval mixed-cut scapolite recently came to the attention of the East Coast laboratory (figure 15). This

Figure 16. This magnificent 15.18-ct dark violetish blue tourmaline is from the newly discovered São José da Batalha mine, in Paraíba, Brazil.

26.11-ct stone was reportedly from Burma. The largest cut scapolite, also from this locality, is believed to be the 288-ct colorless stone reported in the January 1978 issue of the *Journal of Gemmology.* However, fine-color purple scapolites in sizes over a few carats are not common.

Scapolite also occurs in a fibrous and translucent form that may display chatoyancy when cut *en cabochon.* A 52.92-ct cat's-eye scapolite

Figure 15. This 26.11-ct purple scapolite is unusually large for such a color.

was reported by our West Coast laboratory in the Summer 1985 *Gems & Gemology.* Nicholas DelRe

Blue TOURMALINE from Brazil

In recent months, laboratories on both coasts have seen a number of tourmalines from the new locality in Paraíba, Brazil. The East Coast laboratory examined two tourmalines from this locality of a fine "sapphire" blue color, known in the trade as "indicolite," the larger one weighing 5.71 ct. The samples tested had the normal gemological properties for tourmaline. DH

The West Coast laboratory received for identification an extraordinary 15.18-ct oval modified brilliant cut, dark violetish blue tourmaline (figure 16) that was reported to be from this same locality. When viewed table up with standard "daylight equivalent" illumination, the stone somewhat resembles a fine tanzanite. This color is unlike any previ-

ously reported for blue tourmalines (particularly in this size range).

As mentioned in the Gem News section of the Fall 1989 issue of *Gems & Gemology*, faceted stones from this new Paraíba find (more precisely known as São José da Batalha) are usually less than 1 ct. To the best of our knowledge, this is the largest fine faceted violetish blue tourmaline reported from that locality to date.

Identification of the stone as tourmaline was confirmed by standard gemological testing. It was determined to be uniaxial negative and to have refractive indices of 1.620 and 1.640, with a corresponding birefringence of 0.020; a specific gravity of 3.07 was determined by the hydrostatic method; very strong pleochroism was obvious to the unaided eye. With a calcite dichroscope, we observed strongly dichroic colors of dark blue-violet parallel to the c-axis and medium greenish blue perpendicular to the c-axis.

The visible-light absorption spectrum was examined with a GIA Gem Instruments spectroscope unit with a Beck prism spectroscope at room temperature. This unusually colored tourmaline had a very interesting absorption spectrum. Parallel to the c-axis there were only two major areas where light was transmitted: one in the violet, violet-blue, blue, and part of the blue-green; and the other in portions of the blue-green and green regions. Within the violet, violet-blue, and blue transmission areas we observed a moderately strong diffuse band centered near 453 nm and a thinner diffuse band of moderate intensity at approximately 461 nm. We also noted, in the green region, a strong sharp line slightly above 539 nm, with a vague emission (bright) line at around 538 nm. In addition to these areas, there was a broad strong absorption area blocking out all of the red and most of the orange (approximately 605 to 700 nm) as well as a general, moderate to weak, absorption from around 500 to 540 nm and a somewhat narrower strong dark absorption in the violet

from approximately 400 to 428 nm.

The spectrum observed perpendicular to the c-axis was very similar, except for the absence of the line slightly above 539 nm and the fact that the lines at 453 and 461 nm were weaker. As reported in the Gem News section of this issue, preliminary work by the GIA Research Department indicates that the color of this stone is probably caused by the presence of Mn^{3+} together with Cu^{2+}. European researchers have reached a similar conclusion based on like-color material from this locality (E. Gübelin, pers. comm., 1989).

To insure observation of even the weakest fluorescence, we exposed the stone to both long- and short-wave U.V. radiation in a darkened room, placing it within a few inches of the ultraviolet lamp. The tourmaline showed no visible fluorescence to either source.

We also checked the stone for color zoning by immersing it in sesame oil (R.I. of 1.47), which was chosen because it is nontoxic. When the stone was viewed over diffused illumination, the overall blue coloration as seen with the unaided eye was even. However, there was a very subtle zone, moderate in size, of faint purple arranged in a "Y"-shaped pattern oriented parallel to the c-axis that appeared to extend throughout most of the stone. The "Y" shape was reminiscent of the growth features that run down the c-axis of some Brazilian "imperial" topaz.

Examination of the stone with a microscope and darkfield illumination revealed subtle, straight parallel growth features throughout most of the interior. In addition, a few small needles and minute white crystals were observed in random orientation.   *RK*

Imitation
CUBIC ZIRCONIA

By definition, an imitation is fashioned to closely resemble a more valuable gem. Many diamond imita-

Figure 17. These 5-mm "zirconia" earrings were found to be foil-backed glass.

tions, for example, are familiar to jewelers and consumers alike. At the East Coast laboratory, however, we were surprised to encounter glass imitations of cubic zirconia, which in itself is a relatively inexpensive material and certainly not a gem.

The earrings shown in figure 17 were offered as an incentive to attend a real estate sales presentation. These 5.00-mm round brilliants were labeled *zirconia*. A trained observer would immediately notice the molded appearance and the lack of the dispersion that is characteristic of true CZ. The pavilions of both stones were coated with a reflective substance (foil backed) to give them the appearance of having more brilliance than the low refractive index (1.57) would provide.   *DH*

WINTER 1964

The New York laboratory reported on their examination of the famous 43.48-ct Nassak diamond, which is of top color and flawless. Additional notes referred to Brazilian emeralds without chromium, pressed amber, odontolite, and some rare-earth synthetic crystals.

A pink pearl that was sawed in half to make a pair of earrings was seen in the Los Angeles laboratory. Large knots in diamond, "pigeon's eye" nephrite, and needles in quartz that were identified by X-ray diffraction as tourmaline were also discussed. The American Gem Society's definition of *flawless* was mentioned and illustrated with photos.

WINTER 1974

Synthetic opal, Slocum stone, and a number of other opal imitations were compared with natural opals in the report from the New York laboratory.

The Los Angeles laboratory discussed at length a new pulled synthetic alexandrite. Its transparency to short-wave ultraviolet light was compared with that of flux-grown synthetics and natural alexandrite. Photos showed that the pulled material was more transparent than its flux-grown counterpart, which in turn was more transparent than the natural stone. Different types of coral were mentioned, including black from Hawaii and a calcareous type of a rare blue color that was from an unknown source.

WINTER 1984

A very small (0.02 ct) single-cut diamond was seen to have a unique diamond crystal inclusion. Because it was loose in a cavity that was open to the surface, the included crystal actually protruded above the table of the host diamond when the host was inverted. Other items of interest were a color-change spinel, natural pale color corundum beads with red dye that was visible in the drill holes, and illustrations to help separate oolitic opal from sugar treated. To someone who is not familiar with the appearance of these two opal types, separation can be difficult. The comparison photomicrographs are repeated here to help clarify the difference.

Circular black spots identify the natural structure of oolitic opal. Magnified 20×.

In sugar-treated opal, shown here at 45×, the small black irregular concentrations of dye appear only in the interstices and cracks of the opal.
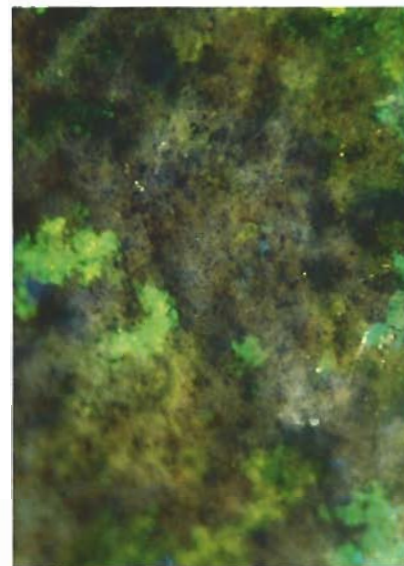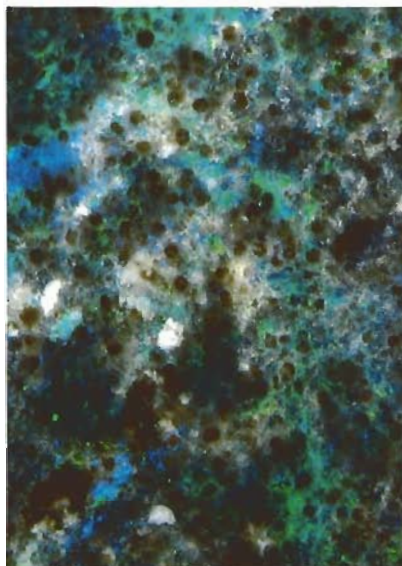
GEM NEWS

John I. Koivula and Robert C. Kammerling, *Editors*

DIAMONDS

Filled diamond update. The Summer 1989 *Gems & Gemology* article on filled diamonds stated that "there is no practical way to remove all of the filling material" from a treated stone. Following publication of the article, Mr. Isaac Landerer, one of the principals of the New York firm that performs diamond filling, Dialase, advised us that the filling material could, in fact, be completely removed. To support his claim he offered to supply a treated stone that we could examine and document both before and after the filling material was removed.

