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TABLE OF CONTENTS

ABOUT THE COVER: Cultured pearls are one of the most popular gem materials. The three-strand necklace on the cover consists of 9–9½ mm Japanese cultured pearls; the earrings feature 12½ mm South Seas cultured pearls. Because of the popularity and rarity of fine pearls, there have been numerous attempts to imitate them throughout history. The Spanish company Majorica S.A. currently produces one of the most effective imitations. Recently, three GIA staff members traveled to Spain to learn about the making and distribution of the Majorica imitation pearls. They report on their findings, and on the separation of the imitations from Japanese cultured saltwater pearls, in this issue. Jewelry courtesy of Shima Pearl Company, Inc., Los Angeles, CA.

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Answers (see pp. 113 and 114 of the Spring 1990 issue for the questions) are as follows: (1) D, (2) B, (3) D, (4) B, (5) A, (6) D, (7) B, (8) C, (9) A, (10) C, (11) B, (12) D, (13) C, (14) C, (15) C, (16) B, (17) A, (18) C, (19) B, (20) A, (21) B, (22) B, (23) A, (24) A, (25) A.

Richard T. Liddicoat

MAJORICA IMITATION PEARLS

By June Hanano, Mary Wildman, and Philip G. Yurkiewicz

Pearls are one of the most popular gem materials, but only in the past few decades has technology advanced to the point that good-quality imitations could be made. The Majorica S.A. product is remarkably similar in appearance to saltwater cultured pearls. These imitations, often set in high-karat gold in contemporary styles, are sold throughout the world. This article discusses the history of the Majorica imitation pearl, the manufacturing and marketing processes, and the separation of the Majorica product from its cultured counterparts.

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Ms. Hanano is supervisor of instructor training, Ms. Wildman is general manager of residence gemology, and Mr. Yurkiewicz is supervisor of extension gemology, at the Gemological Institute of America, Santa Monica, California.

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With the increasing cost of cultured pearls and the astronomical cost of the rare natural pearls, people have turned to imitations as an affordable alternative. The trademark *faux* pearls of U.S. First Lady Barbara Bush have also helped bring this fashion alternative to the attention of millions (Reilley, 1990). Among the many imitation pearls currently available, the Majorica product is perhaps the most widely marketed and meticulously manufactured imitation today. Their sales figures mirror the rise in interest by the general populace, with a 50% increase in total sales (to US$60 million) from 1986 to 1989. The Majorica imitation pearls closely resemble cultured pearls (figure 1), although they are produced in an entirely different manner.

In the fall of 1989, the authors visited the headquarters of Majorica S.A. in Barcelona and their production plant on the island of Majorca, off the eastern coast of Spain. Through interviews with a number of senior executives, including Director General Jaime Peribañez and Executive Vice-President Luis Bonel, and a rare behind-the-scenes look at the actual production process, we obtained a comprehensive picture of the Majorica imitation pearl. This article reviews the history of the material and the manufacturing process used, describes the different products available and how they are marketed, and examines the separation of the Majorica imitation from saltwater cultured pearls.

HISTORICAL PERSPECTIVE

The story of Majorica pearls begins in 1890, when German immigrant Eduardo Hugo Heusch established a small factory in the Spanish city of Barcelona (J. Peribañez, pers. comm., 1989). There he manufactured sewing notions such as needles, clasps, zippers, and imitation pearl buttons. In the early 1900s, he started to produce imitation pearls for use in jewelry. These early imitations were essentially glass beads coated with man-made resins. With

Figure 1. Majorica S.A. manufactures imitation pearls that closely resemble cultured pearls. These 6-mm imitations are from their line of "Lady Di" jewelry. Courtesy of Majorica S.A.; photo by Shane McClure.

time, the operation advanced and expanded considerably.

In 1920, the Heusch family moved the factory to Majorca, the largest of the Balearic Islands, located approximately 180 km southeast of Barcelona in the Mediterranean Sea. Majorca was chosen in part because its geographic isolation left it relatively free from the political and social unrest that plagued Spain at the time, but also because it was the home of fine lace makers, whose dexterity would become valuable for stringing the beads.

In 1939, at the end of the Spanish civil war, the managers of the Heusch operation gathered to discuss the creation of a special imitation pearl that truly duplicated the appearance of the natural material. By 1951, 12 years after the decision was made to produce a more natural-appearing product, research finally produced the imitation pearl that is now marketed as Majorica.

Before 1939, all of the Heusch family's imitation pearls had been sold simply as "Spanish pearls." For the new product, however, the name *Majorica* was chosen. *Majorica* comes from the old Roman spelling for the island now known as Majorca or, in Spanish, Mallorca. It was trademarked in Spain in 1950 and worldwide in 1961, for use exclusively by the Heusch company for their imitation pearls. The only exception to worldwide trademarking is Brazil, which does not allow the importation of man-made pearl imitations (J. Peribañez, pers. comm., 1989).

Today, Majorica S.A. struggles to maintain its established trademarked name. Other imitation-pearl producers on the island sell their products as "Majorca Pearls" after the current spelling. The very subtle differences in spellings may lead to consumer confusion.

PRODUCTION

Two components make up the imitation pearl produced by Majorica S.A.: a translucent to opaque, white bead nucleus (figure 2) and a special iridescent coating. The material used to form the nucleus is imported from Belgium; the Majorica people refer to it as "opalene" (L. Bonel, pers. comm., 1989). When examined with magnification in transmitted light, a sample of uncoated nucleus showed gas bubbles and swirl striations (figure 3). These visual characteristics and the spot refractive index of 1.52 are typical of glass. To confirm the nature of this material, we asked Robert Kane of the GIA Gem Trade Laboratory to perform an X-ray powder diffraction analysis. Using a diamond scraper, he removed a minute amount of powder from a sample nucleus. The X-ray diffraction pattern produced showed no evidence of a crystalline structure. This proves that the material is amorphous, and probably a glass. Subsequent energy dispersive X-ray fluorescence (EDXRF) analysis of this same material by Sam Muhlmeister and Dr. Emmanuel Fritsch of the GIA Research Department established that the nucleus material is a lead silicate.

Figure 2. The Majorica imitation pearls typically contain transparent to opaque white nuclei similar to those shown here. Referred to as "opalene" by Majorica S.A., the material used to form these nuclei is actually a lead-based glass. Photo by Robert Weldon.

Figure 3. Examination of one of the Majorica bead nuclei with 10× magnification revealed the swirl striations and gas bubbles that are typical of a glass. Photomicrograph by John I. Koivula.

The nuclei are produced in one of two ways, depending on the size and shape desired. Currently, all spherical nuclei larger than 9 mm and all pear-shaped nuclei are still manufactured entirely by hand (figure 4). Specially trained technicians work long, narrow glass rods under a stationary hot flame until the end of the rod melts into a ball onto a rotated metal wire. During the authors' visit to the factories, there were only two women with the skill to produce these nuclei manually. For the smaller round nuclei, automation has replaced what once required the efforts of as many as 240 workers. Special machinery designed by in-house engineers allows the material to be melted in the form of a ball onto the metal wire. The wire remains either partially embedded for post mounting or passed completely through the nucleus for stringing. The finished beads are checked for roundness (figure 5), and those that don't meet quality standards are removed and reserved for use in lesser-grade imitations (E. Blauer, 1985). Last, the beads are placed in an acid bath to dissolve the metal wire and then are passed through sieves that sort them into size categories with a tolerance of 0.2 mm (figure 6).

Figure 4. Although most nuclei are produced by Majorica's specialized machinery, those larger than 9 mm and those used to form pear-shaped beads are generally produced by hand. Today there are only a few women with the developed skill to make the near-perfect glass beads. Here, the technician controls the flame in one hand and manipulates the glass rod from which the nuclei are formed in the other. The end of the rod is worked under the flame until it begins to melt into a sphere onto a rotating wire. Photo by June Hanano.

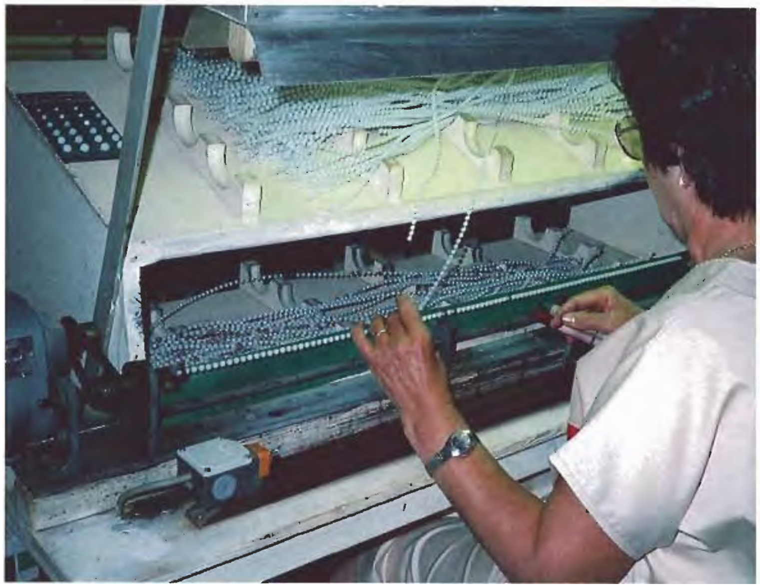


Figure 5. The glass bead nuclei are rotated and inspected for roundness. Rejected nuclei are marked and later used for a lower-grade imitation pearl that Majorica S.A. markets under a different trade name. Photo by June Hanano.

The second component of the process is the coating of the nucleus with a material referred to by Majorica S.A. as "essence of orient" or "pearl essence," which is produced through an exclusive process developed by Majorica (J. Peribañez, pers. comm., 1989). The raw material used for the coating comes from scales taken from fish found in the Atlantic Ocean and concentrated around the Canary Islands. Majorica S.A. has developed special machinery that removes the necessary fish scales while leaving the fish in marketable condition for the food industry. The gathered fish scales are sent to Barcelona, where the substance that causes the iridescence of the fish scales is removed. It is this substance that is mixed with coloring and binding agents to manufacture a form of "pearl essence" (figure 7). When this transparent to translucent material is applied to the bead in consecutive layers, it produces the interference and diffraction of light that causes the prismatic colors seen on these imitations.

"Pearl essence" was discovered in the late 17th century by a French rosary maker named Jacquin.

Figure 6. After the nuclei pass inspection, each "strand" is placed in an acid bath to remove the wire on which they were originally formed. Then, as shown here, the loose beads are sorted through sieves that place them into size categories with a tolerance of 0.2 mm. Photo by June Hanano.

Figure 7. The iridiscent material ("pearl essence") used on the Majorica imitation pearl to simulate nacre is formed by mixing the guanine extracted from fish scales with binding and coloring agents. Photo by June Hanano.

Jacquin noticed that after his servant had scaled bleak fish (*Alburnus lucidus*), the water contained iridescent reflections. Closer examination revealed that these reflections were produced by the dissolution of a fine thin film that covered the scales. Jacquin then filtered the water to recover the pearly substance and mixed it with a varnish (Taburiaux, 1985). Since then, it has been determined that the iridescence is caused by minute crystals embedded in the skin covering the fish scales. These crystals are an organic waste material named guanine, which is closely allied to uric acid (Farn, 1986). Because approximately 2,000 bleak are needed to produce one liter of essence, other fish such as shad, herring, and salmon have also been used.

GIA's Research Department used a Nicolet 60SX Fourier transform infrared (FTIR) spectrometer to analyze the coating material on one black and one white Majorica imitation pearl. Their data showed that in the near-infrared range, outside of the total absorption caused by the glass nucleus, there are a number of weak features consistent with a reference spectrum of guanine ($C_5H_5N_5O$).

In preparation for the coating process, the glass beads are placed on posts set in frames. The beads then undergo a number of consecutive dipping and drying steps (figure 8), each of which is followed by cleaning and polishing with an increasingly finer grade of brush. During the final production phase, a special chemical dipping—possibly cellulose acetate and cellulose nitrate (Read, 1986)—polymerizes the organic material, hardens the surface, and protects it from chipping and ultraviolet radiation (which could cause discoloration). Majorica offers a 10-year guarantee against deterioration of their product.

Figure 8. The glass bead nuclei are placed on posts in preparation for the coatings of "pearl essence." They then undergo a series of dipping and drying steps, each followed by a cleaning and polishing. For the final coat, Majorica uses a special chemical that hardens the surface and protects the color from U.V. radiation. Although some beads are processed by hand, as shown here, most are done by automation. Photo by June Hanano.

Because the dipping produces a tail-like accumulation of the coating, each bead is trimmed by hand with a razor to form a more perfect sphere (figure 9). However, some of the imitations examined showed evidence that the final chemical dipping was done after the trimming: With magnification, a transparent layer could be seen covering the drill hole. Majorica claims that approximately 25% of their total production of finished beads

Figure 9. Once the final coating is dry, the tail-like accumulation of pearl essence (left) is trimmed by hand. This ensures a more perfect sphere (right). Photo by Robert Weldon.

does not pass quality standards and is destroyed (J. Peribañez, pers. comm., 1990).

The finished imitation pearls are either mounted for use as earrings, pendants, pins, or rings, or are strung on a strand comprised of 80% silk and 20% rayon. The stringing work is farmed out to cottage laborers, who hand knot 2.5 million strands per year (L. Bonel, pers. comm., 1989). Selected finished strands are then mounted on a special machine that literally "beats" them for several minutes to confirm their durability (figure 10). Once a strand has passed quality control, it is tagged and numbered, then boxed in a distinctive red jewelry case for final distribution.

Figure 10. As a final step, selected strands of the finished Majorica beads are subjected to strenuous durability testing. Here, the strands are mounted on a special machine that literally "beats" them against a rotating bar to simulate years of wear. Photo by June Hanano.

VISUAL APPEARANCE OF MAJORICA PEARLS

Colors. The main colors that Majorica S.A. produces are cream rosé, white, black, and gray (figure 11). The principal colors are based on the demands of three key markets: Europe (cream rosé) and the United States (cream rosé with white on the

Figure 11. These strands of 8-mm Majorica imitation pearls are typical of the four main colors produced: white, cream rosé, gray, and black. Photo by Robert Weldon.

increase); Japan (cream rosé); and Scandinavia and Canada (white). Cream rosé represents 85% of Majorica's total production; white, gray and black represent the remaining 15%. White is the most expensive color to produce, because it is more difficult both to extract the guanine from the fish scales to produce white and then to apply the resulting "pearl essence" to the bead; the slightest contamination of the solution (e.g., dust) will also contaminate the color (L. Bonel, pers. comm., 1989).

Sizes. The Majorica imitations range from as small as 1 mm to as large as 22 mm. The 6-mm and 7-mm beads dominate the market, with 8 mm following closely behind (J. Peribañez, pers. comm, 1989). Demand for larger sizes (10+ mm) is rapidly growing in the U.S. market. Majorica attributes this to First Lady Barbara Bush's use of imitation pearls, her open fondness for larger pearls, and the increasing popularity of large South Seas cultured pearls.

Shapes. Most Majorica pearls are round, but other shapes are also produced, including half spheres, heart shapes, pear shapes, and ovals. There are a limited number of baroque shapes as well. However, because these shapes are more difficult to manufacture, they cannot compete monetarily with many of the cultured freshwater baroques.

MARKETING

In 1955, the Majorica imitations were virtually unknown outside of Spain. Today, the Majorica product is sold in 76 different countries. Cooperative advertising with major department stores in the U.S. and abroad has stimulated this international recognition. Currently, the largest market is

TABLE 1. Comparison of the gemological properties of saltwater cultured pearls and four different colors of Majorica imitation pearls.[a]

Test	Saltwater cultured pearl	Majorica white	Majorica gray	Majorica cream rosé	Majorica black
Refractive index (spot)	1.53–1.68 (birefringence blink)	1.48	1.48	1.48	1.48
Specific gravity (hydrostatic)	2.72–2.78	2.67	2.57	2.67	2.51
Hardness	3	2–3 (coating)	2–3 (coating)	2–3 (coating)	2–3 (coating)
X-radiography	Large nucleus, contrast between nucleus and nacre layer apparent	Opaque	Opaque	Opaque	Opaque
X-ray fluorescence	Faint to medium greenish white	Strong yellow	None	Strong yellow	None
Fluorescence to U.V. radiation					
Short-wave	None to faint medium greenish blue	Weaker pink	None	Weak pink	None
Long-wave	None to medium greenish blue	Weak pink	None	None	None
Hydrochloric acid (10% solution)	Effervesces	None	None	None	None
Magnification of drill hole	Dark conchiolin layer between nacre and mother-of-pearl nucleus; sharp edges	No dark separation layer; ragged edges	Same	Same	Same
Tooth test	Gritty	Smooth	Smooth	Smooth	Smooth

[a] *Testing performed on several saltwater cultured pearls and a representative 8-mm Majorica bead from each color category by David Hargett, GIA Gem Trade Laboratory, Inc., New York.*

Spain, followed by the U.S., France, and, surprisingly, Japan (L. Di Cristofano, pers. comm., 1990). For 1989, Majorica S.A. reported total sales of imitation pearls at US$60 million.

Distribution is controlled by 45 diversified distributors who sell to jewelry and department stores, as well as to airlines, duty-free shops, cruise-ship gift shops, military bases, and boutiques. Jewelry is produced only in direct response to orders received, all of which are processed through corporate headquarters in Barcelona. Inventory is kept at a minimum.

Majorica continues to expand their product line. Today, the company is trying to increase the appeal of their product by designing with 14K gold and colored stones for the U.S. market, and with 18K gold and diamond accents for the European market (A. Corbero, pers. comm., 1989).

IDENTIFICATION

Of paramount importance to the jeweler-gemologist is the separation of the Majorica imitations from their costlier counterparts: saltwater cultured pearls. Although natural pearls are another possibility, they are extremely uncommon today and therefore were not included in this study. Most of the surface characteristics of natural pearls, however, overlap those of cultured pearls and so would provide similar identification clues.

To establish standard means by which the two products could be separated, we submitted a representative bead from each of four 16-inch strands of Majorica pearls – one each of 8-mm white, cream rosé, gray, and black beads (again, see figure 11) – to standard gemological tests. We then compared our results to those gained on several saltwater cultured pearls of similar color and shape. The results are reported in table 1 and discussed below.

To the untrained eye, Majorica imitation pearls look very much like saltwater cultured pearls (figure 12). An iridescence resembling the orient seen on some cultured pearls may also be observed on Majoricas. On cultured pearls, however, this phenomenon more commonly occurs on irregular surfaces rather than smooth. On the Majorica imitations, obvious iridescence is often seen in conjunction with a smooth surface. The Majorica beads also have a very high luster which, in combination with the iridescence and on the smooth surface, provides visual indication that the bead is an imitation (figure 13). Note that the process used to produce most other imitation pearls involves dipping or painting the beads with a resin; thus, these imitations lack the iridescence of the Majorica product and its cultured counterpart.

Figure 12. To the untrained eye, Majorica imitation pearls may be confused with cultured pearls. The larger beads are Majorica imitations; the two smaller strands are cultured pearls. Photo by Shane McClure.

Since visual observation is not always conclusive, gemological testing may be needed to separate the Majorica imitation from cultured pearls. We determined that four tests are conclusive in making this separation: refractive index, magnification, X-radiography, and the tooth test.

As table 1 indicates, the spot refractive index of the Majorica imitations is significantly lower than that of a cultured pearl. Also, the Majorica beads do not exhibit birefringence.

Ten-power magnification of the drill hole also proved to be conclusive in making the separation. A cultured pearl shows the thin, often dark layer of conchiolin that separates the mother-of-pearl bead nucleus from the nacre, and the edges of the drill hole are sharp and well defined (figure 14). In contrast, there is no separation between the glass

Figure 13. The prismatic colors known as orient are most apparent on cultured pearls with irregular surfaces. However, Majorica imitation pearls often exhibit iridescence in combination with a relatively smooth surface. This uncommon combination (for cultured pearls) of obvious iridescence and a smooth surface provide visual indications that the bead is actually a Majorica imitation. Photo by Robert Weldon.

nucleus and the coating of the Majorica imitation pearl, and the drill hole itself shows the ragged edges of the coating (figure 15). Higher magnification (50 ×) of the surface also revealed the recessed, step-like depressions on the nacre of a cultured pearl in contrast to the more pitted and dimpled texture of the Majorica imitation (figure 16).

With X-radiography, the Majorica imitations appear almost opaque, with no distinction between the bead nucleus and the coating (figure 17). The mother-of-pearl bead that forms the nucleus in cultured pearls, is significantly less opaque than the glass bead of the Majorica product and there is usually a distinct difference in opacity between the layers of nacre and the nucleus.

The separation is most easily made by the tooth test. When gently rubbed against the cutting edge of the front teeth, cultured pearls feel gritty while the Majorica imitations feel smooth. However, this can be a damaging test. Also, note that Majorica S.A. indicated to the authors that they have the technology to produce their product with a gritty surface texture, but they have made a conscious decision not to do so (L. Bonel, pers. comm., 1989). Other manufacturers are not as conscientious, so the test does not exclude other imitations if a gritty texture is encountered.

With regard to the other tests performed, the results for specific gravity and hardness indicate an overlap between the Majorica products and

Figure 14. When examined with 10× magnification, the drill hole of a cultured pearl shows the outer nacreous layer separated from the mother-of-pearl nucleus by the slightly darker layer of conchiolin. Note also that the edges of the hole are sharp and well defined. Photomicrograph by John I. Koivula.

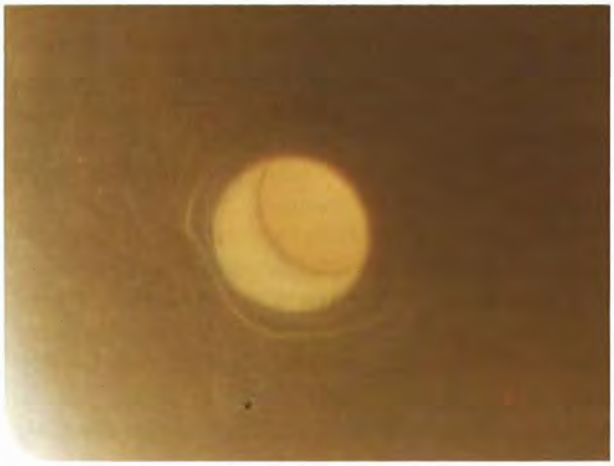
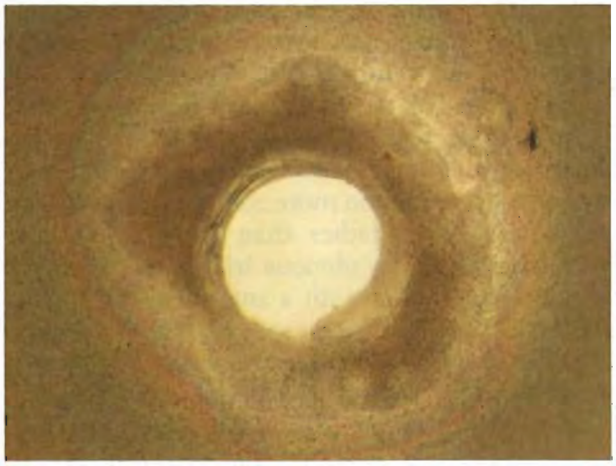


Figure 15. In contrast to figure 14, the drill hole of the Majorica bead shows the ragged edges of the coating and no distinct separation from the glass nucleus. Photomicrograph by John I. Koivula; magnified 10×.



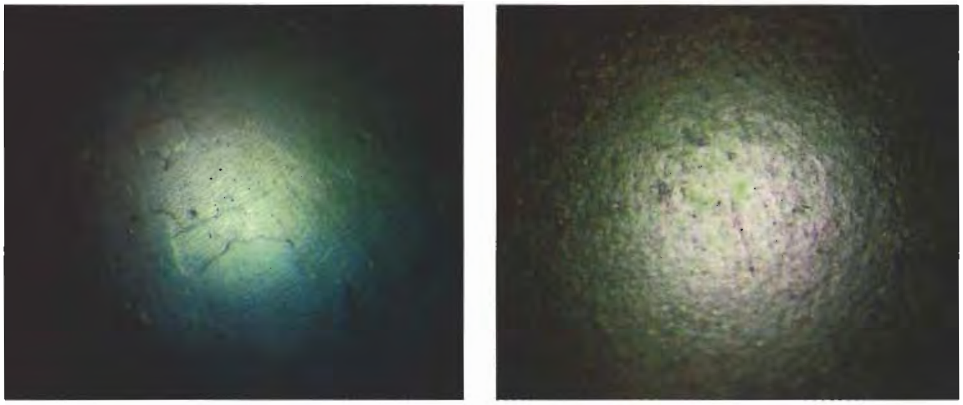


Figure 16. At 50× magnification, the surface of a cultured pearl (left) typically reveals recessed, step-like depressions, while that of a Majorica imitation (right) shows a more pitted and dimpled texture. Photomicrographs by John I. Koivula.

cultured pearls. Although X-ray fluorescence is considered conclusive when it is used in conjunction with X-radiography, this test is of questionable value when used alone. This is also the case with fluorescence to both long- and short-wave ultraviolet radiation. Although reaction to a 10% hydrochloric acid solution is definitive (cultured pearls effervesce, but the Majorica imitations do not), this test is highly destructive and so is not recommended. Also, some other imitation pearls may effervesce (C. Fryer, pers. comm., 1990).

To further substantiate the thickness of the coating or nacre seen with magnification, C. Y. Sheng of GIA's Jewelry Manufacturing Arts Department cut one Majorica imitation and one cultured pearl in half for comparison (figure 18). In the cultured pearl, the wavy, parallel structure of the mother-of-pearl nucleus is seen, surrounded by the dark conchiolin layer and then the outermost layer of nacre. The thickness of the nacre layer will vary depending on the amount of time the nucleated mollusk was allowed to grow before harvest. Generally, however, it is significantly thicker

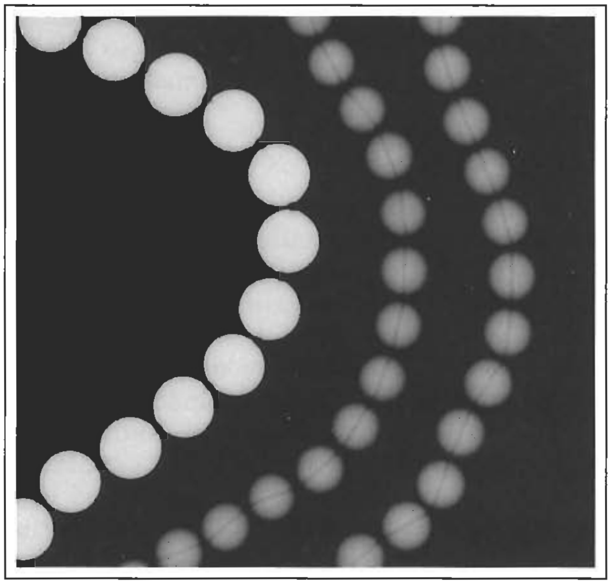


Figure 17. With X-radiography, the Majorica imitation pearls (here, the larger beads) are typically very opaque compared to their cultured counterparts. X-radiograph by Robert E. Kane.

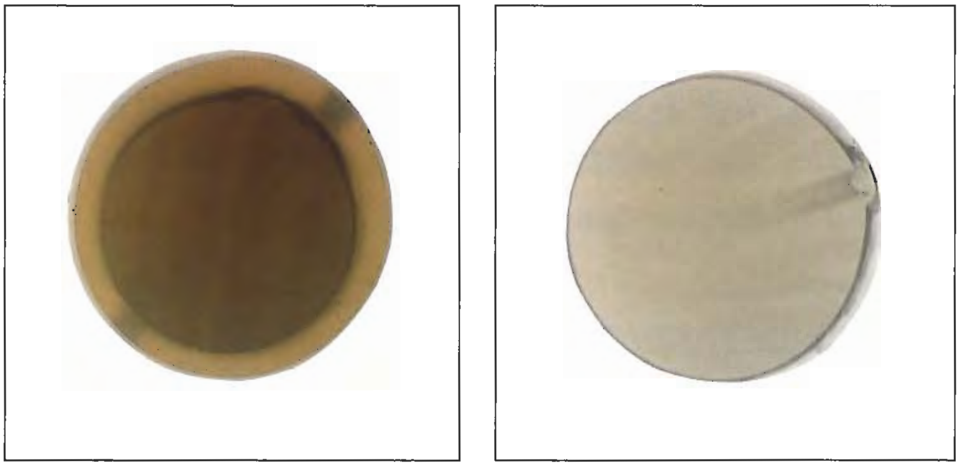


Figure 18. Typically, the nacreous layer of a cultured pearl (left) is significantly thicker than the "pearl essence" coating on a Majorica imitation (right). Note also on these cross-sections the wavy, parallel structure of the mother-of-pearl nucleus in the cultured pearl and the swirl striations of the glass nucleus in the Majorica imitation. Photos by John I. Koivula.

(0.5–0.8 mm on the section in figure 18) than the coating on the glass bead of the Majorica imitation (0.2 mm in figure 18). The Majorica imitation pearl also shows the swirl striations of the glass nucleus. Gas bubbles were again observed in the nucleus.

