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TABLE OF CONTENTS

ABOUT THE COVER: Blue sapphires, such as those in this sapphire and diamond necklace and earrings, have been one of the most sought-after colored stones for centuries. Many efforts have been made to produce this fine color, most frequently by heating colorless or light-colored corundum. Diffusion treatment is a newer form of enhancement in which coloring agents are used to create color at and just below the surface of a stone. In this issue, a team of GIA specialists investigate blue diffusion-treated sapphires and describe the treatment techniques used, identification of the enhancement, and the durability of the treated stones.

The sapphire and diamond necklace (total weight of sapphires is 109 ct) and earrings (total weight of sapphires is 18 ct) are courtesy of Harry Winston, Inc.

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THE IDENTIFICATION OF BLUE DIFFUSION-TREATED SAPPHIRES

By Robert E. Kane, Robert C. Kammerling, John I. Koivula, James E. Shigley, and Emmanuel Fritsch

Blue diffusion-treated sapphires are becoming more prevalent than ever before. The diffusion technique, which involves the addition of color-causing chemicals during heat treatment, results in a thin layer of color at the surface of colorless or light-colored sapphire. The color was found to be stable to routine cleaning procedures; however, it may be partially or completely removed if the stone is repolished or recut. Recently, significant quantities of so-called "deep" diffusion-treated sapphires have entered the market. This article documents the properties of these and other blue diffusion-treated sapphires, and presents means of identifying this method using simple gemological tests.

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Acknowledgments: The authors are grateful to the following for providing information, gem materials, and research assistance: Karla and Bob Brom, The Rainbow Collection; Jeffery Bergman, Gem Source; Robert K. Stevenson, Long Gems Ltd.; Edward Boehm, formerly of Overland Gems, now of the Gübelin Gemmological Laboratory; Barry Hodgin. Dino DeGhionno, Lorri Dee Rascoe, J. Michael Allbritton, Terry Payne, Loretta Loeb, Sam Muhlmeister, Mike Moon, and Maha Smith, all of GIA; and Shane McClure and Karin Hurwit, of the GIA Gem Trade Laboratory. John Armstrong and Paul Carpenter, of the California Institute of Technology, provided the electron microprobe analyses.

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The heat treatment of pale, colorless, or milky white "geuda" sapphires to produce attractive blue stones has been practiced for a number of decades. These stones have become a staple in today's international gem markets. A different but related color-enhancement technique that emerged in the late 1970s and early 1980s is now also becoming prevalent in the trade: diffusion treatment (see figure 1). This process involves the diffusion at very high temperatures (1700°C and higher) of color-causing transition elements such as iron, titanium, chromium, or nickel (depending on the color desired) into a region that extends just below the surface of the otherwise colorless or very light colored corundum (Carr and Nisevich, 1975). The result is a thin color layer at and just below the surface of the gemstone (see figure 2). This layer may be partially or completely removed if the stone is repolished or recut. It is commonly used on corundum that does not respond to standard heat treatment. Unlike some treatment methods, the diffusion treatment of sapphires does not have any parallel in nature. As Nassau (1981) stated, "the results of diffusion treatment . . . remind one more of Lechleitner synthetic emerald overgrowth on a natural beryl than of heated aquamarine."

Since 1979, numerous brief reports of diffusion-treated corundum have been published (Crowningshield, 1979a and b, 1980; Brauner, 1981; Crowningshield and Nassau, 1981, 1982; Fryer et al., 1981, 1982a and b; Graziani et al., 1981; Leone and Cumo, 1981; Mai, 1981; Nassau, 1981, 1982; Herzberg, 1981; Scarratt, 1981, 1983; Hänni, 1982; Read, 1982; "New CIBJO guidelines given to sapphire description," 1983; Hughes, 1987; Ohguchi, 1983a and b; Kammerling et al., 1990a; Koivula and Kammerling, 1990).

Although relatively little corundum treated in this manner was seen in the mid- to late 1980s, it appears to have become quite prevalent in the international gem markets in recent months. In late 1989, several blue diffusion-treated sapphires (and samples of starting mate-

Figure 1. These blue sapphires (0.67–2.85 ct) have all been diffusion treated, reportedly by a process that produces an unusually deep layer of color at and just under the surface of the stone. Courtesy of Gem Source; photo by Shane F. McClure.

rial) were donated to GIA by Karla and Bob Brom, of The Rainbow Collection, Honolulu, Hawaii (figure 3). They report (pers. comm., 1990) that they have received 500 ct of faceted and cabochon-cut material from a scientist in Bangkok, Thailand, who purports to use a complex treatment process involving eight to 10 separate heating periods of 40 hours each.

More recently, at the 1990 Tucson Show, significant quantities of faceted blue diffusion-treated sapphires were offered for sale by Gem Source, of Las Vegas, Nevada, and Bangkok, Thailand (again, see figure 1). According to a promotional flier provided by the vendor, these blue sapphires had been subjected to "new techniques resulting in much deeper penetration of the metal ions. The penetration is so deep that many stones treated with this method are entirely recut, with a weight loss of over 10%, yet they retain a fine color." According to a report in *Jewellery News Asia* ("New colour diffusion for sapphires," 1990), the vendor claims that about 25,000 ct of this material have been treated and repolished, with 12,500 ct currently in the world market. Trade sources and our own observations at Tucson indicate that a number of vendors are now selling diffusion-treated blue sapphires.

Another point of interest not previously mentioned in the literature is the experimentation in Bangkok, Thailand, with diffusion treatment that involves not only iron and titanium, but also other color-causing impurities such as cobalt. We had an opportunity to examine a number of these stones as well.

To better understand the different types of diffusion-treated stones on the market, the pro-

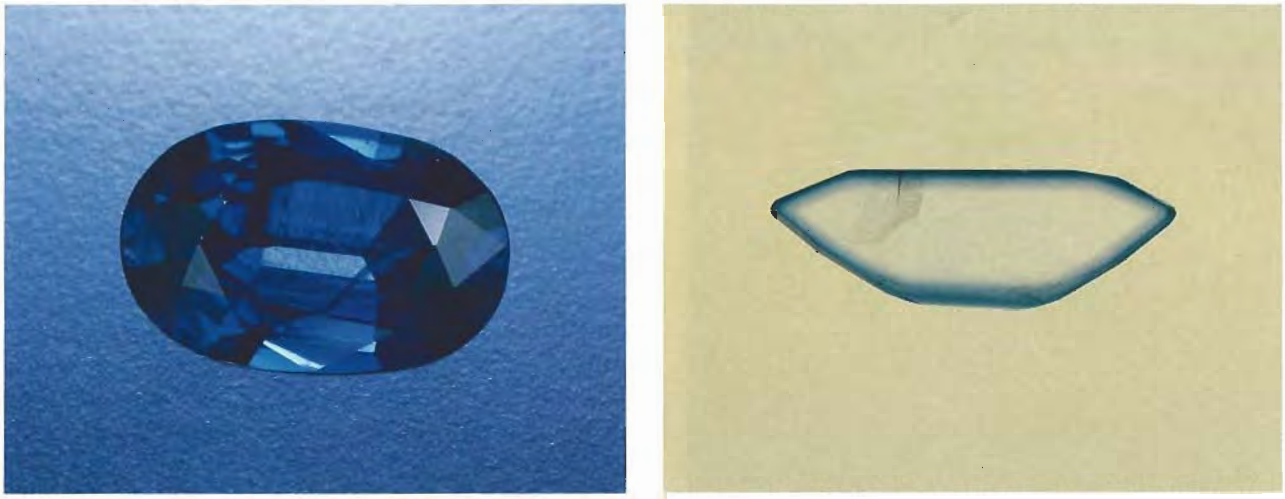


Figure 2. The color of a blue diffusion-treated sapphire is confined to a shallow layer that has been produced by diffusing chemicals into the surface of a fashioned gem. The 1.45-ct stone on the left was supplied by Gem Source, and is marketed as a "deep" diffusion-treated sapphire. A 1.3-mm-thick section was sawed from the center of this stone. The polished section (right) reveals the near-colorless natural sapphire core and the induced blue surface layer, which is approximately 0.4 mm deep. Photos by Shane F. McClure.

cesses used, the best means of identification, and the durability of these stones in various cleaning and repair situations, we performed a variety of tests and experiments on a number of blue diffusion-treated sapphires. The following report reviews the history of this enhancement, discusses the results of our research, and presents simple techniques that can be used to readily identify natural fashioned sapphires that have been treated in this manner.

Although some references will be made to the (apparently experimental) cobalt-doped material, the article will focus an iron-titanium diffusion, which appears to be most common.

HISTORY OF DIFFUSION TREATMENT AND DISCLOSURE PRACTICES

History. The diffusion treatment of colorless or very light colored corundum to produce blue sapphire is the application of U.S. Patent No. 3,897,529—"Altering the Appearance of Corundum Crystals"—issued on July 29, 1975, to Carr and Nisevich of Union Carbide Corp. Union Carbide's Japanese patent on this same process (No. 115998) was issued on November 6, 1975. In these patents, this particular treatment process was described in detail combined with a process intended for inducing or improving asterism in synthetic rubies and sapphires (which was patented in 1949 by Burdick and Glenn, also of Union

Figure 3. In Fall 1989, we received this group of blue sapphires which had been treated in Bangkok. The faceted stones (1.21–2.22 ct) may represent yet another commercial source of diffusion-treated corundum in the 1990s. The rough pieces (2.85–5.46 ct) represent heat-treated material that did not produce satisfactory results—the type commonly used as the "starting" material for diffusion treatment. Stones courtesy of the Rainbow Collection; photo by Shane F. McClure.

Figure 4. In the early 1980s, a gem dealer in Bangkok supplied six different heat-treating operations with light-colored Montana sapphire rough (as seen in the center of this photo). Five lots of the heat-treated sapphires were returned with little or no improvement in color. The sixth operation, however, returned intensely colored blue sapphires to the dealer (as seen here on either side of the original light-colored rough). Subsequent cutting revealed that the blue color was confined to a thin superficial layer: The sapphires had been diffusion treated. The largest piece weighs 0.75 ct. Photo by Shane F. McClure.

Carbide). Carr and Nisevich later described this treatment procedure as a separate process (1976 and 1977). When the Linde division of Union Carbide ceased production of synthetic star corundum, all four of these patents were assigned to Astrid Corp. of Hong Kong, which had acquired Linde's stock of synthetic star rubies and star sapphires (Nassau, 1981). Astrid Corp., a member of the Golay Buchel group, produced diffusion-treated sapphires in Bangkok until the early 1980s (D. Biddle, pers. comm., 1990).

However, it appears that diffusion treatment is being practiced by other firms. In late 1984, a Bangkok gem dealer reported to one of the authors (R. Kane) that he had given very light colored sapphire rough from Montana to six different persons involved in the heat treatment of corundum in Thailand. Five of the heat treaters returned the treated sapphires with very little or no apparent improvement in color. The sixth person, however, presented the Bangkok dealer with the intensely colored blue sapphire rough shown on either side of the untreated material in figure 4. Elated over the apparently successful heat treatment, the Bangkok dealer began organizing the purchase of large quantities of Montana sapphire rough. When he cut a portion of the treated rough, however, he discovered that the blue color was confined to a very thin area near the surface (R. K. Stevenson, pers. comm., 1984). In June of 1990, Bob Crowningshield of the East Coast GIA Gem Trade Laboratory reported seeing another lot of diffusion-treated Montana sapphire rough that was being marketed as heat-treated material.

Disclosure Practices. Although there is no worldwide agreement concerning disclosure practices for the heat treatment of blue sapphire, there is general consensus in the trade that disclosure of diffusion-treated corundum is essential because the added color is confined to a surface layer. Consequently, while the terminology may vary, corundum treated in this manner is nearly always described as synthetically or artificially colored. For example, the GIA Gem Trade Laboratory issues the following conclusion on identification reports:

> DIFFUSION-TREATED NATURAL SAPPHIRE
>
> Note: The color of this stone is confined to a shallow surface layer that has been produced by diffusing chemicals into the surface by heat treatment.

THE DIFFUSION MECHANISM

The color in blue sapphire is due to Fe^{2+}-O-Ti^{4+} charge transfer, influenced by $Fe^{2+} \rightarrow Fe^{3+}$ charge transfer and Fe^{3+} absorptions (Smith and Strens, 1976; Schmetzer, 1987). Diffusion treatment first brings the necessary iron and titanium coloring agents into contact with the stone's surface. The stone is then heated, sometimes to just below its melting point, causing the corundum lattice to expand and allowing the thermally energized transition metal ions to migrate into a layer at the surface, resulting in a near-surface concentration of color.

Generally speaking, the higher the temperature maintained and the longer the time used for the heating step, the greater the depth of color penetration will be. In this regard, the possible difference between so-called "deep" diffusion treatment and earlier diffusion-treated stones may be in a higher temperature being reached and/or maintained. It may also be in the use of more than one heating stage in the treatment procedure. J. Bergman reports (pers. comm., 1990) that the Gem Source stones undergo multiple heatings; that is, after the stones are cooled, they are usually reheated several times. As mentioned above, a similar process was claimed by the Bangkok supplier of the Rainbow Collection stones. Bergman also reports that their process can require treating over the course of two months for some stones.

The Diffusion Treatment Process. Classically, colorless or light-colored fashioned corundum is first embedded in a powder that consists of a major amount of aluminum oxide, a minor amount of titanium oxide, and a lesser amount of iron oxide, which has been placed in an alumina crucible (figure 5). The crucible is then subjected to extended heating in a furnace. Carr and Nisevich (1975) reported that the heating time can vary from two to 200 hours. The elevated temperature will usually range from about 1600°C to about 1850°C, with 1700°C to 1800°C preferred. At temperatures below 1600°C, the process becomes uneconomically slow; at excessively high temperatures, the surface of the sapphire may be damaged (Carr and Nisevich, 1975). In practice, the surface of the corundum usually does become "pockmarked" and show some melting (figures 6 and 7), which indicates that the higher temperatures have been used. The light repolishing required may result in the complete removal of the diffused color from the girdle and/or some facets. Figure 8 illustrates the appearance of sapphires at various stages in diffusion treatment; again, see figure 2 for an illustration of the color penetration. J. Bergman reports a recovery rate of only 60% for the diffusion-treatment process Gem Source uses, because many of the stones are severely damaged by the high temperatures used ("New colour diffusion for sapphires," 1990).

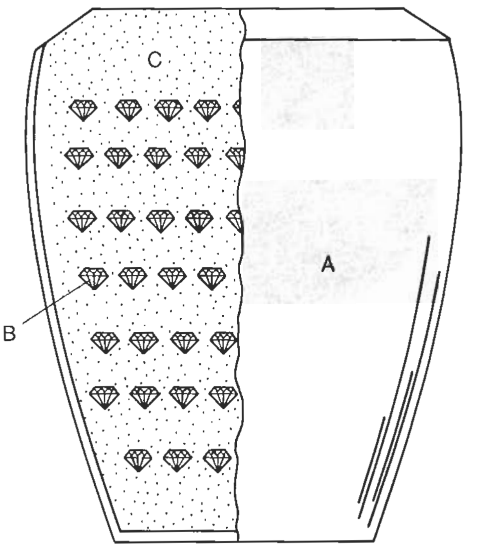


Figure 5. To produce moderate to deep blue coloration by diffusion treatment, the colorless or light-colored corundum (B) is placed in a crucible (A) while its entire surface is in contact with a powder (C) comprising a major amount of aluminum oxide and minor amounts of titanium and iron oxides. The crucible is then exposed to extended heating at very high temperatures (1700°C to near the melting point of corundum, 2050°C). Adapted from U.S. Patent 3,897,529.

The thickness of the treated zone (before repolishing) would logically depend on the length and number of heatings and the temperature attained, as mentioned above. To determine the thickness of the diffusion color layer after repolishing, we sectioned and polished three blue diffusion-treated sapphires representing both early (Astrid Corp.) and more recent (Rainbow Collection and Gem Source) production (figure 9, top).

The polished sections revealed that most of the treated zones consisted of two different levels of color (figure 9, bottom), both of which we measured at the table edge on all stones. The blue diffusion layer of the Astrid Corp. material measured 0.20 mm in total depth; the top portion of this was a darker 0.07-mm primary layer. The blue diffusion layer of the Rainbow Collection stone measured approximately 0.15 mm in total depth, of which 0.03 mm was a darker primary layer. The blue diffusion layer of the Gem Source stone measured a total depth of 0.42 mm; the darker primary surface layer in this stone was 0.12 mm. In

Figure 6. Partially reflected light reveals the rough, sintered surface on this unrepolished 3.37-ct diffusion-treated sapphire. Courtesy of Gem Source; photo by Shane F. McClure.

this instance, the color layer in the Gem Source sample was twice as deep as in one comparison stone and almost three times as deep as in the other.

For additional comparison, we sectioned and measured a Gem Source diffusion-treated sapphire that had not been repolished. This section showed a dark blue layer that measured approximately 0.10 mm at the table edge. In contrast to the finished Gem Source section (figure 9), the "rough" piece did not show an obvious secondary layer. J. Bergman (pers. comm., 1990) reported that this sample had not completed the multiple-heatings procedure because of fracturing early in the process. The fact that the limited heating produced only a single layer suggests that the multiple layers are produced by multiple stages of the diffusion process, as was reported (see above) for both the Gem Source and Rainbow Collection stones.

Figure 8. These three stones (1.10–3.37 ct) represent the various stages involved in producing diffusion-treated blue sapphires: Left, the starting material is a faceted colorless (or light-colored) sapphire; center, the use of chemicals and extreme heat produces a dark blue stone with rough, corroded, and "pockmarked" surfaces; right, repolishing produces a finished blue diffusion-treated sapphire. Courtesy of Gem Source; photo by Shane F. McClure.

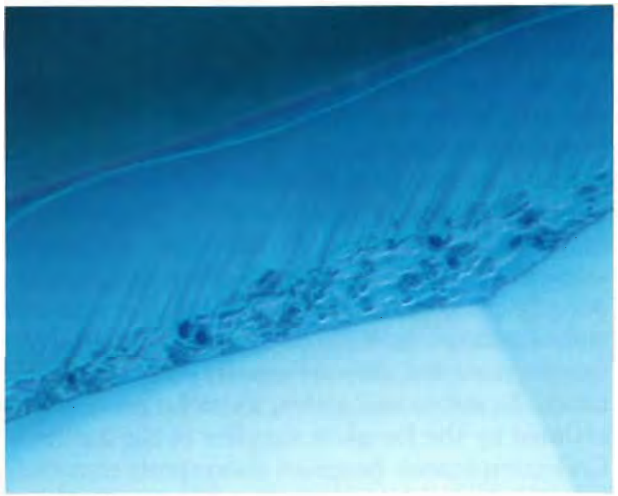


Figure 7. "Light" repolishing of a diffusion-treated stone often produces a "double girdle" and may leave a melted or sintered surface, which is evidence of the very high temperatures used. Photomicrograph by Robert E. Kane; darkfield illumination, magnified 25×.