The stone subsequently provided was a 0.85-ct round brilliant. With magnification, a surface-reaching break in the stone exhibited a number of features characteristic of filled diamonds, including both orange and blue "flash effects" and gas bubbles trapped in the filling material (figure 1, left). EDXRF chemical analysis revealed the presence of lead in the filling. The diamond was then returned to Mr. Landerer for removal of the filling substance, reportedly by a deep-boiling technique in an undisclosed medium. When he sent the stone back, magnification revealed no visual indications of treatment in the previously filled break (figure 1, right). Furthermore, EDXRF analysis did not detect any lead where it had previously been noted. It thus appears that the so-called "Yehuda" filling treatment can be reversed, although we do not know the specific conditions of the removal process.

Diamond exploration in Pilbara, Australia. Perilya Mines and Canada-based Noranda, Inc., have arranged a joint venture to invest US$570,000 for diamond exploration in the Pilbara area of Western Australia. The exploration is in its infancy, but researchers believe the earlier discovery of a 0.3-mm gem-quality diamond on the Nullagine project could lead to a major diamond source. (*Diamond Intelligence Briefs*, Vol. 5, No. 91–92)

Increased diamond output in Botswana. The Botswana Diamond Valuing Company plans to raise its diamond output by 12%, to 17 million carats, in 1990. To achieve this goal, the company will add 60 new diamond sorters to its existing work force of 280 sorters in Gabarone. Additionally, Debswana, the mining company co-owned by De Beers and Botswana, is funding construction of a new recrush plant in Jwaneng; the $105 million plant is scheduled to begin operation in April 1990.

Botswana's output, in terms of value, is second only to that of the Soviet Union; Debswana accounts for approximately 55% of De Beers's total diamond output and about half of its profit. Despite these figures, diamonds are becoming increasingly difficult to recover from Botswana's three mines, and several companies – including De Beers – are exploring for new deposits. None of the many deposits discovered to date is considered commercially viable. (*Diamond Intelligence Briefs*, Vol. 5, No. 88)

Ghana may privatize mines. Sofremines, a French-based firm, is preparing a study on the rehabilitation and possible privatization of the Birim diamond field in southern Ghana. Production in Birim has dropped from 2.6 million carats in 1966 to 200,000 carats in 1988, as a result of unstable funding and outdated equipment. The new study reportedly emphasizes acquiring mobile equipment, which could be used in each sector for three to four years. Total reserves in the Birim field are estimated to be between 26 and 29 million carats. (*Diamond International*, October 1989)

Diamond cutting expands in Mauritius. The tiny Indian Ocean island of Mauritius, known for its stable social, political, and economic environment, is attracting growing interest from diamond manufacturers. Located 2,500 km from South Africa's coast, the island is home to three operating diamond plants, and a fourth is under construction. Currently, the island's diamond industry employs 1,550 workers.

The existing firms in Mauritius – L.S.P. Ltd., Belsdiam, and Universal Diamonds – all have their roots in Antwerp. The new plant is owned by India-based Pattel Ltd. In 1988, Mauritius accounted for just under US$7 million in rough diamond imports from Belgium, a 130% increase over 1987. (*Diamond International*, October 1989)

Diamond exploration on the west coast of South Africa. John Gurney, chairman of the South Africa–based exploration company Benguela Concessions, says there is evidence that approximately 20 million carats of potentially gem-quality diamonds have accumulated off the west coast of South Africa. The diamonds have eroded from river deposits and been carried into the shallow waters of the Atlantic Ocean.
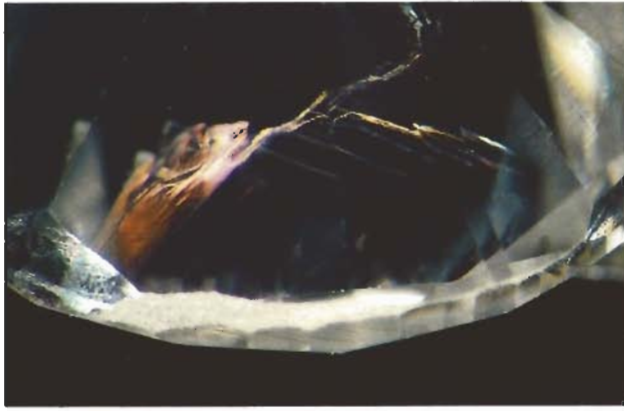
A 1970 survey estimated that there were about 3

Figure 1. The "orange flash" effect (left) noted in a filled break is no longer apparent after removal of the filling material (right) from the diamond. Photomicrographs by John I. Koivula; magnified 15×.

billion carats of diamonds off the west coast of South Africa. Benguela Concessions has options on two concession areas off the coast. A small-scale diamond recovery operation near these two areas has extracted 44,000 ct from the ocean over the past 11 years. (*Diamond Intelligence Briefs*, Vol. 5, No. 91–92)

COLORED STONES

Burmese contract for new mining technology. Gold mines in Myanmar (Burma) have contracted with Min, Yugoslavia's Nis-based mining and metallurgical equipment company, to provide new mining equipment and technology needed to increase Burmese gold production. Experts speculate that this move by the Burmese could preface an opening of their gem resources. (*Mining Journal*, Sept. 15, 1989).

"Adularescent" chalcedony. Shane McClure of the GIA Gem Trade Laboratory in Santa Monica recently encountered some unusual chalcedony (figure 2). The material, marketed as "Mojave Blue" by its discoverers Bill Nicks and Mike Pirtle of Bakersfield, California, is recovered from a desert location near the town of Mojave, north of Los Angeles in the Mojave Desert.

The material has an appearance unlike anything we have previously seen in chalcedony. It ranges from semitransparent to translucent with a very light to medium grayish violet-blue body color. All the specimens we examined had a weak to distinct botryoidal structure. What is unusual about the material is a weak to quite distinct "adularescent" effect that in some instances mirrors the underlying spheroid structure. The effect was notably stronger than the sometimes hazy sheen seen in so-called chalcedony "moonstone." Microscopic examination revealed extremely fine, fibrous inclusions which might produce a scattering of light that could account for the apparent body color and phenomenon.

Star chrysoberyl from Sri Lanka. Chrysoberyl is known to occur in two popular phenomenal varieties, cat's-eyes and color-change alexandrites. Jay Rosenthal of Coral

Springs, Florida, allowed us to examine a most unusual star chrysoberyl (figure 3). The 1.54-ct stone, a translucent greenish yellow oval cabochon, exhibited a strong, four-rayed star centered on the dome. Magnification revealed that the asterism was due to the presence of densely packed, minute fibrous inclusions of unknown composition.

Update on hackmanite. The Summer 1989 Gem News column reported on a faceted hackmanite and illustrated the color alteration induced by exposure to long-wave ultraviolet radiation. Mrs. Willow Wight, editor of

Figure 2. This unusual "adularescent" chalcedony is from the Mojave Desert in California. Photo by Shane McClure.

Figure 3. This unusual 1.54-ct cabochon is a
rare example of star chrysoberyl. Courtesy of
J. Rosenthal; photo by Robert Weldon.

The Canadian Gemmologist, provided us with the
following information regarding this stone and its dis-
covery.

First, she reported that the weight of the stone is
actually 3.23 ct. The rough was recovered by Gilles

Figure 5. Carved basalt as a gem material is be-
ing used in a variety of fashion items. Jewelry
designed by Valerie San Giacomo and Michael
Tope, Class Project Inc.; photo © Sky Hall.
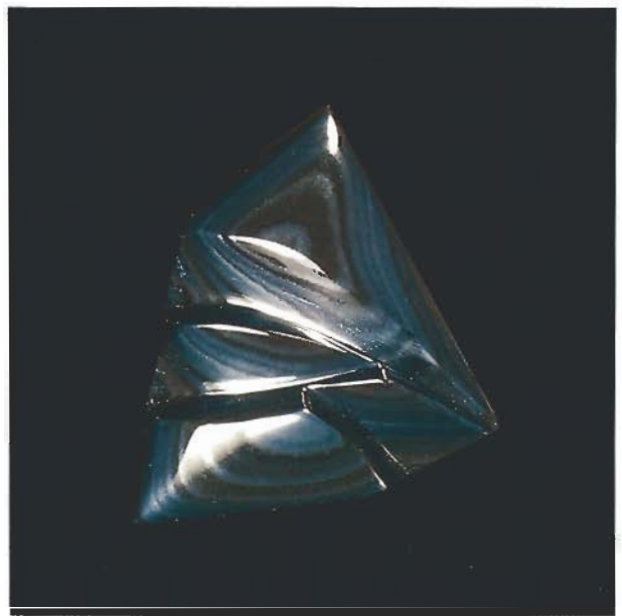
Figure 4. This carved psilomelane exhibits char-
acteristic banding. Photo and carving by Bart
Curren.