Durability testing was approached from the point of view of key concerns during average wear. A strand of cream rosé Majorica imitation pearls was immersed in perfume for a week, then exposed to a week of California summer sun. When the test strand was compared to untested strands of the same color, we observed no color change in the tested beads, only a slight yellowing of the thread. While this test is not conclusive, it does provide some indication of the general stability of the product.

CONCLUSION

More and more consumers are choosing imitation pearls as a less expensive alternative to the natural or cultured gem material. Greater consumer acceptance of imitations can also be attributed to the influence of those – such as First Lady Barbara Bush – who are spotlighted by the media.

Majorica imitation pearls are manufactured by a meticulous process that involves multiple dippings of a glass nucleus into a compound extracted from fish scales. Each dipping is followed by a separate polishing of the bead. A final coating serves to harden the bead and protect it from discoloration by ultraviolet radiation. It is this process that sets the Majorica product apart from most other imitations, which use coatings of resin paints.

Although Majorica imitation pearls are produced in many colors and in a variety of shapes and sizes, the most popular are the round, 6–7 mm cream rosé beads. Majorica jewelry is marketed throughout the world; in 1989, sales reached US$60 million.

At a glance, it is possible to mistake Majorica imitation pearls for cultured pearls; however, they are easily separated with standard gemological testing. The high luster, absence of blemishes, and distinct iridescence of the Majorica product are strong visual clues. The significantly lower refractive index (and absence of birefringence) in the Majorica product, together with the ragged drill hole edges viewed with magnification and its opacity to X-radiography, provide conclusive means of identification. The smooth surface of the Majorica product when rubbed against the cutting edge of the front teeth (as compared to the gritty surface of cultured or natural pearls) is also conclusive, but this test is potentially damaging.

The Majorica imitation also appears to be durable under normal conditions of wear. Overall, it is a useful substitute for cultured or natural pearls.

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GEM-QUALITY CUPRIAN-ELBAITE TOURMALINES FROM SÃO JOSÉ DA BATALHA, PARAÍBA, BRAZIL

By Emmanuel Fritsch, James E. Shigley, George R. Rossman, Meredith E. Mercer, Sam M. Muhlmeister, and Mike Moon

Unusually vivid tourmalines from the state of Paraíba, in northeastern Brazil, have attracted great interest since they first appeared on the international gem market in 1989. This article describes what is known of the locality at this time, but focuses on the most striking characteristic of these gem tourmalines: the unusual colors in which they occur. Quantitative chemical analyses revealed that these elbaite tourmalines contain surprisingly high concentrations of copper, up to 1.92 wt.% Cu (or 2.38 wt.% CuO). Their colors are due to Cu^{2+} or a combination of Cu^{2+}, Mn^{3+}, and other causes. Some colors can be produced by heat treatment, but most also occur naturally.

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A new find of gem-quality elbaite tourmalines that occur in unusually bright shades of green and blue, among other colors, appeared on the international market in 1989. Some of the colors were so exceptional (figure 1) that they were described as "neon," "fluorescent," or "electric" in the trade (Reilley, 1990). A number of the hues, especially a slightly violetish "sapphire" blue, had seldom if ever been seen before in gem tourmaline (Koivula and Kammerling, 1989a). Prices for large, clean stones reached US$1,000 or more per carat (Reilley, 1990; Federman, 1990); recently, they have begun to appear in fine jewelry (figure 2). It was subsequently revealed that some of the material has been heat treated (Koivula and Kammerling, 1990a), but it has not been clear whether certain colors are due only to such treatment or if they also occur naturally.

These exceptional gem tourmalines come from a small mine near the village of São José da Batalha, in the state of Paraíba, northeastern Brazil. They are commonly referred to (and will be so here) as "Paraíba tourmalines" (although more common varieties of gem tourmaline have been found elsewhere in the same state; W. Larson, pers. comm., 1990). This article reviews what is currently known about this locality and the tourmalines produced there, and reports the results of a comprehensive study into the cause of these unusual colors and the effect of heat treatment.

LOCATION AND ACCESS

The mine is called Mina da Batalha (B. Cook, pers. comm., 1990). It is located on the upper flank of a hill known as Serra da Frade (figure 3), 4.5 km (2.7 mi.) northeast of the town of Salgadinho and very close to the village of São José da Batalha. As in most of the state of Paraíba, the area around the mine is a harsh dry scrubland, locally known as the *sertão*. The small local mining industry focuses primarily on industrial pegmatite minerals, especially tantalite. As of September 1990, access to the tourmaline deposit was restricted and required prior arrangements.

Figure 1. Paraíba tourmalines have generated major interest in the gem industry because many occur in unusual colors, some of which have never been seen before in this gem species. Some of the names used in the trade to describe these exceptional colors, illustrated here, are "neon," "electric," "turquoise," "sapphire," or "tanzanite" blue and "mint" green. These stones, which range from 0.39 to 1.47 ct, are courtesy of Gerhard Becker, Idar-Oberstein; photo by Robert Weldon.

HISTORY

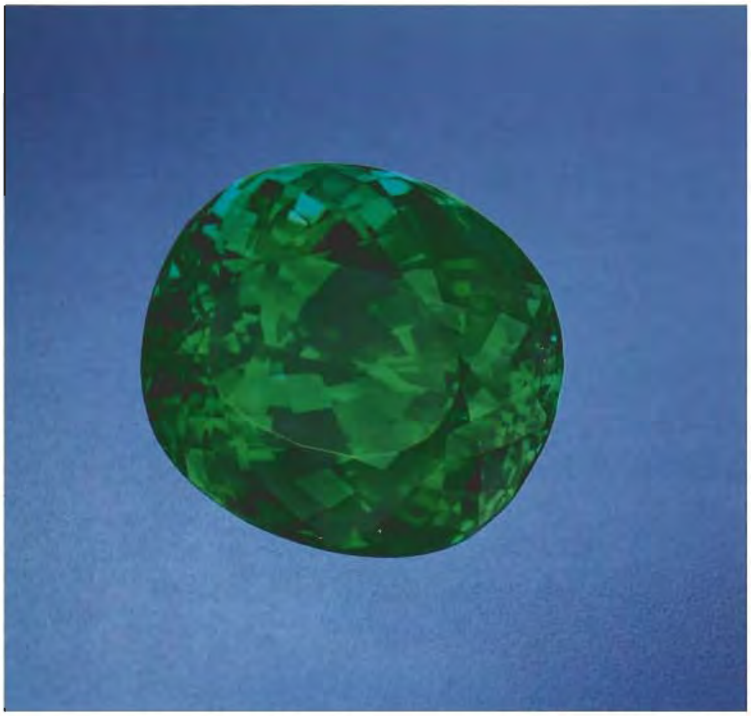
The story of the Paraíba tourmalines began in 1982, when Heitor Dimas Barbosa, who had once mined tourmaline in Minas Gerais, noticed brightly colored specks in samples of pegmatite ore shown to him by José Pereira, a local Paraíba *garimpeiro* (Koivula and Kammerling, 1990b). The two men searched numerous pegmatite deposits throughout this region for the next several months. Eventually, they located similar colored fragments (later identified as tourmaline) in the tailings of a small manganotantalite prospect on a hillock at the base of Serra da Frade. Over the next few years, Barbosa and a team of about 15 *garimpeiros* dug deep (up to 50 m) shafts and a number of galleries into a decomposed granitic pegmatite. They operated under difficult climatic conditions (little water and high daytime temperatures), using only hand tools. During 1985–1987, their efforts produced tourmalines of various shades of green. Not until August 1987, however, did they encounter the distinctive "electric" and "sapphire" blue stones for which this deposit has become famous. Mr. Barbosa and his associates filed a joint claim on the mine in 1988 and formed the mining cooperative COGASBRA, which was registered by the National Department of Minerals (DNPM) on March 13, 1990. Currently, Mr. Barbosa holds exploration rights to the area that he has been mining, although the mining rights are in dispute.

Figure 2. The new Paraíba tourmalines are particularly attractive in fine jewelry, as indicated by this pin set with three Paraíba stones (total weight 2.13 ct). Created by the Gold Rush, Northridge, CA; photo by Shane McClure.

Figure 3. The Mina da Batalha workings can be seen here at the top of Serra da Frade, a hill composed of gently dipping beds of gray quartzite. Dumps of decomposed white rock mark entrances to the mine shafts that have been dug into the weathered pegmatite. Photo, taken August 1990, by Brian Cook.

Figure 4. White clay (altered feldspar) can be seen surrounding the main shaft of the tourmaline mine on Serra da Frade. The village of São José da Batalha appears in the background. Vertical shafts and horizontal tunnels have been dug into the weathered pegmatite in search of gem tourmaline. Photo, taken August 1990, by Brian Cook.

Figure 5. This 24.69-ct round brilliant cut is reportedly one of the largest faceted tourmalines to emerge to date from the new locality in the state of Paraíba. Courtesy of Kahlil Elawar Ltda.; photo © Harold & Erica Van Pelt.



GEOLOGY AND OCCURRENCE

Gem tourmalines from São José da Batalha are found in a small, decomposed granitic pegmatite, in association with quartz, feldspar (altered to white clay), and lepidolite (figure 4). The pegmatite is a narrow dike cutting across the quartzite host rock. Tourmaline occurs mostly as crystal fragments that weigh less than a gram, although cut stones over 20 ct (4 grams) have been faceted (figure 5) and the authors have examined rough fragments as large as 10 grams. In rare instances, small crystals are recovered. The external features of these crystals often indicate that they have been broken in nature, and some are also severely etched (figure 6). Occasionally, tourmaline crystals have been found completely included in quartz matrix (as illustrated in Koivula and Kammerling, 1990a, p. 166).

Some crystals display a distinct, sometimes complex color zoning. Several contain a deep pink core, surrounded by a zone of "turquoise" blue and a thin pink rim; others have a blue center surrounded by violet, light blue, green, and gray areas. Other combinations have also been seen. Slices of these crystals are quite attractive (figure 7).

MINING

The area continues to be mined primarily with hand tools. Dynamite is used only occasionally to break the surrounding host rock, which is considerably harder than the altered pegmatite. The miners have sunk vertical shafts into the decomposed pegmatite at various intervals; at different levels along these shafts, they have dug narrow horizontal tunnels (1.8 m high × 0.6 m wide) to follow the pegmatite dike. All of these underground workings have been excavated using candlelight as the sole source of illumination. Mining has been hampered by the lack of a proper ventilation system, and by the difficulty of hauling loose rock up and out of the mine. The conflict over mining rights has also led to periods when the operation had to be halted.

It is difficult to estimate how much gem material this mine has already produced, but the quantities available at the February 1990 Tucson gem show plus those stocks reported by other dealers (e.g., G. Becker, pers. comm., 1990) amount to at least 10,000 ct of rough and finished stones. There are indications that more is to be found at the mine (see, e.g., Koivula and Kammerling, 1990b), but, in the absence of careful geologic

Figure 6. This 13-mm high, 8.80-ct blue crystal of Paraíba tourmaline is a nice example of the small crystals found at the deposit. The rectangular, step-like surface features are attributed to etching. Stone courtesy of Brian Cook, Nature's Geometry; photo by Robert Weldon.

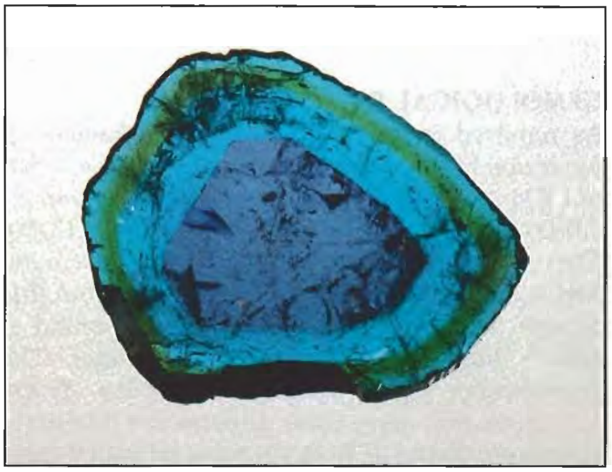


Figure 7. This 5.96-ct slice (15.20 × 12.20 × 3.28 mm) of Paraíba tourmaline is representative of the somewhat complex color zoning that appears in some crystals. This color zoning reflects changes in chemical composition as the tourmaline crystallized. Courtesy of The Gold Rush, Northridge, CA; photo by Shane McClure.

mapping and more systematic exploration, no estimate of the reserves can be provided at this time.

MATERIALS AND METHODS

Over the course of this research project, we examined several hundred rough and faceted gem tourmalines that covered the entire range of colors available from the Paraíba deposit. From these, we selected 13 specimens of representative color for more detailed study. Indices of refraction were measured with a GIA Gem Instruments Duplex II refractometer and a filtered, near-monochromatic, Na-equivalent light source. Specific gravity was determined by the hydrostatic method. To confirm the identity of these specimens as elbaite tourmaline, we obtained X-ray diffraction data for five of them (samples R30, R50, R52, R66, and R67) using an automated Rigaku powder diffractometer operated at 35 kV and 15 mA.

Chemical analyses of all 13 specimens were obtained using a JEOL Model 733 electron microprobe (for operating conditions, see table 1; because two of the original samples virtually duplicated the color of other samples in the test group, only 11 are reported in the table). A Pye-Unicam Model 8800 ultraviolet-visible spectrophotometer was used to record absorption spectra in the range of 250–850 nm for the same samples. We found it necessary to prepare crystallographically oriented pieces of some of these specimens to obtain quantitative absorption spectra that could be directly compared with their chemical composition. For this purpose, we selected three crystal fragments (R30, R50, and R52) and two faceted stones (R66 and R67) in the green to bluish purple color range on the basis of their color and color homogeneity. From each specimen, we cut a flat, parallel-windowed section in an orientation parallel to the optic axis (as determined either from striations on the prism faces of the crystal fragments – which are parallel to the optic axis – or, when there were no striations, by X-ray alignment photography). These five sections were subsequently ground to an appropriate known thickness (0.2 to 5 mm) and then polished using 1-micron-diameter alumina powder.

Quantitative absorption spectra in the 300–2000 nm range were recorded for these five specimens using a Cary Model 17I ultraviolet-visible/near-infrared spectrophotometer. The heating experiments were carried out in a Lindberg Model 51442 furnace.

GEMOLOGICAL PROPERTIES

As reported in table 1, we recorded indices of refraction for the 13 specimens as epsilon = 1.618 to 1.621 (± 0.001), and omega = 1.638 to 1.646 (± 0.001). These values are typical of elbaite (Dietrich, 1985). Slightly lower values were reported by Bank et al. (1990) for material from this deposit. All of our specimens were also found to have a uniaxial negative optic character. The birefringence varied from 0.018 to 0.025. As expected for this gem, these elbaites are distinctly pleochroic (figure 8), with the most saturated color seen looking down the optic axis, that is, parallel to the direction of the omega refractive index (i.e., with the polarizer oriented perpendicular to the optic axis; see Bloss, 1961, p. 147). The specific gravity of our samples ranged from 3.03 to 3.12 (± 0.01), which is slightly higher than for most elbaites (2.84–3.10; Dietrich, 1985).

The Paraíba tourmalines we examined were inert to both long-and short-wave ultraviolet radiation, as is commonly observed in other gem tourmalines. The inclusions are typical of those seen in all varieties of gem tourmalines (see, e.g., Gübelin and Koivula, 1986): three-phase inclusions (figure 9); liquid inclusions, sometimes in veils or "fingerprint" patterns; thin growth tubes parallel to the optic axis; and some doubly refractive crystal inclusions. Of particular interest are rare inclusions of tourmaline in tourmaline. Fig-

TABLE 1. Some gemological properties and electron microprobe analyses[a] of elbaite tourmalines from Paraíba, Brazil.

Property/ chemical component	R50	R378	R308	R362	R66
Property					
Color[b]	Yellowish green	Greenish gray	Purple-pink	Purple	Bluish purple ("tanzanite")
R.I.					
ϵ	1.619	1.620	1.621	1.620	1.620
ω	1.639	1.640	1.640	1.640	1.638
S.G.[c]	3.05	3.07	3.03	3.05	3.04
Pleochroism[d]					
ϵ	Grayish green	Light gray	Light purplish pink	Light pink	Light, slightly grayish green
ω	Medium yellowish green	Medium grayish green	Medium purplish pink	Medium purple	Medium bluish purple
Chemical Component (wt.%)					
Na_2O	2.27	2.36	1.94	2.00	2.16
CaO	0.46	0.45	0.08	0.07	0.62
K_2O	0.03	0.02	0.02	0.01	0.02
Li_2O[e]	1.62	1.62	1.62	1.62	1.62
MgO	0.54	0.30	BDL	BDL	BDL
TiO_2	0.10	0.07	BDL	BDL	BDL
V_2O_3	0.01	0.01	BDL	BDL	BDL
Cr_2O_3	BDL	BDL	BDL	BDL	BDL
MnO	1.47	2.99	0.53	0.52	1.32
FeO	0.22	0.12	BDL	0.01	BDL
ZnO	0.08	0.11	0.03	0.04	BDL
CuO	0.37	0.49	0.51	0.52	0.62
PbO	BDL	0.02	BDL	0.01	BDL
Bi_2O_3	0.39	0.06	BDL	0.02	0.15
Al_2O_3	39.04	38.73	42.37	42.14	39.66
B_2O_3[e]	10.94	10.94	10.94	10.94	10.94
SiO_2	37.27	37.29	37.42	37.39	37.11
H_2O[e]	3.13	3.13	3.13	3.13	3.13
Cl	0.01	BDL	BDL	BDL	BDL
Total	97.95	98.71	98.59	98.42	97.35

[a] *Electron microprobe analyses were performed on an automated, five-crystal JEOL 733 spectrometer operating at a beam accelerating potential of 15 kV, a current of 35 nA, and a spot size of between 10 and 25 μm. K-alpha lines were analyzed for each element except Pb and Bi, for which M-alpha lines were used. Standards include: (Na)—Amelia albite, (Mg)—MgO, (Al, Si)—kyanite, (K)—microcline, (Ca)—anorthite, (Ti)—TiO_2, (V)—pure element, (Cr)—Cr_2O_3, (Mn)—Mn-olivine, (Fe)—synthetic fayalite, (Cl)—sodalite, (Zn)—ZnO, (Cu)—pure element, (Pb)—galena or synthetic PbS, and (Bi)—pure element. Total iron is calculated as FeO; total manganese is calculated as MnO (even though it can be present as both Mn^{2+} and Mn^{3+}). Entries indicated by "BDL" were below the detection limits of the instrument (less than 0.01 wt% oxide). The data were corrected using the program CITZAF (Armstrong, 1988) employing the absorption correction of Armstrong (1982), the atomic number correction of Love et al. (1978), and the fluorescence correction of Reed (1965), as*

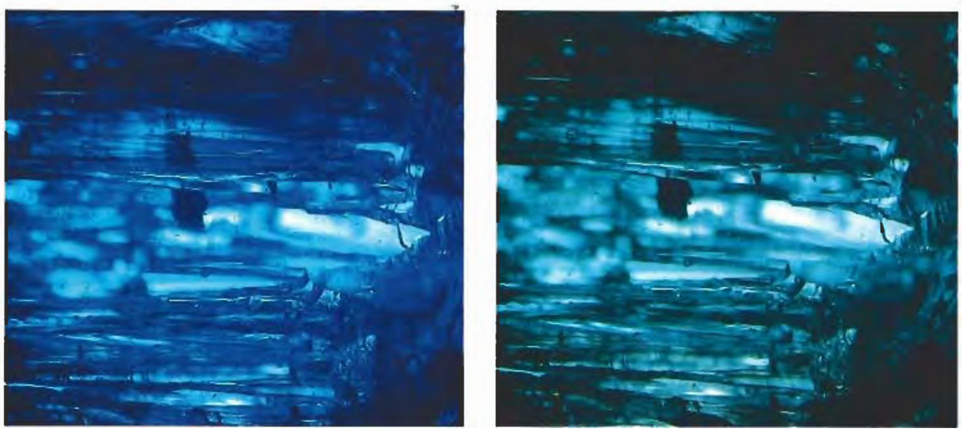


Figure 8. As with most elbaite tourmalines, the pleochroism in this "sapphire" blue Paraíba tourmaline is distinct: medium dark blue (left, polarizer perpendicular to the optic axis) and medium light greenish blue (right, polarizer parallel to the optic axis). Photomicrographs by John I. Koivula; magnified 6×.

R52	R67	R305	R30	R319	R376
Blue	Violetish blue ("sapphire")	Bluish green ("mint")	Blue-green ("turquoise")	Bluish green	Green ("emerald")
1.619	1.618	1.620	1.621	1.620	1.620
1.639	1.638	1.640	1.646	1.640	1.640
3.11	3.06	3.09	3.12	3.12	3.11
Very light blue	Medium light greenish blue	Very light green	Medium bluish green	Light, slightly greenish blue	Medium bluish green
Medium light blue	Medium dark blue	Medium, slightly bluish green	Medium green-blue	Medium green	Medium green
2.26	2.35	2.32	2.49	2.47	2.51
0.55	0.47	0.19	0.05	0.24	0.30
0.02	0.02	0.02	0.02	0.02	0.04
1.62	1.62	1.62	1.62	1.62	1.62
BDL	BDL	0.18	BDL	0.95	0.06
0.01	0.01	0.07	0.06	0.11	0.02
BDL	BDL	0.01	0.01	0.01	BDL
BDL	BDL	BDL	BDL	BDL	BDL
2.30	2.55	1.32	1.48	0.85	2.16
BDL	BDL	0.15	0.07	0.34	0.04
0.01	0.01	0.11	0.25	0.08	0.52
0.72	0.74	1.08	1.76	2.37	2.38
0.01	0.02	0.01	0.01	0.02	0.01
0.11	0.08	0.83	0.01	0.03	0.05
38.95	38.47	38.99	38.58	39.35	38.31
10.94	10.94	10.94	10.94	10.94	10.94
36.97	37.06	36.75	36.53	36.83	36.89
3.13	3.13	3.13	3.13	3.13	3.13
BDL	0.01	BDL	0.01	BDL	BDL
97.60	97.48	97.92	97.01	99.36	98.98

modified by Armstrong (1988). Each specimen was analyzed at three different randomly selected locations; in this table, an average analysis is shown for each sample. Analyses were performed by Paul Carpenter.

[b] Color hue descriptions visually estimated. The "emerald" green specimen (R376) has been heat treated.

[c] Specific gravity values determined by the hydrostatic method.

[d] Pleochroic colors visually estimated using a calcite dichroscope. ϵ = epsilon (color seen with light vibrating parallel to the optic axis). ω = omega (color seen with light vibrating perpendicular to the optic axis).

[e] Values of Li_2O, B_2O_3, and H_2O were calculated based on an assumed elbaite tourmaline stoichiometry.

Figure 9. For the most part, the inclusions observed thus far in Paraíba tourmalines—here, a three-phase inclusion—are typical of those seen in tourmalines from other localities. Photomicrograph by John I. Koivula; magnified 40×.

ure 10 illustrates a needle of bright green tourmaline (identity confirmed by X-ray diffraction analysis) that cuts across a dark "sapphire" blue slice of Paraíba tourmaline. This specimen reportedly has not been heat treated (G. Becker, pers. comm., 1990).

Also, numerous yellowish specks—referred to as "gold" by some of the Brazilian miners—have been seen on a few crystals (see figure 11). Although microscopic examination revealed that these "specks" are pinkish yellow and have a metallic luster, X-ray fluorescence analysis of the specimen shown in figure 11 revealed the presence of Mn, Fe, Cu, Zn, and Bi, as well as some S. This implies that these inclusions could be composed of a sulfide, possibly iron containing, since the iron content of the stone for which the inclusions were analyzed is unusually high compared to other Paraíba tourmalines.

Because of their bright colors, Paraíba tourmalines could easily be mistaken for other gem materials, such as haüyne, lazulite (Bank and Henn, 1990), blue sapphire, tanzanite, or even emerald. However, these gem materials have very different gemological properties. Haüyne is isotropic with a lower R.I. and S.G. than tourmaline; lazulite has a similar R.I. and S.G. but a higher birefringence and is biaxial; sapphire and tanzanite have higher R.I.'s and S.G.'s, and in the case of sapphire there is usually a distinctive absorption spectrum; and emerald has a lower R.I. and S.G. and, again, a distinctive absorption spectrum. At the February 1990 Tucson gem show, we saw a new production of apatites from Madagascar with colors similar to those of some Paraíba tourmalines, in particular, "turquoise" blue, bluish green, and light green (see also Bank and Henn, 1990; Koivula and Kammerling, 1990b). These two gem materials are easily separated on the basis of specific gravity or absorption spectrum.

X-RAY DIFFRACTION ANALYSIS

Measured lines in the X-ray diffraction patterns of the five tourmalines analyzed were determined to be closely related in both position and relative intensity to those from the pattern of a representative elbaite (1986 JCPDS Mineral Powder Diffraction File 26-964). Least-squares refinement of data for a Cu-rich specimen (R30) yielded unit-cell dimensions of $\underline{a} = 15.883\ (\pm 0.004)$ Å and $\underline{c} = 7.111$

Figure 10. A needle of bright green tourmaline is readily seen as an inclusion in this slice of dark violetish blue tourmaline (R32) from Paraíba. The slice, 12.10 × 6.60 × 3.52 mm, is courtesy of Gerhard Becker; photo by Robert Weldon.

(± 0.001) Å. The five strongest lines in this pattern are 3.978(56)(220), 3.445(76)(012), 2.938(100)(122), 2.567(90)(051), and 2.029(54)(152), where these values represent the d-spacing (in Ångstroms), relative intensity, and Miller index (hkl) of each diffraction line. No significant differences were noted between the diffraction patterns of this specimen and those of the other four elbaite specimens. The a and c dimensions of the other four specimens were within 0.020 Å and 0.003 Å, respectively, of those for sample R30.

CHEMICAL ANALYSIS

The electron microprobe analyses (again, see table 1) show that these tourmalines are typical elbaites and contain little Ti ($\leq$ 0.11 wt.% oxide), and Fe ($\leq$ 0.34 wt.% oxide), virtually no V or Cr ($\leq$ 0.01 wt.% oxide), and have Cu and Mn as major transition-element impurities. The highest concentration of copper measured in our samples was 2.38 wt.% CuO (or 1.92 wt.% Cu) for the "emerald" green cabochon (R376), and the largest concentration of manganese, 2.99 wt.% MnO, was found in the greenish gray crystal fragment (R378). Analyses performed at three random locations on each specimen with uniform coloration showed only very slight compositional variations.

As mentioned previously, however, some Paraíba tourmaline crystals exhibit distinct color zoning (again, see figure 7). Examination of such unusual crystals provides interesting information on the chemical environment that produced them. As shown in figure 12, the greatest differences in chemistry as one crosses boundaries between zones of various colors are for Cu and Mn. To a lesser extent, differences were also noted in the Fe and Ti contents.

It is interesting to note that small amounts of Bi, Pb, and Zn were detected in many specimens. These elements appear to have no influence on color, and have not often been reported in gem tourmalines (see Dietrich, 1985). Bank and Henn (1990) reported gold concentrations of 8.6 parts per million in this material; we did not attempt to confirm their finding.

Results of both the site-occupancy calculations based on charge-balance considerations and the microprobe analyses indicate that copper and manganese are present in the Y crystallographic site (using the site terminology for tourmaline of Deer et al., 1986).

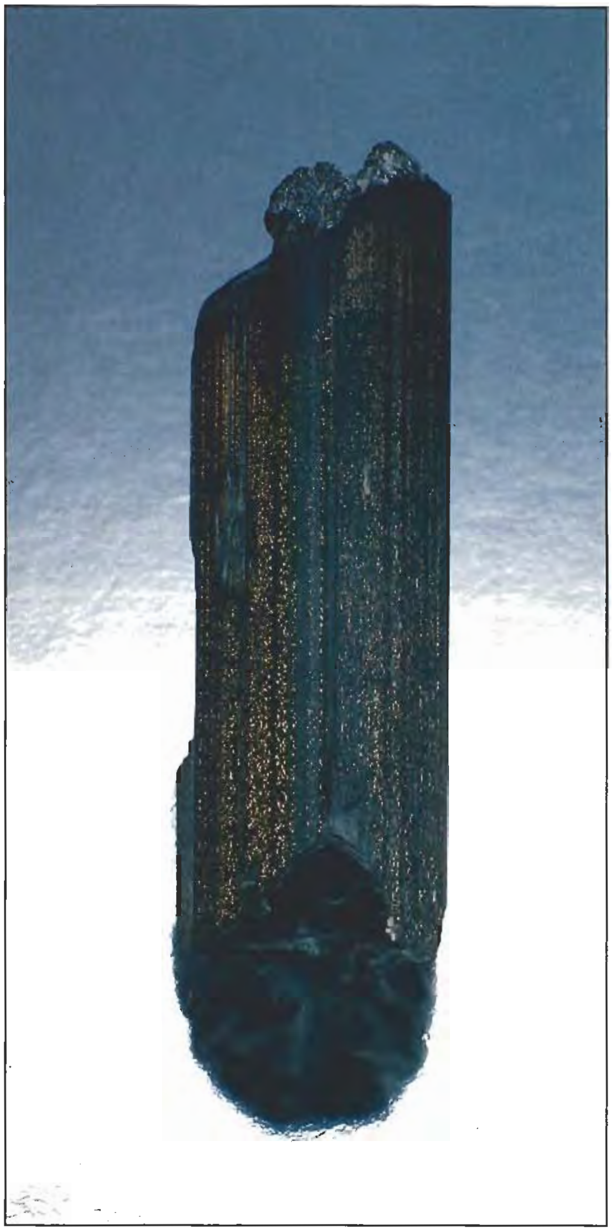


Figure 11. Numerous gold-colored specks near the surface of this Paraíba tourmaline crystal create an interesting optical effect. Stone courtesy of Beija Flor Gems; photo by Robert Weldon.