It is important to note that the measurements provided here can vary significantly because of several different factors: (1) temperature and length of heating, as well as number of heatings; (2) extent of repolishing; (3) preparation of the sample for measuring (if the large "face" on the polished section is not perpendicular to the table, the true thickness of the treated zone will be exaggerated); and (4) variation in measurements from one side of a particular section to the other.

Although any of several colors can be induced by this process (Carr and Nisevich, 1975; see table 1), blue diffusion-treated sapphires are the most prevalent on the market at the present time. It is interesting to note, however, that the first diffusion-treated sapphire seen in the GIA Gem Trade

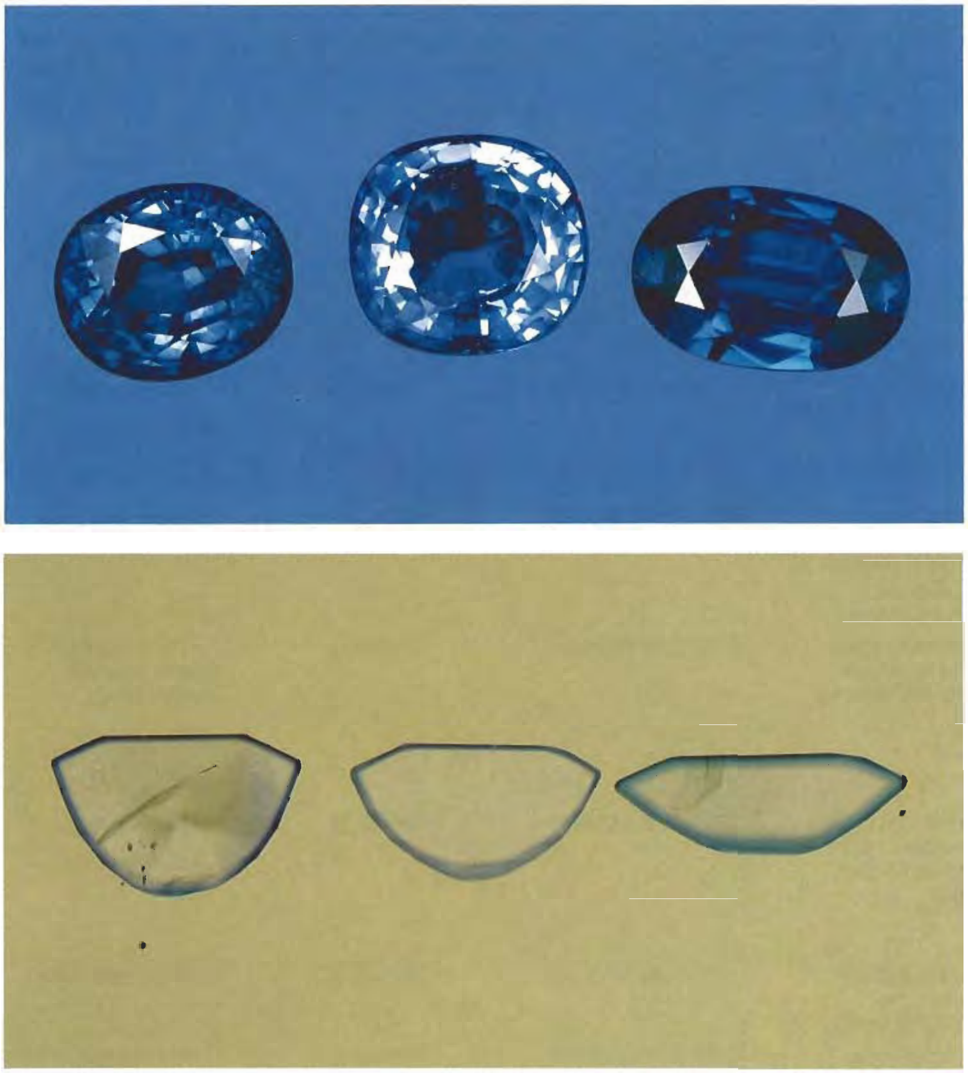


Figure 9. To determine the thickness of the diffusion color layer after repolishing, three representative samples were selected (top): left, 2.24 ct, from the Astrid Corp.; center, 2.22 ct, from the Rainbow Collection; and, right, 1.45 ct, from Gem Source. All show a dark outlining of blue around the girdle that is common in diffusion-treated stones. The three samples were sawed down the center and polished, producing sections about 1.3 mm thick. As seen here (bottom), immersed in methylene iodide over diffused transmitted light, the color layer ranged from 0.15 to 0.42 mm thick. Note the two layers of color in the stones. In this limited sample, the color layers are thicker in the "deep" diffusion-treated stone on the far right. Photos by Shane F. McClure.

Laboratory was red-orange (Crowningshield, 1979).

IDENTIFICATION OF BLUE DIFFUSION-TREATED SAPPHIRES

Materials and Methods. To establish identifying features of blue diffusion-treated sapphires, we examined 40 stones, ranging from 0.63 to 5.46 ct: nine faceted samples obtained from Astrid Corp. in 1981; 11 (five faceted and three cabochon-cut diffusion-treated stones, plus three rough heat-treated stones that were allegedly the starting material for the diffusion-treated stones) obtained from the Rainbow Collection in late 1989; 14 (one faceted untreated colorless sapphire plus two faceted [not repolished] and 11 faceted [repolished] diffusion-treated stones) obtained from Gem Source in February 1990; and six "rough" preforms that had been diffusion treated in Thailand using various oxides including iron, titanium, and cobalt. We also referred to numerous stones examined in the GIA Gem Trade Laboratory over the past 10 years to draw our conclusions.

The study material was subjected to standard gemological testing procedures (refractive index, specific gravity, pleochroism, absorption spectra as viewed through both prism and diffraction-grating spectroscopes, reaction to ultraviolet radiation, microscopy using various types of illumination, and immersion). Specific samples were also subjected to high-resolution spectrometry analysis of the ultraviolet-visible and near-infrared portions of the spectrum; microprobe analysis; and energy-dispersive X-ray fluorescence spectrometry (EDXRF) analysis. The results for the Astrid Corp., Rainbow Collection, and Gem Source stones—all of which were diffusion treated with iron and titanium—are presented below. The results for the

TABLE 1. Examples of diffusion-treated corundum experiments cited in United States Patent 3,897,529, July 29, 1975, titled "Altering the Appearance of Corundum Crystals," by R. R. Carr and S. D. Nisevich of the Union Carbide Corporation.

Starting color of corundum	Powdered addition agents (in wt.%)	Temperature and length of heating	Heating environment	Resulting appearance and color
1. Reddish purple sapphire and ruby with low color saturation or nonuniform color	6% chromium oxide, 24% titanium oxide, and 70% alumina	1750°C for 96 hours	Oxidizing	Uniform "ruby red"
2. Yellow sapphire with nonuniform color or too high or too low a color saturation	3%–6% chromium oxide, 24% titanium oxide, and the remainder alumina	1750°C for 48 hours	Oxidizing	Uniform "salmon pink"
3. Yellow sapphire with nonuniform color or too low a color saturation	2.5% nickel oxide, 3.5% chromium oxide, 15% titanium oxide, and the remainder alumina	1750°C for 96 hours	Oxidizing	Uniform light gray-green
4. Pink sapphire with nonuniform color, black sapphire with nonuniform color, and white sapphire with nonuniform color	22% titanium oxide and the remainder alumina (no coloring agent)	1750°C for 96 hours	Oxidizing	Uniform color (pink, black, or white, respectively)
5. Milky white sapphire with nonuniform color or undesirable color such as grayish tinge	6% chromium oxide, 22% titanium oxide, and the remainder alumina	1750°C for 96 hours	Oxidizing	Uniform pink
6. Pale blue sapphire with nonuniform color	10%–15% titanium oxide and the remainder alumina	1750°C for 96 hours	Reducing	Uniform pale blue
7. Deep blue sapphire with nonuniform color	0.1%–0.5% ferric oxide, 12%–18% titanium oxide, and the remainder alumina	1750°C for 30 hours	Reducing	Uniform deep blue

stones into which cobalt was incorporated, which are not commonly seen commercially, are presented in the accompanying box.

Most of the gemological properties of the iron and titanium–doped blue diffusion-treated sapphires studied overlap those of unheated and heat-treated blue natural sapphires. Visual examination of immersed stones reveals easily detectable identifying characteristics of surface-diffused coloration.

Visual Appearance and Optical and Physical Properties. The refractive indices, birefringence, and specific gravity of diffusion-treated stones do not differ significantly from those of natural-color and heat-treated stones. Furthermore, the pleochroism is consistent with that of natural-color and heat-treated blue sapphires of comparable depth of color even though the color is concentrated in a shallow surface layer. This indicates that the diffusion layer is crystalline, not amorphous. In addition, the fashioned diffusion-treated sapphires studied varied from blue to violetish blue in moderate to very dark tone, which overlaps the colors seen in both natural and heat-treated sapphires.

However, when we examined these diffusion-treated sapphires with the unaided eye in sunlight or overhead artificial illumination, we observed in many of them a "watery" appearance, that is, a decrease in transparency that was not caused by visible inclusions. This is probably a result of the concentrated diffusion of color-causing impurities

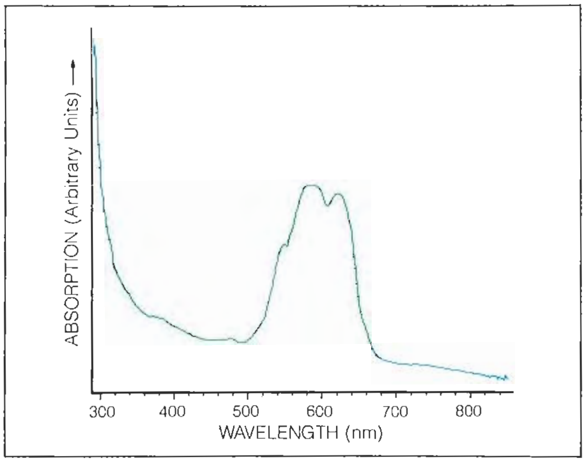
EXPERIMENTAL(?) COBALT-DOPED BLUE DIFFUSION-TREATED SAPPHIRES FROM BANGKOK

In the course of this study, we also examined six blue diffusion-treated sapphire "preforms" that were reported to contain varying amounts of cobalt. The samples were obtained by one of the authors (R. Kane) in Bangkok, where they reportedly were treated, in 1984.

The U.V.–visible absorption spectrum of a cobalt-doped blue diffusion-treated sapphire is illustrated in the accompanying figure for random orientation. The color is mainly caused by three intense merging absorption bands with apparent maxima at about 550, 590, and 620 nm. Minor absorptions are present at about 375, 388, 410, 450, and 479 nm.

These bands correspond to those attributed to cobalt in synthetic blue spinels by Anderson and Payne (1937) and Webster (1983), and in natural blue spinel by Shigley and Stockton (1984). Therefore, we interpret this spectrum as being due to Co^{2+}. Because these absorption bands are not naturally occurring in sapphire, when observed in corundum they can be considered diagnostic of cobalt diffusion treatment.

It is interesting to note that the diffusion process introduces cobalt in the corundum lattice as Co^{2+}, although this element is incorporated as Co^{3+} in Co-doped synthetic sapphires. Co^{2+} has never been reported in the spectrum of natural sapphire.



In this U.V.–visible absorption spectrum of a cobalt-doped blue diffusion-treated sapphire, the three merging bands between 500 and 700 nm are due to Co^{2+}.

The cobalt-doped diffusion-treated sapphires were also examined through a Chelsea color filter while illuminated by intense transmitted light. Through the filter the stones appeared a moderate patchy to intense uniform red, the intensity and distribution of the filter color correlating with the depth and distribution of blue color of the stones. The reaction is consistent with that of cobalt-doped synthetic blue spinel of similar color.

into the surface of the sapphire. Also, a dark outline of blue could be seen around the girdle in a number of stones (again, see figure 9, top).

Absorption Spectra. The absorption spectra (400 nm to 700 nm) of all the treated sapphires were examined through both a Beck prism spectroscope mounted on a GIA GEM Instruments spectroscope unit and a GIA GEM DISCAN diffraction-grating spectroscope. Five of the Astrid stones and one of the Gem Source stones exhibited a weak absorption band at 455 nm, while four of the Gem Source stones, one of which was the colorless "starting material" stone, exhibited a fluorescent line at 693 nm; none of the other stones examined showed any lines or bands. All of these features are consistent with those seen in natural-color or heated sapphires from various localities. Thus, spectra observed through a hand-held type of spectroscope do not provide a means of identifying blue diffusion-treated sapphires.

Ultraviolet Fluorescence. The reactions of the sample stones to long- and short-wave U.V. radiation were found to overlap those of natural-color and/or heat-treated blue sapphires from various localities. In this regard, it is interesting to note that many heat-treated blue sapphires exhibit a chalky whitish blue to green fluorescence when exposed to short-wave U.V. radiation, whereas natural-color blue sapphires do not exhibit this characteristic reaction (Crowningshield and Nassau, 1981). Despite the extreme heat used in the process, some of the blue diffusion-treated sapphires did not fluoresce to short-wave U.V. radiation. This was the case for all but one of the Astrid Corp. stones and for one of the Rainbow Collection samples. It is possible that the dominance of iron as a coloring agent in these stones (see discussion of chemistry below) quenches any fluorescence that may otherwise have been induced by heat.

One of the Astrid stones, however, showed a small, chalky patch of moderate yellowish green

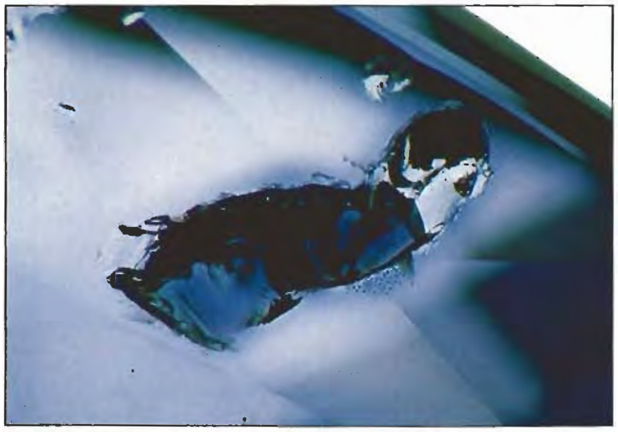


Figure 10. Dark concentrations, or "bleeding," of color are often seen in and around surface-reaching breaks and cavities in blue diffusion-treated sapphires. Photomicrograph by Robert E. Kane; diffused illumination, magnified 30×.

fluorescence when exposed to short-wave U.V. radiation; eight of the Rainbow Collection stones and 12 of the stones from Gem Source fluoresced a moderate chalky yellowish green, and one of the Rainbow Collection stones fluoresced a strong bluish white, also to short-wave U.V.

In addition, one of the Rainbow Collection stones fluoresced a strong orange to long-wave U.V. and a weak orange to short-wave U.V.; one of the Gem Source diffusion-treated stones fluoresced a weak pinkish orange to long-wave U.V. and a chalky yellowish green to short-wave U.V. A strong pinkish orange fluorescence to long-wave U.V. and very weak pinkish orange to short-wave U.V. has been noted in the past for some natural, untreated Sri Lankan sapphires, both colorless and blue. The combination of a pinkish orange reaction to long-wave, and a chalky yellowish green reaction to short-wave, U.V. would be consistent with some heat-treated Sri Lankan sapphires, although it would not separate those that had been diffusion treated.

In general, then, U.V. fluorescence reaction does not provide diagnostic information for the identification of diffusion treatment.

Magnification. While magnification alone is usually not sufficient to identify that a stone has been diffusion treated, it will provide clues to the fact that the stone has been heated in some fashion.

The evidence of treatment at high temperatures that is seen in sapphires with magnification includes: stress fractures surrounding inclusions; melted crystals; partially absorbed and dot-like rutile "silk"; blotchy color banding or diffused zoning; and pockmarked surfaces (see, e.g., Kammerling et al., 1990b). These features are frequently seen in diffusion-treated sapphires, but they provide proof only of high-temperature treatment. Of particular use in the identification of diffusion treatment is the "bleeding" of color in and around surface-reaching pits and fractures (figure 10), which is a localized reaction to the diffusion process.

Immersion. The most effective means of detecting a diffusion-treated stone is its appearance when immersed in methylene iodide and examined in diffused transmitted light; this simple procedure is described and illustrated in figure 11. When examined in this fashion, all of the diffusion-treated stones studied (figure 12) showed one or both of the following:

1. Greater relief, as indicated by a concentration of color along facet junctions and around the girdle (figure 13).
2. Localization and blotchiness of color caused by a combination of uneven diffusion and light repolishing (figure 14); the girdle and some facets may have the diffused color completely removed (figure 15).

Blue sapphires not treated in this manner will show low relief in methylene iodide; the facet junctions generally are not easily visible (see left view in figure 16). Note, however, that abraded facet junctions may have high relief when immersed. To illustrate this effect, we selected two virtually identical flame-fusion synthetic blue sapphires and held one as a control sample while the other was polished for approximately 48 hours in a vibratory tumbler with Linde A as an abrasive. Figure 17 shows the two stones immersed in methylene iodide; although the effect was exaggerated for the purpose of this research, the greater relief of a stone with abraded facet functions (e.g., with an appearance similar to that of the stone on the left in figure 17) could cause some confusion for the gemologist.