Haineault from a pocket in the back wall of the Poud-
rette Quarry at Mont Saint-Hilaire, Quebec, about 20
mi. (32 km) south of Montreal, in the late summer of
1988. Apparently, it is not unusual to find opaque,
whitish hackmanite at this locality, with the material
appearing "magenta" when first uncovered but fading on
exposure to sunlight. The stone illustrated in the Gem
News column was faceted from one of two large,
transparent broken crystals found. These crystals cut
approximately 40 stones in all, the largest weighing
15.33 ct. The same pocket that yielded the hackmanite
also produced pectolite and villiaumite specimens.
Among the other unusual minerals collected from the
Mont Saint-Hilaire locality are catapleiite, serandite,
and light blue willemite.

Psilomelane and basalt: novel black carving materials.
Recently a number of black gem materials such as
hematite and dyed chalcedony have seen a resurgence in
popularity in the form of carved stones in geometric and
free-form shapes. In response to this demand for black
gems, Bart Curren of Glyptic Illusions, Topanga, Califor-
nia, began carving some materials not generally thought
of as having gem application. One of these, psilomelane,
is an oxide primarily of manganese with lesser amounts
of barium and sometimes sodium and potassium to-
gether with some water. It is usually found in botryoidal
or stalagmitic form and has a Mohs hardness in the range
of $5^1/_2$–$6^1/_2$. Because of its mode of formation it often
exhibits attractive banding, as can be seen in figure 4.

Even more unusual as jewelry items were carvings
made from basalt, a fine-grained igneous rock (figure 5).
Examination of a thin section of the carving material

revealed the presence of some glass, in addition to plagioclase feldspar, augite, and olivine. This is the first time to our knowledge that basalt has been carved for use as an ornamental gem material.

Quench-crackled, dyed-green quartz. From time to time throughout history, rock crystal quartz has been quench crackled and dyed to imitate such gems as ruby and emerald. Timothy D. Schuler of Schuler Gemological Services, Palm Harbor, Florida, recently informed us that quartz that had been quench crackled and dyed green was being marketed in his area, mounted in 14K yellow gold ear studs, as "green amethyst." According to Mr. Schuler, customers were not being told that the material had been treated.

Huge, doubly terminated sapphire crystal. Mr. E. Gamini Zoysa, of the State Gem Corporation in Sri Lanka, reports the recent discovery of an extremely large, doubly terminated sapphire crystal (figure 6). Found in Rakwana, the crystal weighs approximately 40.3 kg and measures 25 × 50 cm (10 × 20 in.). According to Mr. Zoysa, the crystal contains some good "gemmy" blue areas, as well as some areas that appear milky and may respond favorably to heat treatment.

Sapphires found in Burundi. Geologist and gem miner Campbell Bridges reports the discovery of a very large new deposit of sapphire in Burundi, near the border with Rwanda. The deposit is said to be of volcanic origin. The material recovered thus far includes stones of good color as well as some described as "geuda-type" which Mr. Bridges feels will probably heat treat favorably.

Mining ventures are reactivated in Southeast Asia. After years of war and economic hardship, Vietnam is gradually implementing new policies to check inflation and encourage international investments. The government's move to pull out of Cambodia and demobilize hundreds of thousands of troops is expected to bring the country global recognition, most importantly from the United States. As a result, mining operations are beginning to re-open, particularly in the areas of metals and petroleum. Currently, small-scale operators are producing an estimated 1,000 kg per year of gold. Similarly, minor operators are reportedly finding considerable quantities of "world class" rubies and sapphires in Ha Tuyen province. The Vietnamese government will work with Thai interests in a joint venture to market these gems.

Experts say that the joint venture with the Thais is one example of the Vietnamese government's willingness to open up to foreign investments and modernize their industrial sector. Furthermore, their receptiveness to joint ventures could lead to greater mining development in this country.

Elsewhere in the region, Laos and Cambodia have asked the Thai Gems & Jewellery Traders' Association to

Figure 6. This 40.3-kg doubly terminated corundum crystal from Sri Lanka dwarfs the pocket calculator used as a size reference. Photo courtesy of E. Gamini Zoysa.

consider investing in gem-mining operations in their countries. Already, Laotian companies have established joint ventures with the Thais, including one operation that is producing sapphires. Several other joint operations are expected to begin, and at least four of those include Australian interests. (*Mining Journal*, September 15, 1989; *Mining Magazine*, September 1989; *Journal of Gem Industry*, June 1989)

Large faceted Pamir spinel. A number of reports have appeared in the literature recently about pink spinels coming from the Pamir Mountains in the Soviet Central Asian republic of Tadzhikistan (see Gem Trade Lab Notes, Spring 1989, pp. 39–40, and *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, August 1989, pp. 85–88). Recently a 146.43-ct intense reddish pink brilliant was cut from a deformed crystal by Justina Wright of Fallbrook, California. Mrs. Wright acquired the crystal from Marius Van Dyk. The rough also yielded a 30.03-ct free-form.

Sri Lanka update. Gordon Bleck recently returned from Sri Lanka with news of conditions that may adversely affect the supply of gems from that country. He reports that from January to mid-April of 1989 there was severe drought and, in most mining areas, inadequate water to wash the gem gravels. Then, in June, the nation experienced the worst flooding in 15 years, which stopped mining in the central southern district for approximately one month. A significant increase in terrorist activity in June also led to decreased mining in outlying areas because miners were afraid to venture to the more remote mines.

Figure 7. This 3.55-ct zircon from Sri Lanka lacks the secondary brownish component often seen in green stones of this species. Courtesy of G. Bleck; photo by Robert Weldon.
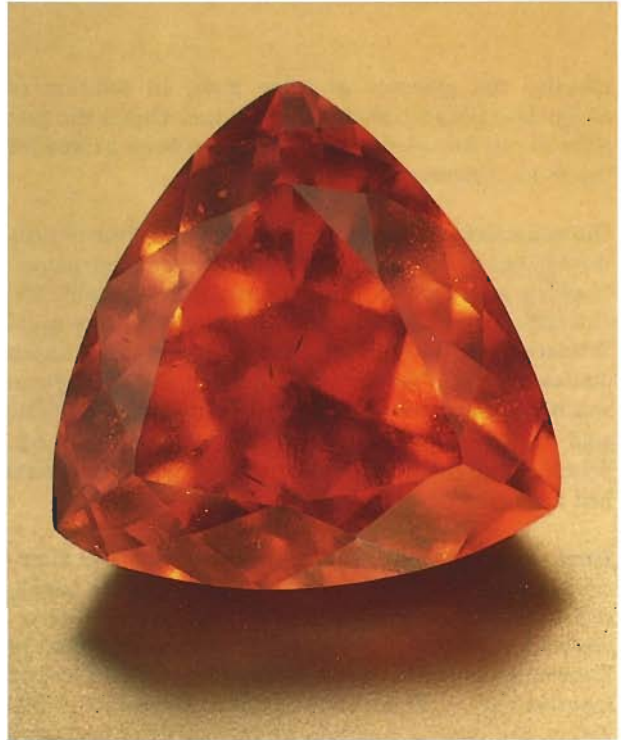

Figure 8. The color in this 8.77-ct hessonite is unusually saturated. Courtesy of G. Bleck; photo by Robert Weldon.

Mr. Bleck also confirmed that approximately two years ago emeralds were discovered at Hambantota, on the southeastern coast of Sri Lanka, in a former rice paddy. The emeralds are found under a layer of sandy soil about 2 ft. (72 cm) below the surface, not far from the sea. Reportedly about 2 kg of material has been recovered to date, but most of this is not gem quality. The largest stone faceted thus far weighs approximately 0.5 ct. The color of the one crystal we examined was very saturated.

In addition, Mr. Bleck reports examining a number of unusual stones during his last trip, including a 3 + -ct light brown faceted monazite. The stone reportedly came from the Trincomalee area in the northern part of the island. He also showed us a 40.91-ct piece of gem rough that could not be identified by gemologists who examined it in Sri Lanka. The stone, which was recovered from a pit mine near Eheliyagoda, exhibited dark blue and near-colorless areas. EDXRF spectroscopy, performed by GIA's Dr. Emmanuel Fritsch, identified the stone as cassiterite. However, we found no reference to either Sri Lanka as a source of cassiterite or its occurrence in blue in the current editions of Webster's Gems and Liddicoat's Handbook of Gem Identification.