COLOR

The cause of color in elbaite tourmaline has been extensively investigated. Most colors are due to small amounts of transition elements (Dietrich, 1985). In particular, blue to green hues have been attributed to various processes involving both Fe^{2+} and Fe^{3+} ions (Mattson and Rossman, 1987)

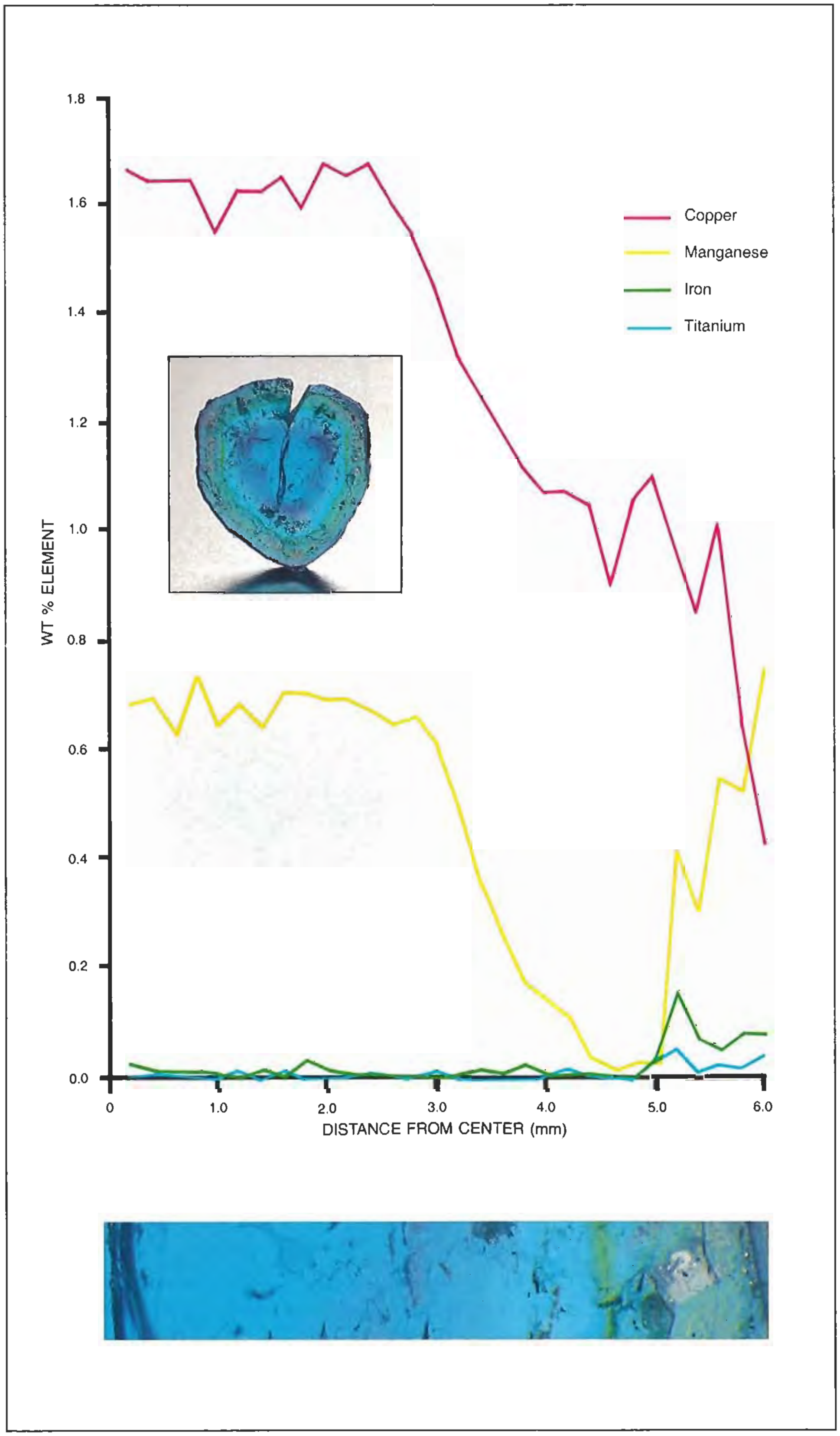


Figure 12. Changes in the chemical composition of the coloring agents—as determined by microprobe analyses taken at 30 points along a linear traverse (6 mm total distance) from the center to the edge of this Paraíba tourmaline crystal section (R363)—relate to the various color zones in the section. The copper concentration decreases from the center toward the edge. The manganese content decreases in a similar fashion, but reaches a low value at the narrow light blue and yellowish green zones (about 4.5 mm from the center), and then increases in the pink areas near the edge. Iron and titanium contents remain very low across most of the section, but show a slight increase near the edge. Note that the electron microprobe analyses were performed on an automated, five-crystal JEOL 733 spectrometer operating at a beam accelerating potential of 15kV, a current of 150 nA, a 5-second counting time, and a spot size of 30 µm. K-alpha lines were analyzed for each element; standards include: (Ti)—TiO_2, (Mn)—Mn-olivine, (Fe)—synthetic fayalite, (Cu)—pure element. Values are plotted for TiO_2, MnO, FeO, and CuO. Thirty analyses were performed at 200 µm intervals along a linescan between the core and rim of this crystal. The data were corrected using the same procedure as described in table 1.

and to $Fe^{2+} \rightarrow Ti^{4+}$ charge transfer (Mattson, as cited in Dietrich, 1985, p. 129). Cr^{3+} and V^{3+} have been identified as coloring agents in green dravite and uvite (Schmetzer and Bank, 1979), but never in elbaite.

Several earlier investigators have mentioned Cu^{2+} as a potential cause of color in blue and green elbaites on the basis of atomic emission spectrography. Warner (1935) observed that blue samples have a lower copper concentration than yellow-green ones, whereas Carobbi and Pieruccini (1946, 1947) found, on the contrary, greater amounts of copper in blue crystals. None of these authors, however, proved that this ion actually acts as a coloring agent in tourmaline. Staatz et al. (1955) mentioned the presence of trace amounts of copper in tourmaline (up to 0.0017 wt.%) but, again, did not relate it to color. Cu^{2+} was recently proposed as a possible coloring agent for the Paraíba material (Fritsch, as cited in Koivula and Kammerling, 1989b; and Bank et al., 1990), but this hypothesis was not proved at that time. Using ultraviolet-visible and near-infrared absorption spectroscopy, however, we can now demonstrate that copper is indeed partially responsible for the unusual coloration of these gem tourmalines.

Figure 13 illustrates the visible-range absorption spectra of nine Paraíba tourmalines that span the range of colors available. Several key features are evident in these spectral curves. First, there is an ultraviolet absorption "edge"—increasing absorption toward the U.V.—beginning at about 450 nm (most conspicuous in R376). Several of the spectra display a weak, sharp band at about 415 nm (especially notable in R67). Several others exhibit a broad band of varying intensity centered at about 515 nm (R308, R362). Finally, there is another broad absorption band beginning at about 600 nm and extending into the near-infrared (e.g., R376). The reader should note that element concentrations listed in table 1 as oxides cannot always be directly correlated with intensities of absorption features in a spectral curve (such as those in figure 13). Intensities of absorption features depend not only on the concentration of an element, but also on its valence state, position in the crystal structure, and—in the case of a charge-transfer mechanism—the proximity between the two ions involved in the crystal structure. It is possible that concentrations of coloring agents at much lower values than those shown in table 1 could still produce intense absorption features in the visible spectrum, for example, through charge-transfer phenomena (for further information, see Fritsch and Rossman, 1987 and 1988).

We interpret the features shown in figure 13 as follows. The rise in absorption toward the ultraviolet starts at a higher wavelength and is more gradual in specimens that contain a larger amount of titanium, as listed in table 1. Because all specimens contain much more manganese than titanium, this absorption feature may be attributed to $Mn^{2+} \rightarrow Ti^{4+}$ charge transfer (Rossman and Mattson, 1986). Still, other causes are possible. $Fe^{2+} \rightarrow Ti^{4+}$ charge transfer is known to occur in tourmaline between 400 and 500 nm (Mattson and Rossman, 1987; Taran and Lebedev, 1990). Also, V^{3+} or Cr^{3+}—at concentrations too low to be detected by electron microprobe—could cause a weak absorption in the same wavelength range. However, testing with a more sensitive instrument, an energy-dispersive X-ray fluorescence (EDXRF) spectrometer, did not detect either vanadium or chromium but easily detected the iron and titanium. Therefore, charge-transfer mechanisms involving $Fe^{2+} \rightarrow Ti^{4+}$ and $Mn^{2+} \rightarrow Ti^{4+}$ are the more likely causes of the increase in absorption that starts at about 450 nm.

Mn^{2+} is slowly transformed into Mn^{3+} by exposure to natural radiation such as that produced, for example, in a granitic pegmatite (Reinitz and Rossman, 1988). The darker blue to violet specimens from Paraíba (see figure 13) display a broad absorption band in the green that is centered around 515 nm and is attributed to Mn^{3+} (Manning, 1973). A weak, sharp absorption band at about 415 nm in the blue region, visible in the spectra of several specimens in figure 13, is attributed to Mn^{2+} (Rossman and Mattson, 1986; Reinitz and Rossman, 1988). More intense absorption attributed to Mn^{3+} in Paraíba tourmalines produces a shift toward more violetish colors ("sapphire" blue, violet) and even purplish pink. Note that the broad feature at 515 nm is responsible for the pink color of rubellite, which explains why "sapphire" blue and "tanzanite" bluish purple Paraíba tourmalines display a typical rubellite spectrum in the hand-held spectroscope (Kane, 1989; Hodgkinson, 1990). Their color is not that of rubellite, however, because the color of a gemstone (such as tourmaline) is primarily determined by broad absorption bands that are not always easily observable with a hand-held spectroscope.

Along with manganese, copper is the major

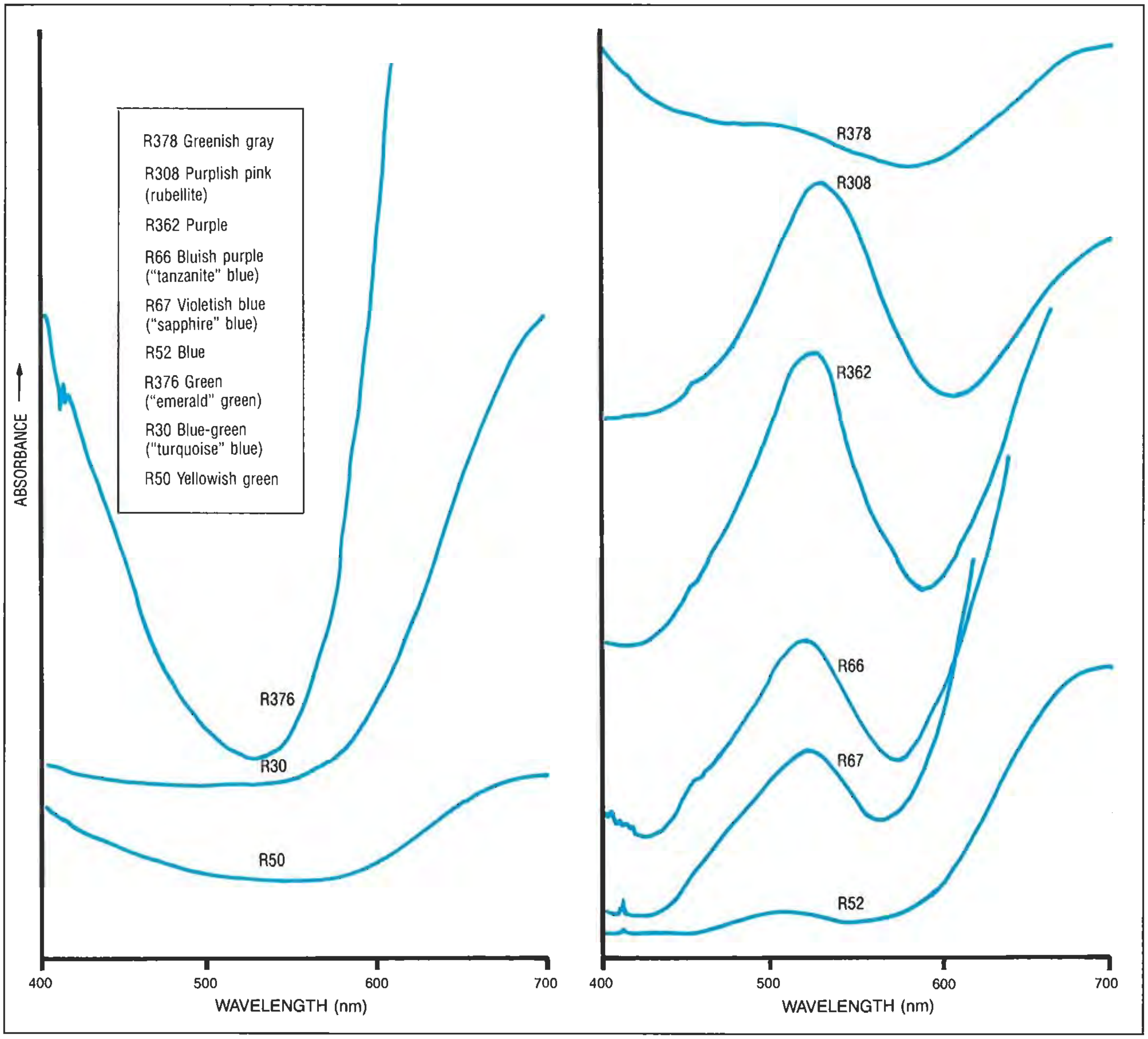


Figure 13. These visible-range absorption spectra for nine Paraíba tourmalines of various colors were recorded using nonpolarized light for samples that varied in size, shape, and optical orientation relative to the position of the incident light. Therefore, the vertical scale is in arbitrary units. However, for a given spectral curve, the intensities of absorption bands relative to one another are meaningful and characteristic of that particular color. The three spectra on the left (R50, R30, R376) illustrate absorption at the red end of the spectrum (above 600nm) due to increasing amounts of Cu^{2+}. The six spectra on the right (R52, R67, R66, R362, R308, and R378) show the broad absorption band centered at about 515 nm that is due to Mn^{3+} (in addition to the absorption from Cu^{2+}). In several spectra of this latter group, a weak, sharp band is visible at 415 nm; this is due to Mn^{2+}. Note that specimen R376 is known to have been heated.

coloring agent for these Paraíba tourmalines. When it is the dominant coloring agent, it is responsible for the spectacular "turquoise" blue hue (see figures 1, 13, and 14). We interpret the broad absorption band above 600 nm (for example, the unpolarized spectra of R30 and R376 in figure 13), which actually is the edge of the pair of bands at approximately 695 and 920 nm, as arising from absorption by Cu^{2+}. As can be seen in figure 14, the maxima of these two broad bands are located at about 690 and 900 nm in the $E \perp c$ direction.* They are shifted slightly in the $E \| c$ direction, and are

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* "E" stands for the electric vector, which is in the direction of light vibration, and perpendicular to the direction of light propagation. For example, $E \perp c$ is what one would see looking down the optic axis.

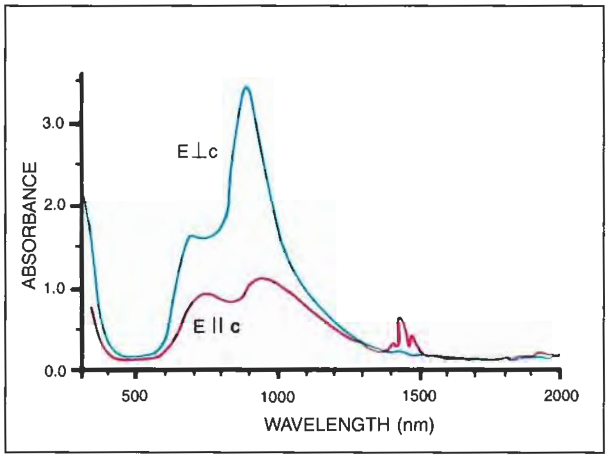

Figure 14. These polarized optical absorption spectra for a "turquoise" blue Paraíba tourmaline (R30) illustrate the absorption features due to Cu^{2+}. The spectra were recorded with light vibrating parallel ($E\|c$), and then perpendicular ($E \perp c$), to the optic axis of the tourmaline. Typically, gem spectra are recorded on a U.V.–visible spectrophotometer with the stone in a random optical orientation, because it is often difficult or impossible to position a cut stone in the instrument precisely. This leads to the spectra one normally sees published (e.g., figure 13). However, spectral features are most accurately recorded from parallel polished pieces of known optical orientation and using a polarizing filter, as was done for the spectra reproduced here.

located at about 740 and 940 nm. The intensities of these broad bands depend on the direction of polarization, especially for the $E \perp c$ band (in contrast to the results reported by Bank et al., 1990). In an unpolarized spectrum, the two pairs of bands merge, and appear at about 695 and 920 nm (and for simplicity, are designated as such in the rest of this text). Also seen in the spectra in figure 14 are a series of sharp bands in the near infrared between 1400 and 1500 nm, which are visible in all tourmalines. These bands, strongly polarized in the $E\|c$ direction, arise from the first overtones of O-H stretching vibrations (Wickersheim and Buchanan, 1959 and 1968; Gebert and Zeman, 1965).

Figure 15 shows that the broad bands at about 695 and 920 nm in both polarization directions correlate in intensity with the copper concentrations determined in these same specimens by microprobe analysis. This is the first proof ever published that these absorption bands are actually caused by Cu^{2+}. In addition, this is the first documented evidence of Cu^{2+} acting as a coloring agent in tourmaline (for more details, see Rossman et al., 1990).

It is interesting to note, as a confirmation of the conclusion drawn above, that synthetic Na-Cu tourmaline spherulites hydrothermally grown by Taylor and Terrell (1967) also have a green to blue color. Very recently, Taran and Lebedev (1990) presented polarized absorption spectra of synthetic Na-Al tourmalines doped with copper; these spectra show the same absorption features (at approximately 695 nm and 920 nm) that we obtained on the natural tourmalines investigated here.

Figure 15. This graph shows the direct correlation in samples R30, R50, R52, R66, and R67 between copper concentration (obtained by microprobe analysis) and the intensity of the absorption bands between 690 and 940 in the near infrared that are due to Cu^{2+}. Intensity values were measured for the two broad bands that are present in the polarized spectra, in each polarization direction (see figure 14). Solid circles = 900-nm band; open circles = 690-nm band; solid triangles = 940-nm band; open triangles = 740-nm band. The fact that the groups of symbols for these four bands nearly fall along straight lines is proof that copper is the cause of these bands, and is a principal coloring agent of these Paraíba tourmalines.

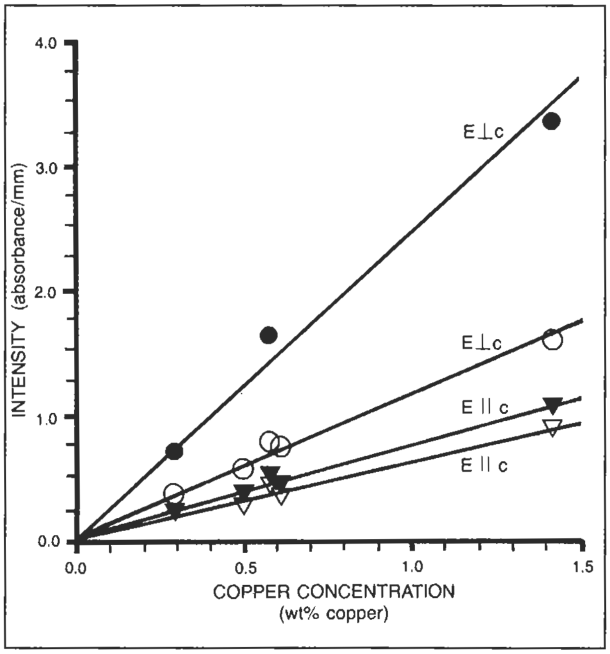

Figure 16. This 5.33-ct "emerald" green mixed-cut cabochon of Paraíba tourmaline (sample R376) is representative of one of the most attractive colors of this material. Photo by Robert Weldon.

The green color in Paraíba tourmalines is due to both an intense absorption edge toward the ultraviolet and strong Cu^{2+} absorptions, without any Mn^{3+} being present. An example of "emerald" green tourmaline from Paraíba is illustrated in figure 16.

None of the absorption features related to Cu^{2+} can be clearly identified with a hand-held spectroscope. Furthermore, classical gemological testing methods cannot be used to demonstrate that a tourmaline indeed contains copper.

HEAT TREATMENT

As mentioned above, some tourmalines from this mine have been heat treated. Identification of a heat-treated stone is confounded by the fact that some colors that occur naturally can also be produced by heat treatment. We subjected five polished sections and 12 rough crystal fragments of Paraíba tourmalines, representing the typical range of color found at this locality, to heat treatment to document the color-change behavior.

First, a sand bath was preheated to 600°C in order to burn out any water or impurities that might influence the results of the heating experiments. The samples were then buried in the sand at room temperature, and the temperature was raised to 550°C over a period of 2.5 hours. This temperature was held for four hours. The samples were then allowed to cool in the unpowered furnace at its natural cooling rate of approximately 50°C an hour. Our results are consistent with those previously published by G. Becker (as cited in Koivula and Kammerling, 1990a).

The most noticeable effect of this heat-treat-

Figure 17. These pairs of Paraíba tourmaline fragments show the effect of heat treatment on this material. Originally, both specimens in each pair were the same color (with the range of colors chosen to represent those typical of this locality); the lower specimens were subsequently heat treated to illustrate the color change produced. As described in the text, heat treatment results in blue to green for virtually all colors of starting material. Photo by Robert Weldon.

ment procedure was that all samples turned green or "turquoise" blue (figure 17). This can be related to the disappearance of the broad, Mn^{3+}-related band at about 515 nm (figure 18). Thus, bluish purple material becomes light blue with heating. During heat treatment, Mn^{3+}, which produces a pink coloration, is reduced to Mn^{2+}, which gives rise to no significant color. The sharp Mn^{2+} band at 415 nm appears during heating, but it is so weak that it is not visible in the spectra in figure 18. Such behavior is well known in rubellite tourmaline (see Reinitz and Rossman, 1988, and references therein).

Contrary to the report of Bank et al. (1990), we found that the Cu^{2+} absorptions were not changed by heat treatment. We conclude, therefore, that heat-treated Paraíba tourmalines exhibit colors attributed to Cu^{2+} and possibly to $Mn^{2+} \rightarrow Ti^{4+}$ and $Fe^{2+} \rightarrow Ti^{4+}$ charge transfer. These colors include "turquoise" blue and several shades of green. This also implies that colors having an Mn^{3+} component in their absorption spectra (violetish blue to purple to pink) are very unlikely to be the result of heat treatment.

Since the heat treatment of Paraíba tourmalines appears to be prevalent (Koivula and Kammerling, 1990a), it is worth noting that some of the colors produced by heat treatment also occur naturally, that is, in tourmalines that have not been heat treated. For example, some color-zoned tourmaline slices show green to blue areas colored by Cu^{2+} alone next to pinkish areas colored by Mn^{3+} (see figures 7 and 12). These slices could not have been heat treated; otherwise, they would have lost their pink coloration due to the reduction

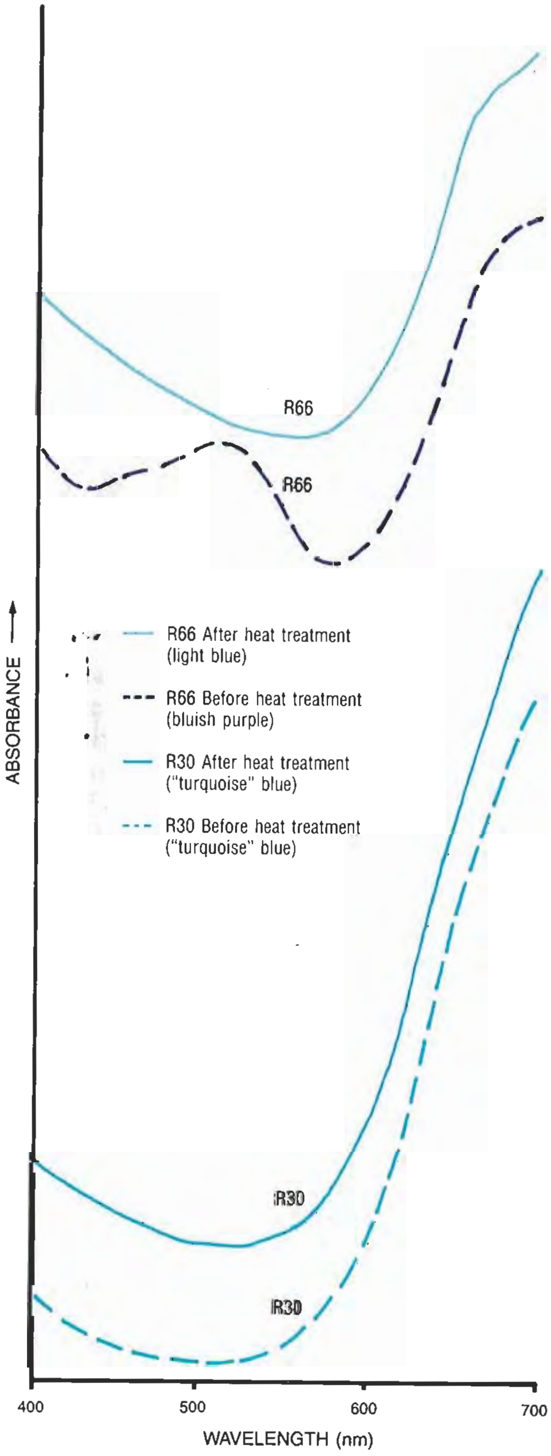

Figure 18. These visible-range absorption spectra were recorded for representative Paraíba tourmaline specimens R66 and R30 before and after heat treatment (at 550°C for four hours in an open atmosphere). Neither stone had been treated prior to coming into our possession (G. Becker, pers. comm., 1989). Heat treatment has not affected the Cu^{2+} absorption above 690 nm in either stone. Therefore, the blue-green ("turquoise") color of specimen R30, which is due to Cu^{2+} alone, remains unchanged after heating. In specimen R66, however, heat treatment has removed the broad band centered at about 515 nm because Mn^{3+} has been reduced to Mn^{2+} (which causes little or no light absorption). Consequently, the color of this material has changed from bluish purple to light blue.

of Mn^{3+} to Mn^{2+}. Thus, the "turquoise" blue areas in these color-zoned crystals, although colored by Cu^{2+} only, are not the result of heat treatment. The same could be said of the green needle in the dark blue slab illustrated in figure 10. To our knowledge, however, the "emerald" green color has been seen only in heat-treated tourmalines from Paraíba.

COMMENTS ON COLOR "BRIGHTNESS"

Such descriptive terms as *neon, fluorescent* (which is actually very misleading), and *electric* have been used in the trade to describe some of the blues and greens in which the Paraíba tourmalines occur. It has been speculated that the "brightness" that makes these tourmalines so desirable can be attributed to three principal factors (K. Hurwit, pers. comm., 1990): a more attractive hue, a lighter tone, and a higher saturation than those green-to-blue tourmalines from other localities that are commonly seen on the gem market. The first factor, the hue, is a judgment on which the trade seems to agree (see, for example, Federman, 1990). The second aspect – a lighter than average tone – is due to the fact that, for faceted stones in the common size range, only a small portion of the visible light going through the stone is actually absorbed, thus leading to a less-dark color as compared to common green to blue tourmalines which absorb more light for the same size range. The third factor – higher saturation than average – may be related to the nature of the absorption spectrum. Three situations can be distinguished. In the Paraíba tourmalines, copper produces a very abrupt increase in absorption around 600 nm in those stones with the highest copper concentration; that results in a "purer," more saturated color that is nonetheless light in tone (since only a small portion of the light passing through the stone is actually absorbed). The presence of the 515-nm band, due to a small amount of Mn^{3+}, reduces the saturation slightly in the "sapphire" blue and "tanzanite" violet stones. Finally, the presence of more intense Mn^{3+} features (the 515-nm band), only slightly less intense than the Cu^{2+} features, results in a very desaturated grayish appearance in some stones because there is nearly equal absorption across the entire visible spectrum.