The two stones in figure 18 are also potentially misleading. The 5.40-ct Montana sapphire on the left has an additional tiny flat facet at the junction of most of the pavilion facets (where ordinarily

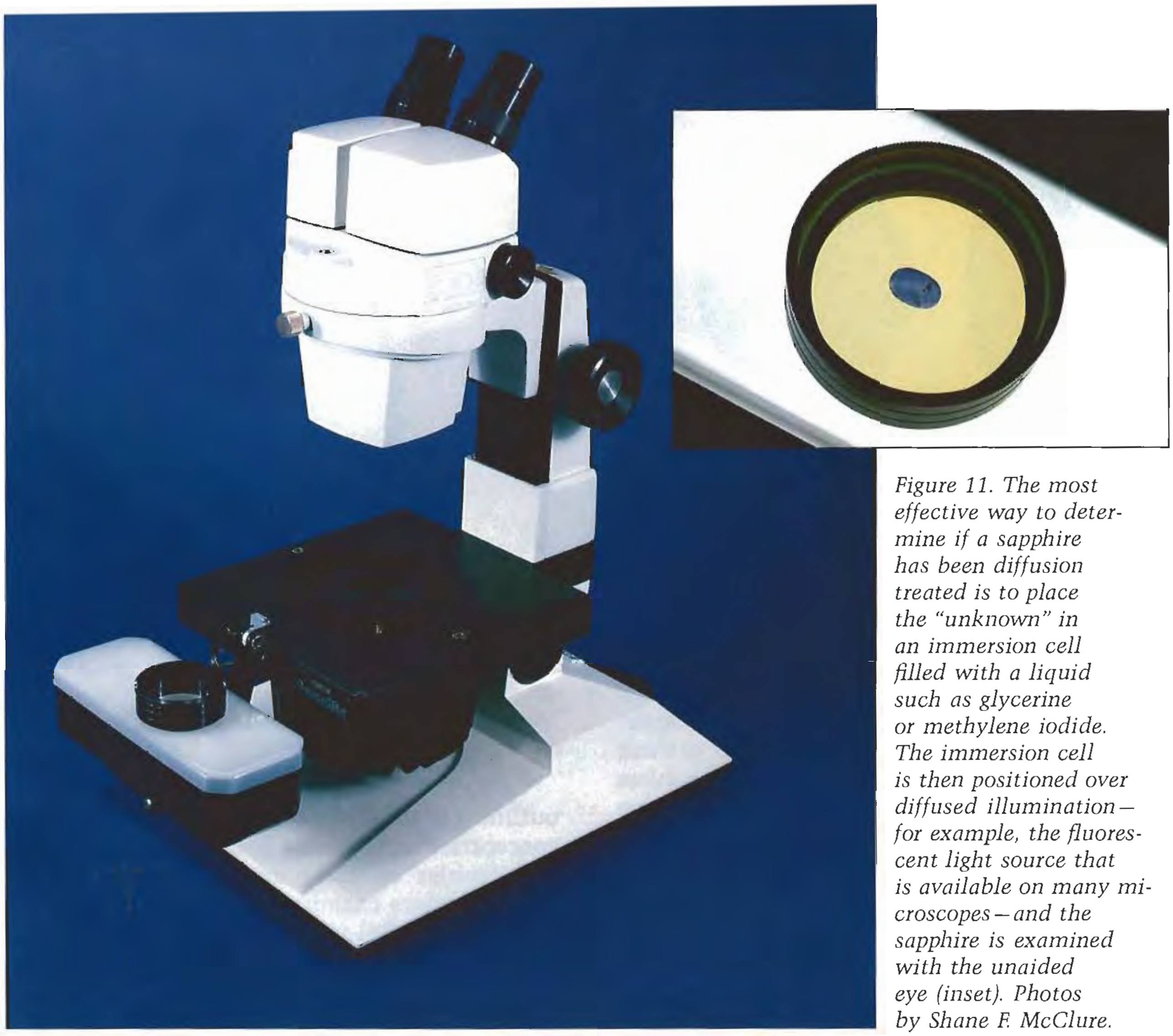


Figure 11. The most effective way to determine if a sapphire has been diffusion treated is to place the "unknown" in an immersion cell filled with a liquid such as glycerine or methylene iodide. The immersion cell is then positioned over diffused illumination—for example, the fluorescent light source that is available on many microscopes—and the sapphire is examined with the unaided eye (inset). Photos by Shane F. McClure.

Figure 12. Immersed in methylene iodide over transmitted diffused illumination, this selection of diffusion-treated sapphires, from various "manufacturers," reveals the characteristic identifying features. These include: greater relief due to color concentrations at facet junctions, blotchiness of the diffused color layer, and areas without color. Photo by Shane F. McClure.

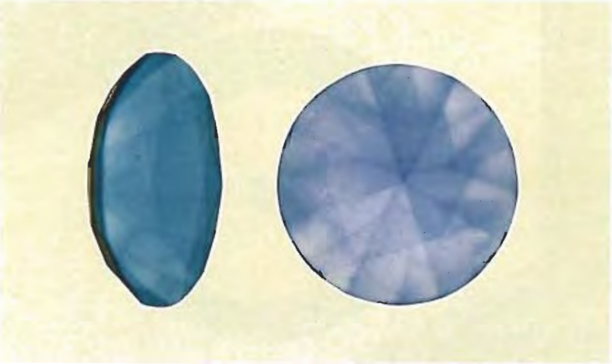


Figure 13. Proof of diffusion treatment in a faceted blue sapphire is provided by concentrations of color along facet junctions and/ or the girdle. Photo by Shane F. McClure.

there would be a sharp edge). This created a subtle blue outlining of these facet junctions when the stone was immersed and examined over diffused illumination. The 1.77-ct Kashmir sapphire on the right has abraded facet junctions. Neither of these stones was diffusion treated. Many blue sapphires also show strong growth and color zoning (figure 19), but their appearance is still significantly different from that of diffusion-treated stones.

Detecting diffusion treatment in cabochons may be considerably more difficult, as they lack the many sharp junctions on which color concentrates in their faceted counterparts. On the three cabochons the authors examined for this report, the one diagnostic feature noted was a dark color outlining of the girdle edge (figure 20). Deep color concentrations have also been observed in cracks and cavities on these and other cabochon-cut stones we have examined.

Because methylene iodide is somewhat toxic to breathe (particularly for extended periods of time)

Figure 14. In addition to high relief and color concentrations at facet junctions, immersion may also reveal a blotchiness of the diffused color layer caused by a combination of uneven diffusion and light repolishing. Photo by Shane F. McClure.

Figure 15. Heavy repolishing of a badly melted or sintered diffusion-treated sapphire can result in the removal of the diffused color from the girdle and some facets. Note that immersion reveals this effect on all sides of the girdle. Photomicrograph by Robert E. Kane; transmitted diffused illumination, magnified 15×.

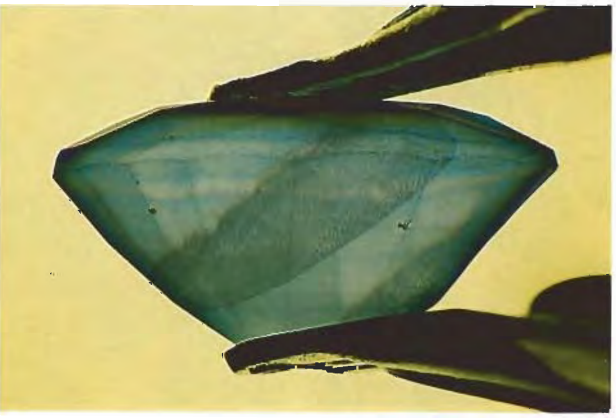
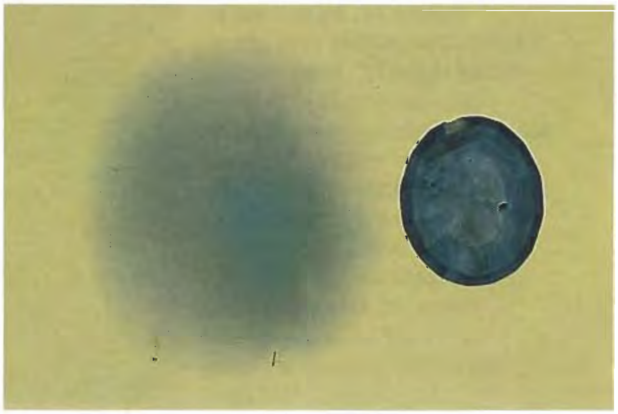


Figure 16. A natural blue sapphire (left) is shown here next to a diffusion-treated sapphire (right), both immersed in methylene iodide over diffused transmitted illumination. With immersion, the natural sapphire on the left has low relief and does not show any facet junctions. In contrast, the diffusion-treated stone has much greater relief, as exemplified by a blue outlining of facet junctions. Photo by Shane F. McClure.



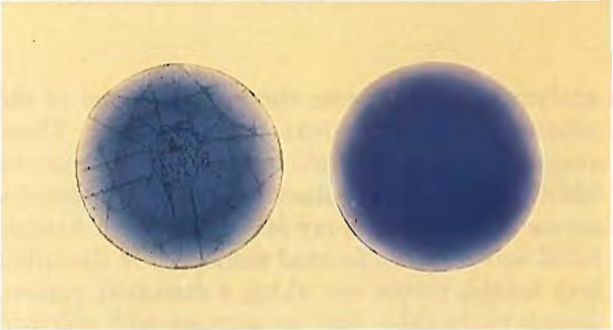


Figure 17. To illustrate how abraded facet junctions on a non-diffusion-treated sapphire could cause confusion—i.e., high relief—we selected two virtually identical flame-fusion synthetic blue sapphires. One was held as a control sample (right) and the other was tumble polished to intentionally abrade the facet junctions. The tumble-polished stone (left) now shows high relief of facet junctions with immersion. Photo by Shane F. McClure.

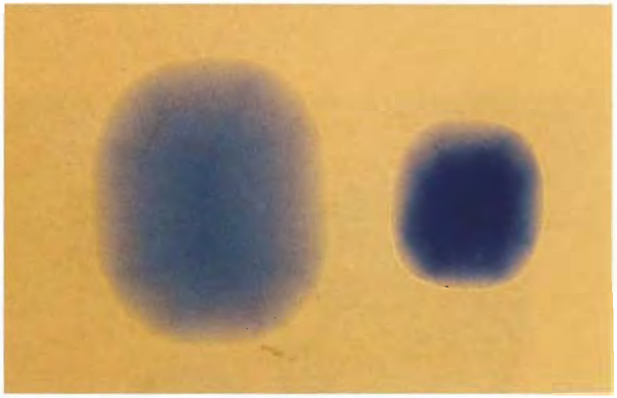


Figure 18. On occasion, natural untreated sapphires may exhibit confusing features when examined with immersion over diffused illumination. The 5.40-ct Yogo Gulch, Montana, sapphire (left; courtesy of Rogers Jewelers, Great Falls, Montana) possessed a tiny flat facet at the junction of most of the pavilion facets. This created a subtle blue outlining of these facet junctions. The 1.77-ct untreated Kashmir sapphire (right) shows a higher relief caused by abraded facet junctions. Photo by Shane F. McClure.

or if absorbed through the skin, we experimented with different immersion media. We selected three stones, one each from Astrid Corp., the Rainbow Collection, and Gem Source (again, see figure 9). We placed the three stones table-down in an immersion cell over diffused (through white translucent plastic) transmitted illumination in: (A) air (R.I. 1.00), (B) water (R.I. 1.33), (C) glycerine (R.I. 1.47), and (D) pure methylene iodide (R.I. 1.75; Weast et al., 1988). Figure 21 shows the appearance produced by each medium. In some cases, diffused illumination in air is sufficient to identify a diffusion-treated sapphire; in others, immersion in methylene iodide is necessary (the closeness in R.I. helps accentuate treatment features). We found that glycerine, which is colorless and quite innocuous, provided an excellent immersion fluid for routine testing. Although it is quite viscous, it cleans off easily with a tissue and water. We also experimented with several other immersion fluids and found that satisfactory results were achieved

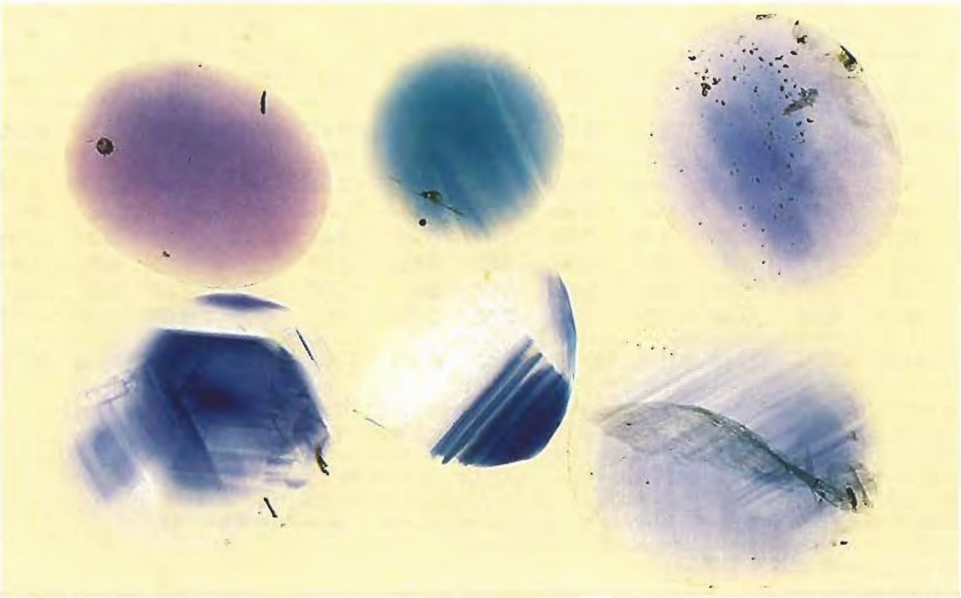


Figure 19. With immersion, non-diffusion-treated blue sapphires can show a variety of appearances, such as color zoning and inclusions. These stones are still easily identifiable by their lack of features typical of diffusion-treated sapphires. Photo by Shane F. McClure.

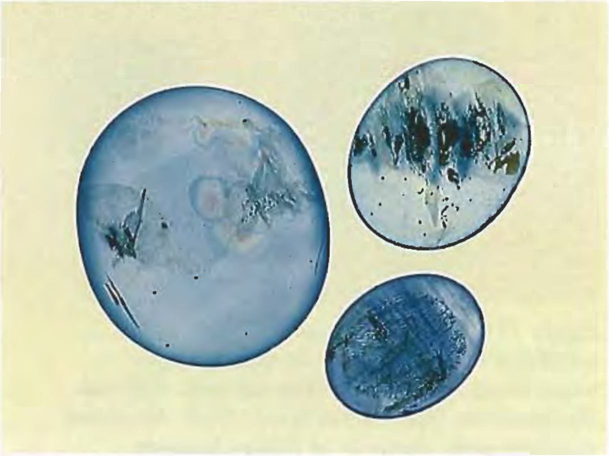


Figure 20. Cabochon-cut blue diffusion-treated sapphires show a characteristic dark blue outlining of the girdle. They may also show "bleeding" (concentrations) of color in surface-reaching breaks. If mounted in a bezel setting, particularly one that is closed backed, cabochon-cut sapphires treated in this manner could, indeed, be difficult to identify. Photo by Shane F. McClure.

with many and, in particular, with oils such as sesame oil.

Chemical and Spectral Data. Five representative blue diffusion-treated sapphires were chemically analyzed to investigate the compositions of the interior and surface areas of each sample. These analyses were performed by electron microprobe (JEOL 733) and X-ray fluorescence (XRF) spectrometry (a TRACOR X-ray Spectrace 5000). Sample R302 was left as a faceted stone, while the other four samples were cut along a direction perpendicular to the table into flat sections with polished parallel sides. This permitted microprobe analysis of both the near-surface region affected by the diffusion treatment process, as well as the unaffected interior portion of each sample.

The electron microprobe was used to obtain quantitative analyses of each sample (table 2). The faceted sapphire, R302, was analyzed at three separate locations on the table. The other four samples, in the form of polished sections, were analyzed at several locations – one near the surface of the table, and three or four further locations at progressively greater depths into the stone. The elements Ca, Cr, Co, Ni, Ga, and Cu were found to be below or near the detection limit of the instrument (approximately 0.01 wt.% oxide), and to display no particular distribution patterns. For Fe and Ti, however, a distinct pattern was noted with both elements increasing in concentration (between two- and 10-fold) from the interior to the surface (where diffusion occurred), as shown in figure 22. The plot of findings in figure 22 also

TABLE 2. Chemical analyses of five blue diffusion-treated sapphires.[a]

Wt.% oxide		R302 (Gem Source)				R296 (Gem Source)					R293 (Gem Source)				
	Analysis no.	1	2	3	Average	1	2	3	4	5	1	2	3	4	5
	Depth[b]	0	0	0	0	>200	170	120	70	~20	>200	150	110	70	~20
Al_2O_3		99.37	98.69	98.96	99.01	100.07	99.73	99.62	99.37	98.64	99.44	98.99	99.23	98.59	98.50
CaO		bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.01	bdl
TiO_2		0.22	0.24	0.23	0.23	0.03	0.14	0.15	0.20	0.19	0.03	0.08	0.12	0.16	0.23
Cr_2O_3		0.01	bdl	bdl	bdl	bdl	bdl	0.03	0.01	bdl	0.01	bdl	bdl	bdl	bdl
FeO		0.87	0.82	0.81	0.83	0.10	0.19	0.25	0.42	0.49	0.09	0.06	0.18	0.41	0.99
CoO		0.01	0.02	bdl	0.01	bdl	bdl	0.02	0.03	0.03	0.02	bdl	bdl	bdl	bdl
NiO		0.05	bdl	bdl	0.01	0.01	bdl	bdl	0.07	bdl	0.03	0.02	0.02	bdl	bdl
CuO		0.07	bdl	0.04	0.03	0.04	0.04	0.02	0.02	0.02	0.02	0.02	0.05	0.02	0.01
Total		100.60	99.77	100.07	100.12	100.25	100.10	100.09	100.12	99.37	99.64	99.17	99.60	99.19	99.73

[a] *Electron microprobe analyses were performed on a JEOL 733 microprobe operating at a beam accelerating potential of 15 kV, a current of 35 nA, and spot size of between 10 and 25 μ. 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). Analyst: Paul Carpenter, California Institute of Technology. Specimen R302 was analyzed at three distinct locations on the table of the faceted stone; these three analyses are shown along with an average analysis. The other four samples consisted of polished sections cut perpendicular to the table of the faceted stone. Each was analyzed at various locations below the surface of the table in order to document changes in trace-element chemistry with increasing distance into the sample. At each of these locations, one analysis was performed.*