A new find of attractive green zircons was also reportedly made this past year, although the exact locality has not been disclosed. The more than 20 stones we examined were primarily medium dark in tone and of fairly high saturation, lacking the secondary brownish component generally seen in green zircons (figure 7). They were also highly radioactive, registering about 60 times the level of background radiation.

Another stone examined was an 8.77-ct triangular brilliant-cut hessonite garnet which had an excep-tionally saturated orange color as well as a strong eye-visible "heat-wave" effect (figure 8), which is typical of hessonite garnets from this classic source.

Paraíba tourmaline update. In the Fall 1989 Gem News column, we described some unusual tourmalines from Paraíba, Brazil. These were notable for their color, ranging from bluish green to violetish blue. Since that time, we have seen additional material from this locality that is light to medium in tone and yellowish green or violet in hue.

Recently, Dr. Emmanuel Fritsch, Meredith Mercer, and Mike Moon of the GIA Research Department had an opportunity to analyze a range of Paraíba tourmalines using EDXRF and UV-visible absorption spectroscopy. They found that the tourmalines contain manganese and copper as possible coloring agents, along with traces of iron. The absorption spectra in the visible range of green to blue tourmalines from Paraíba are charac-terized by a broad band with an apparent absorption maximum at about 700 nm. This band could be related to either Fe^{2+} or Cu^{2+}; oriented quantitative absorption measurements are necessary to ascertain its exact origin. Less intense features attributed to Mn^{3+} (the main coloring agent of rubellite) have been recognized in some of the samples as well. The Paraíba tourmalines are therefore unique for their unusually high copper content and their possible coloration by Cu^{2+}, which has not previously been encountered as a coloring agent in tourmalines.

Figure 9. A·thin dark blue color zone on the base of this multi-colored tourmaline cabochon causes it to appear quite different in reflected (left) and transmitted (right) light. Stone courtesy of Crystal Kingdom, Venice, CA; photos by Robert Weldon.

Unusual multi-colored tourmaline. GIA librarian Robert Weldon recently brought an unusual tourmaline cabochon to our attention. The 48.72-ct bullet-shaped stone reportedly came from somewhere in the vicinity of the Turkish-Iranian border in western Asia. The tourmaline showed a striking difference in appearance when illuminated with reflected versus transmitted light (figure 9). In reflected light, it exhibited a small area of pink at the tip, below which most of the stone appeared slightly bluish green, with a very thin layer at the base that was almost black. When intense transmitted light was directed through the base, however, the majority of the stone took on a pleasing deep blue color, with some of the pink still visible in the tip. In transmitted light, the very dark blue color of the thin basal layer projected into the remainder of the stone.

SYNTHETICS AND SIMULANTS ▬▬▬
Synthetic corundum "crystals." Dr. Henry Hänni and Mr. George Bosshart, of the Swiss Foundation for the Research of Gemstones, recently issued an ICA Laboratory Alert on two samples of synthetic corundum that were sold as waterworn rough (figure 10). The larger of the two weighed 56.04 ct, measured approximately

Figure 10. These two apparently waterworn corundum crystals, 56.04 and 21.80 ct, are actually flame-fusion synthetic sapphires. Photo courtesy of the Swiss Foundation for the Research of Gemstones (SSEF).

Figure 11. Reportedly manufactured in the Soviet Union, this 17.19-ct synthetic spinel crystal was flux grown. Photo by Robert Weldon.

53.50 × 12.47 × 7.82 mm, and had a slight color change, appearing purple in daylight and purplish red in incandescent light. Its most interesting feature was its morphology. It was described in the alert as having "a slender barrel shape and irregularly spaced steps on the finely frosted surface," resembling a natural, waterworn bipyramidal purple sapphire crystal. Inclusions could not be detected, even under immersion; its identification as a synthetic sapphire was based on a combination of the optic axis direction (approximately 30° off the long axis), size, color, and trace-element content.

The smaller "crystal" weighed 21.80 ct, measured approximately 24.64 × 11.98 × 7.74 mm, and was medium blue in color. It had the appearance of "a

Figure 13. These fantasy cuts were fashioned from a new man-made material with a garnet-like structure called "Oolongolite." Photo courtesy of Dominique Robert.

Figure 12. These dark reddish brown inclusions were the only gemological evidence of the flux growth of the synthetic spinel crystal shown in figure 11. Photomicrograph by John I. Koivula; magnified 35×.

broken and waterworn [blue sapphire] pebble, showing one residual pseudo-crystal face with an irregular step-like relief." Concentric color banding, trace-element analysis, and fluorescence to short-wave U.V. radiation supported the identification of a flame-fusion synthetic sapphire.

Neither the steps on the larger "crystal" nor the step-like elevations and depressions on the smaller one were parallel, and both appeared to have been produced by a grinding wheel; the translucent, frosted surfaces displayed by both specimens were believed to be the result of tumbling or sanding. These two synthetic sapphires, fashioned to imitate natural crystals, had been purchased recently in Sri Lanka.

Flux synthetic spinel. The Gem News editors recently examined a 17.19-ct synthetic red spinel octahedron (figure 11) that was brought to our attention by gemologist Bill Vance, who obtained it from a Soviet citizen. Although sold to Mr. Vance as a hydrothermal product, gemological investigation combined with infrared spectrometry and EDXRF analysis proved it to be a flux-grown synthetic. All of the basic gemological properties were virtually identical to those of similarly colored natural spinel, with the exception of flux-like inclusions in one area of the crystal (figure 12). A stone cut from unincluded areas of such a crystal would not be identifiable by standard gemological tests.

A 13.14-ct synthetic red spinel crystal with very similar properties was recently described by Professor Hermann Bank and Dr. Ulrich Henn of the German Foundation for Gemstone Research, Idar-Oberstein, in ICA Lab Alert No. 26, "Flux-Grown Synthetic Red Spinel from USSR."

New man-made crystal. GIA's Dr. Emmanuel Fritsch reports that an apparently new man-made crystal with a garnet-like structure is now commercially available.

The material is produced and marketed by Dominique Robert of Lausanne, Switzerland, in a variety of cuts including "fantasy"-type carved gems (figure 13), under the trade name "Oolongolite." It comes in colorless, dark blue, medium blue, medium green, dark bluish green, and "lilac" hues. Gemological properties reported by the manufacturer are as follows: R.I. of 1.93 to 2.00, singly refractive, S.G. of 6.7 to 7.0, and Mohs hardness of $7^{1}/_{2}$–8.

ANNOUNCEMENTS

The Art of Van Cleef & Arpels makes its debut at the Los Angeles County Museum of Art on April 7, 1990. The exhibition features the historical creations of the famed jewelry company and will highlight brooches, bracelets, necklaces, earrings, vanity and powder boxes, watches, evening bags, and special commissions dating from the 1920s through the 1950s. After the exhibit leaves Los Angeles on June 17, the display travels to the National Museum of Natural History, Smithsonian Institution (July 12–October 30), and the Honolulu Academy of the Arts (January 16–February 24, 1991).

John Sinkankas's book *Gem Cutting*, originally published by D. Van Nostrand Co. in 1955 and now in its third edition, was chosen by the Mir Publishing House of Moscow for translation into Russian, under the title *Handbook for Working Precious and Ornamental Stones*. Mir published 70,000 copies in 1989. *Gem Cutting* is the first lapidary book to be translated into Russian and reflects the desire of the Soviet government to encourage local artisans to take advantage of the many gem deposits that occur throughout the Soviet Union.

The Aurora Gem Collection, one of the largest collections of "fancy" colored diamonds ever to be shown in public, is again on display at the American Museum of Natural History in New York City. The collection now consists of 244 diamonds with a combined weight of approximately 221 ct. Many different colors are represented, as are a variety of cuts and localities.

The 8th Hong Kong Jewelry & Watch Fair will be held at the Hong Kong Convention & Exhibition Centre September 17–20, 1990. At the 1989 fair, more than 1,500 companies from 30 countries were represented, and more than 25,000 buyers from 60 countries attended. The Hong Kong Fair will also give out eight awards to showcase the latest jewelry designs based on beauty, originality, wearability, adaptation to fashion trends, and craftsmanship. For more information on the fair or how to enter the competition, contact Headway Trade Fairs, Ltd., 9/F Sing-Ho Finance Building, 168 Gloucester Road, Hong Kong. Telephone: 5-8335121; fax: 5-8345164.

Jewelex '90, the second Korea International Jewelry & Watch Fair, will be held September 20–24, 1990, at the Korea Exhibition Center in Seoul. The fair features the newest designs in jewelry and the latest models of clocks, watches, manufacturing equipment and accessories. For more information, contact the Korea Exhibition Center, 159, Samsung-dong, Kangnam-ku, Seoul, 135-731 Korea. Telephone: (02) 551-5213; fax: (02) 555-7414 or 551-1313.

The ruby petals in this peony clip, created by Van Cleef & Arpels in 1936, illustrate the "invisible setting" for which the company is noted; the stem and leaves are made of diamonds.