CONCLUSION

Copper concentrations recorded for elbaite tourmalines from São José da Batalha (0.37–2.38 wt.% CuO) are so high that they are significantly above the range of copper content documented so far in natural elbaites (see Staatz et al., 1955; Dietrich, 1985; and analytical data gathered by the authors). Therefore, a copper content of more than 0.1 wt.% CuO can at this time be considered proof that the elbaite under investigation comes from this deposit.

This is the first time that Cu^{2+} has been shown to be a coloring agent in tourmaline. Alone, it causes a "turquoise" blue color. If $Mn^{2+} \rightarrow Ti^{4+}$ or $Fe^{2+} \rightarrow Ti^{4+}$ charge-transfer mechanisms are also present, the color shifts to various shades of green. Additional absorption by Mn^{3+} causes violetish, purplish, or pinkish hues to appear and reduces saturation.

During heat treatment, Mn^{3+} is reduced to Mn^{2+} (but Cu^{2+} is unaffected). Thus, the "rubellite" component of the color is removed, and heat-treated Paraíba tourmalines are green or "turquoise" blue.

We believe that the copper concentration found in the Paraíba tourmalines is among the highest reported in silicate minerals that do not contain copper as a major constituent (as compared to, e.g. chrysocolla or dioptase). This raises the question of why copper occurs in these gem-quality tourmalines, since this element is not often concentrated in silicate minerals.

Copper concentration in a granitic pegmatite environment is also quite unusual. In the absence of additional information on the mineralogy and chemistry of this pegmatite, one can hypothesize that tourmaline must have provided the most favorable crystallographic site for copper incorporation during crystallization of the pegmatite minerals.

Standard gemological testing alone cannot provide evidence of the presence of copper or the use of heat treatment in Paraíba tourmalines. However, advanced analytical techniques, such as ultraviolet-visible absorption or X-ray fluorescence spectroscopy, can help identify the presence of copper (and hence this locality of origin). U.V.–visible spectroscopy can also reveal the presence or absence of Mn^{3+} absorption bands to evaluate the likelihood of heat treatment.

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NOTES
· AND ·
NEW TECHNIQUES

HYDROTHERMALLY GROWN SYNTHETIC AQUAMARINE MANUFACTURED IN NOVOSIBIRSK, USSR

By Karl Schmetzer

Physical, chemical, spectroscopic, and microscopic characteristics of a sample of hydrothermally grown synthetic aquamarine from the USSR are presented. Physical and spectroscopic data are correlated with the chemical composition of the synthetic beryl to establish cause of color. Diagnostic criteria to separate natural from synthetic aquamarine are given, and the growth conditions of this synthetic blue beryl are discussed. This is the first description of synthetic aquamarine in the English gemological literature.

In the course of experimental investigations of Russian hydrothermally grown synthetic emeralds (e.g., Schmetzer, 1988), the author consulted with Dr. A. S. Lebedev, of the Institute of Geology and Geophysics, Siberian Branch of the USSR Academy of Sciences, Novosibirsk. Dr. Lebedev, who helped develop the hydrothermal synthesis of emeralds, gave the author several specimens of hydrothermally grown synthetic beryl doped with different transition metal oxides. For those synthetic beryl samples doped with cobalt, nickel, or copper, no natural counterparts are known. This is not the case, however, for the iron-bearing blue synthetic beryl that resembles the gem variety aquamarine.

Although iron-doped synthetic aquamarines have been described in the Russian literature (e.g., Klyakhin et al., 1981; Pugachev, 1984), the specimen received from Dr. Lebedev is the first synthetic aquamarine the author has seen. At present, there is no commercial production of synthetic aquamarine in the USSR, although such production is planned for several new gem materials (Dr. A. Rodionov, Novosibirsk, pers. comm., 1989). Since there is no technical obstacle to a commercial synthesis of aquamarine in the USSR, it is possible that this will be one of the materials released. Accordingly, this article provides what the author believes to be the first description of synthetic aquamarine available in the English gemological literature.

MATERIALS AND METHODS

The rough specimen of synthetic light blue beryl examined (figure 1) was a slice of a crystal that measured about 1 cm in diameter. One 0.29-ct rectangular faceted sample (figure 2) was cut from the crystal slice.

Refractive indices were obtained by a standard gemological refractometer, and specific gravity was determined hydrostatically. Unit-cell parameters were determined by X-ray powder diffraction using a Guinier camera and refined from 27 measured d-values. Microprobe analysis was per-

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All photomicrographs are by the author.

Gems & Gemology, *Vol. 26, No. 3, pp. 206–211*

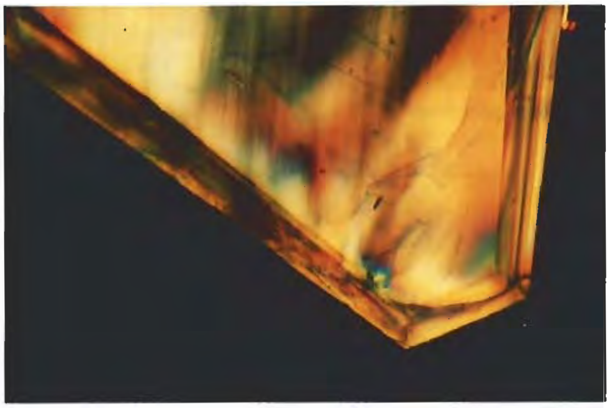

Figure 1. The rough synthetic aquamarine crystal from which this 1-cm-diameter slice was cut was hydrothermally grown at the Institute of Geology and Geophysics, Novosibirsk, USSR. A view parallel to the c-axis reveals the presence of three distorted prism faces m (1010). Crossed polarizers, magnified 30×.

formed on an ARL SEMQ instrument with an operating voltage of 20 kV and a beam current of 10 nA; values were calculated by the MAGIC IV correction program provided by the manufacturer. Spectral data in the U.V.–visible range were obtained with a Leitz-Unicam Model SP.800 spectrophotometer, and infrared spectra were obtained with a Perkin Elmer Model IR 180 infrared spectrometer. Photomicrography was performed on a Schneider immersion microscope with Zeiss optics.

VISUAL APPEARANCE

The sample revealed three highly distorted prism faces m $(10\bar{1}0)$, as well as one nearly planar surface that had been sawn parallel to the boundary of the synthetic aquamarine with the colorless beryl seed. This boundary is at a 32° angle with the c-axis of the synthetic beryl crystal. The light blue faceted piece has a pleochroism of medium intense blue parallel to the c-axis and light yellowish green perpendicular to the c-axis.

PHYSICAL, CHEMICAL, AND SPECTROSCOPIC PROPERTIES

Optical and Physical Properties. The specific gravity (measured as 2.69 and calculated as 2.694) and refractive indices (o = 1.583, e = 1.575, birefringence = 0.008) of the sample of synthetic light blue beryl examined are within the range known for natural aquamarines. The unit-cell dimensions of this particular synthetic aquamarine (a_0 = 9.224 Å, c_0 = 9.200 Å, c/a = 0.9974 Å) are identical, within the limits of experimental error, to those reported by Pugachev (1984).

Figure 2. A 0.29-ct stone (4.61 × 4.57 × 2.06 mm) was faceted from the synthetic aquamarine slice shown in figure 1. Photo by O. Medenbach, Bochum, Germany.

Chemical Analysis. A chemical analysis of the specimen was provided by the producer (table 1). These data are identical to those reported for the synthetic aquamarine described by Pugachev (1984) as sample No. 131 and suggested that the sample received from Novosibirsk was part of Pugachev's specimen No. 131; this was subsequently confirmed (A. S. Lebedev, pers. comm., 1989).

Microprobe analyses performed for this study confirmed the chemical properties submitted by the producer and reported by Pugachev (table 1), with one small but remarkable difference: The distinct amounts of nickel detected in this sample were not mentioned by Pugachev (1984).

It is worth noting here that the high Fe content of these synthetics is accompanied by low Mg and Na. By comparison, while these same elements can vary considerably in natural aquamarines, it is the author's experience that high Fe contents usually correlate with high Na and Mg in the natural stones.

Spectroscopy. Absorption spectra in both the visible and ultraviolet ranges revealed the presence of distinct absorption bands of iron and nickel (table 2, figure 3; cf. Schmetzer, 1988), which is consis-

TABLE 1. Chemical composition of a hydrothermally grown synthetic aquamarine from the USSR (in wt.%).

Oxide	This study (range of 5 microprobe analyses)[a]	As provided by manufacturer and published in Pugachev (1984)
Li_2O	NA	0.20
BeO	NA	13.24
Na_2O	<0.02	ND
Al_2O_3	16.90–17.35	16.96
SiO_2	64.42–65.35	64.76
Fe_2O_3[b]	2.67– 2.99	2.82
Ni_2O_3[b]	0.01– 0.02	ND
CuO	<0.01	ND
H_2O	NA	1.15

[a] *MgO, K_2O, CaO, and Cs_2O were found to be below detection limits (<0.02 wt%), as were MnO, V_2O_3, and Cr_2O_3 (<0.01 wt%). NA = not analyzed; ND = not determined.*

[b] *Total iron as Fe_2O_3 and total nickel as Ni_2O_3.*

TABLE 2. Spectroscopic features of a hydrothermally grown synthetic aquamarine from the USSR.

Absorption maxima		Polarization[a]	Assignment[b]
nm	cm^{-1}		
833	12,000	$\parallel c$	Fe^{2+}/oct.
820	12,200	$\perp c$	Fe^{2+}/tet.
752–599	13,300–16,700	$\parallel c$	$Fe^{2+/3+}$/oct.
606	16,500	$\parallel c$	Ni^{3+}/oct.
595	16,800	$\parallel c$	Ni^{3+}/oct.
455	22,000	$\perp c$	Ni^{3+}/oct.
426	23,500	$\parallel c > \perp c$	Fe^{3+}/oct.
413	24,200	$\perp c$	Ni^{3+}/oct.
370	27,000	$\perp c >> \parallel c$	Fe^{3+}/oct.

[a] *$\parallel c$ = parallel to c-axis, and $\perp c$ = perpendicular to c-axis.*

[b] *See Schmetzer 1988.*

tent with the chemical data (table 1). Infrared spectroscopy confirmed the presence of water molecules and lithium ions in channel sites of the beryl structure (figure 4) and, therefore, the hydrothermal origin of the sample (cf. Schmetzer, 1989). The infrared spectra revealed three absorption maxima, at 3694 cm^{-1} (designated band A, assigned to non-alkali-bonded water molecules) and at 3592 cm^{-1} and 3655 cm^{-1} (designated bands B and C, both assigned to alkali-bonded water molecules). The presence of lithium in channel sites is confirmed by the absence of distinct amounts of sodium (again, see table 1). In general, these spectra are typical of those that have been measured for natural aquamarines from various localities.

Figure 3. The U.V.–visible absorption spectrum of the sample of synthetic aquamarine reveals typical aquamarine absorption bands, caused by ferric and ferrous iron, on which a weak nickel spectrum is superimposed (not visible at scale illustrated).

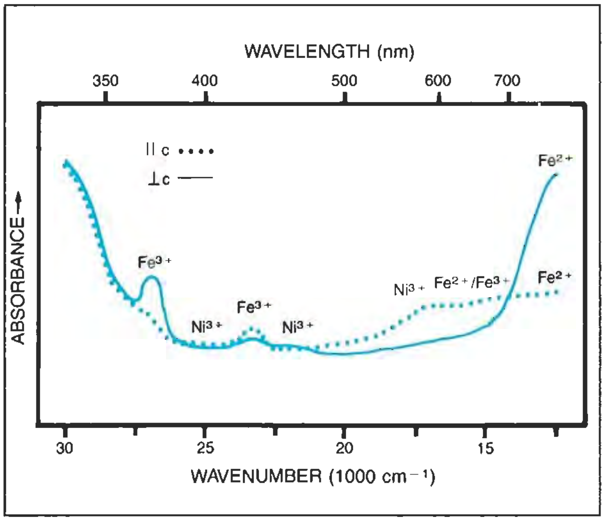

Figure 4. The infrared absorption spectrum of the sample of synthetic aquamarine reveals absorption bands of non-alkali-bonded (A) and alkali-bonded (B and C) water molecules, which prove the hydrothermal origin of the sample.

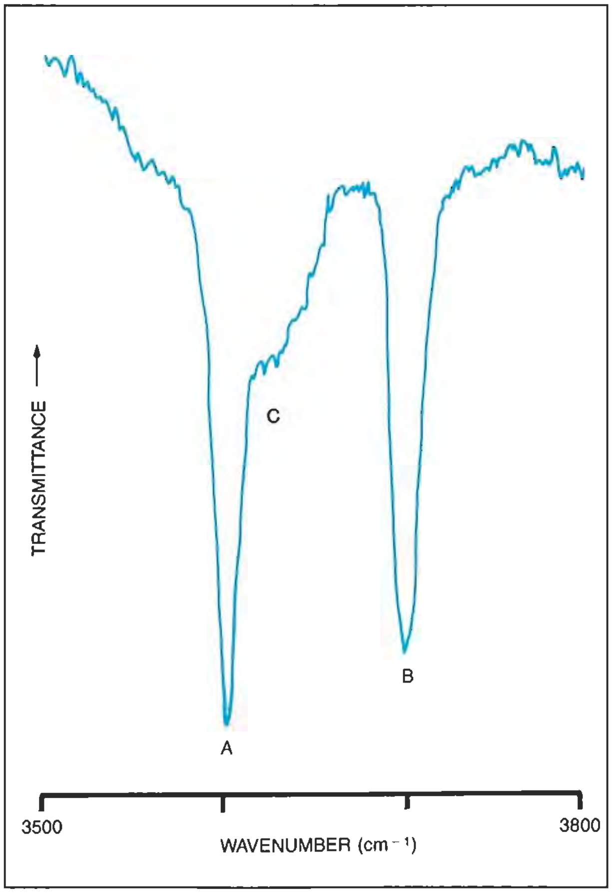

Figure 5. In the faceted sample of Russian hydrothermally grown synthetic aquamarine, "feathers" consisting of either liquid or two-phase inclusions are found in both the seed (above) as well as in the light blue portion (below). Immersion, magnified 40×.

Figure 6. Irregularly changing subgrain boundaries between subindividuals in Russian hydrothermally grown synthetic aquamarine are among the diagnostic characteristics of this material that can be used to distinguish it from natural aquamarine. Immersion, magnified 60×.

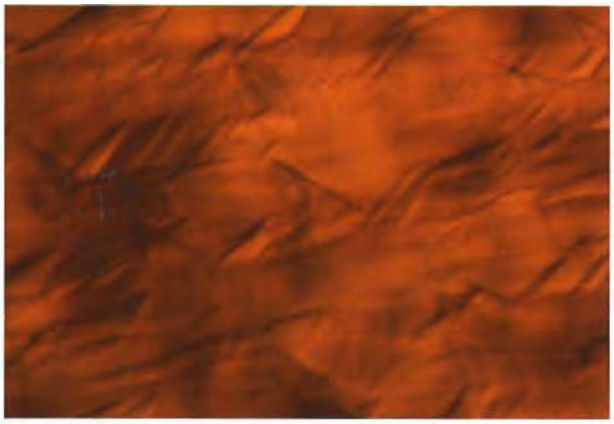

Figure 7. The cellular pattern of the subgrain boundaries described in figure 6 is similar to that described for synthetic emeralds that have been hydrothermally grown in the USSR. Immersion, magnified 60×.

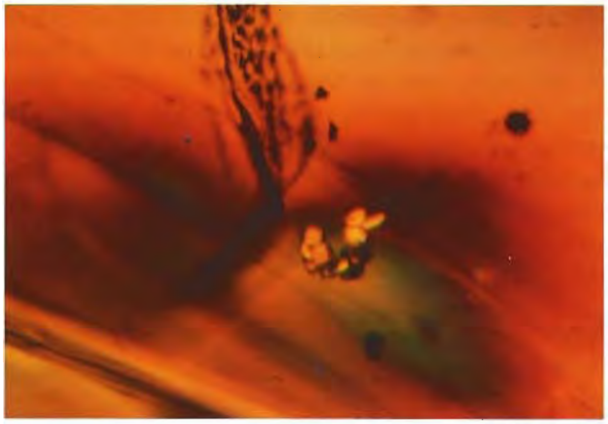

Figure 8. The sample hydrothermally grown synthetic aquamarine was also observed to contain groups of doubly refractive transparent inclusions as well as opaque hexagonal platelets. Immersion, crossed polarizers, magnified 100×.

MICROSCOPIC CHARACTERISTICS

Microscopic examination revealed a distinct boundary between the almost-colorless seed and the synthetic light blue beryl. The similarity in growth features and inclusions between the seed and the synthetic aquamarine grown from it suggested that the seed is also a synthetic hydrothermally grown beryl (figure 5). The fact that the seed/synthetic aquamarine boundary formed an angle of about 32° with the c-axis of the synthetic beryl indicates that the seed plate used had been sawn parallel to the face $(5\ 5\ \overline{10}\ 6)$. The same seed-plate orientation was observed for hydrothermal synthetic emerald grown in the USSR (Schmetzer, 1988).

In the immersion microscope, extremely weak growth zoning was observed in the synthetic aquamarine parallel to the boundary with the seed plate. Although this zoning is much weaker than the distinct growth and color zoning noted in synthetic Russian emerald from the USSR, in oblique orientation to this plane there can be observed subgrain boundaries between subindividuals (figure 6), as well as a typical cellular structure (figure 7) that has also been described for the hydrothermally grown synthetic emerald.

The synthetic aquamarine examined contained several groups of small, doubly refractive crystals as well as several hexagonal opaque platelets, possibly hematite (figure 8; cf. Schmetzer, 1988, and Klyakhin et al., 1981). Irregularly shaped cavities with multiphase fillings were also observed, as were two different types of "feathers": nearly planar "feathers" with liquid and two-phase fillings, and residues of the growth solution trapped in the form of twisted veil-like "feathers" (again, see figure 5).

DISCUSSION

Crystal Chemistry and Color. The iron absorption bands observed in the visible and ultraviolet spectra of this synthetic sample are typical of those seen in natural aquamarine. Three different types of iron are responsible for the blue coloration of aquamarine (for further details as well as for a summary of the literature, see Schmetzer, 1988). According to Solntsev et al. (1984, 1985), the synthetic-aquamarine spectrum described here reveals absorption bands of divalent and trivalent iron in octahedral aluminum sites as well as bands of divalent iron in tetrahedral beryllium sites (table 2). The blue color of the sample is due to a strong and broad absorption in the red and yellow areas, which is assigned to a charge-transfer transition between ferric and ferrous iron replacing aluminum in adjacent octahedral sites of the beryl structure.

In the synthetic specimen examined here, weak absorption bands of trivalent nickel (table 2, figure 3) were found superimposed on the normal aquamarine absorption spectrum. Because the nickel doublet in the spectrum parallel to the c-axis at 606 and 595 nm – i.e., in the yellow to orange range – is superimposed on the dominant color-causing Fe^{2+}/Fe^{3+} charge-transfer band, it intensifies the blue coloration. On the other hand, the nickel absorption band in the spectrum perpendicular to the c-axis at 455 nm – i.e., in the blue to bluish green range – is responsible for an absorption minimum in the green. Thus, the light blue coloration of nickel-free natural aquamarine is converted to a light yellowish green in the nickel-bearing synthetic specimen examined.

The presence of water and lithium in combination with the absence of sodium (table 1) indicated assignment of the absorption bands in the infrared between 3500 cm^{-1} and 3800 cm^{-1} to non-alkali-bonded and lithium-bonded water molecules in channel sites of the beryl lattice (Schmetzer, 1989). However, it is also generally accepted that part of the lithium replaces beryllium in tetrahedral sites. These basic crystal chemical considerations are confirmed by the unit-cell dimensions of the synthetic aquamarine, the c/a value of which is typical for "normal" beryl, in which both octahedral and tetrahedral substitutions occur to a limited extent (Aurisicchio et al., 1988).

GROWTH CONDITIONS OF SYNTHETIC AQUAMARINES

According to the Russian literature (Klyakhin et al., 1981; Pugachev, 1984; Solntsev et al., 1984, 1985), the synthetic aquamarine is grown in stainless steel autoclaves without noble metal inserts. The following growth conditions were published: temperature, 590°–610°C; temperature gradient, 70°–130°C; and pressure, 1000–1500 bars. Since nutrient oxides of beryllium, aluminum, and silicon are used, the high iron content (and the small amount of nickel, as has been confirmed by A. S. Lebedev, pers. comm., 1989) must derive from the walls of the steel autoclaves. As mentioned above, the seed used is probably a synthetic colorless beryl. The synthetic crystals grow at a rate of 0.32 mm per day.

To grow blue aquamarine rather than iron-bearing colorless beryl, the process must incorporate large amounts of divalent iron (Fe^{2+}) into octahedral sites of the lattice. This is accomplished by adding to the solution variable quantities of iron-carbonyl (to reduce oxygen partial pressures) and lithium salts (to provide the charge-compensating ion). According to the Russian literature cited, colorless iron-bearing beryl is grown at oxygen partial pressures above the hematite/magnetite equilibrium, and aquamarine is obtained in the wide field of magnetite stability below the hematite/magnetite line. The most intense coloration was obtained for beryl samples grown under oxygen partial pressures in the magnetite stability field close to the magnetite/iron equilibrium.

The aquamarine sample examined in the present paper reveals a light blue coloration. The identical specimen reported by Pugachev (1984) was grown at about 600°C under an oxygen partial pressure of $\lg P_{O_2} -25$ (Pugachev, 1984; figure 9).

The conditions used by Russian scientists to grow hydrothermal synthetic aquamarine are similar to those they have used to grow hydrothermal synthetic emerald (Schmetzer, 1988). It is likely that identical or almost identical steel autoclaves without precious metal inserts are used, as are similar pressures, temperatures, and temperature gradients. The same orientation of the seed plates is chosen for both. The most important differences are the absence of divalent iron in synthetic

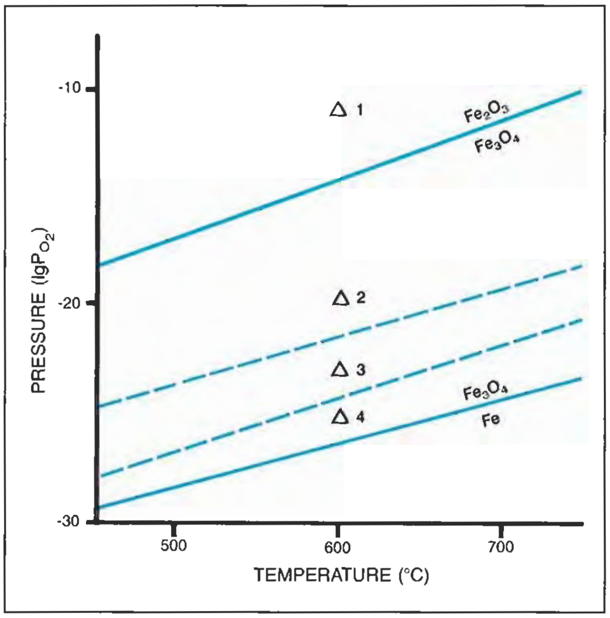

Figure 9. Synthetic iron-bearing beryl was grown at the four positions marked on this pressure-temperature diagram adopted from Pugachev (1984). The samples in group 1, grown under oxygen partial pressures above the hematite/magnetite (Fe_2O_3/Fe_2O_4) equilibrium line, are colorless. The samples in groups 2, 3, and 4, grown at decreasing oxygen partial pressures in the magnetite stability field, reveal increasing intensities of blue color. The specimen examined for this article probably belongs to group 3.

emerald, and the absence of chromium and of high amounts of copper and nickel in synthetic aquamarine. These differences would appear to be the result of the different oxides used as nutrients during growth as well as the different oxygen partial pressures.

DISTINCTION OF NATURAL FROM SYNTHETIC AQUAMARINE

The most characteristic features of this synthetic aquamarine are the growth structures, that is, the subgrain boundaries between cellular subindividuals (figures 6 and 7), which are caused by the orientation of the seed plate parallel to the crystal face $(5\ 5\ \overline{10}\ 6)$. Also readily visible with the microscope, when they are present, are residues of the seed plate (figure 5) and small opaque platelets (figure 8). Doubly refractive crystals (figure 8), cavities with multiphase fillings, and various types of planar and twisted feathers (figure 5) may also be conclusive in some cases.

The observation of nickel bands in the visible range of the absorption spectrum (figure 3) is another clue to the recognition of a blue beryl of unknown origin as synthetic aquamarine. Unfortunately, these features are too weak to be seen with a hand spectroscope. These traces of nickel are caused by the use of stainless steel autoclaves without precious metal inserts. Of course, if a different type of autoclave were to be used in future production, this criterion could be changed. If chemical data can be obtained, the absence of distinct amounts of sodium and magnesium in combination with a high iron content (table 1) also indicate that the material is synthetic aquamarine.

Specific gravity, refractive index, and the infrared spectrum of the hydrothermally grown synthetic aquamarine from the USSR are all within the ranges for natural aquamarines.

SUMMARY AND CONCLUSION

Synthetic aquamarine has been manufactured in the USSR for experimental purposes. No technical obstacles to the commercial growth of synthetic aquamarine are known. The growth technique is similar to that used to manufacture hydrothermal synthetic emeralds in the USSR. The color is the result of a charge-transfer process. The synthetic aquamarine examined showed several microscopic features that would serve to separate it from its natural counterpart.

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RECENT DISCOVERIES OF LARGE DIAMONDS IN TRINITY COUNTY, CALIFORNIA

By Rudolph W. Kopf, Cornelius S. Hurlbut, and John I. Koivula

Although California has produced over 600 diamonds, some of which have been of gem quality, the largest until recently weighed approximately 6 ct. In the early 1980s, however, Edgar J. Clark found a 3.90-ct stone; in 1987, he discovered three stones weighing 32.99, 17.83, and 14.33 ct. These four diamonds were recovered from stream gravels of Hayfork Creek in Trinity County, California. All four are of industrial grade and all have one interesting feature in common, that is, two generations of diamond growth. The initial crystal, or group of crystals, is encrusted by a later generation of diamond overgrowth that, although it conforms crystallographically to the underlying crystal, shows different crystal forms. This unusual feature, common to all four crystals, would indicate that they originated from the same source.

During the 1980s, Edgar J. Clark, a retired geologist and miner, recovered four large diamonds, three of record-breaking size, in northern California. According to Mr. Clark, all were found on Hayfork Creek, in the Trinity County portion of the Klamath Mountains. The first and smallest, found in the early 1980s, weighed 3.90 ct. Burton Westman, a consulting geologist in Boulder City, Nevada, examined the stone and confirmed its identity as diamond. Mr. Clark has since named the diamond "Jeopardy."

On January 4, 1987, while demonstrating the art of gold panning to a novice, Mr. Clark made his next find: a 14.33-ct diamond that, because of its accidental discovery, he named "Serendipity." Six months later, on June 12, he recovered a third diamond, of 32.99 ct. Over twice the size of Serendipity, this exciting stone was dubbed "Doubledipity." Most recently, in September 1987, Mr. Clark found yet a fourth large diamond, a 17.83-ct stone that he named "Enigma." None of the four diamonds is of gem quality, but all have similar external characteristics. The specific gravities of all four stones, as determined by hydrostatic weighing, lie within 3.510 ± 0.005, which is typical for diamond. The diamonds are presently on loan to the Mineralogical Museum at Harvard University.

This article reports on an examination of these four diamonds and their significance both historically and geologically, especially with regard to the information they provide on the original source of diamonds found in this area.

PREVIOUS DIAMOND DISCOVERIES IN CALIFORNIA

More than 600 diamonds have been found in California since the first was discovered near Placerville, El Dorado County, in 1848 (Kopf, 1989). Most of these are very small, less than 1 ct, and only a few, like the 0.24-ct octahedron shown in figure 1, are of gem quality. The most notable California diamonds are listed in table 1. Until Mr. Clark's discoveries in Trinity County, the largest diamond found in the state weighed approximately 6 ct.

An anonymous item published in the *Mining and Scientific Press* ("Diamonds in Trinity Co., Cal.," 1871) reveals, however, that Mr. Clark may not have been the first to discover a large diamond in Trinity County. The entry describes the finding by I. Woodbury of a "queer looking pebble" while mining in the Weaverville area of Trinity County in the late 1860s. The stone was described as "having a glazed metallic coating. The crust was broken off on one side . . . revealing the grain of the stone." Mr. Woodbury subsequently became con-

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ABOUT THE AUTHORS

Mr. Kopf is a consulting geologist in Grass Valley, California; Dr. Hurlbut is professor emeritus of mineralogy at Harvard University, Cambridge, Massachusetts; and Mr. Koivula is chief gemologist at the Gemological Institute of America, Santa Monica, California.

Acknowledgments: This study could not have been undertaken without the information kindly supplied by Edgar Clark and by his guidance in the field. Other residents of Trinity County, also of invaluable help, include Bertha Carlson and Mike MacDonald, who supplied information about personal finds, and James O'Donnell, who led a guided field trip. We are also indebted to Burton Westman of Boulder City, Nevada, for allowing us to study one of the diamonds.