[b] *Depth = Approximate depth below the surface of the table (in microns).*

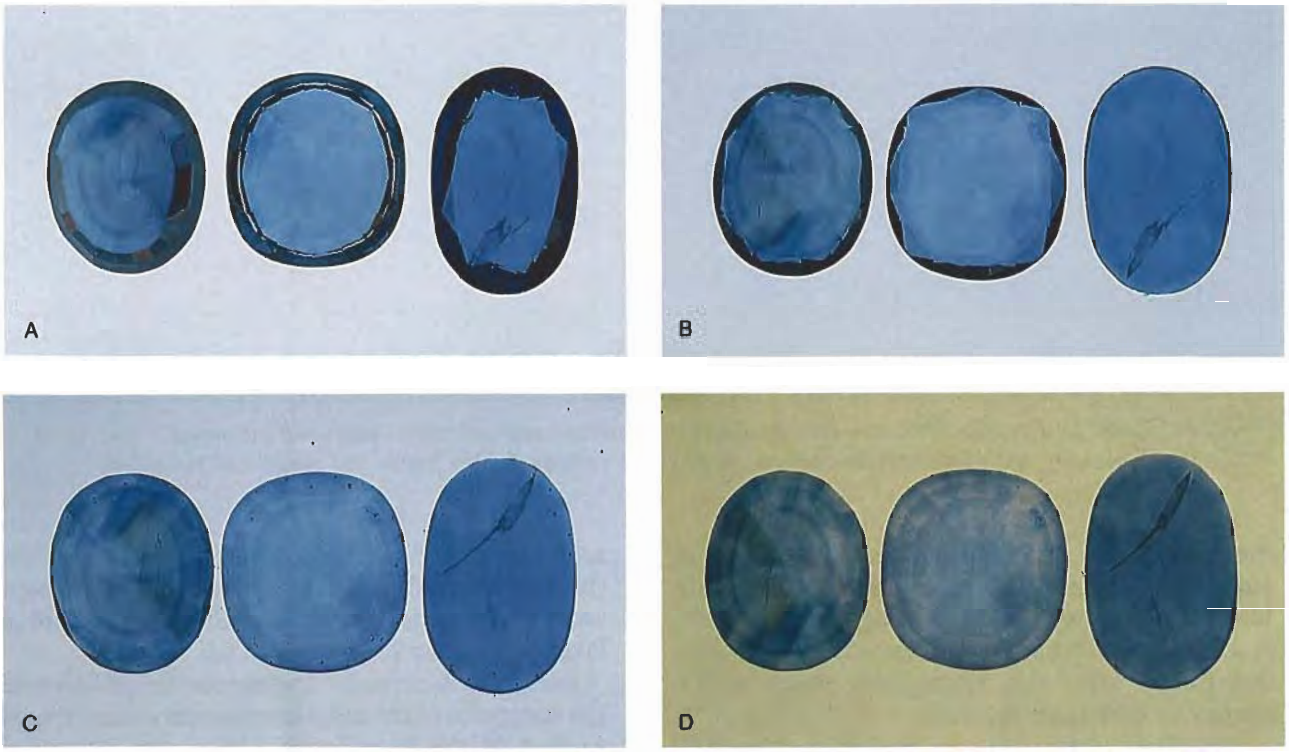


Figure 21. These photos illustrate the differences observed when blue diffusion-treated sapphires are immersed in different media and viewed with the unaided eye. The stones are, from left to right: 2.24 ct from the Astrid Corp., 2.22 ct from the Rainbow Collection, and 1.45 ct from Gem Source. The stones are placed table down in an immersion cell over diffused transmitted illumination in (A) air (R.I. 1.00); (B) water (R.I. 1.33); (C) glycerine (R.I. 1.47); and (D) pure methylene iodide (R.I. 1.75). In some stones, the identifying features may be visible in air or while immersed in water; in others, methylene iodide is necessary. Glycerine was found to be excellent for routine testing. Note that even with different orientations, key features are evident. Photos by Shane F. McClure.

R294 (Rainbow Collection)				R295 (Astrid Corp.)		
1	2	3	4	1	2	3
150	110	70	~20	400	200	~20
99.46	99.87	99.05	98.41	100.54	100.52	99.76
0.02	bdl	0.01	0.02	bdl	0.01	bdl
0.05	0.12	0.15	0.22	0.03	0.04	0.17
0.01	bdl	0.01	bdl	bdl	bdl	bdl
0.02	0.02	0.01	0.08	0.05	0.03	0.14
bdl	bdl	0.06	bdl	bdl	0.01	0.02
0.04	0.04	0.01	0.02	0.04	0.02	bdl
bdl	0.02	0.03	0.03	0.05	bdl	0.05
99.60	100.07	99.33	98.78	100.71	100.63	100.14

suggests that diffusion of iron and titanium into these sapphires resulted in these elements being distributed (at progressively lower concentrations) to depths as great as approximately 200 microns below the surface. This gives some idea of how deep into the sapphires these coloring agents were able to diffuse during treatment. It is interesting to note, too, that among these five stones, which were randomly selected from the full suite of stones available for study, there did appear to be a greater depth of diffusion in the three from Gem Source. Because of the small size of this sample, however, we cannot draw firm conclusions in this regard. Chromium was occasionally detected in each sample at levels that would have no significant influence on color, but would allow resolution of a fluorescent line at 693 nm through the hand-held spectroscope.

Qualitative XRF analyses (more sensitive to low concentrations than the microprobe) of both the inner (near-colorless) and outer (diffusion-treated) surfaces of the sawn, polished sections confirmed

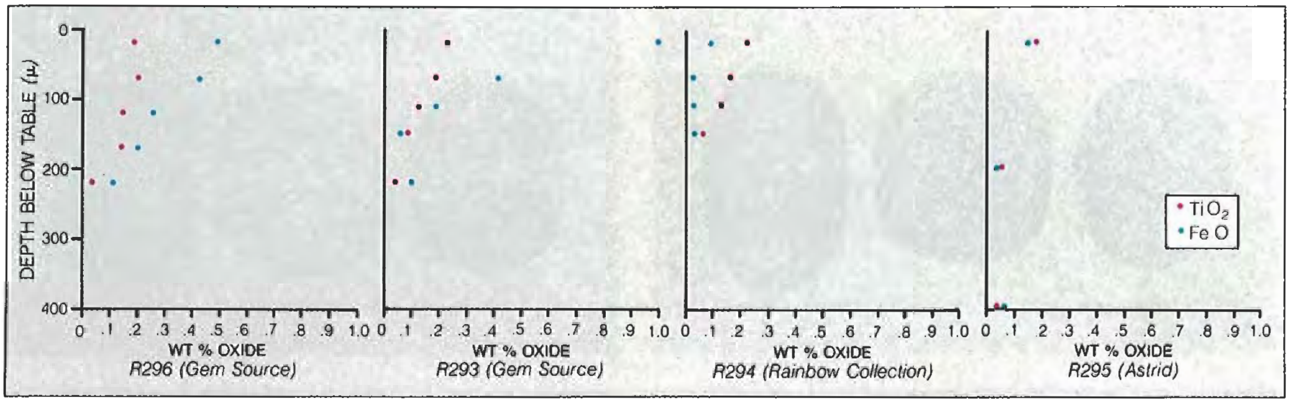
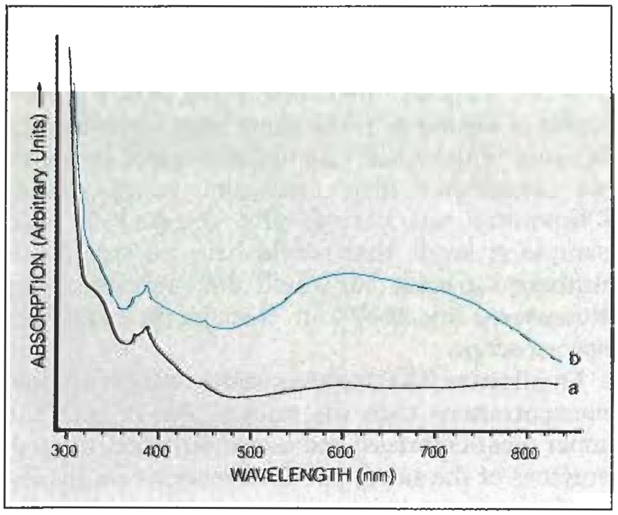


Figure 22. These four graphs illustrate the changes in iron (blue) and titanium (red) content noted in the study samples with microprobe analysis of areas at various depths below the surface of the table.

the presence in each sample of Al, Ca, and Ga, along with the transition elements Fe, Ti, and Cr. In addition, Cu was noted in samples R295, R294, and R293, and Ni was noted in R293. The diffusion-treated layer was consistently richer in titanium and iron than the core.

The ultraviolet/visible absorption spectra of all five samples were measured at room temperature using a Pye Unicam 8800 spectrophotometer, at a resolution of 0.5 nm. The spectra were run through the center of the polished slabs, in order to document the absorption in the untreated part of the sapphire (see figure 23, spectrum a), and then through one of the other two pieces left by sectioning, to document absorption in the superficial blue layer (see figure 23, spectrum b).

Figure 23. These U.V.–visible absorption spectra were taken in a central colorless part (spectrum a), and in the outer blue region (spectrum b), of a diffusion-treated blue sapphire in the same random optic orientation. The features at 335, 375, 390, and 450 are attributed to Fe^{3+}, and the broad bands at 560 and 700 nm are attributed to Fe^{2+}-O-Ti^{4+} charge transfer.



Spectrum b actually represents the addition of the spectrum of the colorless portion of the crystal to that of the blue layer. The major difference between spectra a and b is two broad bands with maxima around 560 and 700 nm, which have been interpreted to be the result of $Fe2^{+}$-0-$Ti4^{+}$ charge transfer (Ferguson and Fielding, 1971). The sharper bands at about 375, 390, and 450 nm are due to Fe^{3+} (Lehmann and Harder, 1970), and the broader band at about 335 nm could be due to either isolated Fe^{3+} ions (Lehmann and Harder, 1970) or exchange coupled pairs of the same ions (Ferguson and Fielding, 1971). The spectra of the diffusion-treated sapphires we studied are identical to those of natural blue sapphires from Mogok, Burma (Schmetzer, 1987) or Sri Lanka (Schmetzer and Kiefert, 1990). This confirms the statement made earlier that absorption spectra are not diagnostic indicators of this kind of diffusion treatment.

DURABILITY AND STABILITY OF THE TREATMENT

One of the first questions most jewelers and gemologists ask about a gemstone enhancement is how well it holds up to routine wear, jewelry cleaning, and repair procedures. Therefore, we conducted a number of tests on three faceted diffusion-treated sapphires in order to determine the durability and stability of this treatment under a wide range of conditions to which sapphires might routinely be subjected. The stones used were (1) a 1.23-ct mixed-cut pear shape from Gem Source, (2) a 1.21-ct oval mixed cut from the Rainbow Collection, and (3) a 0.75-ct oval mixed cut from Astrid Corp. To test this material under

TABLE 3. Durability and stability of the treatment in diffusion-treated sapphires.[a]

Test	Procedure	Result
Ultrasonic cleaning	Placed in ultrasonic cleaner containing a solution (10%) of commercial jewelry cleaner (BRC) and water for 47 minutes on the high setting at a maximum temperature of 68°C:	
	[b]Placed in stainless steel wire basket and suspended in solution	No effect on treatment
	[c]Placed in plastic cup half-filled with concentrated jewelry cleaner	No effect on treatment
	[d,e]Hung from wire in cleaning solution	No effect on treatment
Steam cleaning	[b,c,d,e]Used two steam cleaners with pressure maintained between 35 and 80 psi, stones placed one-half to one inch from nozzle for approximately 15 minutes	No effect on treatment
Boiling in detergent solution	[b,c,d,e]Stones boiled in solution of dishwashing liquid and water for 25 minutes	No effect on treatment
Heat and chemicals from jewelry repair	[b]Set in 14K gold cast head; one prong tip removed by sawing; stone and mounting fire-coated with boric acid/methyl alcohol solution and prong retipped with 14K yellow gold ball and 14K yellow gold hard solder (flow point approximately 750°C) and green flux	Moderate surface etching in vicinity of new prong[h]
	[b]Remaining three prong tips sawed off and retipped, care taken to minimize contact of flux with stone's surface	Minor surface etching in vicinity of new prongs[h]
	[d,e]One prong tip removed by sawing; stone and mounting fire-coated with boric acid/methyl alcohol solution and prong retipped with 14K yellow gold ball and 14K yellow gold hard solder (flow point approximately 750°C) and green flux	Moderate surface etching in vicinity of new prong[h]
	[d,e]Prong tips built up with 18K hard white gold solder (flow point approximately 768°C), care taken to minimize contact of solder with stone's surface	Moderate to severe etching, especially on stone's table[h]
	[c]Set in 14K gold cast head; four prong tips removed by sawing; stone and mounting fire-coated with boric acid/methyl alcohol solution and prongs retipped with 14K yellow-gold ball and 14K yellow-gold hard solder (flow point approximately 750°C) and green flux, care taken to minimize contact of flux with stone's surface	Minor surface etching in vicinity of new prongs[h]
Rhodium electro-plating	[b,c,d,f]Stones and mountings cleaned, then flash rhodium electroplated for five minutes at 6 volts, then 10–15 seconds at average of 3 volts; two-step plating procedure repeated for all three stones, followed by second cleaning	No additional changes noted in stones' surfaces
Low temperature/ thermal shock	[b,c,d,g]Stones dropped into cup containing liquid nitrogen, cooled to −185°C	No additional changes noted in stones' surfaces

[a]*All tests performed by GIA Jewelry Manufacturing Arts staff members with exception of low temperature/thermal shock which was performed by the authors.*
[b]*1.23-ct pear-shaped mixed cut from Gem Source.*
[c]*1.21-ct oval mixed cut obtained from the Rainbow Collection.*
[d]*0.75-ct oval mixed cut purchased from the Astrid Corporation.*
[e]*0.75-ct oval mixed cut (same as stone "d" above) mounted in used six-prong 14K white gold oval setting and attached to a ring shank before this test was performed.*
[f]*All three stones in mountings when this test was performed.*
[g]*All three stones removed from mountings before this test was performed.*
[h]*Surface etching may result in stone requiring repolishing; repolishing may partially or completely remove diffusion-induced color layer. This would be expected with any corundum—treated or untreated natural or synthetic—when so exposed to borax-containing chemicals.*

the greatest number of circumstances, the 0.75-ct stone was mounted in a used six-prong 14K white gold oval setting attached to a ring shank before the durability testing began.

Table 3 outlines the tests used and the results observed. Neither ultrasonic or steam cleaning nor boiling in a detergent solution appeared to have any effect on the treated stones, which were examined with magnification both before and after the cleaning procedure.

To test the response of the sample stones to stress received during such jewelry repair procedures as the retipping of prongs, we also had the other two test stones mounted but in 14K yellow gold cast heads. One prong tip was removed by sawing on all three of the stone-set mountings, and the prongs were retipped following the procedures described in table 3. Eventually, all four prongs were sawed off and retipped on the 1.23-ct pear shape. As would be expected with any corundum, the use of borax-containing chemicals (both firecoat and flux) contributed to moderate surface etching of the diffusion-treated sapphires. We did find, though, that the retipping of prongs with 14K gold solder produced only minor etching when care was taken to minimize the contact of the borax-containing flux with the surface of the stone. However, when one of the prong tips was built up with 18K gold, even though care was taken to avoid contact of the flux with the stone's surface, the higher temperatures required by the higher melting point of 18K (versus 14K) solder resulted in moderate to severe etching, especially on the surface of the table, as would happen with any corundum. If etching is severe enough, the stone might have to be repolished. Inasmuch as the color of a diffusion-treated sapphire is confined to a thin surface layer, such repolishing might lighten or totally remove the diffused color.

The best way to avoid this potential problem is to unmount the stone before retipping. Should the decision be made to retip prongs with the stone in place, however, a cotton swab dipped in alcohol should be used to carefully remove the firecoat from the stone before heat is applied (M. Allbritton, pers. comm., 1990). Although another option might be to use a non-borax-containing soldering flux, the only one we know to be available, a fluoride-based flux, is more toxic than borax-based fluxes and thus is not widely used (M. Allbritton, pers. comm., 1990).

When the three mounted diffusion-treated sapphires were subjected to rhodium electroplating, magnification revealed no additional changes in the appearance of the stones' surfaces.

As a final step in durability testing, the three treated sapphires were unmounted and then checked for their reaction to low temperatures and thermal shock by instantaneously lowering the temperature of each to −185°C by means of immersion in liquid nitrogen. The stones were then removed from the nitrogen bath and allowed to return to room temperature. This procedure tested not only the effects of extreme cold but, in the rapid way the cooling was performed, it also subjected the stones to extreme thermal shock. Again, though, there were no additional signs of damage.

Since the origin of the blue color in diffusion-treated sapphire is identical to that in natural-color blue sapphire, the diffusion-induced color can be considered to be as stable as that of natural blue sapphire.

CONCLUSION

The fact that more blue diffusion-treated sapphires have entered the gem market than ever before has increased the need for awareness on the part of the gemologist. With this procedure, color-causing chemicals are diffused into the surface of a stone by high-temperature heat treatment for extended periods of time, as long as a week or more. Apparently, by using higher temperatures, longer periods of heating, and/or multiple heatings, a deeper diffusion layer can be produced. This was evident in the one polished Gem Source stone in which we actually measured the diffusion layer and in the three Gem Source stones that were chemically analyzed. Even so, although the surface color layer produced by diffusion is stable to routine cleaning procedures, the shallowness of the layer makes it susceptible to partial or complete removal if the stone is subsequently repolished or recut.

Diffusion treatment can best be detected by examination of the stone while it is immersed in a liquid such as glycerine or methylene iodide over diffused transmitted illumination. In most cases, the unaided eye is more effective than magnification.

The 1975 Union Carbide patent listed numerous examples of the colors that could be produced in corundum with diffusion treatment, including red and orange. We have been told by Karla Brom (pers. comm., 1990) that diffusion-treated rubies and "padparadscha" sapphires have already been produced in Bangkok on a limited experimental basis; a red-orange diffusion-treated sapphire was examined by Bob Crowningshield at the GIA Gem Trade Laboratory in 1979. Inasmuch as large quantities of blue diffusion-treated sapphires—from a variety of treaters—are now being sold in the gem market, it is possible that the trade will also begin to see other colors of diffusion-treated corundum in the not-too-distant future. If procedures similar to those described above are used to produce these other colors, it is likely that they, too, will be readily identifiable.