THE RETAIL JEWELLER'S GUIDE
5th edition

*By Kenneth Blakemore, 412 pp., illus., publ. by Butterworths, Great Britain, 1988. US$49.95**

Blakemore's book is intended to acquaint the reader with most aspects of the retail jewelry business. Ten chapters cover the basics for precious metals, gemstones, antique jewelry and silverware, hallmarks, modern jewelry making, silversmithing, and horology both past and present. For this fifth edition, two new chapters—on glassware and pottery—have been added, prompted by the giftware departments now in many jewelry stores. Blakemore has also added updated information on hallmarking in Holland, Portugal, and the United Kingdom to reflect recent changes in legislation. The last 50 pages provide six glossaries relating to jewelry, gemology, horology, and giftware, along with five appendices that cover such topics as "Exemptions from Hallmarking" and "Touchstone Testing in the Workshop." The book is well structured and generally informative, but it is somewhat out of balance. Where some of the sections are covered in depth (antique silverware, jewelry from the Renaissance through the 19th century), others (gemology, 20th century jewelry) are given only superficial treatment.

In his preface to this new edition, Blakemore states that he has updated the gemology chapter to cover new developments in the field. However, the section on synthetics is already out of date in that no mention is made of either the Russian hydrothermal synthetic emeralds or the Sumitomo synthetic diamonds, both of which were discussed in the literature before this edition went to print. He also states that in 1974 a parcel of blue topaz faded completely, although the current literature agrees that the color of treated blue topaz is stable unless heated to 500°C.

BOOK REVIEWS

Elise B. Misiorowski and Loretta B. Loeb, Editors

Blakemore could also have taken the time to update his section on diamond grading. Only the CIBJO categories for color and clarity are listed, while GIA, AGS, and ScanDN grading systems are represented by vague and, in GIA's case, incorrect descriptions. It would have been clearer and more equitable if the author had simply printed a chart comparing all four systems.

This book contains a lot of useful information. Unfortunately, its uneven character undermines confidence in the book as a whole. However, the reader should keep in mind that, as the title states, this is simply a guide for retail jewelers and not the last word on the subject.

COS ALTOBELLI
Altobelli Jewelers
North Hollywood, CA

ARTISTS' JEWELLERY: PRE-RAPHAELITE TO ARTS AND CRAFTS

*By Charlotte Gere and Geoffrey C. Munn, 244 pp., illus., publ. by The Antique Collectors' Club, Woodbridge, Suffolk, U.K., 1989. US$69.50**

This book was produced as a pendant to a splendid exhibition mounted in London by the firm of Wartski, and was sold to persons attending the show and a number of charity evenings with Royalty present. A more recent exhibition was also held in New York at the Fifth Avenue shop of Asprey & Co.

The book deals somewhat unevenly with an interesting and sadly neglected period in jewelry history. Beginning in 1848 with the formation of the Pre-Raphaelite Brotherhood—a group of artists whose designs related directly to their romantic private lives—it carries through to the end of the 19th century and the Arts and Crafts Movement. Insofar as their jewelry designs were concerned, the artists of this period were most interested in symbolism, romantic associations, and secret meanings. It was a fascinating era of passion and intrigue, and perhaps this book will stimulate additional scholarly consideration.

The authors have made a judicious selection of spectacular jewelry with many original design renderings, paintings, and photographs of the period to place the jewels in their proper socio-historical perspective. The illustrations are both numerous and handsome, there is a useful index, and the book feels comfortable in the hand. The graphics, in fact, carry the day. The authors, although respected and frequently published authorities in the field, have a writing style that often obscures, rather than clarifies, the subject. A tremendous amount of research was obviously undertaken, but it is ponderously presented. The bewildering text contains sentences that run to almost a hundred words, leaving the reader exhausted and unsatisfied. Perhaps the fault lies more with the editors than with the writers, but even with all its virtues the book somehow fails to live up to the excitement and charm of the subject.

NEIL LETSON
New York, NY

GEMOLOGICAL ABSTRACTS

Dona M. Dirlam, Editor

COLORED STONES AND ORGANIC MATERIALS

Barium- and strontium-enriched apatites in lamproites from West Kimberley, Western Australia. A. D. Edgar, *American Mineralogist*, Vol. 74, No. 7/8, 1989, pp. 889–895.

Because lamproites are now recognized as an important host rock for diamonds, their mineralogy and chemistry represent an important field of study. Lamproites from the West Kimberley area of Australia contain apatites that are enriched in BaO and SrO. Both elements are

uncommon in apatites that occurr in igneous rocks. Electron microprobe analyses indicate BaO values up to 12.5 wt.% and SrO values up to 5.8 wt.%. Both elements are thought to substitute for Ca in the apatite crystal structure. Ideas on the genesis and crystallization of the apatites and their host lamproites are presented. *JES*

The characteristics of Burmese spinel. T. Hlaing, *Australian Gemmologist*, Vol. 17, No. 3, 1989, pp. 84–87.

This report, part of the author's master's thesis, covers the gemological, mineralogical, and chemical properties of spinel from the Mogok region of Burma. Examination of crystals revealed that most are well formed or only slightly distorted. Statistically, about 70% of those recovered are considered too small to facet, with crystals between 0.40 cm and 0.90 cm being fairly common.

For the 13 specimens examined, refractive index ranged from 1.714 to 1.730 and specific gravity ranged from 3.477 to 3.721. S.G. increased with Fe, Mg + Fe, or Mg + Cr content. Spectrochemical analysis showed that the depth of color in red spinel correlates with increasing chromic oxide content. A comparative study of the trace-element content of red spinels from Mogok, Sri Lanka, and Hunza (Pakistan) revealed a significantly higher chromium content in the Mogok material.

The article includes a number of charts and tables of data to support the author's conclusions. *RCK*

Dayboro variscite. G. Brown, *Australian Gemmologist*, Vol. 17, No. 3, 1989, pp. 98–100.

This report begins with a review of the sometimes confusing literature describing an aluminum phosphate mineral from the Dayboro deposit, located 40 km north-northwest of Brisbane, Queensland, Australia. The deposit, on the summit of a low hill, occurs in a thinly bedded brecciated black chert. Most of the material occurs as an intimate intergrowth of variscite with quartz; slabbed surfaces of the chert reveal randomly scattered nodular masses and veins of variscite. Cabochons of the variscite often contain various amounts of the host matrix.

Gemological investigation of the variscite revealed the following properties: opaque with a bluish green color, 1.56 spot R.I., waxy luster, chalky green fluorescence to long-wave U.V. and inert to short-wave U.V., no diagnostic visible-light absorption features, S.G. of 2.4 to 2.5, Mohs hardness of 4, and an uneven fracture.

The author concludes that the Dayboro variscite has more historic than economic significance and that the distinctive matrix may help in determining the provenance of the material. *RCK*

Flame-like markings on the surface of conch pearl [in Japanese]. H. Komatsu, J. Yazaki, and Y. Matsuda, *Hoseki Gakkai Si*, Vol. 11, No. 1–4, 1984, pp. 30–31.

The conch. "pearl," a type of calcareous concretion produced by the giant conch (*Strombus gigas*), often has flame-like markings on its surface. In this article, the authors attempt to determine the cause of this peculiar marking by studying the structure of the internal surface layer of this animal's shell.

When examined with an optical microscope (40 ×), the internal surface of the shell showed a striped pattern similar to the "flame" of the conch "pearl." This pattern, however, could not be observed with a scanning electron microscope, which indicates that the pattern is visible only when light penetrates the surface layer of the specimen.

The authors then examined the various sections of the surface layer. They observed rows of thin aragonite crystals forming one block, with each adjacent block intersecting at a certain angle. Because of this angle, two adjacent reflected light beams, with different rates, create the striped pattern. The authors concluded that the flame-like markings on a conch "pearl" are directly related to the striped pattern on a flat surface of a shell. Six photographs and one drawing illustrate the features described. *Himiko Naka*

Iridescent natural glass from Mexico. H. A. Hänni, *Journal of Gemmology*, Vol. 21, No. 8, 1989, pp. 488–495.

"Iris opal" from San Luis Potosí exhibits spectral colors caused by optical interference. Although the transparent light brown material is isotropic, stress-induced birefringence can be observed with crossed polarizing filters. Refractive index and density values of 1.462–1.467 and 2.241–2.270, respectively, fall within the ranges for glasses. SEM micrographs of this material showed the minute layers that provide the interference phenomenon. Electron microprobe analysis revealed a composition that, while silicon-rich, includes sufficient minor elements to identify the material as a glass rather than opal. This conclusion was supported by X-ray diffraction analysis, which indicated amorphous structure; by infrared spectroscopy, which showed a lack of water; and by thermogravimetry, which revealed a reaction inconsistent with opal. The authors thus conclude that this material is a natural glass, possibly formed from late-magmatic vapors, steams, or aqueous solutions deposited in rhythmic layers. This article is well illustrated with photographs, photomicrographs, micrographs, and analytic graphs. *CMS*

New data on the cause of smoky and amethystine color in quartz. A. J. Cohen, *Mineralogical Record*, Vol. 20, No. 5, 1989, pp. 365–367.