Gems & Gemology, *Vol. 26, No. 3, pp. 212–219*

Figure 1. This 0.24-ct gem-quality diamond octahedron from Trinity County, California, was discovered as a by-product of gold panning in 1974. Photomicrograph by John I. Koivula.

vinced that the stone, described as "half an inch or more in diameter," was a diamond. At that size, and assuming it was a diamond, it probably weighed between 10 and 15 ct. Unfortunately, the stone was subsequently lost. The significance of this report, however, will become apparent from the following descriptions of Mr. Clark's discoveries.

THE FOUR LARGE TRINITY COUNTY DIAMONDS

The four large diamonds found by Mr. Clark in Trinity County are described below and summarized in table 2.

Jeopardy. The 3.90-ct diamond crystal that Mr. Clark first discovered measures 9.19 × 8.36 × 6.99 mm (figure 2). This diamond consists of two parts with different surface features. About two-thirds of the crystal is encrusted with a yellow-brown semitranslucent to nearly opaque overgrowth that is inert to U.V. radiation. The other portion is yellow, translucent, and fluoresces a dull yellow to long-wave U.V. but does not phosphoresce.

Two surfaces of the encrusted portion are essentially square and at right angles to each other, while a small third surface is at right angles to them. This leads one to suspect that the underlying faces are cubic. Measurements made on a two-circle goniometer indicate that this is indeed the case, since not only were reflections from the overgrowth parallel to underlying "cubic" surfaces but reflections from tiny octahedral and dodecahedral surfaces were as well. The reflections

TABLE 1. The four largest authenticated California diamonds reported in the literature prior to 1980 (listed in order of decreasing weight).

Weight given in reference	Weight (in metric carats)	Year found	Finder	Locality	Reference
6 ct	6 ±	1868	John Moore	Cherokee, Butte Co.	Hill, 1972, p. 43
0.53 grams	2.65	1934	Robert Echols	Near Plymouth, Amador Co.	Sperisen, 1938, p. 39; Woods, 1986, p. 186
7¼ grains[a]	2.3	1867 or earlier	Unknown	French Corral, Nevada Co.	Whitney (in Silliman, 1867, p. 355)
255 mg	1.28	1883	George Evans	Amador Co.	"Diamonds in California," 1959, pp. 26, 28; Hill, 1972, p. 41

[a] *Many reports published during the last century state that the largest California diamond was found in French Corral, Nevada County, and report its weight between 7 and 7.5 ct. In reality, the weight of the stone was originally reported by Whitney (in Silliman, 1867) as 7¼ grains. The weight of the stone was erroneously given by Kunz (1885, p. 730) as 7¼ ct, an error that has been perpetuated for over 100 years. This error was discovered by one of the authors (RWK) in 1988 during a search of the literature.*

TABLE 2. Comparison of large diamonds found by Edgar J. Clark in Trinity County, California. Listed in order of decreasing weight.

Name	Date of find	Weight (ct)	Measurements (mm)	Color	Surface
Doubledipity	June 1987	32.99	21.27 × 15.10 × 14.76	Moderate yellowish brown	Rough, encrusted
Enigma	September 1987	17.83	19.72 × 15.33 × 9.95	Grayish brown	Rough, encrusted
Serendipity	January 1987	14.33	16.25 × 12.64 × 10.60	Pale grayish olive green	Rough, encrusted
Jeopardy	1982 or 1983	3.90	9.19 × 8.36 × 6.99	Yellow-brown	Rough, partially encrusted

Figure 2. The 3.90-ct crystal subsequently named Jeopardy is the first of four large rough California diamonds discovered by Edgar Clark in Trinity County in the 1980s. Photo by Robert Weldon.

from a given crystal form were not from a well-defined face but were seen at the same angular position as many points of light from the irregular overgrowth.*

The portion of the stone with no overgrowth has no well-defined crystal faces, but reflections from small areas show that it and the overgrown portion have a parallel crystallographic orientation. At the junction of the two different-appearing parts, the overgrowth terminates with no indication of fracturing.

Serendipity. Mr. Clark's identification of this 14.33-ct pebble as a diamond was verified at the GIA Gem Trade Laboratory in Santa Monica. A brief description of the stone was given in Koivula (1987).

Serendipity is pale grayish olive green. It fluoresces a weak brown to long-wave U.V. radiation and a weak reddish brown to short-wave U.V. No phosphorescence was observed in either situation.

Macroscopically, this diamond is semitranslucent with an almost greasy adamantine luster (figure 3). At first glance, it appears to be composed of a number of irregular nodular masses with a rough surface and no obvious crystal form. On closer inspection, however, one can discern that the bulk of the specimen is composed of at least seven randomly intergrown cubes, the largest of which is about 5 mm on an edge. The rough surfaces and rounded edges and corners of the cubes are the result of an irregularly distributed overgrowth of diamond that tends to obscure the cubic form of the underlying diamond crystals. There is no direct means to measure the thickness of the overgrowth. However, since the cubic nature

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**The two-circle optical goniometer is an instrument used to measure crystal angles. A collimated light beam is reflected from successive faces as the crystal is turned. The reflections are observed through a telescope and the angles of reflection read from two graduated circles. The crystal form of the specimen can then be identified from the known angular positions of the faces. For the present study, the diamond specimens were mounted on the goniometer so that what appeared to be underlying cube faces were in positions to reflect the light beam. By rotating on both vertical and horizontal axes of the instrument, all faces (on the upper half of the crystal) were brought into positions to reflect. In these diamonds, the tiny faces of a given crystal form on the crystalline overgrowth all reflect simultaneously at angles consistent with those of single isometric crystals and conform crystallographically to the underlying cubes. Were the overgrowths polycrystalline aggregates, the reflections from the faces of the encrusting crystals would be random.*

Figure 3. With a weight of 14.33 ct, Serendipity is the third largest diamond found to date in the state of California. Photo by Robert Weldon.

of the primary crystals in this diamond is less evident than in the 3.90-ct stone, it is presumed that the overgrowth is thicker, and possibly as thick as 2 mm. When viewed in reflected light, the overgrowth gives reflections from a multitude of tiny, step-like crystal faces. Measurement on the two-circle goniometer showed that all faces of the overgrowth on a single "cube" have common angles of reflection, those of the octahedron.

Doubledipity. This diamond, the largest yet to be reported from California, is approximately 33 ct (32.99) and measures 21.27 × 15.10 × 14.76 mm (figure 4). It is a moderate yellowish brown but lacks the adamantine luster usually associated with diamond. It is opaque except on the edges, where it is translucent, and does not fluoresce to either long- or short-wave U.V. radiation.

Examination of the stone shows that it is composed essentially of seven interpenetrating cubes that are in random crystallographic orientation to one another. The bulk of the aggregate comprises three cubes of nearly equal size (10.0 to 10.6 mm on an edge). Four smaller cubes are about 5 mm on an edge. The cuboid surfaces are, with the exception of one small area, completely encrusted with an overgrowth of small diamond crystals. Because of the larger size of the primary crystals and, presumably, a thinner and more uniform secondary overgrowth, their cubic habit is more obvious than in the 14.33-ct stone (Serendipity). The corners and edges of the stone's surface are rounded by the overgrowth. When the diamond is examined in reflected light with both the microscope and the two-circle goniometer, there is no reflection from the faces of the cubes, but brilliant reflections do occur from their corners (the octahedron). Other reflections, as in the 14.33-ct stone, are not from single faces but are from a myriad of tiny surfaces of parallel octahedral faces. Thus, the secondary coating of this stone, too, consists of a parallel growth of octahedral crystals conforming crystallographically to the underlying cubes.

The encrusting overgrowth on one of the large cubes is locally absent and forms a depression, about 6 × 7 mm, where three nearly plane surfaces intersect at a common point. The angles between these intersecting planes, measured on a wax impression of the cavity, are 120°, the angles of the dodecahedron. From this we infer that a dodecahedral crystal, which had grown either before or contemporaneously with the diamond cubes, had separated from the cluster after the diamond became encrusted. Since the core of the diamond aggregate is composed of crystals with a cubic habit, the faced cavity probably resulted from the displacement of a different mineral with different crystal form, possibly a garnet. At the edges of this cavity, the encrustation can be observed to be approximately 0.5–1.0 mm thick.

In two areas (the larger about 2 × 3 mm) on the surface of Doubledipity, the encrusting diamond appears to be underlain by fractures that partially separate the crust from the main mass. The fact

Figure 4. At 32.99 ct, Doubledipity is the largest diamond yet recovered in California. Photo by Robert Weldon.

that these areas are yellow suggests that the entire aggregate may be yellow and appears brown because of its greater thickness.

Enigma. Mr. Clark's latest find is a 17.83-ct tabular stone that is roughly in the shape of an equilateral triangle. It is grayish brown and semitranslucent to opaque (figure 5). Microscopic black specks scattered throughout the specimen contribute to the grayish appearance. The broad surfaces are encrusted with a diamond overgrowth that is fine-grained and regular on one side. On the opposite side, a small area has a similar overgrowth made up primarily of overlapping hummocks rising about 4 mm above the essentially planar surface. Two of the bounding edges of the triangular stone are cleavage surfaces, which indicates that the stone was originally larger. When the stone was exposed to short-wave U.V. radiation, the cleavage surfaces fluoresced yellow, the encrustation brown; but to long-wave U.V., all parts of the stone fluoresced a brilliant yellow. There was no phosphorescence.

The triangular shape suggests that, before the overgrowth, the stone was an octahedron flattened on an octahedral face. The angular relationship of the relatively flat triangular surface to the octahedral cleavages supports this hypothesis. The surface of the overgrowth is a multitude of tiny crystal faces, many unidentified. But, assuming that the overgrowth conforms crystallographically to the underlying crystal, the strongest reflections are from the octahedron and the cube. The most impressive evidence that the two generations of diamond are in parallel position is that the cleavage surfaces pass uninterrupted through both the original crystal and the encrusting hummocks.

The cleavage surfaces are not single planes but are composed of a mosaic of small surfaces 0.5–3 mm^2, each of which is disoriented 1°–2° with respect to its neighbors. This shows that the original crystal, and probably the overgrowth as well, is made up of many small subparallel crystalline units. An unresolved problem presented by the two bounding cleavages is that they are at 60° to one another rather than at 90°, as they should be for a single crystal. This suggests that the stone is twinned with one cleavage belonging to each of the two individuals, but the overgrowth prevents location of the twin plane.

Figure 5. The 17.83-ct stone called Enigma is the most recent large diamond discovered in California. Photo by Robert Weldon.

SOURCE

Many early published reports of California diamonds note the presence of microscopic diamonds in black sand in the Trinity River. Inasmuch as the river flows through both Trinity and Humboldt Counties, it is not readily apparent which county or counties yielded these historic diamonds. Sperisen (1938, p. 40) reported that they were in the Trinity County portion, whereas Hanks (1870, p. 162) cited the lower Trinity River, considered by later compilers to have been in Trinity County, as the source. Originally part of Trinity County in 1850, however, the lower Trinity River region was reassigned to northern Humboldt when that county was created in 1853 (Beck and Haase, 1974, p. 62). Murdoch and Webb (1948, p. 131) describe the Trinity County (actually Humboldt County) diamonds as "many" and "minute," yet MacFall (1963, p. 94) cites Joseph Murdoch as the source of a report of a 2-ct diamond found near the junction of the Trinity and Klamath Rivers in Trinity County.

The four large stones found by Mr. Clark were recovered from auriferous sand and gravel on Hayfork Creek (figure 6), a tributary of the south fork of the Trinity River in Trinity County. Recently, a number of minute transparent stones have also been recovered from this area, specifically, from auriferous sand and gravel on Hayfork Creek (E. J. Clark and B. Carlson, pers. comms., 1987); on the east fork of the Trinity River at Helena (M. MacDonald, pers. comm., 1988); on Canyon Creek (E. J. Clark, pers. comm., 1987); and

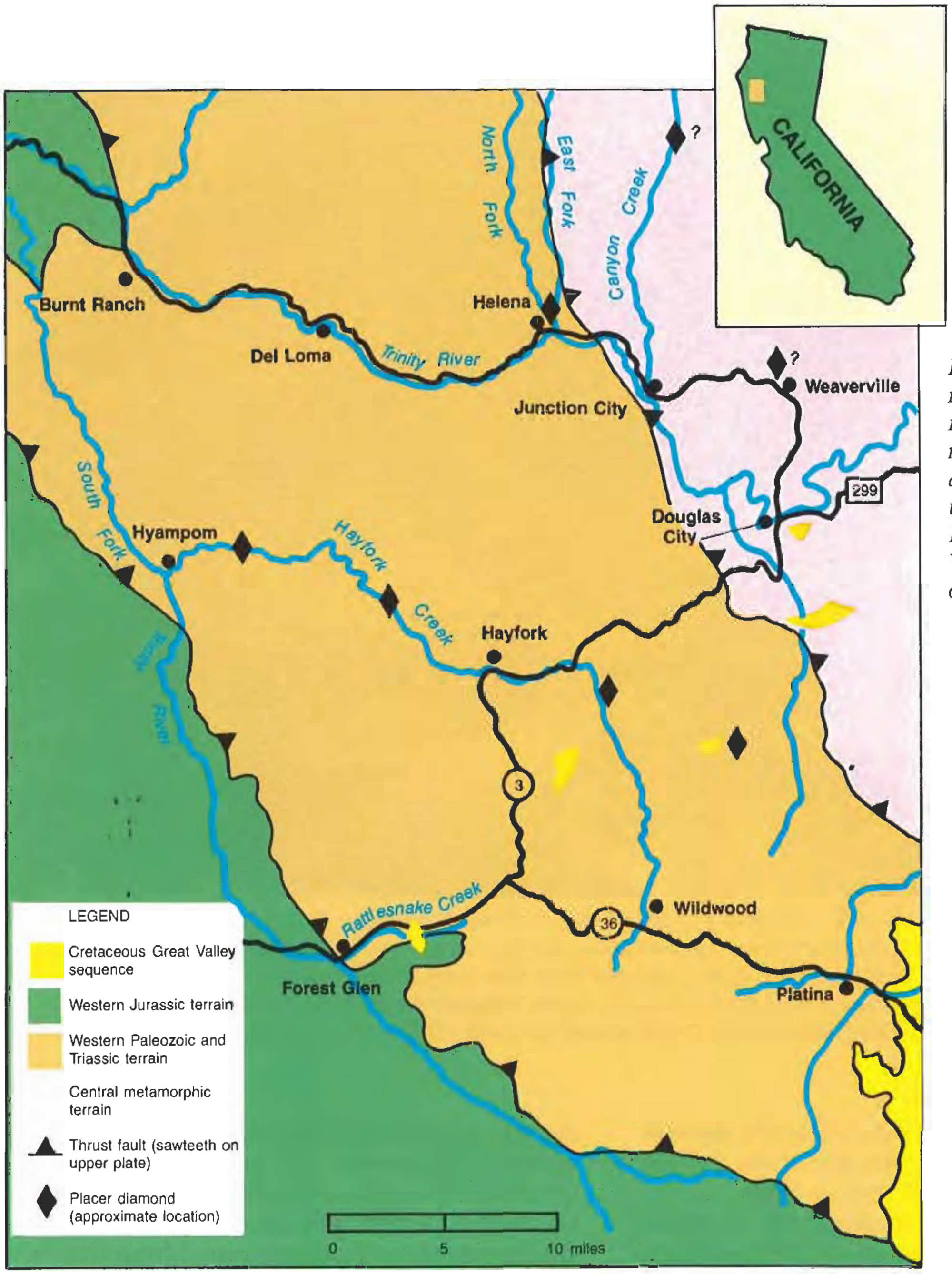

Figure 6. Four large diamonds have been found in Trinity County in northern California, along Hayfork Creek, a tributary of the Trinity River. Artwork by Carol Winkler; geology based on Irwin (1972).

on other tributaries of the Trinity River in Trinity County (figure 7).

Hayfork Creek has yielded not only the largest diamonds found in the western United States but also considerable quantities of coarse-grained platinum-group metals. In fact, it was the principal source of the nation's platinum production around the turn of the century (Day, 1898).

Hershey (1902) described five isolated erosional remnants of Early Cretaceous strata in the Hayfork-Weaverville area of Trinity County. These rocks have subsequently been designated part of the Great Valley sequence (Irwin, 1963, 1974, 1985; Jones and Irwin, 1971; and Irwin et al., 1974, 1985). The basal portion of these outliers is overlain by marine conglomerate rich in well-rounded and well-sorted quartz pebbles and contains placer gold (Hershey, 1902, p. 36). Interestingly, the diamonds found by Mr. Clark and Mr. MacDonald were recovered near or downstream from such Cretaceous erosional outliers. This suggests that the Cretaceous conglomerate is a secondary source

Figure 7. This is a downstream view of Hayfork Creek in Trinity County, northern California, a typical stream in the Klamath Mountains. Diamonds, including the four large stones described here, as well as gold, platinum, and chromite, have been recovered from this creek. The largest stream boulders are about 3 m across and consist mainly of Mesozoic mafic volcanic rocks. Here, the stream flows over the Triassic and Jurassic Rattlesnake Creek terrane of Irwin (1985). Photo by Rudolph W. Kopf.

of the placer diamonds in Trinity County. According to this interpretation, the age of the lode or lodes must be Early Cretaceous or older.

Another method of locating the diamond lode(s) is to determine the source of anomalous minerals associated with the placer diamonds. Gold appears to have been derived from gold-bearing quartz veins, and chromite and platinum-group minerals from podiform chromite deposits in the ultramafic portion of ophiolite complexes in the western Paleozoic and Triassic terrane (Irwin, 1972; Page et al., 1986). Mr. Clark (pers. comm., 1990) reports having recognized chrome diopside, rare crystals of highly rounded pyrope, and possibly perovskite from heavy mineral concentrates in placers in the drainage of the Trinity River in Trinity County.

This coarse-grained placer mineral assemblage appears to occur sporadically in an arc-shaped north-trending belt that extends from Trinity County northward into Josephine County, Oregon. On the basis of available data, diamonds in Trinity County appear to have originated from this belt, here termed the Klamath Mountains diamond belt, which seems to coincide largely with the western Paleozoic and Triassic terrane or subprovince of Irwin (1974) and Ando et al. (1983), although other more distant source rocks cannot yet be ruled out.

CONCLUSION

The four record-sized California diamonds described herein have an unusual feature in common, that is, a coarsely crystallized core encrusted with a fine-grained diamond overgrowth. In all of the cases, the overgrowth conforms crystallographically to the underlying crystal. This would indicate that the four diamonds underwent the same physicochemical changes during crystallization and thus came from a common source. Although diamond aggregates are common, aggregates of cubic diamond crystals with octahedral overgrowths such as the 14.33-ct (Serendipity) and 32.99-ct (Doubledipity) stones reported here may be unique to this locality. The account of Mr. Woodbury's 1860s find suggests that his stone was a similarly encrusted diamond and, further, that the larger diamonds of Trinity County are typically encrusted.

Gem and mineral prospectors in California and Oregon are encouraged to carefully examine their heavy mineral concentrates for diamonds. Moreover, those in Trinity County should watch for pale-colored, semitranslucent, rounded pebbles having a high luster and a rough surface. Such stones may also be diamond.

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Gem Trade LAB NOTES

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Dyed Natural BERYL

The trade has given much attention recently to the "oiling" of emeralds, that is, the filling of surface-reaching fractures with balsam oil, Opticon, or another substance to lessen their visibility. In most such procedures, the filling material is colorless.

The dyeing of green beryl is an ancient process whereby a green oil is introduced into the natural fractures to imitate emerald. From time to time, we see dyed green beryl or "emerald" melee lots in the laboratory, but only rarely do we see green dye in larger stones. Recently, however, the East Coast laboratory identified green dye in a fracture in an 8.38-ct natural "emerald" (figure 1). Figure 2 shows a patch of waxy green material (probably dop wax) left on the girdle of this relatively large "emerald." Both of these materials would artificially enhance the color of the stone.

Although we observed weak chromium lines in the Beck hand spectroscope and a weak red reaction to the color filter, we could not determine the true body color of the stone because of the artificial coloring agents present. Consequently, the stone could only be identified as dyed natural beryl. *DH*

Figure 1. Green dye is evident in this fracture in an 8.38-ct beryl. Magnified 12×.

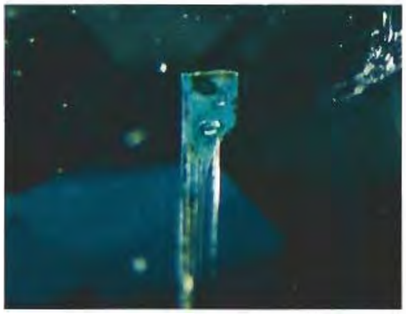
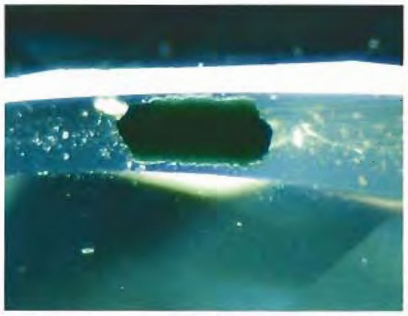


Figure 2. Green wax (probably dop wax) was also observed in a cavity on the girdle of the 8.38-ct beryl. Magnified 25×.



Carved CHRYSOBERYL

On occasion we see a well-known gem material used in an uncommon way. The West Coast laboratory recently saw a fine example of a carved horse's head made out of a piece of chrysoberyl (figure 3) that would have produced a cat's-eye if it had been cabochon cut. The carving measured approximately 20.3 × 28.7 × 6.2 mm and weighed 31.04 ct.

A spot reading of 1.75 on the refractometer and a strong 445-nm absorption band observed in the hand-held spectroscope confirmed the identity of the material. The stone was translucent to semitranslucent and an uneven yellow-brown (with some greenish component).

While no one area had a surface with enough curvature to display an eye, there was a strong sheen over the entire stone that gave rise to shimmering bands of light along the contours of the carving. According to our client, the piece was carved in Idar-Oberstein, Germany.

Shane F. McClure

DIAMOND

Electron Irradiated

Electron irradiation of diamonds ordinarily produces a blue or green color. When a 1.19-ct light bluish green round brilliant was recently submitted to the East Coast laboratory, it appeared to be a stone that could owe its color either to natural irradiation – that is, alpha or beta and attendant gamma rays – or to laboratory irradiation by neutrons. It is very often not possible to determine whether a green diamond has been artificially or naturally irradiated.

It is known, however, that electron irradiation of diamonds may produce characteristic zoning, such as around the culet or girdle edge, or along keel lines or facet junctions. In the case of this 1.19-ct light bluish green diamond, immersion in methylene io-

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Editor's Note: The initials at the end of each item identify the contributing editor who provided that item.

Gems & Gemology, Vol. 26, No. 3, pp. 220–227

Figure 3. The chrysoberyl from which this 31.04-ct carving was fashioned is chatoyant.

dide and examination over diffused illumination readily revealed the blue coloration around the culet (figure 4). The original body color of the diamond was probably a light yellow before treatment. The combination of the yellow body color and the blue treated zone produces the appearance of a bluish green diamond.

For further information, see "Contribution to the Identification of Treated Colored Diamonds: Diamonds with Peculiar Color-Zoned Pavilions," by E. Fritsch and J. Shigley, *Gems & Gemology,* Summer 1989, pp. 95–101.

Figure 4. The zone of blue color around the culet of this diamond, seen here immersed in methylene iodide, shows that this bluish green stone had been subjected to electron irradiation. Magnified 6×.

The penetration of electrons into the diamond and the resultant coloration is very shallow, only about 0.5 mm. If a diamond treated in this manner were to be recut, the thin surface layer might be removed, thus altering the color. *DH*

Fancy Black

A 4.26-ct fancy black round brilliant–cut diamond (figure 5) was examined in the East Coast laboratory and found to be natural color and electroconductive in certain areas. Ordinarily, such conductivity would indicate a rare type IIb diamond. Although gray diamonds are often IIb's, we have never encountered a type IIb black diamond.

Exposure of the stone to long-wave ultraviolet radiation produced a distinct patchy blue fluorescence (figure 6) that was confined to clear areas of the diamond. The fluorescence changed to a chalky greenish yellow with exposure to short-wave U.V. These reactions indicate that the stone must be a highly included type I diamond. We subsequently confirmed this conclusion with infrared spectroscopy.

We concur with Kenneth Scarratt, head of the Gem Testing Laboratory of Great Britain, who speculated in a letter to the editor of the *Journal of Gemmology* (April 1990, p. 120) that the conductive property of such diamonds is due to the black inclusions, which are probably graphite. *GRC*

Laser Drill Hole Anomaly

In the 20 years since the application of laser drilling to improve the clarity appearance of diamonds was first reported in this column (Fall 1970, p. 224), we have noted numerous variations in the use and appearance of laser drill holes. For instance, in one case obvious cleavages radiating out

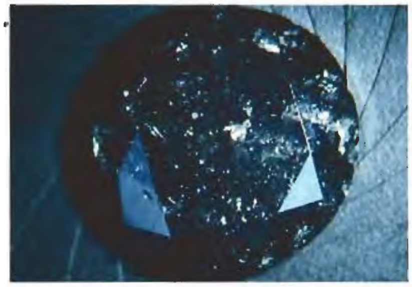
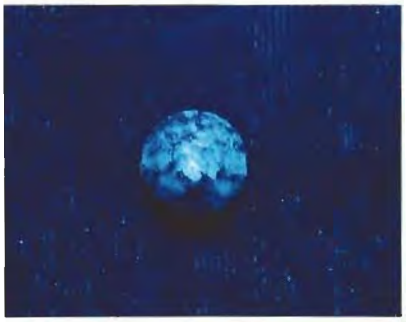


Figure 5. This 4.26-ct natural-color black diamond was found to be electrically conductive in selected areas. Magnified 10×.

Figure 6. The patchy blue fluorescence to long-wave U.V. radiation of the stone in figure 5 indicated that it was a highly included type I diamond.



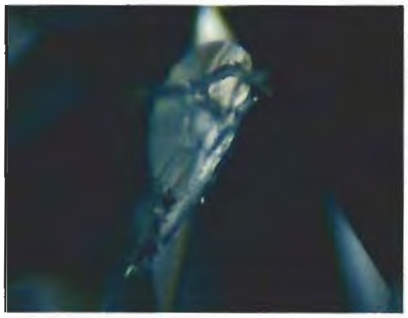


Figure 7. An unusual tubular channel pattern can be seen branching from the laser drill hole (here, slightly out of focus to the left of the inclusion) in this diamond. Magnified 63×.

from a long laser drill hole resulted in a poorer clarity appearance than expected (Fall 1976, p. 218). One laser hole reached two rather widely separated crystals, allowing them both to be bleached. We have also noted stones with natural tubular channels that individually resembled laser drill holes, but in aggregate appearance looked like branching "roots" within the stone (Spring 1973, p. 138; Winter 1973–74, p. 250; Fall 1979, p. 199).

Our latest observation of a laser drill hole anomaly is shown in figure 7. The diamond, a 1.55-ct pale green marquise, had natural brown irradiation stains on the girdle. The laser drill hole either has reached an internal cleavage or fracture and continued on erratically in several directions, causing a root-like pattern along the fracture, or has reached preexisting branching tubules that happen to have the same diameter as the drill hole. If the latter is the case, then the fracture may have originally been a black-appearing "light trap" that has been made white by laser drilling and bleaching. GRC

Laser Drilled to Reach an Included Diamond Crystal

Although we occasionally encounter diamond crystals as inclusions in a host diamond, the West Coast laboratory recently examined a 0.50-ct round brilliant-cut diamond that was both unusual and somewhat puzzling. A well-formed modified octahedral diamond crystal, measuring approximately 0.35 mm × 0.40 mm, was observed as an inclusion in this stone (figure 8).

Ordinarily, an included diamond crystal would have low relief and be barely discernable, since it has the same refractive index as its host. The unusually high relief exhibited by this diamond inclusion is probably due to a very minute separation, or interface, between the inclusion and the host. As light passing through the diamond goes from diamond to air at the point of the interface and then back to diamond, it "frames" the included crystal.

The most puzzling aspect of this stone, however, was the presence of a laser drill hole extending from the table down to the surface of the included diamond crystal. Laser drilling is used to remove or bleach dark inclusions from gem diamonds or to introduce a filling into fractures and cleavages that will make them less visible. It is not clear why it was attempted in this instance, because the included diamond crystal is impervious to the agents used to remove inclusions after laser drilling and thus could not be altered in size or appearance.

Mark Kazibutowski

OPAL, with an Unusual Inclusion

Recently, an unusual ring was brought to the West Coast laboratory for examination (figure 9). The ring contained a large (25.6 × 16.5 × 14.5 mm) Mexican opal that was quite transparent and had a nice play-of-color, displaying prominent flashes of green, orange, and red with lesser flashes of yellow and blue. The opal gave a spot refractive index reading of 1.43, and was inert to both long- and short-wave ultraviolet radiation. The hand-held spectroscope revealed a general absorption area up to approximately 440 nm, with a weak absorption band from approximately 500 to 540 nm. These properties are typical of many Mexican opals.