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JADEITE OF GUATEMALA: A CONTEMPORARY VIEW

By David Hargett

Although lost for literally hundreds of years after the Spanish conquest of the Aztecs, many deposits of jadeite have been found in Guatemala during the last two decades. Following the discovery of the first significant outcrop in 1974, literally tons of jadeite in a wide variety of colors have been removed from the area and sent to cutting shops for use in tourist carvings, in fine reproductions of Indian artifacts, and in jewelry.

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Of all the world's occurrences of jadeite, Guatemala may be the least known. Ironically, the English word *jade,* which most people associate with the Far East, is actually derived from the Spanish phrase *piedra de ijada,* or "loin stone," from the material's reputed value as a cure for kidney ailments. Between about 1300 B.C. and the Spanish conquest in the 16th century A.D., a number of highly civilized, complex societies flourished in Central America, including the Olmecs, the Mayans, and the Aztecs. These great civilizations left behind carved jadeite in many forms. In modern times, several pieces were taken from ritual burial sites (Proskouriakoff, 1974); most are believed to have been the property of the wealthy, the nobility, and the priests. Items found include burial masks, rings, collars, and ear flares, as well as disks and pendants. The Aztecs are believed to have used jade during human sacrifices while the Olmecs are noted for their striking ax-god pieces (figure 1). The finest ax gods were found primarily in Costa Rica, although it is virtually certain that jade does not occur there (Desautels, 1986).

Jadeite artifacts of these ancient civilizations have been unearthed throughout Central America, Mexico, and even Peru; yet the actual sources were lost for nearly 500 years. Recently, however, commercially significant deposits have been found in Guatemala. This newly rediscovered jadeite is fascinating not only because its very study recalls the grand civilizations that existed before the Spanish Conquest, but also because it occurs in a wide variety of qualities and colors. The author visited Guatemala in 1988 and returned with samples of the materials that are currently being mined there, as well as information on the recent history and development of these deposits. The samples were subsequently tested, and their gemological properties are also reported here.

HISTORY, LOCATION, AND ACCESS

When the Spaniards arrived in the region that is now Guatemala (about 1519), Mayan chiefs dispatched entire

Figure 1. "The Kunz Ax," made of translucent dull blue-green jadeite that undoubtedly originated from the area that is now Guatemala, is typical of the ax gods fashioned by the Olmecs in pre-Columbian times. This 27.2-cm-high artifact was found in Oaxaca, Mexico, around 1869. Courtesy of Department of Library Services, American Museum of Natural History.

families to guard the mines and the secret of their location. The Mayans did not realize that the Spanish had little use for, or interest in, jadeite; they were after gold and emeralds. With the decline of the indigenous cultures and the eventual deaths of the guard families, the knowledge of where the great mines had been was lost.

In 1952, however, Robert Leslie of the Smithsonian Institution identified some green jadeite that had been found near the small town of Manzanal, in the department of El Progreso (figure 2), when it became lodged in a cultivating disker being used on a field of tomato plants (J. Ridinger, pers. comm., 1989). Leslie subsequently found a number of detrital nodules in the alluvial terraces of the Motagua River near Manzanal (McBirney et al., 1967). In 1963, McBirney reported finding detrital jadeite in the gravels of the same river, but about 70 km upstream. As late as 1967, McBirney et al. lamented that no occurrences of the jadeite in bedrock had yet been reported.

In 1973, Jay and Mary Lou Ridinger, American expatriates living in Antigua, Guatemala, began their search for jadeite. For almost a year, they explored the mountainous region on foot; the difficult task was made even more dangerous by the ongoing guerrilla warfare in these remote regions. Another concern is the deadly "cigarette" snake; once bitten by this serpent, the victim lives only long enough to smoke a single cigarette.

In 1974, Mary Lou Ridinger discovered a major block of jadeite in a serpentinite body on a hillside in the Zacapa region of the Motagua River Valley. Located about 10 km east of Manzanal, this occurrence of jadeite was about 2 × 3 m (6 × 9 ft.), while the surrounding albitic material extended another 6–7 m in each direction. These and the other eluvial deposits (drift from the weathering of jadeite tectonic blocks; Harlow, pers. comm., 1990), are probably the source of the alluvial material reported by Foshag in 1955 and McBirney in 1963.

The Ridingers have since found jadeite in a number of locations in the Motagua River Valley; they and others (primarily independent operators) continue to prospect in the area (figure 3). Small boulders or "cobbles" are also recovered from the beds of streams (notably, Río La Palmilla and Río Huijo) that pass near the outcrop (figure 4). George Harlow, of the American Museum of Natural History, has visited the region and believes that there may be other sources yet undiscovered in the valley (pers. comm., 1990).

Today, for the most part, sophisticated techniques are not used to search for jadeite in Guatemala. According to Harlow, searchers commonly explore until they encounter serpentinatious terrain, then walk along the area's river and stream beds until they sight jadeite. Sometimes aerial photos are examined for tectonic blocks of jadeite in the serpentinite. Because of the proprietary

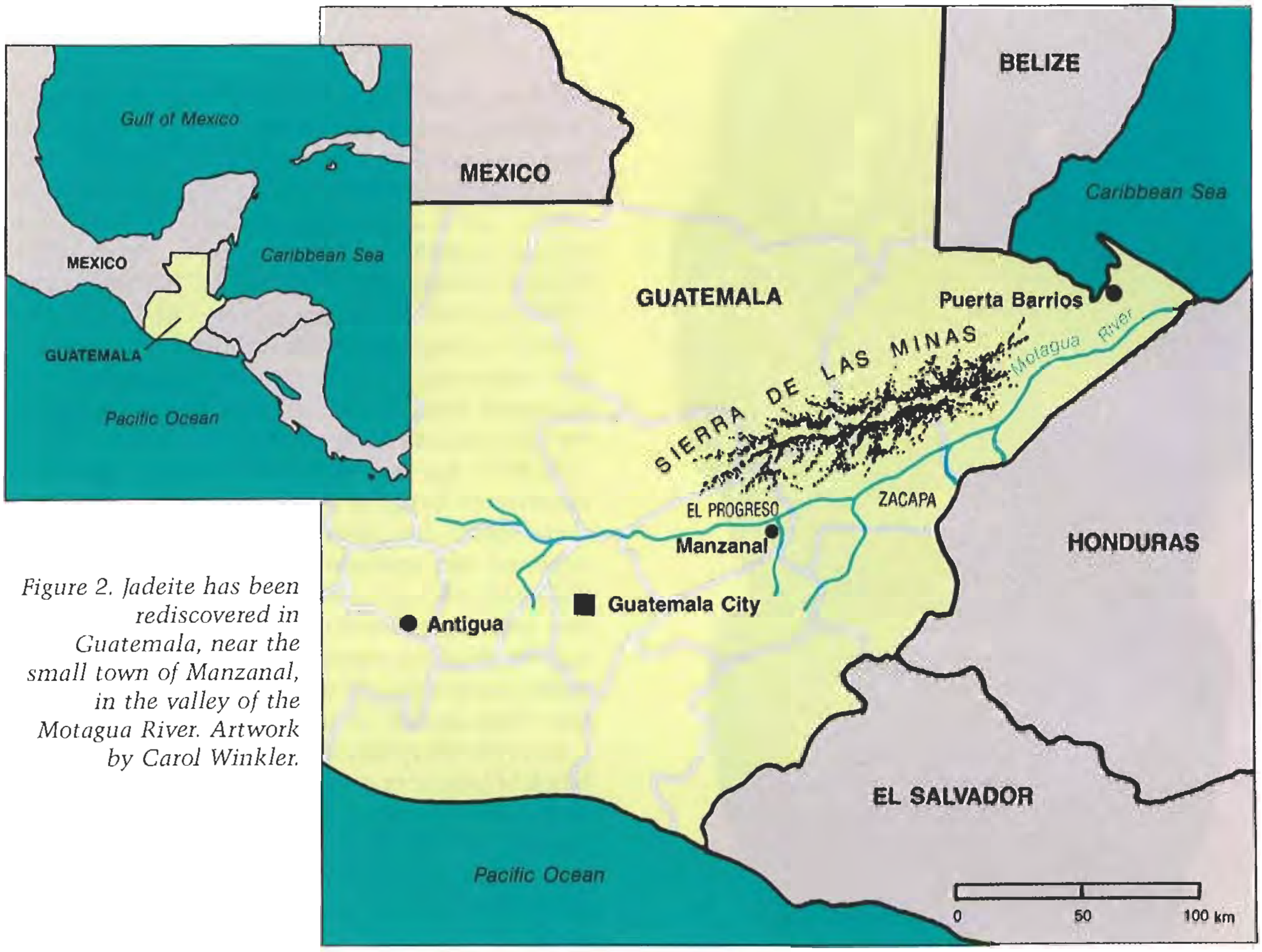

Figure 2. Jadeite has been rediscovered in Guatemala, near the small town of Manzanal, in the valley of the Motagua River. Artwork by Carol Winkler.

nature of the mining sites, precise directions to the locality are not provided with this article.

GEOLOGY OF JADE

Formed as a result of metamorphic activity, jadeite the world over occurs in lenses and masses, usually in serpentinatious rock (Desautels, 1986). Specific information on the occurrence and formation of Guatemalan jadeite is available in Harlow (1986 and in press). Guatemalan jadeite itself is coarsely grained, often with large, eye-visible crystals of jadeite. This is consistent with the detrital material examined by McBirney et al. (1967).

MINING METHODS

Commercial mining of jadeite in Guatemala is a rudimentary process. In the Ridinger operation, a pick-up truck carries the equipment as close as possible to the site, but a full day or longer may be needed to then transport the materials by mule or on foot to the mining area. Gasoline-powered jackhammers are used to remove the jade lenses and boulders from the host rock (figure 5). These pieces are then moved by animal and human power back to the truck, to be driven to the factory in Antigua. No more than five to 10 people at a time are involved in any one mining operation (J. Ridinger, pers. comm., 1988).

DESCRIPTION

The jadeite found in Guatemala is wonderfully varied (figure 6), although even in its finest qualities, it does not approach the translucency, texture, or rich "emerald" green of the classic Burmese "Imperial" jadeite. Nevertheless, the Spaniards originally thought that fine Guatemalan jadeite was emerald (Foshag, 1957). As with many gem products, colorful commercial names have been created for Guatemalan jadeite; these include "Olmec Blue," "Galactic Gold," "Watermelon," and "Emerald Green." The following are brief descriptions of the Guatemalan jadeite commercially available today:

Figure 3. Prospectors in Guatemala uncovered this field of eluvial (weathered tectonic block) jadeite on the northwest side of Cerro Colorado, near the town of La Palmilla. To the north can be seen Sierra de las Minas. Photo courtesy of George Harlow.

Green: Slightly variegated medium to dark green; semitranslucent to opaque; fine to medium texture. This color variety includes the best quality found to date in Guatemala (figure 6, bottom).

"Blue": Actually a slightly variegated bluish green; translucent to semitranslucent; fine to medium texture (figure 7). This is the rarest color found by the Ridingers (pers. comm., 1990), although they have not seen the almost pure "Olmec Blue" illustrated in Easby (1968), and its source remains a mystery.

Variegated Green: Small, randomly oriented patches of white and light grayish green; semitranslucent to opaque; coarse texture with eye-visible single crystals of allanite or jadeite (figure 6, top).

White: Slightly variegated with brown and gray (again, see figure 4); semitranslucent; coarse texture with eye-visible single crystals. This is the most abundant color (J. Ridinger, pers. comm., 1990).

"Black": Actually very dark green, as is readily apparent when viewed with transmitted light through a thin section; uniform color; opaque; fine texture; potentially commercially important (figure 6, left; figure 8).

Figure 4. This stream-polished boulder of white jadeite was found in one of the small rivers (Río La Palmilla, a tributary of the Motagua River) in the department of Zacapa. Photo courtesy of George Harlow.

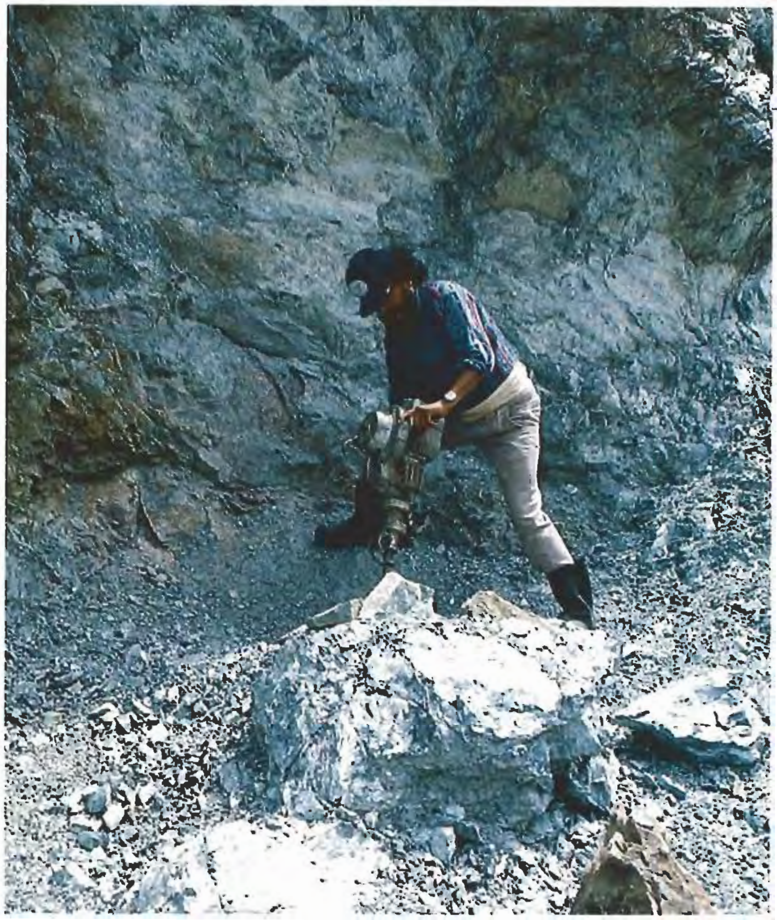

Figure 5. To remove jadeite from the area, large pieces are usually broken up with a gasoline-powered jackhammer. Photo courtesy of Jades S.A.

Figure 6. The jadeite found to date in the Motagua River Valley occurs in many different "varieties." Shown here are: top, variegated green; left, "black" (actually, very dark green); right, pyrite bearing; bottom, green. The largest piece (top) is 24.04 × 17.12 × 5.29 mm. Photo © Tino Hammid.

Pyrite-bearing: Uniform dark green with flecks of pyrite throughout; fine to medium texture; opaque (figure 6, right). Guatemala is the only known source of this material.

No precise production figures are available for the individual "varieties" of Guatemalan jadeite or for the total mined to date. At the end of 1989, however, Jay Ridinger (pers. comm.) reported that he currently had on hand 20,000 tons of "top quality" carving material.

GEMOLOGICAL PROPERTIES AND CHEMISTRY

The author performed standard gemological tests on 43 pieces of jadeite from this locality: two green, one "blue," 28 variegated green, four white, four black, and four pyrite bearing. The gemological properties of the various colors were remarkably similar. Also, despite the higher content of diopside in Guatemalan jadeite, the gemological properties are the same as for jadeite from other localities with the exception of the coarse granular crystalline structure. Table 1 compares the gemological properties of Guatemalan jadeite to those of jadeite from Burma (now Myanmar).

The refractive index (spot or shadow) of the Guatemalan material ranged from 1.65 to 1.67, but was usually 1.66. The specific gravity of the material tested was within the normal range for jadeite, from as low as 3.20 to, more commonly, approximately 3.34. Most stones showed the 437-nm absorption line in the Beck hand-held spectroscope. Several of the green stones also showed chromium-related bands at about 630, 660, and 690 nm. Although the "black" material did not show the 437-nm line, X-ray diffraction analysis proved it to be jadeite. Incidentally, X-ray diffraction analysis also proved that the yellow mineral found in some Guatemalan jadeite is, indeed, pyrite. The color filter reaction was inert for all but the bluish green material, which was faint red.

Guatemalan jadeite contains about 10% diopside, which is significantly more than the 1%–2% found in Burmese material (Foshag, 1957). Chemical analyses of various specimens of jadeite from the earlier Manzanal discovery as well as from archeological finds in Guatemala were performed and compared to the theoretical composition of pure jadeite by McBirney et al. (1967); their results are reproduced here as table 2, and include Foshag's (1955) analyses.

Figure 7. This slab (12.73 × 9.51 × 2.00 mm) is typical of the rare "blue" jadeite that has been found in the rediscovered jadeite deposits of Guatemala. Photo © Tino Hammid.

TABLE 1. Gemological properties of jadeite from Guatemala and from Burma (Myanmar).[a]

Property	Guatemala	Burma
Physical appearance	Granular appearance with eye-visible crystals; pyrite inclusions; greasy luster	Individual crystals rarely visible; no pyrite; greasy to vitreous luster
Colors	"Black" (very dark green); bluish green; white; variegated green; dark green; pyrite-bearing	Green; white; brownish orange; lavender; "moss in snow"
Transparency	Semitranslucent to opaque	Semitransparent to opaque
Refractive index (spot or shadow)	1.65–1.67	1.65–1.67
Specific gravity	3.20–3.34	3.25–3.40
Color filter	Negative except for the bluish green material, which showed faint red	Negative
Mohs hardness	Approx. 7	6½–7
Chemical composition	$NaAl(SiO_3)_2$ with $CaMg(SiO_3)_2$ up to 10%	$NaAl(SiO_3)_2$ with $CaMg(SiO_3)_2$ 1–2%
Visible absorption spectrum	437 nm in all except black; Cr bands in some green	437 nm; Cr bands common in green

[a] Properties for Burmese jadeite are from GTL files.

Figure 8. "Black" jadeite is actually a very dark green. This material is frequently used in fine jewelry (here, a 13.0 × 11.0 × 6.2 mm cabochon set with fancy-intense yellow diamonds in an 18K gold and platinum ring). It also holds a polish well: With normal wear, the polish on this cabochon should last many years, owing to the hardness and tough interlocking structure of the jadeite. Photo by Robert Weldon.

Diopside-jadeite and acmitic jadeite are also found in Guatemala, but neither was examined for this article. The refractive index of diopside-jadeite, which contains about 50% diopside, is 1.68 (Foshag, 1957). None of the Guatemalan material tested for this study had a refractive index that high. According to C. W. Fryer, West Coast director of the GIA Gem Trade Laboratory (pers. comm., 1988), if the material being tested possesses all of the gemological properties of jadeite—that is, the appropriate refractive index, specific gravity, spectrum, and hardness—it can be correctly called jadeite even though the diopside content is higher than that usually associated with jadeite.