This informative article puts in perspective the inter-relationship between the amethystine and smoky colors in quartz. When the aluminum impurity (Al^{3+}) substituting for silicon is in large excess compared to the interstitial Fe^{3+} impurity, natural radioactivity will turn the quartz a smoky color. The color center is a missing electron (hole) on an oxygen bound to the aluminum atom.

Inversely, when the interstitial Fe^{3+} is more abundant than the Al^{3+}, the amethystine color appears after irradiation. The color is due to an Fe^{4+} ion, stabilized by charge transfer with the Al-trapped hole. Therefore, the presence of Fe^{3+} protects against the formation of "smoky" color centers. Smoky quartz can also be turned amethystine in color, although only temporarily, by cooling to liquid nitrogen temperature or below. Apparently, Fe^{3+} or Fe^{2+} atoms, by losing one or two electrons, respectively, form Fe^{4+} and bring about the amethystine color regardless of the Al:Fe ratio.

The presence of Fe^{3+} in channels perpendicular to the major rhombohedron produces Brazil-law twinning to relieve the strain in the quartz structure. Such channels do not exist perpendicular to the minor rhombohedron, which does not show such twinning. Twinned zones are often of amethystine color, or, if they are yellow, they can be turned amethystine by irradiation; untwinned zones might not change color. *EF*

Pink corundum is ruby. *Jewellery News Asia*, No. 59, July 1989, pp. 1, 28, 32.

Pink corundum is now to be called ruby, according to the International Colored Gemstone Association (ICA), based on a vote taken at the association's third biennial

congress held in May 1989 in Sri Lanka. The ICA members from Asia were unanimous in their support of this change, noting that consumer confidence was being eroded in Japan when a stone purchased as a ruby was determined to be pink sapphire by a lab. On the other hand, a number of U.S. and European members voted against the change, stating that pink sapphires already have high recognition and demand in the U.S. One fear is that if pink sapphires were now to become fair rubies, prices would drop. Thai delegates argued that the term *pink sapphire* was introduced only recently and reflects the problem of linguistic differences between the Thai language and English. In Thai, there is no separate word for lighter tones of red, which are called pink in English.

Yianni Melas

OH substitution in garnets: X-ray and neutron diffraction, infrared, and geometric-modeling studies. G. A. Lager, T. Armbruster, F. J. Rotella, and G. R. Rossman, *American Mineralogist*, Vol. 74, No. 7/8, 1989, pp. 840–851.

This study was undertaken to understand better the nature and extent of OH substitution in natural garnets. Three titanian andradites and a synthetic hibschite were investigated. Details of the crystal structures of these samples are presented. According to the authors' data, OH substitutes for Si^{4+} in the tetrahedral site. Infrared absorption spectra indicate the amount of structurally bound water (as OH^-) to be between 0.8 and 5.7 wt.% OH. The geologic implications of the occurrence of water in garnets in the mantle are also discussed. *JES*

Star sapphire from Kenya. N. R. Barot, A. Flamini, G. Graziani, and E. J. Gübelin, *Journal of Gemmology*, Vol. 21, No. 8, 1989, pp. 467–473.

In 1987, star sapphire from Kenya began to appear on the market in commercial quantities and qualities. The material reportedly comes from sedimentary topsoil of the desert-like plains of northwest Kenya near the Ethiopian border, although the primary source has not yet been located. The 10 cut specimens studied by the authors include various tones of blue, greenish blue, greenish yellow, and dark brown body colors, with six- or 12-rayed asterism of various strengths.

Optical microscopy and electron microprobe analysis revealed the presence of a number of different types of inclusions in the study specimens. Cloudy areas were, in at least some cases, caused by parallel striae possibly related to lamellar twinning. Color zoning was observed with straight or angular edges. Two types of acicular inclusions that contribute to asterism were identified: micro-striae similar in composition (according to electron microprobe analysis) to the host sapphire and resulting from alternating growth and temperature variations; and larger needles of, possibly, hematite and rutile. All three acicular inclusions also contribute to

the colors of the samples: Micro-striae and rutile needles correlate with fine blue hues, while hematite occurs in conjunction with darker colors. Thread-like needles of rutile formed the silk present in all samples. Several other inclusions were observed, among them: tube-like primary cavities filled with scaly aggregates of iron hydroxides or oxides; transparent birefringent crystals that revealed a tabular hexagonal shape and chemical composition consistent with corundum; and reddish brown prismatic idiomorphous crystals that consist of titanium oxide, suggesting rutile or brookite. Also observed were feathers of minute inclusions composed of Al and/or Ti, as well as healed fractures filled with a fluid and, sometimes, yellow or brownish red iron hydroxides or oxides. Color photographs and photomicrographs illustrate the features discussed. *CMS*

Structural variations in natural F, OH, and Cl apatites. J. M. Hughes, M. Cameron, and K. D. Crowley, *American Mineralogist*, Vol. 74, No. 7/8, 1989, pp. 870–876.

As with any gem mineral, the gemological properties of apaties are closely related to the chemical composition of the material. Natural apatites of composition $Ca_5(PO_4)_3(F,OH,Cl)$ exhibit large variations in F, Cl, and OH contents. This article reports the results of a crystal-structure refinement study of near-end-member specimens of each of these three compositional varieties. These three ions (F^-, Cl^-, OH^-) occupy slightly different positions within the anion site in the crystal structure, but this has little effect on the positions of the other constituent atoms. However, these minor structural differences suggest that the three end members are immiscible in solid solution. Therefore, one might expect a continuous variation in some gemological properties with changes in composition. *JES*

DIAMONDS

Mantle-derived fluids in diamond micro-inclusions. O. Navon, I. D. Hutcheon, G. R. Rossman, and G. J. Wasserburg, *Nature*, Vol. 335, No. 6193, October 27, 1988, pp. 784–789.

The authors studied six cubic and nine coated diamonds from Zaire and Botswana for the numerous submicrometer, subrounded inclusions found in their fibrous zones. The study of these inclusions gives important indications on the environment of diamond formation. The diamonds in this report were grayish brown to green to yellowish green; the yellow color of many of the coatings was attributed to their type Ib character.

The microinclusions studied differ in composition from the more common large inclusions found in diamond, such as garnet, olivine, and pyroxene. As a whole, though, the chemistry of these microinclusions is broadly similar: rich in SiO_2, K_2O, CaO, and FeO. They apparently also contain a mixture of heavily hydrated

clay minerals, carbonates, phosphates, and sometimes molecular CO_2. This chemistry resembles that of potassic magmas, from which diamond-containing rocks such as kimberlite and lamproite crystallize. However, the inclusions are also enriched in water, carbonate, potassium, and magnesium, indicating that they formed during the growth of the diamond from trapped fluids that may have been remnants of a volatile-rich fluid or melt from the upper mantle in which diamond grew. The authors conclude with two possible scenarios for the growth and emplacement of microinclusion-bearing diamond. *EF*

Mechanism of self-diffusion in diamond. J. Bernholc, A. Antonelli, T. M. Del Sole, Y. Bar-Yam, and S. T. Pantelides, *Physical Review Letters*, Vol. 61, No. 23, 1988, pp. 2689–2692.

In this article the authors describe theoretical calculations that show that the diffusion of intrinsic defects in the diamond structure is dominated by the vacancy mechanism, independent of the number of electrons at the defect. The dominance of this mechanism is due to the stiffness of diamond bonds, which precludes twisting or large deformations, and the great electronic density, which causes large repulsive forces for self-interstitial defects, an alternate possibility for diffusion. This explains why the vacancy is the lowest energy defect in diamond, and also why there is a lack of annealing of grain boundaries in polycrystalline thin-film diamond. The migration energy calculated for the GR1 center, 1.9 eV, agrees well with that measured experimentally by another team, lending support for the identification of the GR1 center as a vacancy.

Difficulties in the growth of synthetic single-crystal diamond films have arisen as a result of mechanisms that involve migration of atoms in the structure. The authors' calculations indicate that the use of dopants such as boron could help produce the desired growth. *EF*

Nitrogen and ^{13}C content of Finsch and Premier diamonds and their implications. P. Deines, J. W. Harris, P. M. Spear, and J. J. Gurney, *Geochimica et Cosmochimica Acta*, Vol. 53, 1989, pp. 1367–1378.