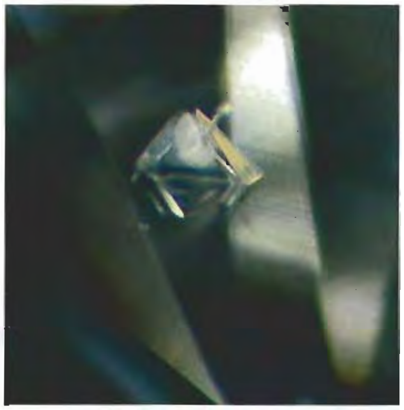


Figure 8. This diamond crystal included in a cut diamond shows unusually high relief. Note the laser drill hole extending from the surface of the faceted stone to the included crystal. Magnified 40×.

This opal is unusual because of the presence of a large (9 × 12.5 mm) centrally located egg-shaped inclusion that is best seen with transmitted light (figure 10). The inclusion was made up of an opaque white material that had a slightly "fuzzy" appearance at its surface. Because of the location of the inclusion in the middle of the stone, we could not perform any tests to determine its true identity. Although similar inclusions have been reported in opals before, it is rare to find such a large and dramatic example.

Christopher P. Smith

PEARLS

Cultured, with Colored Bead Nuclei

The laboratories on both coasts were given the opportunity to study a new type of bead nucleus used in pearl culturing in Japan. According to Yoshiko Doi, president of GIA's affiliate in Japan, AGTA, these beads are composed of powdered oyster shell that has been bonded with a type of cement and then dyed and fashioned

Figure 9. The 25.6 × 16.5 × 14.5 mm Mexican opal in this ring contains an unusually large oval inclusion, the outline of which is barely visible with reflected light.

Figure 10. When the stone in figure 9 is illuminated by transmitted light, the opaque, whitish inclusion is much more obvious.

into spheres. The sample beads we examined were dark grayish green and measured approximately 8 mm in diameter. An aggregate surface structure was observed with magnification. Transparent near-colorless and opaque white rounded grains were embedded in the dense green matrix material.

Specific gravity was determined by the hydrostatic method to be 2.74 ± 0.02. The refractive index was determined by the spot method to be on the low side of 1.50. The strong birefringence and the effervescence that occurred when a small droplet of a 10% hydrochloric acid solution was applied to the bead indicate that it is a carbonate material. When a cotton swab soaked with acetone was applied to the surface, a small amount of green dye was removed.

X-ray diffraction analysis showed that the material is calcite. An EDXRF chemical analysis performed by GIA's Dr. Emmanuel Fritsch revealed calcium plus titanium, cobalt, vanadium, and strontium, with smaller amounts of chromium and iron. Permission was granted to prepare a thin section from one of the beads. Dr. Ilene Reinitz, of GIA New York, obtained an infrared spectrum that showed distinct absorption peaks which were identified as calcite and the polymer or plastic that was used as the bonding agent in the material.

Subsequently, we received a few cultured pearls, averaging approximately 8.5 mm in diameter, that reportedly contained this new type of bead nucleus. Two of these pearls are shown in figure 11 with a section of a green bead nucleus. Magnification revealed that the nacreous layer was remarkably transparent. The drill hole of one of the pearls (figure 12) shows the thin nacre over a green bead nucleus, as well as some of the plastic bonding agent that melted from the heat of drilling. Because the nuclei were not freshwater shell, we did not expect these pearls to fluoresce to X-radiation and they did not. An X-radiograph showed a definite conchiolin layer, as well as the differences in the X-ray transparencies of the nucleus material and the nacreous layer.

KH, Ilene Reinitz, and Tom Moses

Freshwater Natural

The West Coast laboratory recently received for examination the interesting strand of freshwater natural pearls illustrated in figure 13. These pearls possessed a variable fair to very good luster and ranged in color from brownish to purplish pink, with a few being pinkish orange. They ranged in diameter from approximately 3.70 mm to 8.15 mm. Although some were slightly "off

Figure 11. These two cultured pearls, 8.5 mm in diameter, were reportedly grown using as nuclei green beads similar to that shown here.

Figure 12. The drill hole in one of the cultured pearls in figure 11 shows the thin nacre and the plastic binding agent which apparently melted from the heat of drilling. Magnified 15×.

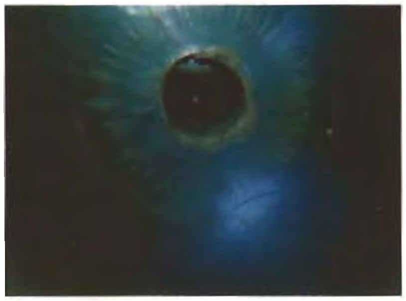


Figure 13. The natural freshwater pearls in this strand were found in the San Angelo area of West Texas over the course of 15 years. They range in diameter from approximately 3.70 to 8.15 mm.

round," most were spherical. They were identified as natural pearls on the basis of X-radiography performed by Robert Crowningshield, which revealed the very compact structure and extremely thin layers of conchiolin that are typical of some freshwater natural pearls.

Freshwater pearls generally show X-ray luminescence, caused by the presence of trace amounts of manganese. With this type of pearl, however, the staffs of both the East and West Coast laboratories have noted that the greater the intensity of the pink "body" color is, the weaker the fluorescence appears. The X-ray fluorescence reaction of the pearls in this strand, which ranged from inert to a weak slightly orangy yellow, supports this observation.

Our client reported that these pearls were recovered from lakes and rivers in the San Angelo area of West Texas. Over a period of 15 years, more than 30,000 pearls of variable quality were collected, ranging in diameter from 2 mm to 13 mm, with an average of 3.5 to 4 mm. Rarely are the pearls from this area spherical. Thus, it took nearly 15 years to accumulate the round pearls assembled in this strand. *RK*

Gray Baroque Cultured

Most of the natural-color gray to black cultured pearls from Polynesia that have been examined at the GIA Gem Trade Laboratory have been larger than Japanese pearls and have been round, oval, or ringed, but symmetrical in shape. Recently, however, we examined some attractive baroque Polynesian pearls (figure 14). An X-radiograph of this necklace (figure 15) shows that the nuclei vary from approximately 7.50 to 9.00 mm. The latter is larger than most Japanese mollusks can accommodate.

We were told by the client that baroques from Tahiti are more valuable than those from Japan. This prompted us to determine whether gray baroque cultured pearls from Japan were available and if they could be confused with natural-color gray cultured pearls from the South Seas. Figure 16 shows the result of our investigation. The nine baroques arranged in a square were loaned to us by a dealer in Japanese cultured pearls. The 10th pearl, shown by itself in the bottom row, is very similar in appearance and came from a parcel of Polynesian baroques. The X-radiograph (figure 17) shows that the Tahitian pearl has a very large nucleus (9.5 mm), contrasted with the 6.50 to 7.00 mm nuclei in the Japanese products. The X-radiograph also suggests that the gray color of the Japanese pearls is probably due to the appearance of the dark conchiolin through the nacre, the fragility of which may explain the dealer's remark about relative values. *GRC*

SAPPHIRE

Diffusion-Treated Montana Rough

During the last several months, the East Coast laboratory has heard rumors about heat-treatable sapphires from Montana being offered for sale. We were shown several lots of reportedly heatable pale greenish rough reputedly from mines along the Missouri River. Currently, lab staff members are conducting investigations both here and in Thailand to determine what type of Montana rough will respond to heat treatment.

One dealer contacted us after he was offered several hundred carats of

Figure 14. Tahiti has produced some fine gray baroque cultured pearls as well as rounds. The Tahitian pearls in this necklace are approximately 11.5 to 14 mm in diameter.

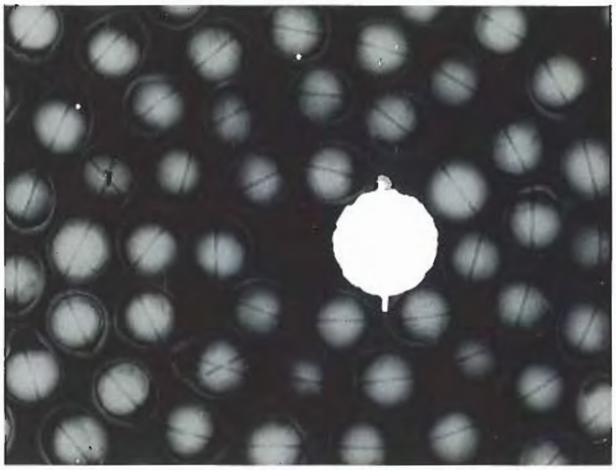


Figure 15. An X-radiograph of the necklace in figure 14 shows that the nuclei range from 7.5 to 9 mm in diameter.

Montana rough by a supplier who claimed the stones could be heated to improve the color. The dealer showed us several blue rough specimens that he was told were examples of this material after heat treatment. The seven palest of the 10 crystals were clearly heat treated, but the color was splotchy. The three most attractive darker blue stones had areas of dark blue color bleeding from included crystals, a characteristic of heat-treated stones, but closer examination revealed that there was also clear evidence of surface diffusion treatment (see, e.g., Kane et al., "The Identification of Blue Diffusion-Treated Sapphires," *Gems & Gemology,* Summer 1990, pp. 115–133).

Figure 18 shows a 2.73-ct rough specimen with lighter areas in the center and the ends that were not affected by the diffusion process. When the crystal was immersed in methylene iodide, we readily determined that the color was the result of a surface diffusion treatment. Clearly, use of such material to influence a potential investor is dishonest, since the layer of diffused color would be removed when the rough was faceted. *DH and GRC*

Large Colorless

Although colorless sapphires are not extremely rare, large ones are seen only infrequently. A 63.65-ct colorless emerald-cut sapphire (figure 19), the largest yet encountered by our laboratory, was recently submitted to the West Coast laboratory for an identification report. Our client stated that he purchased this stone nearly 40 years ago and that it reportedly was found in Sri Lanka.

Refractive indices of 1.760–1.768 were as expected for this material. Using polarized light and a glass sphere as a condensing lens, we observed the uniaxial optic figure through the table in a direction nearly perpendicular to it. A very weak 450-nm absorption band was resolved with a hand-held type spectroscope, indicating the presence of at least some iron.

Some of the gemological properties are consistent with those reported in the literature for Sri Lankan sapphires. Specifically, a strong yellow-

Figure 16. The nine cultured baroque pearls in the square are from Japan, while the single cultured baroque at the bottom is from Polynesia (11.5 to 14 mm). All are similar in appearance.

Figure 17. An X-radiograph of the cultured pearls in figure 16 reveals both the larger nucleus (approximately 9.5 mm in diameter) of the Polynesian sample at the bottom and the large areas of dark conchiolin in the Japanese samples.

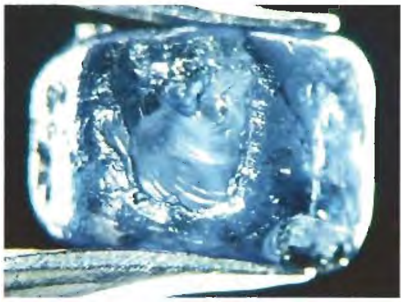


Figure 18. Immersion in methylene iodide revealed areas of diffusion treatment in this approximately 6.89 × 6.07 × 4.90 mm piece of sapphire rough from Montana. The thin layer of blue color would undoubtedly be removed during cutting.

ish orange fluorescence was observed when the stone was exposed to long-wave U.V. radiation. The same color fluorescence, but of very weak intensity, was seen with short-wave U.V. No colored transmission luminescence was seen. In addition, a dozen or more crystals with white-appearing strain halos were apparent with the unaided eye under the step facets at one end.

Magnification revealed that most of these inclusions appeared to be small to large opaque black uraninite crystals with characteristic tension halos. As is generally observed with this type of inclusion, when the gemstone is tilted to allow the background to become bright, the small tension fractures take on a distinct brown appearance. A number of straight and irregular, randomly oriented, "stringers" of minute white particles were also visible throughout the stone, as were several randomly oriented flat "flakes" and short needles. Although they were subtle in appearance, these features were easily seen with darkfield illumination in the gemological microscope. *RK*

Figure 19. This unusually large, 63.65-ct, colorless natural sapphire is reportedly from Sri Lanka.

Cobalt Colored Color-Change SPINEL

The West Coast laboratory had an opportunity to examine a cobalt spinel that exhibited a very unusual change of color: a dark, richly saturated, slightly violetish blue in fluorescent light, and a dark purple in incandescent light (figure 20). The color change was nicely enhanced by the contemporary design of the bicolored white and yellow metal man's ring in which the stone was set.

Figure 20. The 2.24-ct cobalt-colored spinel in this ring appears blue in fluorescent light and, as seen here, purple in incandescent light.

We found the stone's properties to be consistent with natural cobalt-blue spinels the lab has examined in the past (which reportedly originate in Sri Lanka; see *Gems & Gemology*, Summer 1986). A single refractive index reading at 1.720 was obtained using a Duplex II refractometer. Examination with the polariscope showed a singly refractive reaction, with very slight ADR. The stone exhibited a weak red transmission and a moderate red color when viewed through a Chelsea filter. The diagnostic absorption band of a natural cobalt spinel was present at 460 nm in the hand-held spectroscope, as were the other bands at approximately 480, 552, 559, 575, and 622 nm, with a broad general absorption from 660 nm up. (For more information on cobalt-blue spinels, see J. Shigley and C. Stockton, " 'Cobalt-Blue' Gem Spinels," *Gems & Gemology*, Spring 1984, pp. 34–41).

With magnification, under one end of the crown we observed a cluster of moderate-size inclusions that consisted of a well-formed octahedral crystal and several whitish irregularly shaped crystals. Radiating from this crystal group and throughout the stone were rain-like pinpoint "stringers" and numerous small fine needles. *Patricia Maddison*

SYNTHETICS and SIMULANTS in Period Jewelry

One of our Austrian readers, Karl H. Heldwein of Vienna, saw the earring mentioned under this heading in the Summer 1990 issue of *Gems & Gemology* and was kind enough to send a letter with his comments on similar items seen in his country. He states, "We in Vienna, Austria, frequently run into pieces like that. The stamp is the current Russian hallmark which, to my knowledge, has been used since the mid-1950s." He enclosed a photo of an item very similar to figure 16 in the Summer 1990 issue. However, it had a blue cabochon for the center stone instead of a faceted piece. In his letter, he says that the cabochon was glass and the near-colorless brilliant-cut diamonds were VS to I_1 in clarity. The piece would obviously have to be considered a reproduction.

Charles C. Cage, of New Orleans, Louisiana, sent us a very comprehensive review of Russian hallmarking in the 19th and 20th centuries. He confirmed that the "hammer and sickle" mark is the current one used in Russia, and that it has been in use since 1958.

We thank Messrs. Heldwein and Cage for sharing this information with us. Comments from our readers are always welcome. *CF*

FIGURE CREDITS

Photos in figures 1–2, 5–6, 14, 16, and 17 are by Nicholas DelRe. Shane F. McClure took the photographs in figures 3, 9, 10, 13, and 19. Holly Baxter provided the photo in figure 8. Vinnie Cracco is responsible for figure 7. The photomicrograph in figure 4 is by John I. Koivula. Robert Crowningshield did the X-radiography in figure 15. Robert Weldon shot the photos in figures 11, 12, and 20. Dave Hargett furnished figure 18.

A HISTORICAL NOTE

Highlights from the Gem Trade Lab 25, 15, and five years ago

FALL 1965

The New York laboratory described and illustrated a 10+-ct Montana sapphire crystal, the largest yet encountered. Also discussed were abalone pearls, the danger of leaving cultured pearls in jewelry cleaner, and the confusion arising from calling maw-sit-sit jade albite, rather than chrome albite. X-ray diffraction analysis established that this material actually contains ureyite, now renamed kosmochlor, rather than jadeite.

FALL 1975

The Los Angeles lab had the opportunity to examine a very unusual cyclotron-treated diamond. The fact that this stone was treated from one side of the girdle, rather than from the culet or the table as is usually done, made it unique in our experience. In this stone, the color zoning associated with cyclotron treatment was apparent only on the side of the keel line and that side of the girdle that was treated. In addition, the lab identified as marble a ceremonial sword that showed, under 50× magnification, some tiny fossil foraminifera.

Several imitations and simulants were seen in the New York lab, including coated garnet to imitate cuprite, prosopite to imitate turquoise, coated green beryl to simulate emerald, and a parcel of Thai-cut synthetic rubies that to the inexperienced eye were very natural looking. These proved to be flux-grown stones, many with the bluish bands usually associated with Chatham synthetic rubies.

FALL 1985

Our East Coast lab had occasion to examine a star stone that was in fact a flux-grown synthetic sapphire. The star was surface induced by diffusion treatment. A hydrothermally grown synthetic emerald, heavily included with spicules, was also illustrated.

Unusual items encountered in the West Coast lab were an 11.73-ct gambling die that was cut from an industrial-quality diamond, a black star sapphire doublet, and a carved material that somewhat resembled jade (see figure). X-ray diffraction analysis revealed that the carving was a rock consisting of plagioclase feldspar and green muscovite mica.

GEM NEWS

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

DIAMONDS

Diamond prospects in Brazil. Current monetary restrictions in Brazil have led some Brazilian mining concerns to solicit foreign investment. In the diamond sector, the engineering and mining group Odebrecht is hoping to dispose of five current prospecting permits and a government-issued "permission" to open four prospecting pits at its Cipolândia alluvial diamond property in Mato Grosso do Sul. This deposit extends for 15 km along the Taboco River, some 90 km from Campo Grande. It contains a high proportion of gem-quality stones, with reserves estimated to be in the range of 150,000 to 500,000 ct.

In 1989, Brazil produced approximately 500,000 ct of diamonds; according to the Departamento Nacional da Produção Mineral, 70% are of gem quality. As much as 84% of the total production was from the activities of independent miners, or *garimpeiros*. (*Mining Journal,* June 15, 1990)

New venture in Botswana. Molopo Australia has reported collecting several kilograms of diamondiferous ore from a 950-km^2 concession adjacent to the Jwaneng mine. This concession contains six of the nine kimberlite pipes identified to date in the Jwaneng field; two of these six have already been developed by Debswana and accounted for 55% of the country's 15.3-million-ct total output in 1990. Molopo currently holds over 9,000 km^2 under 11 licenses. (*Mining Journal,* June 15, 1990)

New Sierra Leone mining policy. The Sierra Leone government has instituted new policies that affect diamond-mining operations in that West African nation. Under the new regulations, designed to curb the smuggling of foreign currency, 60% of foreign exchange earnings must be turned over to the government. Also, diamond exporters must now make an advance payment of US$500,000, in addition to the US$10,000 annual license fee, and pay 2% of the value of exports to cover administrative costs plus an annual royalty of 3% of the value of goods exported. (*Mining Magazine,* June 1990)

Australian firm prospecting in China. Ashton Mining Ltd., the Australian operator of the Argyle mine, has signed an agreement with the Chinese government for the exploration rights to a 100,000-km^2 area in northern Hunan Province. Several potential primary deposits they have identified will be explored this year. The agreement also gives Ashton exclusive rights to the cutting and marketing of the diamonds. In addition, the firm has signed a letter of intent with the Guizhou Bureau of Geology for exploratory work in a 60,000-km^2 area in the northeast of that province. The bureau has already identified lamproite pipes that grade as high as 20 ct per 100 tons of ore in that region. (*Diamond Intelligence Briefs,* July 2, 1990)

Goa, India, seeking diamond merchants. . . The government of Goa, formerly a Portuguese enclave and now an Indian state south of Bombay, is attempting to attract diamond merchants to establish operations there. The state's deputy chief minister has announced plans to build a 100-acre jewelry park in an area of northern Goa where a number of five-star hotels are also planned. The Economic Development Corporation of Goa, Daman & Diu Ltd. reportedly is offering a number of tax incentives to help attract new industrial units. (*Diamond Intelligence Briefs,* June 8, 1990)

. . . But overall, prospects in India worsen. Burdened with approximately six to seven months' worth of unsold stock, the Indian diamond industry has been laying off workers. About 30% of the factories at Navsari are reported idle, as are about 10% to 15% of the cutting units in Palanpur, Vishnagar, Bhavnagar, and Amreli. Factory owners predict that the situation will worsen, since they are not getting enough work from exporting firms. (*Diamond Intelligence Briefs,* June 8, 1990)

Diamond prospecting in India. The Geological Survey of India has reported progress at diamond pipe no. 7 in the Wajrakarur area, Anantapur District, Andhra Pradesh State. According to the Survey, 1,903 diamonds (total weight 345.11 ct) have been recovered from 790 tons of overburden, and 287 diamonds (total weight 35.47 ct) have been taken from 314 tons of kimberlite. Sixty percent of the stones are reportedly of gem quality, with an average weight of 0.17 ct. A 16.3-ct gem-quality stone was recovered from the colluvial material. (*Diamond World,* May–June 1990)

Revised figures for Kalimantan. The Indonesian Diamond Corp. (formerly Acorn Securities Ltd.) has issued revised development proposals and figures for diamond-gravel reserves at their Kalimantan (Borneo) operation. The program is based on combined proven (2.94 million m^3), probable (15.32 million m^3), and possible (29.79 million m^3) gravel reserves, with proven/probable diamond production for the first five years of operation estimated at more than 550,000 ct. Capital costs are anticipated to be US$23.6 million, while operating costs are projected at US$5.5 per cubic meter of pay gravel mined, or US$60 per carat of diamond recovered. The firm plans to market its diamonds, mostly sawable goods in the 0.3–1 ct range, directly through Antwerp dealers rather than through the CSO. (*Mining Magazine,* June 1990; *Diamond Intelligence Briefs,* June 8, 1990)

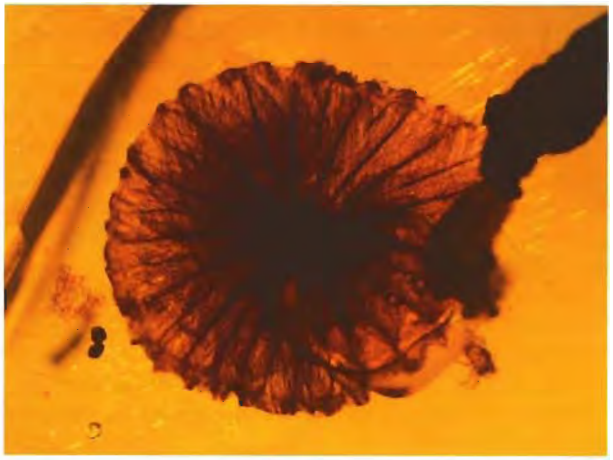
Sri Lanka attracting diamond industry investment. The Greater Colombo Economic Commission (GCEC) has identified the Sri Lankan diamond industry as an industrial sector for attracting new investments. To this end, they have drawn up of plans for establishing a diamond guild and an exclusive diamond zone near the airport.

Recently, a GCEC delegation visited firms in Antwerp and obtained sponsorship for a diamond-cutting project from two Belgian firms. When maximum capacity is reached, this project is expected to employ 235 workers. (*Mining Magazine,* June 1990)

Thailand auctions smuggled diamonds. The Thai Customs Department recently auctioned 2,236 diamonds, with a total weight of 403.51 ct, that had been confiscated over the last two years from smugglers bringing them in from Belgium. Approximately 30% of the proceeds from the sale went to informers. (*Diamond Intelligence Briefs,* June 8, 1990)

New diamond discovery in USSR. According to *Radio Moscow,* a new, major diamond deposit has been discovered approximately 100 km from Arkhangel'sk in the far north of the Russian Federation. The diamonds reportedly are of very high quality, with about 50% described as "suitable for use in the jewelry industry." Western involvement through a joint venture has been proposed for the development of the deposit as well as possibly for the processing of the stones. (*Mining Journal,* June 22, 1990)

Figure 1. The delicate gills are clearly evident in the ventral view of this 40-million-year-old mushroom encased in amber from the Dominican Republic. Photo courtesy of Dr. George O. Poinar, Jr., University of California at Berkeley.



Soviet delegation visits Israel. This past May, a delegation representing the Soviet diamond industry paid its first visit to Israel. Included among the Soviets were high-level executives of Almazjuvellirexport, the marketing arm for polished diamonds in the USSR; Kristal, that country's largest diamond-cutting plant; and the Department of Precious Metals and Diamonds, which was formed only recently—as a result of the Soviet Union's economic restructuring—to bring into one department segments of the diamond industry that had previously been under separate ministries. According to one of the Soviet officials, technical developments in diamond processing in Israel seem to be paralleling those in the Soviet Union. (*Israel Diamonds,* April–May 1990)

Eastern Europe opens to diamond cutters. The dramatic changes in Eastern Europe are apparently leading to positive developments for the diamond industry in that part of the world. Recent reports indicate that two Israeli diamond manufacturers were opening a plant in Warsaw, Poland. Initially the plant, which will specialize in baguettes and tapered baguettes, will employ 25 workers.

Another plant is being set up in Bucharest, Romania, by a partnership between a Romanian and an Israeli firm. The facility will initially employ 60 workers and will cut small rounds. (*Diamond Intelligence Briefs,* July 2, 1990)

Diamond rush in Australia. Diamond exploration is booming in Australia, with over 90 companies now involved in the search. Among the areas being prospected are Kununurra, North Pilbara, Halls Creek, Norseman, Geraldton, Nullagine, and Philips Range in Western Australia; Regional in the Northern Territory; Armidale, Sofala, and Copeton in New South Wales; Roxby Downs and Quorn in South Australia; Wooragee in Victoria; and Camooweal in Queensland. Twenty-three other projects are under way to locate diamonds off Australia's coastline. (*Diamond Intelligence Briefs,* June 8, 1990. The listing of locations is abstracted from a table compiled by Min-Met Information Services that was included in the referenced report.)

COLORED STONES

Ancient mushroom inclusion in amber. The University of California at Berkeley has announced the discovery of the oldest and best-preserved mushroom ever found, which was identified in a 40-million-year-old amber specimen (figure 1) by Dr. George O. Poinar, Jr. The amber came from a commercial mine in the northern mountains of the Dominican Republic. The mushroom, identified by botanist Rolf Singer of the Field Museum of Natural History in Chicago, represents a previously unknown genus and has been named *Coprinites dominicana.* It is the only known fossil mushroom from the tropics. According to Dr. Poinar, "the mushroom points out how amber can preserve very delicate organisms, and gives us hope for discovering a great deal more from that time."

Greenish blue cat's-eye apatite. In the Summer 1990 Gem News column, we reported seeing quantities of greenish blue apatite from Madagascar at the February Tucson show. The color of some of this material was very similar to new colors of tourmaline coming from Paraíba, Brazil, and some of the apatite was being sold as "Paraíba apatite" or simply as "Paraíba."

At a recent gem and mineral show in Santa Monica, GIA Instructor Yianni Melas was shown a chatoyant, medium dark greenish blue 5.72-ct oval double cabochon that was presented as a cat's-eye apatite (figure 2). The owner, Manu Nichani of Temple Trading Co., Encinitas, California, subsequently loaned the stone to GIA for investigation.

The stone measured 11.58 × 8.66 × 7.09 mm; it was translucent and exhibited a fairly sharp chatoyant band. Magnification revealed the cause of chatoyancy as numerous parallel growth tubes, some of which were partially filled with an unknown residue. Pleochroism was distinct but not strong, in grayish yellowish green and greenish blue; the stone appeared brownish green through the Chelsea color filter. With a desk-model spectroscope, we were able to resolve a weak absorption band at approximately 594–618 nm; there was also some weak general absorption from 633 to 700 nm. The stone had a spot R.I. of 1.64, an S.G. of approximately 3.16, was doubly refractive, and was inert to long- and short-wave U.V. radiation.

Figure 2. The greenish blue color of this 5.72-ct cat's-eye apatite is very unusual for this gem variety. Photo by Robert Weldon.

Although we had not previously seen chatoyant apatite in this color, all properties were consistent with apatite. Because of the possible overlap in properties with greenish blue cat's-eye tourmalines, we asked C. W. Fryer of the West Coast GIA Gem Trade Laboratory to perform an X-ray diffraction analysis of a powder sample from this stone. The pattern matched that of apatite.

Zimbabwe emerald update. This past June, Tom L. Lee of Victoria Mines Ltd. visited emerald-producing mines and developing prospects in southern Zimbabwe. Some of these had not previously been visited by outsiders, as they are located in an area with severe travel restrictions. Mr. Lee provided the following report.

The emerald mines are located in the Mweza Range in southeastern Zimbabwe, within the Mberenga Communal Lands (formerly known as the Tribal Trust Lands). Throughout most of the emerald mines inspected by Mr. Lee, concentrations of emerald were frequently—but not exclusively—identified in pegmatite wall/serpentinite contact zones, most notably in the "nose" of such contact zones, which had been extensively folded and altered.

Emerald was first discovered in this region in May 1957. At the time of Mr. Lee's visit, 27 emerald mines were operating with the authorization of the Zimbabwe government, although most were rudimentary diggings that were being worked primarily with picks, shovels, and wheelbarrows.