CUTTING AND POLISHING

The first step of the cutting process requires that the large boulders, many of which weigh hundreds of pounds, be broken up. The Ridingers use a magnesium torch to heat the boulders (Ward, 1987)

Figure 9. These reproductions of Olmec carvings in jadeite, with jadeite and rose quartz beads, are typical of jewelry found in tourist shops in Guatemala. Courtesy of Jades S.A.

and then douse them with water to create cracks. Smaller pieces can be placed directly on a 12-inch or smaller diamond saw. The pieces are then carved or cut *en cabochon* or into beads. Most of the material is processed in Antigua, where there are a number of factories, the largest of which is Jades S.A., with 10 people employed in cutting and polishing.

COMMERCIAL ASPECTS

There are three commercial uses for modern Guatemalan jade: tourist jewelry and art (figure 9), reproductions of Mayan and Olmec carvings (figure 10), and cabochons or smaller carvings for karat-gold jewelry. The black jadeite is often used in fine jewelry like that shown in figure 8 because jadeite's hardness (approximately 7) and interlocking crystalline structure prevent it from becoming dull over time, a common problem with nephrite (Crowningshield, 1973).

Presently, Guatemalan jadeite is not being extensively marketed worldwide, although it has been exhibited at international gem shows such as the one held in February at Tucson, Arizona. Recently, some material (mostly black) has been sold and shipped to cutters in Hong Kong (G. Harlow, pers. comm., 1990).

TABLE 2. Chemical analyses of Guatemalan jadeite. Table reproduced from McBirney et al., 1967.

	1	2	3	4	5	5a	5b		
SiO_2	59.40	58.21	58.12	58.26	59.18	58.97	Si	1.996	2.000
TiO_2	0.00	0.04	0.31	0.04	0.00	0.00	Al^{IV}	0.004	
Al_2O_3	25.25	23.72	20.32	22.23	23.73	23.77	Al^{VI}	0.942	1.999
Fe_2O_3	0.00	0.91	2.49	0.71	0.31	0.32	Ti	0.000	
FeO	0.00	0.24	0.77	0.21	0.11	0.11	Fe^{3+}	0.008	
MnO	0.00	0.04	0.07	0.03	0.02	0.02	Fe^{2+}	0.003	
MgO	0.00	1.20	2.16	2.18	0.95	0.97	Mn	0.001	
CaO	0.00	1.79	3.13	3.72	0.95	1.43	Mg	0.049	
Na_2O	15.34	13.07	12.43	11.91	14.36	14.42	Ca	0.051	
K_2O	0.00	0.18	0.10	0.40	0.00	0.00	Na	0.945	
H_2O^+	0.00				0.04	—			
		0.46	0.16	0.44					
H_2O^-	0.00				0.06	—			
Total	100.00	99.86	100.07	100.13	100.17	100.01			

1. *Theoretical composition of pure jadeite.*
2. *Jadeite from Manzanal, Guatemala, W. F. Foshag analyst (Foshag, 1955).*
3. *Jadeite from pea-green colored celt, Guatemala, J. Fahey analyst (Foshag, 1955).*
4. *Jadeite from "jade worker's tomb," Kaminaljuyu, Guatemala, J. Fahey analyst (Foshag, 1955).*
5. *Jadeite from Manzanal, Guatemala, K. Aoki analyst (new analysis).*

5a. *Analysis no. 5 recalculated by subtracting 2 wt.% albite (An_3).*

5b. *Atomic proportions calculated from 5a on the basis of six oxygen atoms.*

Figure 10. This modern reproduction of a famous Mayan burial mask (16 cm in diameter) was fashioned from the newly discovered deposits of Guatemalan jadeite. Photo courtesy of Jades S.A.

CONCLUSION

Mesoamerican jadeite was mined, fashioned, revered, and worn for thousands of years in pre-Columbian civilizations. Although "lost" for hundreds of years, deposits of jadeite were "rediscovered" in Guatemala in 1974 and are presently being mined by very elementary techniques at sites near the small town of Manzanal.

Guatemalan jadeite varies greatly in color, translucency, and texture. It is sold in tourist shops, used in reproductions of ancient pieces, and set in karat-gold jewelry. The "black" material has the greatest commercial potential, while the bluish material is the rarest. To date, thousands of tons of jadeite have been mined in Guatemala.

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NOTES
· AND ·
NEW TECHNIQUES

WELL-FORMED TSAVORITE GEM CRYSTALS FROM TANZANIA

By Robert E. Kane, Anthony R. Kampf, and Horst Krupp

Green grossular garnet crystals of fine form and clarity have been found recently in Tanzania, at the Karo pit of the tanzanite mining belt. Although the crystals tend to be relatively light in color, they are consistent in gemological properties and composition with the grossular variety popularly known as tsavorite. The very distinct and complex morphology of these crystals is remarkable. Eight different crystallographic forms have been identified, including one that has never before been recognized for any member of the garnet group.

Since early 1987, small amounts of gem-quality green grossular garnet (tsavorite) crystals (figure 1) have been recovered from pockets at the Karo tanzanite pit in the Merelani* Hills of Tanzania. The Merelani Hills are located south of Arusha and just west of Kimoingan Mountain. The area referred to locally and in the trade as the original tanzanite mine is actually a mining belt about 4×1 km which encompasses six major pits (figures 2 and 3). These pits are named after the men who originally filed mining claims on them (listed here in numerical order from one end of the belt to the other): 1 – De Souza pit no. 1, 2 – Ali Juuyawatu, 3 – Papanicolaou, 4 – Karo, 5 – Georgi, and 6 – De Souza pit no. 2. The complex tsavorite crystals discovered at the Karo pit are particularly noteworthy for the perfection of their external crystal form (again, see figure 1). Previously, tsavorite found here and elsewhere was almost exclusively massive (front portion of figure 4). Occasional incompletely developed crystals with extremely crude faces had also been recovered (back specimen in figure 4), but euhedral crystals were virtually unknown.

During a recent visit to Moshi, Tanzania (about 70 km east of the Merelani Hills), one of the authors (H. Krupp) obtained a number of well-formed tsavorite crystals. The largest of these (figure 1) weighs 14 grams and is only very slightly

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Acknowledgments: The authors thank George R. Rossman, John Armstrong, and Arthur Chodos, of The California Institute of Technology, for providing the electron microprobe analyses; Campbell R. Bridges, of Bridges Exploration (Nairobi, Kenya), for helpful comments on the manuscript and for providing information on East African tsavorite localities; and Peter and Bobbi Flusser, of Overland Gems, Los Angeles, for making material available for examination.

Gems & Gemology, Vol. 26, No. 2, pp. 142–148

Merelani is an anglicized phonic spelling of the local Masai word for a tree common to the area. This spelling was employed by Bridges (1982), while Gübelin and Weibel (1975) used *Miralani*. A third spelling, *Mererani*, may in fact be more accurate. Nevertheless, *Merelani* is used here to avoid further confusion of the literature.

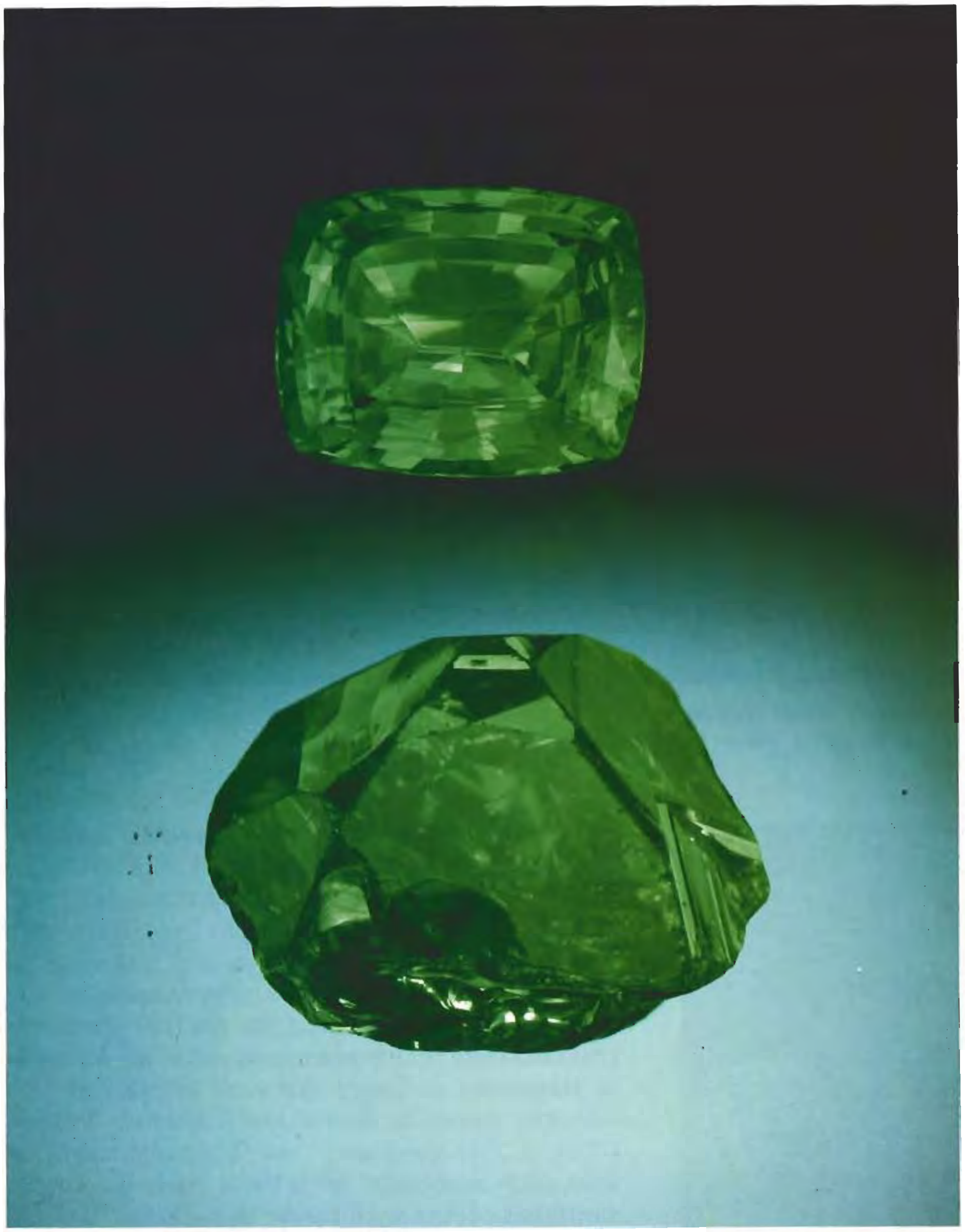


Figure 1. Well-formed tsavorite crystals are exceedingly rare. Recently, the Karo tanzanite pit in the Merelani Hills, Tanzania, yielded this 14-gram crystal and another from which the accompanying 14.84-ct gem was cut. Photo © Harold & Erica Van Pelt.

included. This crystal was used in this study together with a more complete, but also more included, 6-gram crystal and a 10.75-ct pear shape faceted from a Karo-pit crystal. This article describes the occurrence, gemological characteristics, composition, and morphology of the Karo-pit tsavorite crystals.

OCCURRENCE

The gem variety of green grossular garnet known as tsavorite (or, in some areas, tsavolite) was discovered in Tanzania in the late 1960s (Bridges, 1974). Since then, most commercial mining has been based in an area to the south of the Taita Hills in neighboring Kenya known as the Taita/Taveta district (figure 5). According to Gübelin and Weibel (1975), the tsavorite occurs in metamorphic rocks consisting primarily of graphite-bearing gneisses and marbles. It is generally found in rounded forms up to fist size (locally called "potatoes"), which have an interior of more or less fractured tsavorite surrounded by a shell consisting mainly of epidote and scapolite (again, see figure 4). Some of these masses exhibit crude crystal form, but generally they do not show distinct crystal faces.

Tanzanite and tsavorite are found in very similar geologic environments; although tanzanite and tsavorite generally do not occur in commercial

Figure 2. This general overview shows a small section of the 4 × 1 km tanzanite mine belt in the Merelani Hills, south of Arusha in Tanzania. Photo by Horst Krupp.

quantity or quality at the same deposit, they are often found together. Gübelin and Weibel (1975, p. 402) note that green grossular garnets "varying in hue and shade between bright lime-green and dull dark green . . . are occasionally also seen as accessory minerals in the zoisite (tanzanite) mines in the Miralani Hills." And Bridges (1974) reports that tanzanite occurs as a minor accessory mineral in fragments or larger shattered crystals at the tsavorite mines in Kenya and Tanzania. Bridges (1982, p. 274) also states that "The same clay-like mineral is associated with these pockets [of tanzanite] as occurs with tsavorite pockets."

Bridges (pers. comm., 1989) provided the authors with details of the occurrence of tanzanite and tsavorite at his Scorpion mine in the Taita/Taveta district. In the no. 4 tsavorite ore shoot of this mine, what appears to be bluish zoisite (tanzanite) forms kelyphitic shells of about 1–2 mm thickness

Figure 3. Although some operations, such as this one at Karo, are open pit, 90% of the current mining in the Merelani Hills is underground and involves blasting with dynamite. The miners will continue through the hole shown in the central right portion of this photo until they reach the gem-bearing reef, where they will then begin horizontal tunneling. Photo by Horst Krupp.

Figure 4. These tsavorite specimens from the Lualenyi mine, Taita/Taveta district, Kenya, are typical of the form in which most tsavorite is found. The specimen at the top (20 cm across) contains large, crudely formed crystals. The two smaller specimens are typical broken "potatoes." Photo by Shane McClure.

around green grossular (tsavorite) nodules. Bridges interprets the tanzanite shell as being the result of retrograde metamorphism. In this ore shoot, compacted crystal groups and individual crystals with a few distinct faces were encountered. Rare examples of crystals with all faces present, but possessing the kelyphitic tanzanite shell, have been found. A parallel ore shoot in this mine contains beautifully colored but badly shattered tanzanite, sometimes in the form of crystals.

One of the authors (H. Krupp) spoke with miners who have worked the tanzanite mine belt in the Merelani Hills. They confirmed that tsavorite has been found there, but usually in small fractured masses, with only a few pockets yielding tsavorite

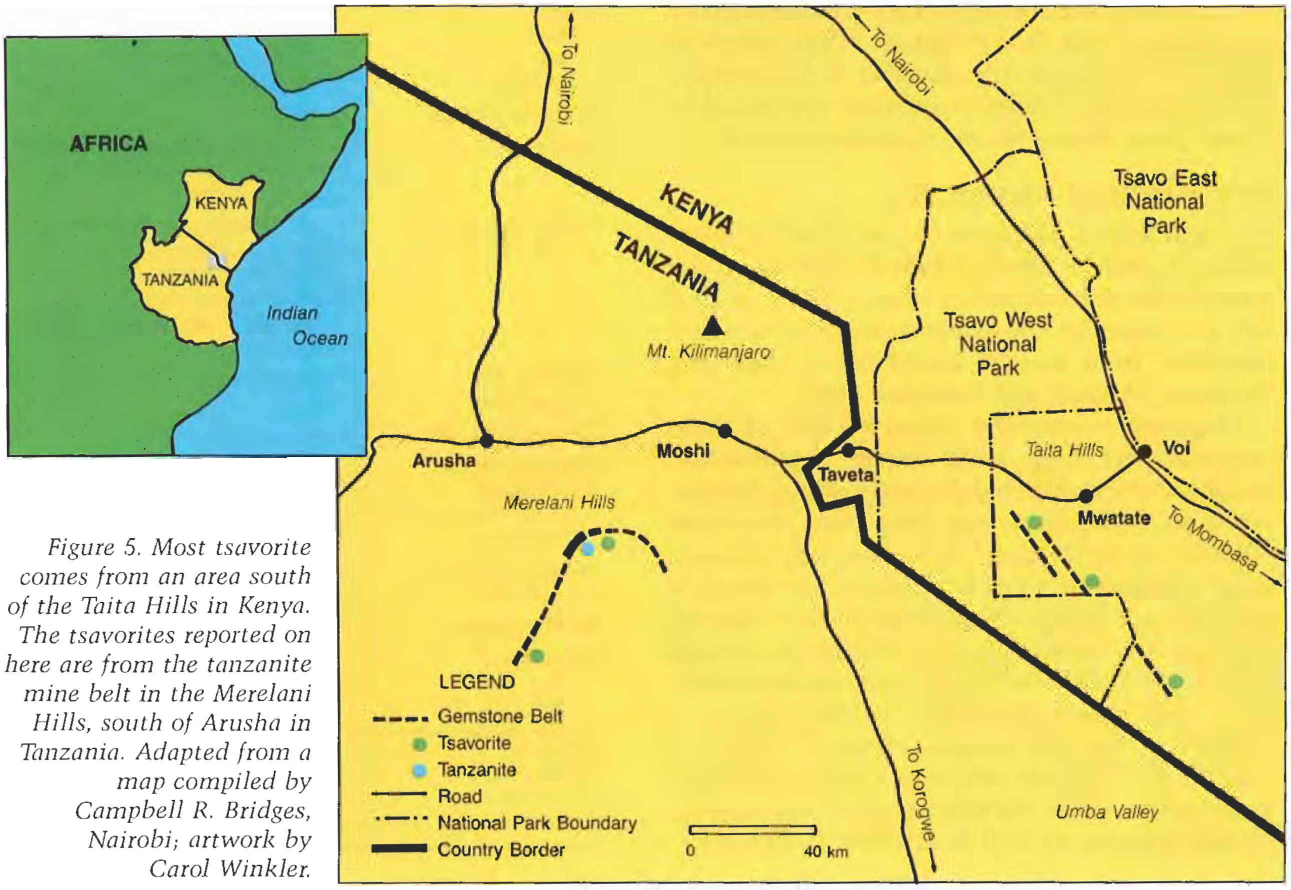


Figure 5. Most tsavorite comes from an area south of the Taita Hills in Kenya. The tsavorites reported on here are from the tanzanite mine belt in the Merelani Hills, south of Arusha in Tanzania. Adapted from a map compiled by Campbell R. Bridges, Nairobi; artwork by Carol Winkler.