Nitrogen content and state of aggregation were determined using infrared spectroscopy for diamonds from the Finsch (93 samples) and Premier (116 samples) kimberlites in South Africa. The authors observed that the nitrogen concentration ranged from 7 to 1639 ppm. Most of the study diamonds with ultramafic or peridotitic (P-type) mineral inclusions contained generally less than 100 ppm nitrogen, whereas diamonds with eclogitic (E-type) inclusions had nitrogen contents anywhere between 0 and 1200 ppm. In both of the kimberlites, nitrogen-free type II diamonds very rarely contained eclogitic inclusions. There was no significant difference in nitrogen aggregation between E- and P-type diamonds, but there was one between the two locations: The Finsch produces diamonds with more nitrogen in B aggregates than the Premier. One of the groups of diamonds of very similar nitrogen concentration, ^{13}C ratio, and mineral inclusion composition may be common to the two mines, indicating a possible common origin for some diamonds of the two kimberlites, but different subsequent histories. The authors conclude with a discussion of the nitrogen content of diamonds as controlled by the local nitrogen concentration, the temperature, the availability of chemical forms that favor the incorporation of nitrogen in the crystal, and, finally, by the oxygen fugacity. *EF*

GEM LOCALITIES

The Brazilian emeralds and their occurrences: Carnaíba, Bahia. D. Schwarz and T. Eidt, *Journal of Gemmology*, Vol. 21, No. 8, 1989, pp. 474–486.

The Carnaíba emerald region was discovered in 1963 and, until the discovery of Santa Terezinha in 1981, was the most important source of emeralds in Brazil. Production for Carnaíba has been increasing in the 1980s, but systematic exploitation with modern mining techniques will soon be required if the deeper deposits are to be exploited. The authors discuss the local geology and provide geologic maps of the two major occurrences at Carnaíba and Socotó. Emeralds occur as aggregates and single crystals in a mica-schist rock, with associated minerals that include molybdenite, quartz, apatite, schorl, alexandrite, pyrite, etc. Emerald mineralization in this region is consistent with that observed elsewhere, and is related to zones of strongest tectonic activity.

The authors provide microprobe analyses of six samples that show typical compositions. The low transparency of most of the emeralds studied was due largely to "flocs" and "stars": minute one- or two-phase inclusions clustered in agglomerations of various compactness. Larger multi-phase inclusions also occur. Other mineral inclusions are rare and consist largely of biotite/phlogopite mica in plate-like and lath-like forms. Muscovite and chlorite also occur, as do tourmaline, albite, and a number of other occasionally observed minerals. Chemical analyses of feldspar, phlogopite/biotite, and muscovite inclusions are presented as well.

Growth features were observed in the form of concentric striation visible when looking down the c-axis, growth pyramids forming zig-zag lines, and growth striae or layers parallel to both the basal face and the prism faces. A number of excellent and informative photomicrographs accompany the article. *CMS*

Yundamindera 'fire' opal. G. Brown and H. Bracewell, *Australian Gemmologist*, Vol. 17, No. 3, 1989, pp. 101–103.

Yundamindera Station, 640 km east-northeast of Perth

in Western Australia, was first revealed as a source of fire opal in a 1903 survey report. Gem-quality material has been recovered from several vertical pits over eight decades, and good-quality material can still be found in abandoned mines or their tailings.

The material from this deposit is described as being a type of "common opal" in that it displays no play-of-color. The authors examined some recently recovered specimens, the finest of which ranges from transparent to translucent with a "rich amber" to "reddish amber" color that is almost identical to some Mexican fire opal. It has a 1.42 R.I. and a resinous luster; is inert to long- and short-wave U.V. radiation; exhibits no diagnostic absorption features; has a hardness of 5 to $5^{1}/_{2}$, a conchoidal fracture, and an S.G. of 1.98 to 2.00. Microscopic examination revealed flow structures, dark dendritic inclusions most likely caused by epigenetic infiltration of fractures, and vein-like internal structures.

The report is nicely illustrated in color with locality photographs, macrophotographs, and photomicrographs.

RCK

INSTRUMENTS AND TECHNIQUES

Some inexpensive improvements to existing instruments. C. Lewton-Brain, *Journal of Gemmology*, Vol. 21, No. 8, 1989, pp. 500–505.

The author describes a number of inventive low-cost adaptations to his gemological testing equipment, including a homemade polariscope, a dual-lens arrangement to improve spot readings on a refractometer, and an alignment wire to improve the accuracy of readings from an S.G. balance. Drawings and photos illustrate the equipment described. *CMS*

JEWELRY ARTS

Collectible watches: An introduction. H. B. Fried, *Jewelers' Circular-Keystone: Heritage*, Vol. 160, No. 8, August 1989, pp. 172–181.

This article is directed toward the new collector of antique watches. Because scarcity is a key factor for collectibles, one should look for watches that represent limited production runs or contain certain unique features such as skeletonized movements or unusual escapements. In addition, there are four grades for watch quality: mint, near mint, fine, and fair. Fried also issues cautions about clever reproductions that can fool a novice, and tells how two famous watchmakers (Tompion and Breguet) dealt with and guarded against forgeries.

The horological editor for JCK, Fried concludes this article with the offer of a readers' service. This service gives JCK subscribers the chance to obtain information as to identity, age, rarity, and history (but not price!) of a particular watch. Many photos and a list of recommended reading accompany the text. *EBM*

Mourning jewellery. J. C. Birmingham, *Australian Gemmologist*, Vol. 17, No. 3, 1989, pp. 82–84.

This brief, interesting article traces the historic use of mourning jewelry. Early examples include Greek and Roman cameos that portrayed commemorative scenes of men and gods, and burial rings that were either engraved or inlaid. Mourning jewelry during Medieval times was usually in the form of rings and pendants made according to the will of the deceased. Mourning jewelry in Tudor England is described as large, heavy, and ornate, while the *Memento Mori* jewelry of the 17th century included the use of rather gruesome images of skulls, skeletons, and coffins. Eye portraits, depicting just the eye of the loved one painted on ivory, date from the Regency Period of the late 18th century. Jet jewelry and hair jewelry, often thought of in connection with mourning periods, date from the early 1800s in England; the use of jet became more fashionable after the death of Prince Albert, when Queen Victoria allowed only black to be worn at court. This was followed by a period of "half-mourning," when women were allowed to wear gray, mauve, or purple, and amethyst and garnet replaced jet.

RCK

Practical goldsmithing: Hinged bracelet sections. A. Revere, *Jewelers' Circular-Keystone*, Vol. 160, No. 8, August 1989, pp. 432–438.

The use of hinges is extensive in the jewelry industry. In this article, Alan Revere demonstrates the fabrication and assembly of a series of bracelet sections, focusing on the cradle, or silversmith's, hinge. The clear and precise descriptions, along with photos and a diagram of dimensions, provide a lucid and concise picture of what is required to perform the task. *Matthew Bezak*

Philippe Wolfers: Master of Art Nouveau. K. Akkerman, *Jewelers' Circular-Keystone: Heritage*, Vol. 160, No. 8, August 1989, pp. 162–170.

At the turn of the century Belgium was an important European cultural center, especially in the development of Art Nouveau. Akkerman focuses here on one of the most notable Art Nouveau jewelers in Belgium, Philippe Wolfers.

Born to a wealthy family of court jewelers, Philippe studied art before he apprenticed with the family firm. His interest in nature, as well as in Eastern and Renaissance art, can be seen in the exotic and hauntingly beautiful jewelry that he began to produce in the early 1890s.

Akkerman discusses some of the distinctive characteristics of Philippe Wolfers's jewels, and gives examples of the different hallmarks that identify his work. He also compares this work with that of some of Wolfers's contemporaries.

Wolfers kept a careful catalog of his one-of-a-kind jewels, and several of these pieces are described and illustrated. Although Wolfers designed each piece and

supervised its making, several craftsmen were involved. Credit is given to some of his skilled enamelists as well.

There is a lot of information in this well-researched article, but it simply whets our appetite for Akkerman's forthcoming book on this talented goldsmith. Color photographs of Wolfers's exquisite jewelry accompany the article. *EBM*

Wearable minerals. B. Jones, *Lapidary Journal*, Vol. 43, No. 7, October 1989, pp. 30–32.

When admiring the natural beauty of mineral specimens, one might wonder why their use in jewelry is not more widespread. This article singles out jeweler Cindy Watlington, who is rapidly becoming recognized as a "pioneer" in the design of jewelry that incorporates gem minerals in their natural state. Not only does she use the natural form, but she also takes special care to set the specimen so as not to damage it through frequent use. The jewelry pictured here includes such minerals as chrysocolla, rhodochrosite, and quartz. This is a welcome article for any mineral enthusiast who scorns the faceting of mineral specimens. *RW*

JEWELRY METALS

Los Angeles Jewelry Project: An innovative approach to education and outreach. C. Wright, *The State of the Workplace*, Vol. 3, No. 2, 1989.