One of the more sophisticated operations is the Machingwe mine (figure 3), an open-cast working that extends for approximately 2 km. Two bulldozers are used to move soil and rock, and to extend the pit workings. During the actual recovery of emeralds, the primary tools are picks and shovels, although there is some black powder blasting. Currently, the active open-pit emerald workings lie some 60 m below the surface. The area is protected by armed guards who are randomly situated throughout the mountainous bush that surrounds the mine.

The Lodge mine (figure 4), located approximately 30 km east of the famous Sandawana emerald mine, is also open cast. Although the Lodge mine has been in operation since 1981, almost all of the excavation and emerald-face working is still carried out with picks, shovels, and wheelbarrows.

Figure 3. This view from the edge of the main pit at the Machingwe mine, southeastern Zimbabwe, shows miners at work recovering emeralds. The pegmatite structure (white area) has been followed downward 60 m. Photo © Tom Lee and Michael Smith.

Unusual cat's-eye diopside. Efraim Katz of African Gem Cutters, Miami Beach, Florida, recently loaned the Gem News editors a very slightly oval single cabochon of unusual color that exhibited a strong chatoyant band across its dome. The stone was a very light grayish brownish green and appeared to be semitransparent when viewed face-up.

R.I. was determined to be approximately 1.67 by the spot method; because there were no polished flat surfaces, birefringence could not be determined. In the polariscope the stone exhibited a doubly refractive reaction that was difficult to resolve due to the presence of many doubly refractive inclusions. The stone was inert to both long- and short-wave U.V. radiation; no absorption features could be resolved with a hand-held spectroscope.

There are a number of gem species in the mid- to high-1.60s R.I. range that produce chatoyant varieties, including actinolite, diopside, enstatite, and kornerupine. Of these stones, however, all but actinolite are typically very dark brown to very dark green in color. We thus asked C. W. Fryer to perform X-ray diffraction analysis on the stone, which resulted in a match for diopside.

Figure 4. Miners at the Lodge mine, approximately 30 km east of the Sandawana mine in the Mweza Range, Zimbabwe, are housed in this compound. Photo © Tom Lee and Michael Smith.

Fine-quality chatoyant iolite. In the Spring 1990 Gem News column, we described a 23.65-ct cat's-eye iolite seen at the Tucson show this past February. Recently, GIA Instructor Yianni Melas assisted in obtaining another of these unusual stones for investigation.

The stone, loaned to us by Manu Nichani of Temple Trading Co., was purchased in southern India. The attractive 8.25-ct oval double cabochon measures 14.84 × 11.78 × 7.58 mm (figure 5). Semitransparent when viewed from above, it would be almost transparent were it not for a rough-ground base. In surface-incident light, it exhibits an exceptionally strong chatoyant band; this is even evident under diffused overhead fluorescent lighting. When examined face-up, it shows a light bluish gray body color on either side of the chatoyant band, while the periphery of the base appears a medium dark violet as a result of the strong pleochroism. A dichroscope was used to isolate the pleochroic colors which were identified as dark violet, light bluish gray, and light brownish yellow.

Magnification revealed the cause of chatoyancy to be minute, whitish fibers. Also noted were small, colorless, low-relief crystals. When the stone was examined with the polariscope, we noted that the chatoyant band appeared to bisect the 2V angle. All other gemological properties were consistent with those previously reported for this gem species.

Figure 5. Chatoyancy is unusual in iolite, especially as exhibited by this 8.25-ct cabochon. Photo by Robert Weldon.

Gem finds in Inner Mongolia. Gem deposits have recently been discovered at 51 sites in the Inner Mongolia Autonomous Region of China. According to a report in the July 1990 issue of *Mining Magazine,* over the course of three years of prospecting a team of geologists found 42 types of gems, including agate, bloodstone, malachite, rock crystal, and topaz. The team also determined that the region contains 196 sites with gem deposits of commercial significance.

Opal with true chatoyancy. Dr. Byron C. Butler of World Gems/G.S.G. in Scottsdale, Arizona, provided the Gem News editors with a very unusual 0.76-ct cat's-eye opal for investigation. The opal, a translucent oval single cabochon, measures 7.33 × 5.47 × 3.31 mm and has a brownish yellow body color (figure 6). Unlike most so-called cat's-eye opals, which exhibit chatoyancy as a band of play-of-color when fashioned as triplets, this unassembled gem exhibits true chatoyancy. As in fine cat's-eye chrysoberyl, the "eye" is very sharp, and the stone also exhibits a strong "milk-and-honey" effect when the cabochon is illuminated from the side at a right angle to the chatoyant band.

The R.I., taken both on the well-polished base and by the spot method, was 1.45. When examined between crossed polars, the opal exhibited an anomalous blinking reaction in the form of a strain-induced snake-like band

Figure 6. This 0.76-ct opal exhibits unusually strong chatoyancy. Photo by Robert Weldon.

along the length of the dome. The stone fluoresced a weak red to both long- and short-wave U.V. radiation, and appeared a grayish bluish green through the Chelsea color filter. S.G. was determined by hydrostatic weighing to be approximately 2.08. Magnification revealed an extremely fine fibrous structure plus minute black inclusions.

The most unusual feature of this chatoyant opal was what appeared to be weak pleochroism in yellow and brownish orange that was noted with a calcite dichroscope. It is possible that this opal formed as a pseudomorph after a doubly refractive fibrous mineral such as goethite (which might also be responsible for the color) and that like-oriented remnants of the original material are responsible for both the strain and the apparent pleochroic reaction in this essentially amorphous material.

Star scapolite. The mineral series scapolite produces some interesting collector gems, including both purple and yellow stones that, because of similar gemological properties, may be confused with the quartz varieties amethyst and citrine, respectively. Also seen occasionally are different colors of chatoyant scapolite.

Efraim Katz of African Gem Cutters, Miami Beach, Florida, recently loaned the Gem News editors an interesting phenomenal scapolite for examination. This translucent, slightly brownish greenish gray oval double cabochon weighs 7.46 ct and measures 12.21 × 11.08 × 7.43 mm. The gemological properties were consistent for scapolite. Magnification revealed small black, reflective inclusions of what may be exsolution ilmenite; a few small plates of what may be mica were also noted.

What made this stone unusual was the presence of a strong reflective band across the long direction of the dome that was intersected by two much weaker but distinct additional bands (one of which was quite faint and difficult to photograph; figure 7). This would qualify the stone as a star scapolite, which is quite rare. Shortly after we examined this stone, GIA Collection Curator Loretta Loeb showed us a similar-appearing 2.82-ct asteriated scapolite that had recently been added to the GIA collection. Both of these stones are reported to have originated in Sri Lanka.

More activity at the sugilite mine. A recent mining industry report notes that Samancor has closed its Hotazel manganese mine near Kuruman, South Africa, because the reserves have been almost totally exhausted. To compensate, the company is increasing production at two nearby mines. One of these, the Wessels mine, is the only known source of the purple manganoan ornamental gem material, sugilite. This increased activity may lead to further sugilite discoveries. (*Mining Journal*, July 13, 1990, p. 25)

Figure 7. The intersecting reflective bands of this 7.46-ct scapolite qualify it for designation as a star stone. Photo by Robert Weldon.

Unusual carved tanzanite. As mined, tanzanite exhibits extremely strong pleochroism in blue, purple-violet, and greenish yellow, a combination that gives untreated material a rather unattractive face-up color with a strong brownish component. Fortunately, heat treatment removes the undesirable greenish yellow component, resulting in stones that, depending on orientation, exhibit fine blue to violet colors.

Because virtually all of the tanzanite used in jewelry has been heated, many jewelers are unfamiliar with the appearance of the untreated material. Recently, Bart Curren of Glyptic Illusions brought to our attention a fine 10.19-ct tanzanite that he had carved and then heat treated, documenting the color both before (figure 8, left) and after (figure 8, right) the treatment process. Note in the two photos how the unusual cutting style helps emphasize the pleochroism. With both distinct purplish and yellowish brown colors showing, the untreated stone superficially resembles some amethyst-citrine quartz.

Cat's-eye tanzanite. Because of the rarity of cat's-eye tanzanite, it came as a pleasant surprise when Peter and Bobbi Flusser, of Overland Gems in Los Angeles, showed us the 2.69-ct stone pictured in figure 9. This semitransparent, high-domed oval cabochon with a slightly convex base exhibits an attractive medium dark grayish violet-blue color and a sharp chatoyant band when examined from above. Magnification revealed the cause of the chatoyancy to be numerous parallel whitish channels running perpendicular to the "eye"; spike-shaped two-phase inclusions were also noted.

The gemological properties determined for this stone were consistent with those reported in the literature for tanzanite. With respect to the pleochroism, it was

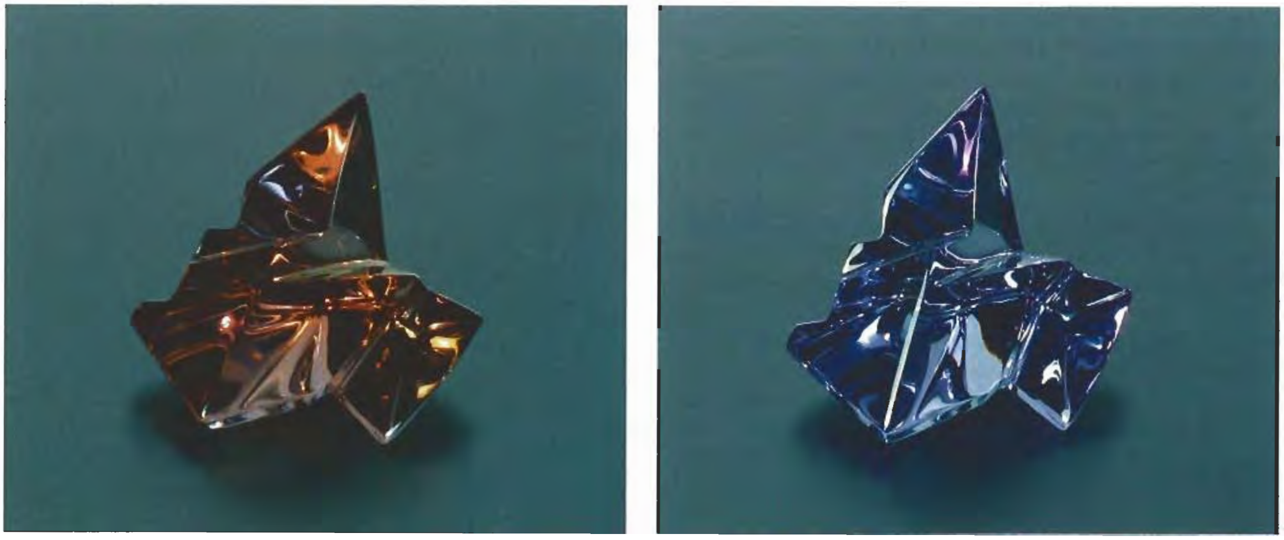
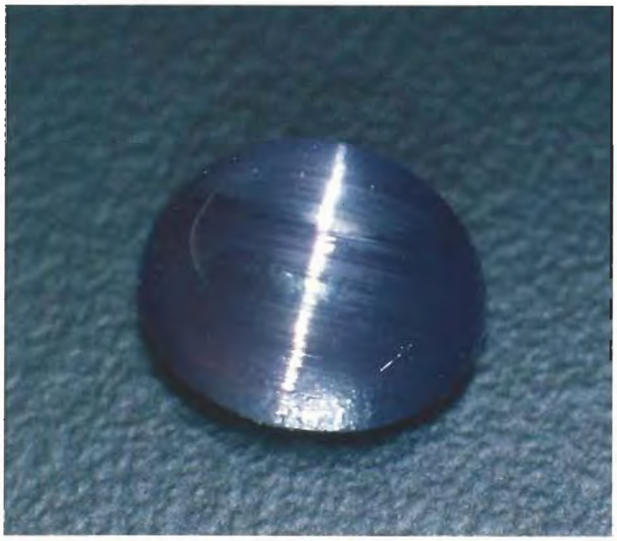


Figure 8. The unusual cutting style of this 10.19-ct tanzanite emphasizes the stone's pleochroism both before (left) and after (right) heat treatment. Carving and photos by Bart Curren, Glyptic Illusions.

interesting to note that a deeper color was observed when the stone was viewed down the sides in both the long and the narrow directions. It appears that, as is the case with cat's-eye alexandrite, orienting the stone to center the chatoyant band across the dome of the cabochon results in less than the best face-up color. No doubt, reflections off the chatoyancy-producing channels also contributed to a slight washing out of the color when the stone was viewed from above.

Figure 9. This 2.69-ct cabochon is a fine example of the very rare cat's-eye variety of tanzanite. Photo by Robert Weldon.



ENHANCEMENTS

Faceted gems with Aqua Aura enhancement. In the Winter 1988 Gem News column we reported on "Aqua Aura" quartz, single crystals and crystal clusters of colorless quartz that had a thin film of gold applied to their external surfaces. These treated specimens displayed both the blue to greenish blue transmission color of the gold as well as a superficial thin-film iridescence. A more detailed report subsequently appeared in the April 1989 issue of the *Journal of Gemmology.*

According to an article in the September 1989 issue of *Rock & Gem,* the process was developed by Bill McKnight and Tom Stecher of Vision Industries, Lynnwood, Washington. The application of this treatment to faceted gems is now taking place on a commercial basis. The Gem News editors obtained two fashioned hexagonal prisms of Aqua Aura–treated quartz (one of which is shown in figure 10) in fall 1989, and shortly thereafter encountered Aqua Aura–treated faceted topaz set in silver pendants. The vendor of the treated topaz, TransGem Corp. of West Bend, Wisconsin, was contacted for further information. In response, Johnathan J. Parentice of TransGem informed us that they planned to begin marketing this material nationwide soon, and that some 10,000 ct were submitted for enhancement in December 1989. Mr. Parentice also kindly provided us with several samples for examination.

The 11 treated faceted topazes supplied by TransGem (two of which are shown in figure 10) ranged from 0.71 ct to 2.25 ct. They varied in color from medium light to medium dark blue to greenish blue; all of the stones showed a very uniform color face-up. They exhibited an overlying weak to moderately strong iridescence that was most noticeable on the larger stones. R.I., birefringence, optic character, and S.G. were consistent with topaz. Also as is typical for topaz, the specimens were all inert to both long- and short-wave U.V. radiation, appeared brownish green to green through the Chelsea color filter, and showed no absorption features when examined with a desk-model spectroscope. Unlike topaz, however, no pleochroism was noted in any of the stones when they were examined with a dichroscope.

A 0.70-ct pear-shaped brilliant-cut treated quartz supplied by TransGem and the two faceted quartz "prisms" mentioned above were similarly tested. Their R.I., birefringence, optic character, and S.G. were consistent with those reported in the literature for quartz, while their reactions to U.V. radiation, appearance through the Chelsea filter, spectroscopic features, and appearance through the dichroscope were essentially the same as noted above for the treated topaz.

Magnification proved key to identifying the Aqua Aura enhancement (figure 11). When examined with diffused, direct transmitted light, all of the treated specimens—both topaz and quartz—exhibited one or more of the following features: (1) diffused, dark outlining of some facet junctions; (2) white-appearing facet junctions where either the treatment did not "take" or where it had been abraded away; (3) a combination of fine, white-appearing facet junctions immediately bordered on either side by slightly dark blue outlining; (4) irregular, minute, random, white-appearing abrasions on facet junctions and/or surface pits and scratches on facet surfaces; and (5) irregular blue coloration on some facets (some facets exhibited areas of no color). One of the pear-shaped topazes exhibited an exceptionally heavy deposit of the coating near its point. When examined with magnification in surface-reflected light, the iridescence became very noticeable on all specimens and the surface irregularities were easy to detect.

Those specimens that tended to be more greenish blue—especially those displaying fairly prominent iridescence—could be visually mistaken for some heat-treated zircon. R.I., birefringence, and S.G. readings would quickly help identify the gem materials as topaz or quartz, respectively. While there is no natural blue single-crystal quartz with which the Aqua Aura–treated quartz could be confused, it does bear a resemblance to some cobalt-doped blue synthetic quartz. In this instance magnification, as well as Chelsea-filter reaction and absorption spectrum, would make the separation. The "Aqua Aura" topaz might easily be mistaken initially for the irradiated blue topaz that is so prevalent in today's gem market; in fact, Mr. Parentice did report that TransGem's product was being marketed as an alternative. In all cases, however, the superficial iridescence is a strong indicator and magnification would quickly reveal the Aqua Aura treatment.

A final point relates to the durability of this surface enhancement. Both quartz and topaz specimens were exposed to the electrically heated tip of a thermal reaction tester; this produced no noticeable effect on the treatment layer. Furthermore, a number 6 Mohs hardness point failed to scratch an "Aqua Aura" faceted quartz and a number 7 Mohs hardness point had no apparent effect on one of the treated topazes. Testing of a treated stone with dilute hydrochloric acid also had no noticeable effect. It would thus appear that this enhancement is fairly durable. Note, however, that because this is a surface treatment, it would be partially or completely removed during recutting or repolishing.

Figure 10. These two faceted topazes (the oval weighs 2.15 ct) and faceted hexagonal prism of quartz (18.18 ct) have both been treated by the Aqua Aura method. Photo by Robert Weldon.

New opal enhancement. Former GIA student Eunice Um showed the Gem News editors two tumble-polished opals she had purchased in Mexico. The essentially

Figure 11. As is evident in this topaz, the darker color outlining of some pavilion facet junctions and the irregular facet coloration are typical of Aqua Aura–treated stones. Photomicrograph by John I. Koivula; magnified 5×.

colorless, transparent stones exhibited play-of-color. One side of each, however, had been unevenly coated with a translucent, very dark brown, plastic-like material that gave the body color a somewhat dark appearance and accented the play-of-color when the stones were viewed from the uncoated side. When they were viewed from the coated side, even at low magnification (figure 12), gas bubbles could be seen in the coating. With magnification, it was also evident that the coating could be easily indented with a needle probe.

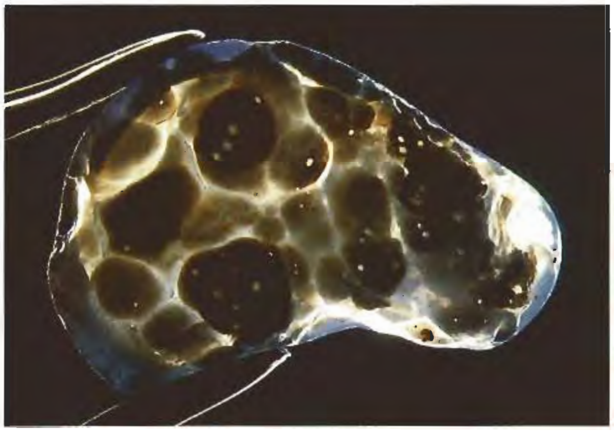


Figure 12. This 10.3-mm-long opal, purchased in Mexico, had been coated on one side with a dark, plastic-like material. Photomicrograph by John I. Koivula.

"Plastic"-coated sugar-treated opal. A number of treatments have been used on otherwise unusable opal from various localities to produce a dark background, thereby reducing light scattering and bringing out play-of-color.

Recently John Fuhrbach, a gemologist from Amarillo, Texas, sent us an unusual 16.58-ct opal (figure 13) for examination. The essentially opaque, low-domed oval cabochon had a uniform black body color and displayed a fairly strong, evenly distributed pinfire play-of-color that was predominantly green with minor amounts of yellow and orange.

The opal displayed some rather interesting gemological properties. Spot R.I. readings on the dome gave values of 1.45, but the base produced values of 1.56 to 1.57. When exposed to long-wave U.V. radiation, the dome fluoresced a very strong yellow-green whereas the base fluoresced a very strong chalky blue-white. The short-wave U.V. reactions were similar but somewhat weaker, and there was no phosphorescence to either wavelength. Microhardness tests on both the dome and the base showed that the stone could be easily indented with the point of a straight pin. Hydrostatic weighings produced an S.G. value of 1.91.

Magnification revealed two key features. First, we noted the typical "peppery," speckled appearance that is associated with sugar-treated opal from Australia. Second, the entire cabochon was seen to be coated with a transparent, colorless material. This coating was significantly thicker on the base than on the dome, and gas bubbles were noted in the thicker base coating. A small scraping taken from the coating on the base was tested with a thermal reaction tester ("hot point"), producing an acrid odor reminiscent of that noted with some plastics.

We concluded that the stone was a sugar-treated opal that had subsequently been coated with a plastic-like substance. The uncharacteristically high R.I. reading on the base was attributed to the thick coating of the plastic-like material on that side; the different U.V. fluorescence reactions of the dome and the base were believed to be due to the variation in thickness of the "plastic" layers; while the unusually low S.G. was attributed at least in part to the significant "plastic" component, with the porosity of the starting material possibly a contributing factor.

SYNTHETICS AND SIMULANTS

Knischka synthetic ruby update. Professor P. O. Knischka of Steyr, Austria, reports that he has produced synthetic ruby crystals over 5 cm in length that have yielded faceted stones as large as 67 ct. Material is being marketed in the form of faceted stones in sizes ranging to over 11 ct, as preforms that may exceed 25 ct, and as rough "macro-clusters," "plates," and "micro-clusters." The fashioned materials are marketed in three qualities based on the extent of inclusions and in colors described

Figure 13. Both sugar treatment and coating with a plastic-like substance were used to enhance this 16.58-ct opal. Photo by Robert Weldon.

Figure 14. This half-crystal of Knischka synthetic ruby weighs 40.65 ct. Photo by Robert Weldon.

by Professor Knischka as "light, medium, [and] dark in Burmese pink tone or Thai purple tone."

Recently, Dr. Edward J. Gübelin provided us with a large half-crystal of Knischka synthetic ruby. The crystal, which had been sawn down its length and the cut surface polished, weighs 40.65 ct and measures 39.66 mm long × 17.90 mm in largest diameter (figure 14). It is dark purplish red, exhibits accordian-like deep growth steps perpendicular to and along the length of the crystal, and contains the glassy two-phase inclusions and platinum platelets previously noted in this material (see E. Gübelin, "New synthetic rubies made by Professor P. O. Knischka," *Gems & Gemology,* Vol. 18, No. 3, pp. 165–168).

Fluorite imitating emerald. A number of ICA Laboratory Alerts and reports in the gemological literature have appeared over the past few years concerning imitation emeralds fabricated out of natural as well as man-made materials. Earlier this year, the ICA released a Laboratory Alert Update that describes yet another type of "crafted" specimen.

Submitted by Jean-Paul Poirot of the well-known Paris laboratory, it describes what at first appeared to be an emerald crystal in matrix. The specimen, which originated in Madagascar, was found to consist of a green fluorite crystal that had been attached with a mica-laden glue to a block of tourmaliniferous rock. One end of the crystal had been given a roughly hexagonal shape, and cleavages gave the impression of growth lines.

Mr. Poirot cautions that the spectrum of green fluorite is somewhat similar to that of emerald and that such stones also appear red through the Chelsea color filter. The fluorite fluoresced a strong violet-blue to long-wave U.V. radiation, while the glue around its base fluoresced a strong yellowish white. The identification of the crystal was confirmed by X-ray diffraction analysis.

Imitation jade carving. On a visit to the jade market in Kowloon, Hong Kong, this past January, one of the editors (RCK) obtained a carved sphere that was represented (not surprisingly) as jade (figure 15). Testing of this attractive ornamental object at GIA Santa Monica revealed that it was quite interesting gemologically.

The sphere weighs 186.7 grams (933.5 ct) and ranges from 52.0 to 53.3 mm in diameter. It is opaque except in thin edges, where it is semitranslucent. Although it is predominantly a mottled dark reddish brown grading to medium yellowish brown, approximately 40% of the surface area is a strongly mottled medium yellow-green to vivid, dark yellowish green.

Although we could not obtain a refractometer reading because of the condition of the surface (see below), we did detect a birefringence blink, which indicates a material

Figure 15. Sold as "jade" in Hong Kong, this carved sphere was determined to be a selectively dyed rock consisting of calcite and lesser amounts of serpentine. Photo by Robert Weldon.

of high birefringence. When examined through a Chelsea color filter, the greenish areas appeared grayish green while the brown areas looked red-brown. All areas were inert to both long- and short-wave U.V. radiation, and there was no phosphorescence. Testing on an inconspicuous area revealed a Mohs hardness of approximately 3.

Magnification revealed a very mottled texture with some areas that were near-colorless to white in both brownish and greenish portions. Brown color concentrations were noted in surface-reaching fractures in the brownish areas, while both brown and green color concentrations were seen in green areas; small chipped spots in the brownish areas showed a lighter brown color and had a granular texture. Many of the incised areas contained concentrations of an off-white to yellowish material that readily melted when touched with a thermal reaction tester.

Chemical tests were also performed in inconspicuous spots. Both the brown and the green areas effervesced to a small drop of dilute hydrochloric acid. Rubbing of brown areas with an acetone-dipped cotton swab produced a strong red-brown discoloration, while similar testing in green areas showed a less obvious but still definite green discoloration.

X-ray diffraction analyses of scrapings from both the green and the brown areas were performed by C. W. Fryer. Material taken from the brown area produced a strong pattern for calcite; the X-ray diffraction pattern for the green area showed strong lines corresponding to calcite plus slightly weaker lines that matched a general pattern for serpentine.

On the basis of the above, the editors identified the sphere as a rock consisting of calcite and lesser amounts of serpentine that had been selectively dyed, the whole piece having been wax or paraffin coated. It is possible that before treatment the areas containing serpentine had a light green color which led to the selective dyeing of these portions with a green coloring agent to intensify the effect.

ANNOUNCEMENTS

The Tucson Gem and Mineral Show will be held February 13–17, 1991, at the Tucson Convention Center. The featured mineral for the show is azurite. For more information, contact the Tucson Gem and Mineral Society, P.O. Box 42543, Tucson, AZ 85733.

The American Gem Trade Association will be in Tucson February 9–14 at the Convention Center. They will announce the winners of the Spectrum Awards (a jewelry contest aimed at the effective use of colored stones) at that time. For information, contact the AGTA headquarters at the World Trade Center #181, P.O. Box 581043, Dallas, TX 75258, (214) 742-4367; for reservations, call (800) 972-1162.

The Gemological Institute of America will present various lectures and seminars in Tucson, February 9–14, at the Convention Center. For information, call (800) 421-7250, ext. 227, or write GIA, P.O. Box 2110, Santa Monica, CA 90406.

The Gemological Institute of America is sponsoring the International Gemological Symposium June 20–24, 1991. Experts will be speaking on such diverse topics as colored stone and diamond sources, gem identification, antique and period jewelry, synthetics and simulants, diamond market perspectives, jewelry for the 20th century and beyond, global economics, marketing and merchandising challenges, and pearls. On Sunday, key figures will address some of the most important—and controversial—issues in the industry, including new technologies in gem identification, quality analysis of colored stones, and current concerns in jewelry evaluation and appraisals. Poster sessions, a noncommercial marketplace of new ideas, will also be held on Sunday. Each day also has its share of social events, where attendees can meet each other and the speakers and panelists, including a grand finale at the Los Angeles County Museum of Natural History. For more information, contact GIA at (800) 421-7250, ext. 211, or write to GIA at P.O. Box 2110, Attn: Symposium Office/Resource Development, Santa Monica, CA 90406.

The Israel Precious Stones and Diamond Exchange Ltd. has announced new telephone and facimile numbers as of June 3, 1990. These are (972-3) 5751177-83 and (972-3) 5752547, respectively.

The State Gem Corporation of Sri Lanka has announced that, effective August 1, 1990, the export of "geuda" rough will be open to dealers from all countries who obtain registration with the Manager, State Gem Corporation, Geuda Trading Centre, Ratnapura. Procedural details can be obtained on written request to the manager. In the past, only dealers from Thailand were eligible for permits to export geuda.

Also from the State Gem Corporation comes an announcement of the establishment of a Gem & Jewellery Exchange in Colombo. The exchange will provide rooms that may be rented by foreign buyers and service facilities so that it may serve as a "One Stop Export Shop."

BOOK REVIEWS

Elise B. Misiorowski and Loretta B. Loeb, Editors

EMERALDS OF PAKISTAN: GEOLOGY, GEMOLOGY AND GENESIS

*Edited by Ali H. Kazmi and Lawrence W. Snee, 269 pp., illus., publ. by the Geological Survey of Pakistan and Van Nostrand Reinhold Co., New York, 1989. US$39.95**

This is a major and important addition to the scientific literature on beryl, more specifically, the emerald variety. While the content is largely devoted to the geologic/geochemical aspects of emerald-bearing deposits, with the greatest emphasis and detail placed on those in Pakistan and neighboring Afghanistan, there is much that will prove interesting and useful to the practicing gemologist. The text consists of nine topical chapters followed by a very large bibliography (about 450 entries!), author as well as subject indexes, and short biographies of the 14 authors who were involved in the compilation of the text. I heartily concur in the decision of the publishers to tell us a bit about the writers—all too often biographical notes are placed on dustjacket flaps and sooner or later discarded or lost.