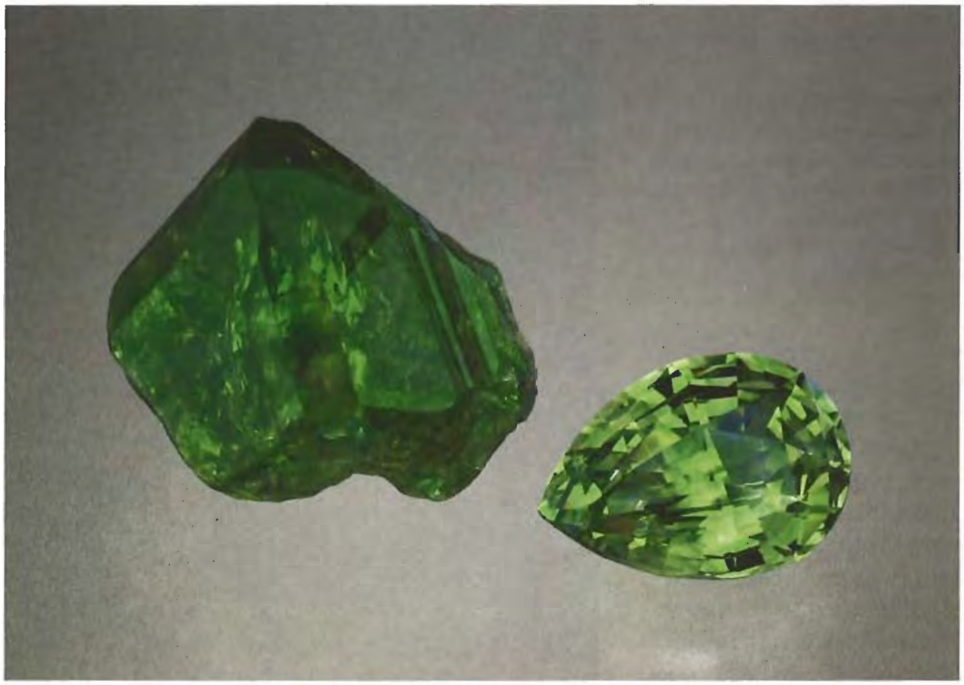


Figure 6. This 5.42-ct faceted tsavorite from the Karo pit was cut from a crystal fragment recovered along with well-formed crystals such as the 6-gram one shown here. Photo © Harold & Erica Van Pelt.

crystals. They did not provide information regarding the quantity or quality of these crystals. Yet no other mining area has produced well-formed, gem-quality crystals of tsavorite.

The well-formed tsavorite crystals examined by the authors were free of matrix. Only traces of graphite were noted still adhering to the crystals; it is not known whether tanzanite was found in direct association with the tsavorite crystals.

GEMOLOGICAL PROPERTIES

The gemological properties of the 6-gram crystal (figure 6) and the 10.75-ct faceted stone from the Karo pit are summarized in table 1. These properties are generally consistent with those of other tsavorites from various localities in Kenya and Tanzania (Manson and Stockton, 1982).

The most noteworthy characteristics of these tsavorites are their weak orange transmission luminescence and their dull chalky orange fluorescence to both short- and long-wave ultraviolet radiation. In the authors' experience, this behavior is not often observed in tsavorite; when it is, it is generally restricted to material with a light to medium-light tone similar to the Karo-pit crystals.

Although these tsavorite crystals are notable for their high degree of clarity, we did observe a number of internal features, none of which is unusual for tsavorite (see, e.g., Gübelin and Koivula, 1986). These include straight and angular growth features, as well as graphite inclusions.

TABLE 1. Gemological properties of tsavorite found as well-formed crystals at the Karo pit, Merelani Hills, Tanzania.[a]

Color	
Hue	Slightly yellowish green
Tone	Light to medium light
Saturation	Moderately strong
Refractive index	1.737
Polariscope reaction	Single refraction, with a weak to moderate anomalous-double-refraction effect
Optical absorption spectrum[b]	Broad absorption blocking out all of the violet and most of the blue portions of the spectrum and a broad diffuse band of weak intensity at approximately 580–610 nm
Transmission luminescence	Weak orange
Chelsea color filter	No reaction
Fluorescence to U.V. radiation	
Long-wave	Moderate dull chalky orange
Short-wave	Very weak dull chalky orange
Phosphorescence to U.V. radiation	None
Specific gravity[c]	Approximately 3.58
Microscopy	Straight and angular growth features; graphite inclusions

[a] *Properties listed were obtained from one rough crystal weighing 6 grams and one faceted mixed-cut pear shape weighing 10.75 ct.*
[b] *As observed through a GIA GEM Instruments fiber-optic spectroscope unit with a Beck prism spectroscope.*
[c] *Determined by the hydrostatic weighing technique.*

CHEMICAL COMPOSITION

The composition of tsavorite from Kenya and Tanzania has been studied by many workers (Switzer, 1974; Gübelin and Weibel, 1975; Amthauer, 1975; Schmetzer, 1978; Bank et al., 1979; Manson and Stockton, 1982; Schmetzer and Bank, 1982). All have reported a composition close to that of pure grossular, but with significant quantities of V_2O_3 and, usually, lesser quantities of Cr_2O_3. The green color has been attributed to V^{3+} and/or Cr^{3+}, and it has been observed to vary in intensity with the amounts of these chromophores present.

Analysis of the 6-gram crystal on an electron microprobe yielded the chemical composition shown in table 2. This is similar to those determined for tsavorites by the other researchers cited above. The amounts of Cr_2O_3 and V_2O_3 determined, 0.05 and 0.19 wt.%, respectively, are toward the low end of the ranges reported in the other studies. This is consistent with the relatively light tone exhibited by the cut stone and crystals examined.

TABLE 2. Chemical composition[a] of a 6-gram tsavorite crystal from the Karo pit, Merelani Hills, Tanzania.

Oxide	Weight %[b]
SiO_2	40.33
TiO_2	0.28
Al_2O_3	22.49
V_2O_3	0.19
Fe_2O_3	0.26
Cr_2O_3	0.05
MgO	0.02
CaO	37.16
MnO	0.27
TOTAL	101.05

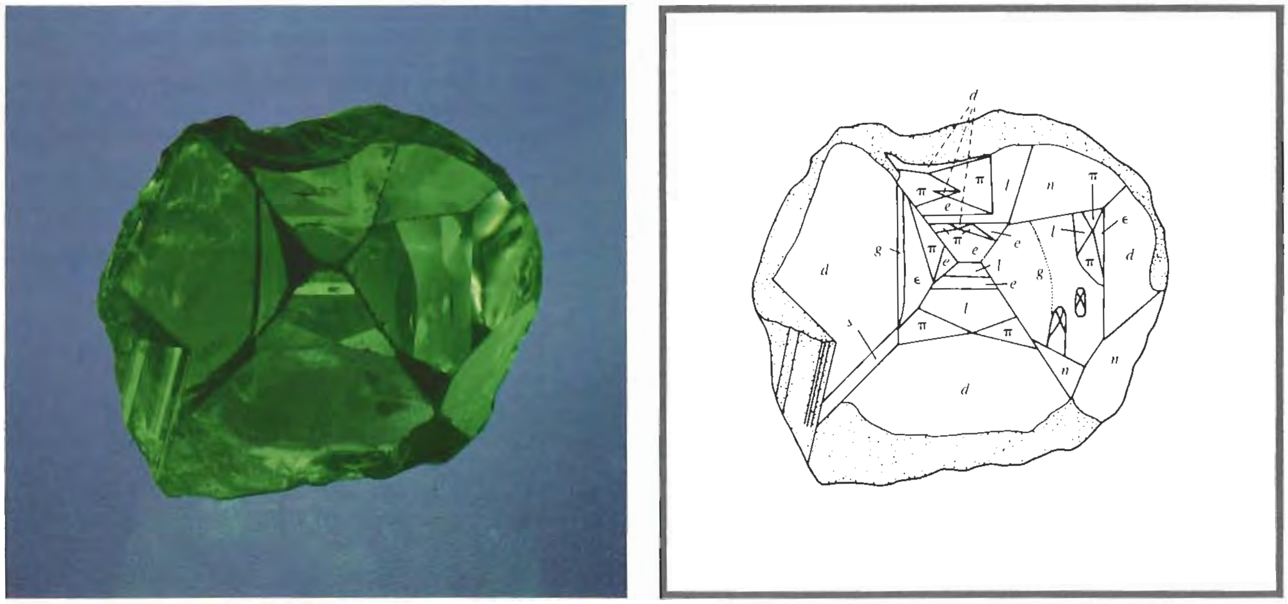
[a] *Analyses were performed on a JEOL 733 microprobe operating at a beam accelerating potential of 15 kV, a current of 35 nA, and spot size between 10 and 25 μm. The data were corrected using the program CITZAF (Armstrong, 1988), employing the absorption corrections of Armstrong (1982), the atomic number corrections of Love et al. (1978), and the fluorescence corrections of Reed (1965), as modified by Armstrong (1988). Paul Carpenter, California Institute of Technology, analyst.*

[b] *Average of five point analyses.*

CRYSTAL MORPHOLOGY

The most remarkable aspect of the tsavorite crystals described here is the perfection of their faces (figure 7). Heretofore, even a crude face on a tsavorite fragment was considered unusual. The distinctness and high luster of the faces on these crystals enabled us to measure precisely their

Figure 7. In this top view of the 14-gram tsavorite crystal shown in figure 1, all 39 of the faces measured on this crystal—and labeled in the accompanying crystal drawing—can be seen. The crystal forms noted are: d *{011},* e *{012},* g *{023},* l *{035},* ϵ *{045},* n *{112},* s *{123}, and* π *{1·10·16}. Photo © Harold & Erica Van Pelt.*



complex morphology with a Huber two-circle optical goniometer.

Both the 6- and 14-gram crystals were found to exhibit the same crystallographic forms (sets of equivalent faces), although the relative development of these forms differed somewhat between the two crystals. A total of eight forms were found. The labels and Miller indices of these forms are as follows: *d* {011}, *e* {012}, *g* {023}, *l* {035}, ϵ {045}, *n* {112}, *s* {123}, and π {1·10·16}.

The eight crystallographic forms have been noted on the appropriate faces in the drawing of the 14-gram crystal that appears in figure 7. The three growth hillocks on the large *g* face are composed of the same group of faces, which is labeled only on the largest of the hillocks. A total of 39 faces were measured on this crystal, and the crystal is less than half complete.

Of special note is the presence of faces corresponding to the π {1·10·16} form. To our knowledge, this crystallographic form has never before been reported for any member of the garnet group.

CONCLUSION

Unlike most other facetable gem minerals, tsavorite generally does not occur in well-formed crystals. The tsavorites documented here from the Karo pit of the tanzanite mine belt, Merelani Hills, Tanzania, are extraordinary for the perfection of their faces. From a crystallographic point of view, these samples are even more remarkable for prominently exhibiting the π {1·10·16} crystal form, which has never before been reported for any member of the garnet group.

Although stones faceted from the green grossular crystals described here are generally less intense in color than is considered optimal for tsavorite, their chemical composition and gemological properties are consistent with those of previously studied tsavorites.

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DIAMOND GRIT–IMPREGNATED TWEEZERS: A POTENTIALLY DESTRUCTIVE GEMOLOGICAL TOOL

By John I. Koivula, Edward Boehm, and Robert C. Kammerling

The authors examined diamond grit–impregnated tweezers that reportedly were being marketed out of Japan. The tweezers were shown to damage virtually any type of gemstone with the possible exception of diamond; owners of these tweezers are advised to use caution.

Just as a tennis racket is an extension of the arm for the professional tennis player, so a pair of tweezers is an extension of the hand for the jeweler-gemologist. The gemologist thinks no more about how to use tweezers when examining a stone than a tennis player does about racket technique during match play. Years of practice make these actions automatic, almost instinctive.

And yet it is this very instinctiveness that can cause problems when a new type of tool is used in the same manner as the more familiar one. It was with this in mind that the authors investigated a new type of tweezers that appeared to be potentially damaging to gemstones.

Instead of the standard metal "waffle pattern" seen on most gem tweezers (figure 1, top), this new type is impregnated with particles of randomly oriented, sharp-edged diamond grit (figure 1, bottom). According to the literature that accompanied the tweezers (which were sold in pairs—one fine point and one medium point—and are reportedly manufactured in Japan), the purpose of the diamond grit is to give them a superior grip in handling diamond melee. It is interesting to note in this regard that our extensive use of these tweezers during testing did not reveal any significant difference in grip from the standard type.

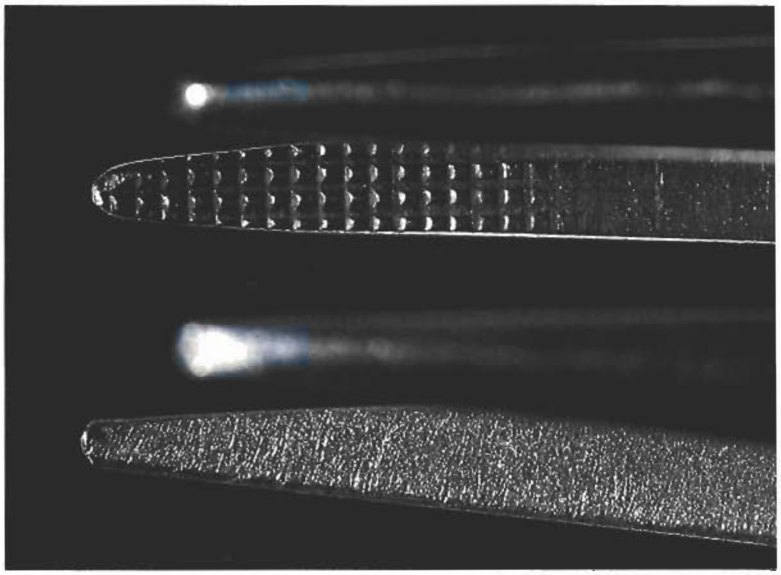

Figure 1. The tweezers at top show the scored metal "waffle" pattern of standard tweezer tips, while those below are impregnated with diamond grit. Photomicrograph by John I. Koivula; magnified 3×.

Although the tweezers were designed for use with small diamonds, it would not be unusual for someone to forget, once the tweezers were in the workplace, and use them to manipulate other gems as well. Given that diamond is the hardest naturally occurring substance known, what is the risk of using these tweezers to handle colored stones such as sapphires, rubies, or emeralds? Also, diamond has directional hardness. And it is reasonable to assume that if the diamond grit was randomly implanted into the tips of the tweezers, some of the grains would be oriented so that their hardest directional surfaces were at the gripping surface of the tweezers. Wouldn't this present a hazard even to diamond?

To answer these questions, we decided to test the tweezers with regard to their potential for damage to synthetic ruby (Mohs hardness 9) and diamond (Mohs hardness 10) round brilliants. If either of these materials was damaged by the tweezers, all

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Acknowledgments: The authors thank Peter and Bobbi Flusser of Overland Gems for providing the diamond-impregnated tweezers investigated for this report and for bringing to our attention the potential for gemstone damage.

Gems & Gemology, *Vol. 26, No. 2, pp. 149–151*

other gem materials (which have comparable or lower hardness) would be at risk as well.

TESTING

For this test, we selected a 2.39-ct round brilliant–cut flame-fusion synthetic ruby (8.32–8.39 mm in diameter) and a 0.21-ct round brilliant–cut diamond (3.70–3.72 mm in diameter).

It is standard procedure in both gem identification and diamond clarity grading to examine a stone first through its largest facet, the table. For this procedure, the stone is usually picked up by the girdle edge. However, the next step commonly is examination through crown and pavilion facets, for which the stone is held table-to-culet (as shown in figure 2) so that it can be easily rotated and then examined through facets around its circumference.

With standard metal-tipped tweezers, such a procedure presents little potential for damage to all but the softest of gem materials, because stainless steel has a Mohs hardness of only about 5 1/2 to 6. The contact surface of the diamond-impregnated tweezers, however, exceeds the hardness of all gems but diamond.

Before handling either the synthetic ruby or the diamond with the tweezers, we photomicrographically documented the condition of their table facets in surface-reflected light (figures 3 and 4). We then picked up the synthetic ruby with standard medium-point, metal-tipped tweezers table-to-culet, using normal finger pressure. The stone was rotated 360° a total of 10 times and then carefully examined with magnification. We observed no damage on the table of the stone.

Next, using normal finger pressure, we picked the synthetic ruby up table-to-culet with the diamond-impregnated tweezers and rotated it once through 360°. This caused considerable damage to the stone: The table was covered with numerous concentric scratches (figure 5).

We then proceeded to pick up the diamond table-to-culet with the fine-tipped diamond-impregnated tweezers and, again using normal finger pressure, rotated it through 360°. When we subsequently examined the stone with magnification, there was no indication of damage. Next, we rotated the diamond a total of nine more times through 360° and reexamined it; again, visual inspection with magnification revealed no damage. We continued the procedure, reexamining the table facet after every 10 rotations. We noted the first evidence of damage after a total of 50 rotations. After a total of 100 rotations, damage was severe (figure 6). Notice the broken circular (as opposed to complete circular) pattern of the scratches. This results from "skipping" as the randomly oriented diamond grains in the tweezers encountered harder directions in the subject diamond.

Figure 2. As part of the identification and evaluation of a gemstone, it is commonly held in the tweezers table-to-culet for examination through the crown and pavilion facets. Photomicrograph by John I. Koivula.

CONCLUSION

Rubies and sapphires are correctly considered hard, durable gems. Yet the diamond-impregnated tweezers easily produced significant surface damage to the table facet of the synthetic ruby tested. If the tweezers can do this amount of damage to such a relatively hard gemstone, it is reasonable to expect that they would be even more destructive to softer gem materials such as alexandrite, garnet, tanzanite, tourmaline, and the quartz varieties. A cursory examination of a hardness comparison table in any standard gemological reference (e.g., Liddicoat, 1989; Webster, 1983) reveals that the majority of gemstones are notably lower in Mohs hardness than diamond and corundum.

While rather extreme handling was necessary to produce the damage shown in figure 6, the fact remains that the diamond-impregnated tweezers do have the potential to scratch even diamond. And a single scratch is all that is needed to remove a diamond from the flawless category. Because the

Figure 3. This photomicrograph shows the condition of the table facet on the 2.39-ct synthetic ruby before it was handled with the diamond-impregnated tweezers. Photomicrograph by John I. Koivula; magnified 5×.