In response to a number of hazardous waste incidents, in early 1987 the Los Angeles County Health Department asked the California Occupational Health Program (COHP) to conduct a study of safety hazards in the Los Angeles jewelry industry. This study found unsafe conditions that include improper handling and storage of hydroflouric acid and of cyanide and peroxide solutions, and excessive levels of cadmium fumes (from solder) and airborne silica dust (from investment casting). COHP also found that many employers and employees were unaware of hazards in their workplaces, and is responding with an education program that focuses on the free distribution of informative booklets. *Polish Up Your Jewelry Shop: A Guide for Employers* discusses the primary hazards identified and cost-effective ways to control them. *Polish Up Your Jewelry Shop: A Guide for Workers* is a simplified booklet printed in English, Spanish, Mandarin, and Armenian.

The State of the Workplace is an internal bulletin published by the Hazard Evaluation System and Information Service, which will provide the above booklets (in limited quantities) free of charge to California residents. Copies are also available at the GIA Library in Santa Monica. *Meredith Mercer*

SYNTHETICS AND SIMULANTS

Intrinsic and extrinsic cathodoluminescence from single-crystal diamonds grown by chemical vapour deposition. A. T. Collins, M. Kamo, and Y. Sato, *Journal of Physics: Condensed Matter*, Vol. 1, 1989, pp. 4029–4033.

The authors describe the cathodoluminescence of some single-crystal diamonds grown by microwave-assisted chemical vapor deposition (CVD). From the observation of intrinsic edge emission, they conclude that the crystals with very low (<1%) methane concentrations are extremely pure with few structural defects. However, the crystal quality seems to deteriorate as the methane percentage in the vapor, and therefore the growth rate, increases. All crystals also exhibit bright blue cathodoluminescence, as is typical for natural type IIa diamond. The width variation of one band indicates that this material is highly strained. In addition, some sharp emission lines were observed that have not been noted in natural or high pressure synthetic diamond. Cathodoluminescence could thus prove to be a very sensitive technique for separating natural from synthetic diamonds. *EF*

A gemmological study of "Opalite" and "Opal Essence." J. I. Koivula and R. C. Kammerling, *Australian Gemmologist*, Vol. 17, No. 3, 1989, pp. 93–98.

This article reports on the examination of three plastic imitation opal cabochons, two marketed under the name "Opalite" and one as "Opal Essence." The three specimens appeared to be milky bluish white with distinct play-of-color in incident light and pink-orange in darkfield or transmitted light. Two of the pieces had a distinct second layer of plastic that coated at least part of the base.

Gemological properties were determined to be as follows: R.I., 1.51; long-wave U.V. fluorescence, a strong bluish white with the edges a slight orange; short-wave U.V. fluorescence, a weaker bluish white with a chalky blue-white overtone; no U.V. phosphorescence; anomalous double refraction in the polariscope; weak general absorption from 550 to 580 nm; S.G. of 1.15 to 1.25; poor thermal conductivity; an acrid smell when tested with a thermal reaction tester; hardness of $2^{1}/_{2}$; a positive hydrophobic reaction; and some unique absorption features in the infrared region. Magnification revealed a distinct to very vague "honeycomb" pattern and a vague columnar structure. Polarized light microscopy revealed some minor strain knots. *RW*

Russian hydrothermally-grown emerald. G. Brown, S. M. B. Kelly, and J. Snow, *Australian Gemmologist*, Vol. 17, No. 3, 1989, pp. 103–106.

Six faceted synthetic emeralds were purchased from a Hong Kong dealer who described them as a "new" hydrothermal synthetic from the USSR. The six specimens, ranging from 0.44 to 1.3 ct, were all transparent with a vitreous luster and a distinctive saturated green color that had a faint bluish overtone. Refractive indices were ω 1.570–1.573 and ε 1.578–1.582, with a birefrin-

gence of 0.008–0.009. Other properties included: uniaxial negative; strong pleochroism of slightly bluish green and slightly greenish blue; no Chelsea filter reaction; inert to both long- and short-wave U.V. radiation, with no white-light transmission luminescence; and an S.G. of 2.71 to 2.84.

Immersion microscopy revealed a number of key features: partially healed fractures composed of two-phase inclusions; tapering two-phase "dagger" inclusions; phenakite crystals; parallel, somewhat flattened wavy growth banding that was frequently intersected by what are described as "arrowhead," "spear," or "quill-like" growth features; and small groups of brassy clusters of acicular metallic crystals.

The authors conclude that while the gemological properties of these hydrothermally grown synthetic emeralds mimic those of some natural emeralds, their characteristic inclusions will positively identify them as synthetic.   *RCK*

Some observations on Helenite. G. Brown and J. Snow, *Australian Gemmologist*, Vol. 17, No. 3, 1989, pp. 88–90.

The authors detail their investigation of two types of green glass claimed to be produced from Mount St. Helens volcanic ash and sold under the name "Helenite." One type, described in the vendor's literature as "pure melted ash" glass, was semitransparent, had an S.G. of 2.51, an R.I. of 1.51, exhibited a conchoidal fracture and a vitreous luster, was inert to both long- and short-wave ultraviolet radiation, and was warm to the touch. Magnification revealed a concentric lamellar structure, flow structures, stretched gas bubbles, and both small masses and smaller grains of grayish volcanic ash–like material. The gas bubbles and flow structures were oriented at right angles to the concentric layers.

The second type was sold as "ash diluted by glass." It was transparent and had an S.G. of 2.53 and an R.I. of 1.526. Its fracture, luster, reaction to U.V. radiation, and feel were identical to those of the other type. Magnification revealed a less obvious concentric lamellar structure, no unmelted ash-like material, rounded gas bubbles, and irregular, unoriented swirl striae.

From these data the investigators draw a number of interesting conclusions. The small grains of ash-like material supported the claim that the first type did contain at least some Mount St. Helens volcanic ash.   *RCK*

Synthetic periclase. S. M. B. Kelly and G. Brown, *Australian Gemmologist*, Vol. 17, No. 3, 1989, pp. 90–92.

After briefly reviewing the properties of both natural and synthetic periclase as described in the literature, the authors report on their own examination of some transparent, slightly greenish yellow material brought to one of them for identification. The material was determined

to have the following properties: vitreous luster, an R.I. of 1.73, singly refractive, inert to U.V. radiation, green through the Chelsea filter, no visible diagnostic absorption features, a hardness of 5 to 5½, three directions of cubic cleavage, parallel parting planes (detected in thin sections between crossed polars), and an S.G. of 3.57. With magnification, a faceted stone cut from a piece of the rough revealed internal cleavage and what appeared to be a gas bubble; the surface showed oriented drag marks which further confirmed its softness.

On the basis of their examination, the authors determined the material to be synthetic periclase, possibly doped with iron. They later learned that the material had been produced in Austria "'by subjecting pure magnesium carbonate to an unspecified electrofusion process.'" A final observation by a cutter who worked with the authors was that after several months the polished surface of the rough became increasingly dull and eventually was coated with a whitish efflorescence of brucite(?), a common alteration product of periclase.   *RCK*

Tracht and habit of synthetic minerals grown under hydrothermal conditions. W. A. Franke, *European Journal of Mineralogy*, Vol. 1, No. 4, 1989, pp. 557–566.

Franke summarizes the variations in tracht (the various crystal faces present) and habit (the relative proportions of those faces) of synthetic minerals grown under hydrothermal conditions. For silicates and oxides, crystal morphology is very dependent on the temperature of formation: With increasing temperature, an increasing number of faces enter the crystal shape and the habit tends to get more isometric. Supersaturation or voluntarily introduced impurities have little influence. This is illustrated in particular by corundum, which is tabular when grown at 600°C and almost equant at 800°C. The author also discusses alkali feldspars and carbonates. Over 20 crystal drawings illustrate the observations.   *EF*

MISCELLANEOUS

Illuminating the Maya's path in Belize. N. Epstein, *Smithsonian*, Vol. 20, No. 9, December 1989, pp. 98–113.

Archaeologists Diane and Arlen Chase discuss their discoveries of the Maya site called Caracol in Belize. Caracol, which means *snail*, in Spanish, refers to the site's location at the end of a logging road in the rain forest. The Chases detail this site; the Mayan activities during the Classic, Middle Classic, and Late Classic eras; the Mayan system of warfare; and the design of the city and its northern neighbor Tikal. Brief mention is made of the jade jewelry found in 1986 in the tomb of a woman dated from the Classic period. Epstein concludes by mentioning plans of the Belizian government to incorporate Caracol into a national park which will take in the surrounding rain forest.   *Rose Tozer*

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SUBJECT INDEX

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Indexes prepared by Dona Dirlam

AUTHOR INDEX

This index lists, in alphabetical order, the names of authors of all articles that appeared in the four issues of Volume 25 of *Gems & Gemology*, together with the inclusive page numbers and the specific issue (in parentheses). Full citation is provided under the first author only, with reference made from joint authors.