The opening chapter, by A. H. Kazmi, is a useful overview of the broad geology and metallogenic provinces of Pakistan. It serves as the foundation for the next chapter—by R. D. Lawrence, Kazmi, and L. W. Snee—on the geologic setting of the Pakistani emerald deposits. While this second chapter offers the reader a more specific geologic discussion of the deposits, it is the third chapter, on the deposits themselves—by Kazmi, J. Anwar, S. Hussain, T. Khan, and H. Dawood—that will prove the most interesting and useful to the reader who wants to know just where the deposits are, and the kinds of stones that can be expected from them. Like the previous chapters, this one is well illustrated with maps, diagrams, and photographs, some in color, and concludes with a long reference list. In chapter four, E. J. Gübelin describes the gemological characteristics of the Pakistani emeralds, and it is here that the practicing gemologist will find those specifics that will serve him well in distinguishing these stones from those found elsewhere in the world. As we have come to expect from Gübelin, there are excellent descriptions of inclusions and many fine supporting color photographs.

Less useful to the lay reader but invaluable to the student of gemstone deposits and causative geology/geochemistry are chapters five and six, which discuss the chemical differences among emeralds and host rocks in Pakistan and Afghanistan with implications for the origin of emerald. The authors are Snee, E. E. Foord, B. Hill, S. J. Carter, and J. M. Hammarstrom. The geochemistry of fluid inclusions in the emeralds is deemed sufficiently distinctive and valuable to merit its own chapter seven by R. R. Seal II, while chapter eight is an excellent précis of the geology of world emerald deposits by Kazmi and Snee. The last text chapter, by the same authors, discusses the origin and classification of both Pakistani and other world-source emerald deposits.

As the author of *Emerald and Other Beryls*, I fully appreciate the enormous amount of work that went into the present treatise. Make no mistake in this regard: *Emeralds of Pakistan* is full of information that will serve the geologist, mineralogist, geochemist, and gemologist for many years to come. I recommend it heartily and I am sure you will also be charmed by its superior touches, including a blue marker ribbon—something one does not often see these days.

JOHN SINKANKAS
Peri Lithon Books
San Diego, CA

THE JEWELRY DESIGN SOURCE BOOK

*By P. Bayer, V. Becker, H. Craven, P. Hinks, R. Lightbrown, J. Ogden, and D. Scarisbrick, 192 pp., illus., publ. by Van Nostrand Reinhold, New York, 1989. US$39.95**

Prominent English jewelry historian Diana Scarisbrick, together with a team of specialists, has produced a well-illustrated, evenly written survey of jewelry design sources from ancient times to the present day.

Mrs. Scarisbrick is responsible for the lively and engaging introduction as well as for the chapters on Renaissance and Baroque jewels and on Romanticism of the 18th century. Each of the other authors covers a particular period of jewelry history, with emphasis on the eminent designers and craftsmen of the time and on events that shaped and influenced jewelry design. Together, they examine the full spectrum of interaction between cultural and aesthetic values and stylistic evolution, capturing, with charm and erudition, the era under consideration. Jack Ogden presents jewelry of the ancient world, Ronald Lightbrown discusses Medieval jewelry arts, Peter Hinks is the authority on Victoriana and the Belle Epoque, and Patricia Bayer describes jewelry of the late 19th century through Art Deco in the first half of the 20th century. Post-World War II is Vivienne Becker's area of interest, and Helen Craven looks at contemporary craftsmen.

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*This book is available for purchase at the GIA Bookstore, 1660 Stewart Street, Santa Monica, CA 90404. Telephone: (800) 421-7250, ext. 282.

This useful book also provides handsomely reproduced photographs, a brief glossary, and, mercifully, a general index. If a minor complaint must be mentioned, it is that the book is somewhat overdesigned: The pages of reverse type (white on black) are difficult to read, and the dimensions make the book somewhat awkward to handle. While this may disconcert overly critical reviewers, it does not detract from an otherwise first-rate book or the wealth of well-researched documentation in an attractive and much-needed reference.

Neil Letson
New York City, NY

ILLUSTRATED GUIDE TO JEWELRY APPRAISING: ANTIQUE, PERIOD, AND MODERN

*By Anna M. Miller, 180 pp., illus., publ. by Van Nostrand Reinhold, New York, 1990. US$34.95**

Jewelry appraising has become increasingly complex, especially in the last decade, and it is essential that the professional be aware of the many aspects involved in writing a responsible appraisal. Anna Miller, author of *Gems and Jewelry Appraising,* has provided a second book on this topic that is an indispensable tool for both novice and veteran. While both books emphasize the importance of education and research, and give detailed information on the nuts and bolts of the profession, there is surprisingly little overlap. Where her first volume focuses on conducting an appraisal, the *Illustrated Guide to Jewelry Appraising* provides more detail on estimating values for specific types of jewelry.

Chapter 1 of the *Illustrated Guide* defines the function and objective of the professional jewelry appraiser today, as well as the purpose of the appraisal itself. These are two seemingly obvious points that, in truth, have far-reaching consequences.

The next chapter outlines the mechanics of performing an appraisal, including the use of price guides, judging the quality of stones and workmanship, and noting the present condition of the piece.

The third chapter underscores the importance of understanding historic elements as they relate to antique and period jewelry. The influences of dress, motifs, and cultures on jewelry design is concisely presented.

Chapter 4 focuses on the evaluation of specific types of jewelry, such as rings, earrings, necklaces, bracelets, brooches, pearls, watches, and charms. For each type of jewelry, the author provides a brief chronology of its use throughout history, along with hints on how to date a piece and judge its quality. Additional insight is offered in a discussion of frequently asked questions with their answers. A sidebar giving a "model appraisal narrative" shows how a well-formulated appraisal for that type of jewelry might be presented.

Chapter 5 examines the appraisal document itself. Information that should be included in every appraisal, a critique of appraisal documents, and samples of different types of appraisals are outlined.

The many useful appendices at the end of the book will serve as ready references on such topics as gem cuts, weight estimation formulas, ring-size equivalents, gemstone handling, and auction houses. The author also provides glossaries together with an extensive bibliography and an index. Many black-and-white photographs and sketches illustrate the text, and most of the jewelry is photographed from both the front and the back, which is very helpful for the appraiser.

The *Illustrated Guide to Jewelry Appraising* adds tremendously to the literature available on this subject. By selecting, organizing, and compiling salient information that pertains to this evolving profession, Miller makes the appraiser aware of the many things that need to be considered before writing an appraisal. The importance of keeping abreast of developments in legislation and the world economy is also highlighted, reminding the reader of the ever-changing nature of this exacting profession.

Elise B. Misiorowski, G.G.
GIA Research Librarian
Santa Monica, CA

OTHER BOOKS RECEIVED

The 4 C's Value of Diamonds, *by Anna Cheng, 199 pp., illus., publ. by China Television Publishing Co., Taipei, Taiwan, 1987, US$39.50.** Those who read Mandarin Chinese will find this book about the 4C's of evaluating diamonds most useful. In 28 concise chapters, long-time gemologist Anna Cheng discusses the history, mining, and cutting of diamonds, diamond grading, and marketing. Additional interesting topics in this book are other grading systems, how to analyze a diamond certificate, and how to interpret a price list. The author also examines the buying and selling of diamonds, touching on quality versus commercial goods, auctions, and cautionary tips. Ms. Cheng captures the mystery and intrigue of diamonds by providing histories of several famous diamonds. Beautifully illustrated with full-color photographs and diagrams, this is a nice educational coffee-table book for those who seek more information on diamonds. LBL

Diamond Cutting: A Complete Guide to Diamond Processing, 3rd Edition, *by Basil Watermeyer, 406 pp., illus., publ. by Cape Town Purnell, Cape Town, Republic of South Africa, 1988, US$59.00.** Like the first edition of this detailed manual (reviewed in the Spring 1983 issue of *Gems & Gemology*), this third edition gives step-by-step instructions for every phase of cutting. The 56 chapters cover almost every aspect of processing diamonds, ranging from the identification of rough, to the operation of automatic faceting machines and the fashioning of several fancy cuts. New to this edition is a chapter on the Princess cut and 70 additional diagrams. This unique book is highly recommended for students and diamond cutters alike.

LBL

GEMOLOGICAL ABSTRACTS

Dona M. Dirlam, Editor

COLORED STONES AND ORGANIC MATERIALS

A contribution to the distinguishing characteristics of sapphire from Kashmir. H. A. Hänni, *Journal of Gemmology*, Vol. 22, No. 2, 1990, pp. 67–75.

Dr. Hänni's article is essentially a discussion of the absorption spectra and inclusions of Kashmir sapphires. According to Dr. Hänni, "the term *Kashmir Sapphire* is used to denote the origin of a stone from a specific location and should not be regarded as a term describing either quality or color." Following brief summaries of history, literature, and visual appearance, a description of absorption spectra and chromogens for blue sapphires in general leads to the conclusion that certain absorption features in the 280–500 nm optical region can be used diagnostically. Details of how to control and use these relative strength comparisons are, however, not provided.

Hänni states that both previously reported and new inclusions were observed in the study samples (of unspecified number). In the discussion of the specific inclusions, however, specific references to previous literature are not always provided, so it is not clear whether a feature is newly observed, newly identified, or simply confirmation of previous reports. Similarly, it is not stated which features, other than the already-known tourmaline and pargasite inclusions, can be considered diagnostic of Kashmir origin. Uraninite and allanite appear to be newly identified, but it is not stated whether these have been reported for blue sapphire from other localities. Eight color and 13 black-and-white illustrations accompany this article. *CMS*

On two colour types of Mn^{3+}-bearing beryls. A. N. Platonov, M. N. Taran, and V. A. Klyakhin, *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 38, No. 4, 1989, pp. 147–154.

The origin of color in morganite, red beryl, and pink to purple Russian hydrothermal synthetic beryls is studied using ultraviolet-visible absorption spectroscopy. The authors state that it is "known" that morganite and red beryl are colored by Mn^{3+}, although the two materials

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This section is designed to provide as complete a record as practical of the recent literature on gems and gemology. Articles are selected for abstracting solely at the discretion of the section editor and her reviewers, and space limitations may require that we include only those articles that we feel will be of greatest interest to our readership.

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have a very different dichroism and color stability: The color of morganite fades completely on heating at 500°C, and can be restored by X-ray irradiation, while red beryl is unaffected by heating to 1000°C or more. From a detailed analysis of the absorption spectra, the authors infer that Mn^{3+} has different coordination symmetries in morganite and red beryl. Also, synthetic pink beryl and natural red beryl from Utah have a much lower lithium (Li) content than morganite. Therefore, color fading in morganite might be due to electron traps created by the substitution of Li^{+} for Be^{2+} according to the reaction:

$2Be^{2+} \rightarrow 2Li^{+} + V^{2+}$ (V = oxygen vacancy)

Such centers have been studied in other materials where they have a similar thermal stability range. With heating to about 500°C, the electron is released from its trap and comes back to the manganese ion, which then becomes a Mn^{2+} ion, which does not produce a significant coloration. *EF*

DIAMONDS

Spectroscopic study of natural diamonds in China. J. Guo, F. Chen, X. Cai, and H. Deng, *Chinese Journal of Geochemistry,* Vol. 9, No. 2, 1990, pp. 161–168.

The authors report on the visible and infrared absorption spectra of natural diamonds from China. Low levels of nitrogen were found to be present in some type II diamonds, but the nitrogen is in different stages of aggregation, suggesting that diamond formation took place under a variety of geologic conditions. Type Ib diamonds (with dispersed nitrogen) may occur in amounts up to 2% in some placer deposits in Hunan; this abundance is higher than has been generally believed for the occurrence of type Ib diamonds. Some type Ia diamonds display a green color due to natural irradiation. Type Ia diamonds from Hunan and Hubei provinces exhibit a variety of absorption bands, including the GR1 (741 nm), 637 nm, 595 nm, 575 nm, 3H (503.6 nm), H3 (503.2 nm), H4 (496 nm), and ND1 (393.6 nm), all of which result from natural radiation damage. Documentation of such diamonds is of great interest because of the continuing debate regarding the separation of natural from laboratory-treated green diamonds. Last, the authors report their observations on the presence of hydrogen in various complexes in diamonds from these deposits. Information on diamonds of known geographic origin is of great value. *JES*

Testing of colourless natural diamonds by room temperature optical absorption. G. Lifante, F. Jaque, M. A. Hoyos, and S. Leguey, *Journal of Gemmology,* Vol. 22, No. 3, 1990, pp. 142–145.

The authors describe a technique whereby weak optical absorption features, specifically those related to the N3 center in diamonds, can be enhanced by taking the first and second derivatives of the spectral graphic. The importance of this absorption feature, and of a method for testing it, is attributed to the potential need to distinguish colorless natural and synthetic diamonds in the future. The authors also discuss the value of this technique as a replacement for cryogenic cooling, which they feel is potentially destructive, although it should be pointed out that GIA has successfully run spectra on thousands of cryogenically cooled colorless and near-colorless diamonds without damaging a single stone. However, a particular advantage of the authors' method is that, since most spectrophotometers come with derivative capabilities as standard equipment, no additional cryogenic apparatus is required—a useful feature to laboratories with a limited budget. Illustrations of absorption spectra and their derivatives clearly demonstrate the potential of this method. *CMS*

GEM LOCALITIES

Gemstones of New Hampshire. J. J. Bradshaw, *Rocks & Minerals,* Vol. 65, No. 4, 1990, pp. 300–305.

New Hampshire has produced a variety of museum-quality gem crystals and rare mineral specimens. This article, written by the curator of the Mineralogical Museum's gemstone collection at Harvard University, provides information on the key localities in New Hampshire. The gem materials found there include: almandine, beryl (varieties goshenite, heliodor, aquamarine, and cat's-eye aquamarine), fluorite, quartz, spodumene, topaz, apatite, brazilianite, iolite, labradorite, phenacite, and rhodonite. Seven color photographs, including a picture of a 730-ct aquamarine carving of a mermaid, illustrate the article. Among the rare minerals are hurlbutite, lazulite/scorzalite, augelite, eucryptite, hydroxylherderite, limonite, and tremolite (actinolite).

This entire issue of *Rocks & Minerals* is devoted to New Hampshire minerals, fossils, and geology; it includes an article on a new find of pseudomalachite. *Ron Conde*

Maricota, un nouveau gisement d'andalousite [Minas Gerais, Brésil] (Maricota, a new andalusite deposit [Minas Gerais, Brazil]). J. Cassedanne, *Revue de Gemmologie a.f.g.,* No. 100, 1989, pp. 7–9.

An extensive review of all reports in the literature of andalusite in northern Minas Gerais precedes the description of a new andalusite deposit, called Maricota, in this area. Although this mineral is of metamorphic origin, all the deposits of this gem in Brazil are alluvial.

The new deposit is close to the Jequintinhonha River, 40 km northeast of Araçuaí, and is easily accessible. The geology of the area principally consists of schists with pegmatite intrusions and irregular quartz-rich veins. Although all three environments contain andalusite, because they are deeply weathered the gem material is collected by digging through colluvial deposits. Mining is primitive: Holes no more than a few meters deep are dug at random, and the gems are sorted by hand, without the aid of water. About 80 *garimpeiros* worked the deposit in July 1989. No production estimates are available.

The faceted gems (some up to 25 ct have been cut) show properties typical of the species. The dichroism is pale olive green to violetish red [*sic*], and the short-wave U.V. luminescence exhibits a "mustard" color. Common inclusions are channels parallel to the c-axis, sillimanite needles, platelet crystals of what appear to be hematite or ilmenite, and two-phase inclusions and "veils" that are generally perpendicular to the c-axis. *EF*

INSTRUMENTS AND TECHNIQUES

The diamond drill used in the Cambay bead industry. R. V. Karanth, *Journal of Gemmology*, Vol. 22, No. 2, April 1990, pp. 91–96.

Mr. Karanth meticulously describes the traditional bow-drill method that has been used for centuries in Cambay, India, to drill bead holes. The combination of bow-drilling action and double-tipped diamond drills creates a characteristic drill-hole impression that the author feels has been inadequately explained by archaeological analysts—hence this article in response. Modern bow-drill methodology, which apparently differs from ancient practices only by the use of metals, should shed light on those practices. According to the author, modern lapidaries continue to use this technique because it allows them to collect the by-product silica powder, which would be lost with an ultrasonic perforator, for use in polishing compounds. The method is relatively rapid in the hands of a skilled lapidary, yielding about 50 drilled 5-mm beads per day. To the complaint of crooked drill holes, the author responds that it is the mark of this unusual lapidary art and should be valued for its aesthetic associations. Black-and-white drawings of the apparatus and its drill-hole patterns accompany the article. *CMS*

Economical microscopes for gemmologists. T. Linton and G. Brown, *Australian Gemmologist*, Vol. 17, No. 4, pp. 120–121 and 156–158.

This instrument evaluation covers three microscopes of largely Chinese manufacture that are marketed by Industrial & Scientific Supply Co. Pty. Ltd. of Wellington Point, Queensland, and a Dutch-manufactured fiber-optic light source.

The SZM-1 stereozoom microscope has a magnification range of 7–40× with 10× eyepieces, and provides an 88-mm working distance and 28-mm field of view at 7×. It has a stable base with a reversible flat and concave light-reflecting mirror, illumination being provided by a 20W, 12V focusable quartz-halogen light source. An accessory darkfield cone supplied with the instrument provided high-intensity, strongly contrasting darkfield illumination. According to the evaluators, however, the darkfield system did produce confusing reflections from the surface of the cone's baffle. [Although not criticized by the authors, it seems to this abstractor that the described procedure required to focus the instrument for the entire zoom range appears to be a bit tedious.]

The basic SM-4G stereoscopic microscope is reportedly made to be used with a wide selection of accessories; one such attachment described is a transmitted-light illuminator base. This microscope has five magnification options of 6.4×, 10×, 16×, 25×, and 40×, with the working distance being constant for all magnifications at 100 mm, making it useful for examining larger gems and gem rough. The field of view is 29 mm at 6.4×. The darkfield accessory, as described for the SZM-1 microscope above, produced confusing reflections with the SM-4G instrument as well. An accessory-articulated side-arm light source received some criticism from the standpoint of its electrical wiring, but overall the evaluators considered this to be an excellent instrument, especially for students.

The SMS-10 is described as a small binocular stereomicroscope with fixed 20× magnification, a 70 mm working distance and a 9.2 mm field of view. It reportedly has good optics; unfortunately, the back focus of the eyepieces makes it unsuitable for use by some wearers of eyeglasses. This microscope can be fitted with the same light base designed for the SM-4G described above.

The EK-1 fiber-optic light source features a 12V, 100W, 3400K quartz-halogen projection light source that can be directed through either a single or a twin 500-mm flexible fiber optic–light guide. The heat generated by the lamp is adequately controlled by a fixed-heat filter and a low-noise cooling fan.

The authors of this report found all instruments examined to be well worth their prices in Australia. *RCK*

La microspectrofluorescence et ses applications en gemmologie (Microspectrofluorescence and its applications to gemology). J. Dubois-Fournier, B. Lenain, and D. Le Maguer, *Revue de Gemmologie a.f.g.*, No. 100, 1989, pp. 15–18.

In this article, the authors explore details of the fluorescence of corundum, in particular, ruby. The causes of chromium luminescence in ruby are discussed in general terms. The authors then describe a prototype microspectrofluorimeter, which helps obtain high-resolution luminescence spectra of sample areas as small as half a micron in diameter. Details of the red-end emission spectra of a series of flame-fusion synthetic rubies are given, including the positions of emission lines related to isolated Cr^{3+} atoms, pairs of Cr^{3+} atoms, and phonons. These lines vary in intensity according to the orientation of the stone. The isolated Cr^{3+} lines increase in strength with chromium concentration, until the

Cr^{3+} pair lines become significant; then they begin to decrease.

This technique has been applied to help separate ruby, red spinel, and pyrope garnet set in jewelry. This instrument can also detect differences in the fluorescence of natural and flame-fusion synthetic blue sapphires. Using a laser emitting at 325 nm, the authors have detected the fluorescence of vanadium in V-rich Burmese rubies: It appears as a golden yellow trace along the laser beam in the otherwise red-luminescing stone.

The authors conclude by emphasizing that not only the presence of iron, but also a higher than average concentration of iron can quench ruby's luminescence. They also point out the usefulness of their prototype instrument in obtaining quantitative measurements of the luminescence. *EF*

The OMF Faceter. R. P. Homer, *Lapidary Journal,* Vol. 44, No. 3, June, 1990, pp. 26–41.

Mr. Homer investigates a "faceting" machine that is capable of cutting concave and convex surfaces on gemstones. The OMF Faceter employs a series of precision-machined cylinders that can be used in a variety of positions. The resulting ability to cut curved surfaces allows cutters to focus, diffuse, condense, or disperse light in ways that are very striking. The amount of technical detail provided by the author makes this article of particular interest to the lapidary. *WRV*

PRECIOUS METALS

Dall'alchimia alla moderna farmacopea, la fortuna e l'illusione dell'oro nella medicina (From alchemy to the modern pharmacopoeia, luck and illusion of gold in medicine). P. Ciampi, *Joy Oro,* Vol. 3, No. 2, December 1989, pp. 20–25.

The author provides an historic account of the use of gold in the alchemic and medical fields. As far back as the 2nd century B.C., Chinese medical practitioners believed that gold would increase longevity. This theory persisted throughout the Middle Ages when the alchemists not only believed in the ability of this precious metal to increase the life span, but also as being the universal cure for diseases such as ulcers, tapeworms, skin ailments, and epilepsy. Evolving in the 18th century as metallotherapy, gold was used in treating nervous disorders and venereal disease. During the 19th and 20th centuries, gold salts were thought to work against the tuberculosis bacteria; colloidal gold, thought to be less toxic, was widely used as anti-infection agents and disinfectants for skin score. Today, this precious metal has lost its luster as a panacea. Those persons who were carelessly treated with the "medicinal gold" have been found to develop gold crystal deposits in the eyes and have increased chances of anemia, dermatosis, and liver and kidney lesions. However, it is still used to treat chronic rheumatoid arthritis. This article is printed bilingually in Italian and English. *Rose Tozer*

Suppliers battle underkarating. M. Thompson, *Jewelers' Circular-Keystone,* Vol. 161, No. 4, April 1990, pp. 78–80.

Underkarating is one of the most common types of fraud in the jewelry industry today. OroAmerica, a manufacturer of 14K gold jewelry, and Engelhard Corp., a gold supplier, decided to take matters into their own hands by instituting highly visible programs whereby they would guarantee the karatage of their gold, thus attacking the problem in the early stages of manufacturing.

OroAmerica now gives every retailer who buys from them a trademark guide that "certifies" the gold content of their jewelry, explains what a trademark is and why it is needed, and provides information on the karat stamp and other facts about gold jewelry. The guide accomplishes two things: It assures retailers that they are receiving genuine goods, and it serves as a marketing tool that retailers can use when discussing gold with their customers.

Engelhard Corp has developed a "Golden Guarantee" program, which assures its manufacturer and wholesaler customers of the quality of its gold sheet, wire, and grain. All of their goods have been assay tested to ensure that the gold content is above the minimum required by law. Engelhard will place a logo guaranteeing the gold content on all paperwork and will attach tags to the gold products sent to manufacturers. *KBS*

SYNTHETICS AND SIMULANTS

Synthèses de l'émeraude [première partie] (Emerald synthesis [part one]). D. Robert, *Revue de Gemmologie a.f.g.,* No. 100, 1989, pp. 4–6.

In the first part of this two-part series, Mr. Robert discusses the earliest successful syntheses of emerald, achieved in France by Ebelmen in 1868 and then by Hautefeuille and Perrey 40 years later. Both used a flux technique, but obtained only millimeter-size crystals.

Mr. Robert then reviews the constraints for successful synthesis from a melt: the problem of incongruent fusion, and determination of the appropriate temperature range. Major progress has been made over the years with the introduction of a seed crystal, the use of vanadium- or molybdenum-based flux materials, and the introduction of the hydrothermal technique.

The various types of synthetic emeralds are mentioned in chronologic order, emphasizing details of the technology and importance of the production. Several identification techniques are also discussed or explained, accompanied by four photomicrographs. *EF*

Synthèses de l'émeraude [2] (Emerald synthesis [2]). D. Robert, *Revue de Gemmologie a.f.g.,* No. 101, 1989, pp. 5–7.

In the second and last part of this series, Mr. Robert explores progress in emerald synthesis over the last two decades, during which the number of growth processes has increased. After a brief description of the Lennix process, the author states that, in his opinion, the mysterious element mentioned in the "Espig report" (Igmerald synthetic emeralds) as being needed to obtain good crystals is not vanadium, but fluorine. He substantiates his claim by summarizing the theory for the formation of beryl deposits put forth by Beus, a Russian scientist, which incorporates fluorine as a major transport agent. This could be the key to understanding the modern hydrothermal synthesis of emerald or other colored varieties of beryl. This renewed interest in hydrothermal growth may also be due to a better choice for the crystallographic orientation of the seed and better lining materials for the autoclaves. The role of fluorine might be to avoid too fast a polymerization of silica tetrahedra and contribute to a better crystallinity. *EF*

A synthetic by any other name. P. Read, *Australian Gemmologist*, Vol. 17, No. 4, 1989, pp. 153–156.

A number of manufacturers of synthetic gem materials, both past and present, have attempted to avoid using the term *synthetic* in describing their products. Enumerated by the author in this category are "Geneva rubies," "reconstructed rubies," "Chatham Created Rubies," "Pool Emeralds," and "Knischka Created Rubies."

In this report, Read touches on some of the marketing aspects related to the use of these names, including some information on the diagnostic inclusions in the products as they relate to the producers' claims.

This brief article is a useful addition to the ongoing debate on the nomenclature for manmade gem materials. *RCK*

Two remarkable Lechleitner synthetic emeralds. K. Schmetzer, *Journal of Gemmology*, Vol. 22, No. 1, 1990, pp. 20–32.

The first part of this article entails an exhaustive chemical and spectral study of two faceted samples of experimental Lechleitner hydrothermally grown synthetic emerald (*not* overgrowth). Both samples exhibit obvious growth planes parallel to the seed-crystal layer and to the table plane. Distinct color zoning corresponds to these growth planes and is attributed by the author to orientation of the seed plane with respect to the c-axis. The chemical data, not surprisingly, correlate to the color zoning. In addition to the expected presence of chromium and iron, small quantities of nickel and copper were detected. Spectroscopic analysis of optical absorptions revealed the roles of Cr^{3+}, Cu^{2+}, and Ni^{3+}; iron was too low in concentration to show up in the optical spectrum, as the pleochroic colors of the samples would also suggest. Chemical data in conjunction with microscopic examination of growth features lead to conclusions and speculations regarding growth conditions.

The latter part of the article (a summary of the various Lechleitner products) was submitted by the author to Johann Lechleitner in 1988 for corrections and can therefore, as proposed by the author, be considered accurate. It is interesting to note that type A, grown between 1956 and 1958, was flux grown. Types B-E, grown between 1959 and 1972, were all hydrothermally grown. Type F, grown subsequent to 1972, represents a return to flux-growth techniques. Only types B, D, and F were sold commercially. It should be noted that type B, referred to here simply as "synthetic emerald," is in fact the well-known Lechleitner overgrowth product: a thin layer of hydrothermal synthetic emerald over a preformed or faceted natural beryl core. Types D (described in the first part of this article) and F are fully synthetic. Gemological properties and/or references provided for all types make this a useful summary for practicing gemologists. *CMS*

TREATMENT

Spectroscopic evidence of heat treatment of blue sapphires from Sri Lanka – additional data. K. Schmetzer and L. Kiefert, *Journal of Gemmology*, Vol. 22, No. 2, 1990, pp. 80–82.

The color of blue sapphires, both heat treated and untreated, results from Fe^{2+}/Ti^{4+} intervalence transfer absorptions primarily at 559 nm perpendicular to the c-axis and 669 nm parallel to the c-axis. Type I blue sapphires lack the Fe^{2+}/Fe^{3+} absorption at 870 nm found in type II material, but there sometimes occurs a weak Fe^{3+} absorption at 450 nm (with accompanying absorptions at 388 and 376 nm) that does not affect color.

Examination of treated and untreated type I blue sapphires (of undisclosed number) revealed that these Fe^{3+} absorptions generally do not occur in heat-treated type I blue sapphires from any of the localities studied. According to the authors, this is due to conversion of Fe^{2+} to Fe^{3+} in association with rutile dissolution during heating. Weak residual Fe^{3+} absorptions were occasionally observed and are attributed to incomplete conversion of iron resulting from too short a heat-treatment period.

In conclusion, the authors propose that, whereas the presence of weak Fe^{3+} absorptions is somewhat ambiguous, the complete absence of these spectral features can be considered proof of heat treatment. The authors have, to judge by the graphic spectra illustrated, employed a spectrophotometer in this study and it is not stated whether a hand spectroscope is of any use. Moreover, given the varying sensitivities of different makes of spectrophotometers and the varying intensities of absorptions that result in relation to sample size and depth of color (i.e., what is detectable by one instrument may appear to another to be "absent"), further study seems to be needed before this apparently promising test can be considered useful to other investigators. *CMS*