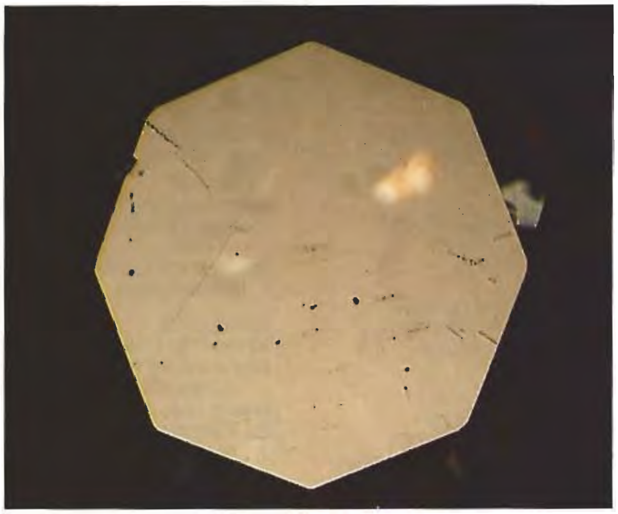

Figure 4. This photomicrograph shows the condition of the table facet on the 0.21-ct diamond before it was handled with the diamond-impregnated tweezers. Photomicrograph by John I. Koivula; magnified 12×.

Figure 5. After only one 360° rotation in the jaws of the diamond-impregnated tweezers, considerable damage was done to the table facet of the synthetic ruby seen in figure 3. Photomicrograph by John I. Koivula; magnified 5×.

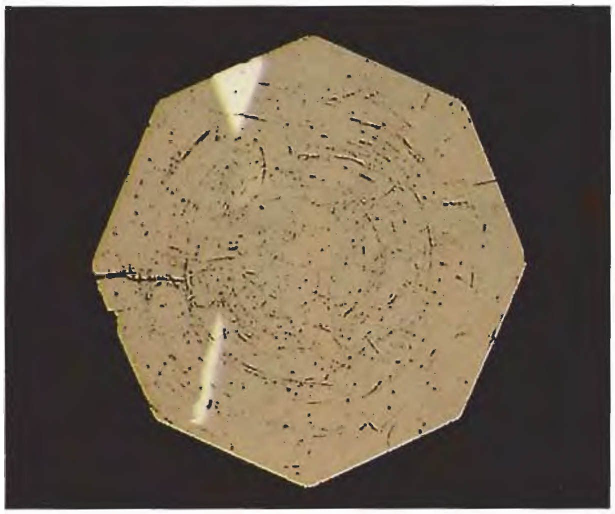

Figure 6. This damage was evident on the table of the diamond illustrated in figure 4 only after one hundred 360° rotations in the jaws of the diamond-impregnated tweezers. Photomicrograph by John I. Koivula; magnified 12×.

table is generally the largest facet on a gemstone, recutting a stone to remove damage from the table area will usually result in a significant loss of weight.

Damage such as that described here is apparently occurring to gems in the marketplace. Gemologists in the GIA Gem Trade Laboratory have reported seeing rubies and sapphires with concentric circular scratches on their tables (R. Crowningshield, pers. comm., 1989). Gem dealers have encountered diamonds, as well as colored stones, with similar damage (H. Adler, pers. comm., 1989). The jeweler-gemologist is advised to exercise great caution when using diamond-impregnated tweezers and to avoid using them on any gem material other than diamond.

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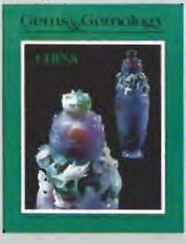

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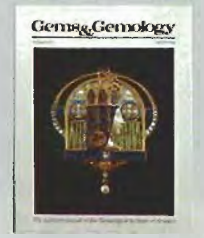

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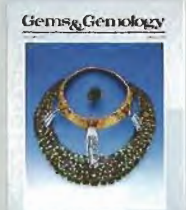

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Gem Trade LAB NOTES

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Cultured CALCAREOUS CONCRETIONS

At the February 1990 Tucson Gem and Mineral Show, several staff members saw a number of concretions that had been found during the harvest of cultured black pearls from *Pinctada margaritifera* mollusks in the South Seas. These concretions, which averaged approximately 12 mm in diameter, were a fairly even dark brown to black in color, but lacked any nacreous deposits. The client asked us to investigate why in these instances the mollusk did not produce the expected cultured pearl but rather a concretion.

With magnification, all of the samples showed a cellular structure in the dark surface areas (figure 1) that is characteristic of most calcareous concretions. In one of the samples, we also noticed an underlying lighter colored area that had no structural characteristics (figure 2). This area did not fluoresce when exposed to long-wave ultraviolet radiation, although the outer layer with the cellular structure did fluoresce a faint yellow, similar in appearance to that seen in some areas of the prismatic calcite layer of the shell itself. An X-radiograph of the concretion revealed the bead nucleus surrounded by a heavy conchiolin layer, thus proving that the concretions were indeed the result of a culturing process. The mollusk had apparently started to build the different shell layers around the inserted nucleus, but had stopped before producing any nacreous layer. We could only speculate that the mantle-tissue graft inserted into the mollusk during the culturing process did not contain (probably by accident; i.e., the critical area was cut off) those cells crucial to the production of this nacreous layer. *KH*

Figure 1. The cellular structure characteristic of calcareous concretions is readily apparent in these dark surface areas. Magnified 20×.

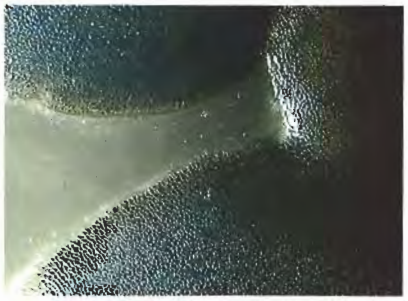

Figure 2. The light-colored nucleus visible under the dark surface of this calcareous concretion has no apparent structure and thus cannot be a shell bead. Magnified 5×.

Figure 3. This 21.26-ct slab of imitation coral is comprised of barium sulfate, a plastic binder, and a coloring agent.

Imitation CORAL, Barium Sulfate

The West Coast laboratory recently received for identification the 21.26-ct orangy red, partly polished, sawed slab illustrated in figure 3. Routine gemological testing quickly identified the material as manmade, apparently intended to imitate coral. When viewed with overhead illumination, the slab appeared opaque, but when placed over an intense light source, it transmitted a moderate amount of light. To the unaided eye, the polished side appeared to be a fairly even orangy red with a waxy

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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. 2, pp. 153-158*

luster. However, with low (less than 20×) magnification and oblique illumination, a subtle inhomogeneous appearance was evident: an irregular, randomly oriented, whitish pink "veining" that somewhat resembles the "spiderweb" pattern seen in some imitation turquoise. Also observed were minute, opaque, metallic-appearing black inclusions.

The material showed an indistinct refractive index reading of around 1.58. The specific gravity, as determined by the hydrostatic method, was approximately 2.33. The hardness – tested in a discreet area – was estimated to be 2 $^{1}/_{2}$ to 3.

To determine the exact nature of the material, we used sophisticated testing methods. X-ray powder diffraction analysis produced a pattern that matched the standard pattern for barium sulfate. An infrared spectrum obtained to determine if a plastic-type binder was used revealed a strong, sharp peak at 1733 cm^{-1}, typical of a polymer. This absorption band has also been observed in plastic-treated (stabilized) turquoise and in some manufactured turquoise imitations (see "The Identification of Turquoise by Infrared Spectroscopy and X-ray Powder Diffraction," by Th. Lind, K. Schmetzer, and H. Bank, *Gems & Gemology,* Vol. 19, No. 3, 1983, pp. 164–168). *RK*

DIAMOND

Etch Channels in

Etching of a diamond crystal by chemical dissolution can take any of several different forms. The appearance of trigons was discussed in the Lab Notes section of the Spring 1990 issue of this journal, while the Winter 1988 Lab Notes mentioned laminar dissolutions on octahedral faces. Recently, the East Coast laboratory observed etch channels along the edges of octahedral faces on a 3.57-ct rough diamond (figure 4).

As stated in Orlov's *Mineralogy of Diamonds* (J. Wiley & Sons, New York, 1973, p. 82): "The internal structure of the crystal has considerable influence on the nature of the dissolution surfaces. Different kinds of defects, twinning, inhomogeneous internal structure, all reveal themselves on the surfaces and in the resulting diversity of striations and sculptures." *DH*

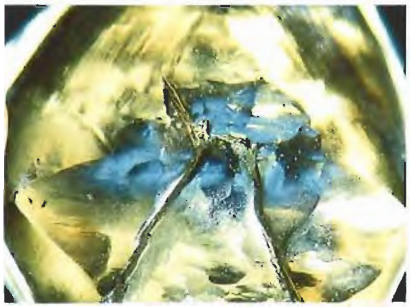


Figure 4. Etch channels are evident on the edges of this octahedral diamond crystal. Magnified 10×.

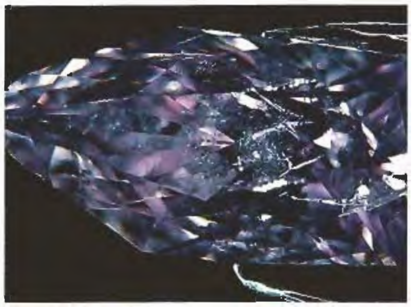
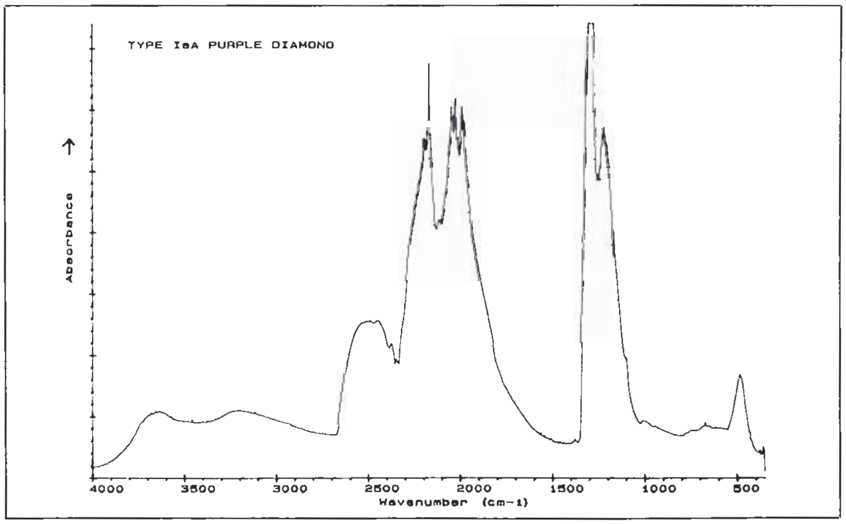


Figure 5. The color of this 1.04-ct modified bullet-shaped purple diamond is quite rare.

Another Purple Diamond

As mentioned in the Summer 1988 Lab Notes section, purple diamonds are rare. The 1.04-ct modified-bullet-shape brilliant cut shown in figure 5 was graded as fancy purple, natural color. The East Coast laboratory thought that the key color was closely matched by ColorMaster coordinates C-23/59/66, with a tone of 5.0 and a saturation of 1.0. Unlike the grayish purple diamond described in the 1988 entry, this stone had no discernible gray component when examined in the GIA Gem Trade Laboratory's standardized grading environment, using a Verilux daylight-balanced light source. Although this diamond did not display the 550-nm line in the hand-held spectroscope seen in other purple diamonds, it showed broad absorption in that area when tested with a Pye-Unicam U.V.-visible spectrophotometer. It was grained internally and had numerous surface grain lines as well.

Figure 6. This infrared absorption curve shows that the purple diamond seen in figure 5 is a type IaA diamond.



The I.R. spectrum (figure 6), obtained using a Nicolet Fourier transform infrared spectrometer, shows that this stone is a type IaA diamond. Type IaA diamonds contain nitrogen in pairs. Unlike type IaB diamonds, in which the nitrogen is bonded in triplets, IaA diamonds do not display the classic Cape series of absorption lines. *DH*

Radioactive GLASS Egg

The 7-oz. (198-gram) glass egg shown in figure 7 was submitted for identification to the East Coast laboratory. It was found to be singly refractive, with the spherical bubbles and swirls typical of glass; it also fluoresced a very strong greenish yellow, similar to the fluorescence seen in some synthetic spinels with this body color.

Figure 7. This yellowish green glass egg, measuring approximately 68.50 × 47.85 mm, proved to be almost 10 times as radioactive as normal background.

Since the body color reminded the staff of that seen in the radioactive uranium glass once used for tableware, we tested this glass egg for residual radioactivity. We found it to be quite "hot," with measurements nearly 10 times that of our normal background radiation. In this respect, it approaches the radioactivity of the rough sample of uranium glass reported by Nassau and Lewand in their article about radioactive synthetic spinel and glass triplets, which appeared in the Winter 1989 issue of *Gems & Gemology.* *RC*

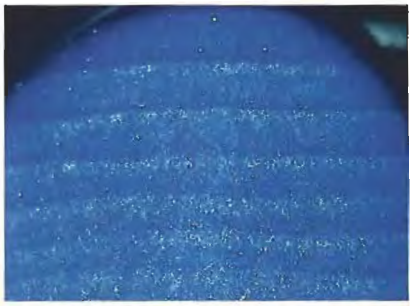


Figure 8. It is unusual to see a banded structure in lapis lazuli. Magnified 4×.

Banded LAPIS LAZULI

The Spring 1988 Lab Notes section described and illustrated a very unusual example of lapis lazuli. As our readers may recall, the distinctive characteristic was a striated structure that was easily visible to the unaided eye. Recently, our West Coast laboratory received for identification a 4-ct oval cabochon showing the same unusual structure (figure 8), with gemological properties almost identical to those of the material previously seen: R.I. (spot) 1.51 and S.G. (hydrostatic method) 2.85. With magnification and a strong overhead light, the unusual arrangement that produced the striated effect became easily visible: Dark blue grains closely packed in layers alternated with areas that contained both transparent near-colorless and opaque dark blue grains. X-ray diffraction analysis resulted in a pattern that showed a mixture of the major components that make up lapis lazuli: lazurite, haüyne, and mica (as well as another, undetermined mineral). We subsequently learned from our client that this banded material originates in Afghanistan; he could not provide information on the exact locality. *KH*

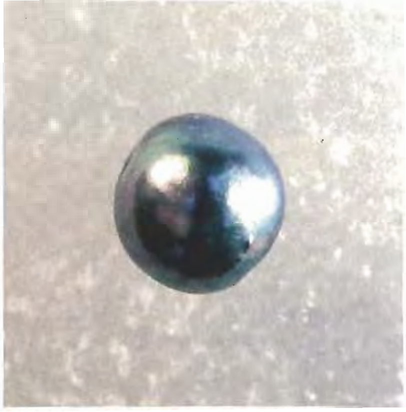
PEARLS

Gray Baroque Cultured Pearl

The dark gray baroque cultured pearl in figure 9, grown in a Japanese saltwater mollusk, was chosen for mounting as a tie tack because of its particularly lustrous appearance. Fortunately, X-radiographs were taken in the East Coast laboratory to locate the nucleus before the pearl was drilled. Had that not been done, it is quite possible that the drill would have missed the nucleus and subjected the very thin nacre to irreparable damage. Figure 10 shows X-radiographs taken from two different directions after the pearl was drilled and the tie tack assembled. It is easy to visualize what could have happened if the drill had missed the point of contact between the nucleus and the nacre. X-radiographs of such cultured pearls suggest that stringing them into a necklace can be quite risky.

Incidentally, people in the trade had mistaken this specimen for a natural-color gray Tahitian cultured pearl. However, the bead nucleus is only 7.5 mm in diameter, smaller than the nuclei customarily used in Tahiti. *RC*

Figure 9. This approximately 12 × 14 mm baroque dark gray cultured pearl was X-radiographed before it was drilled.



"Well-Worked" Pearl

The 22.70 × 15.60 mm natural baroque pearl recently seen in the East Coast laboratory (figure 11) is securely held in a custom-designed gold pendant that appears to be old. It

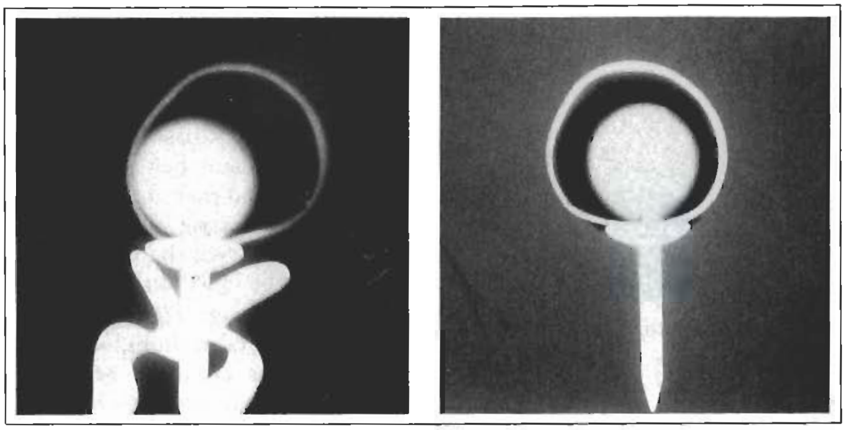


Figure 10. Two different X-radiographic views of the cultured pearl shown in figure 9 illustrate the importance of proper location of the drilling site. Note the large area between the nucleus and the nacre in the view on the left.

Figure 11. This attractively mounted 22.70 × 15.60 mm baroque pearl has been repaired in a number of areas; note the small pearl (on the side near the bottom) that has been used to plug an existing hole.

is an example of the lengths to which jewelers once went to use a rare gem material. The pearl has been half drilled in four places, unwanted areas have been judiciously removed, and other areas show signs of repair—one hole is even plugged with a small natural pearl. This pearl plug can be seen on one side about a third of the way up from the bottom of the pendant. *RC*

Unusual Gem-Quality SODALITE

Figure 12 shows part of an 11-strand hank of more than 2,000 semi-transparent blue beads, averaging approximately 2.0 to 2.5 mm, that recently came into the East Coast lab for identification. At first glance, because of their uniformity in color and appearance, they resembled some sapphire—actually, synthetic sapphire—beads we have seen. However, the spectrum seen with a hand-held spectroscope readily identified them as sodalite. It is surprising that a material with a relatively low refractive index (1.48 versus 1.76) and much lower hardness (5 to 6 versus 9) could so closely resemble corundum. Figure 13 illustrates the relative transparency and fine polish of these handsome beads. *RC*

Figure 12. These fine-quality 2–2.5 mm beads resembled natural or synthetic sapphire in appearance, but proved to be sodalite.

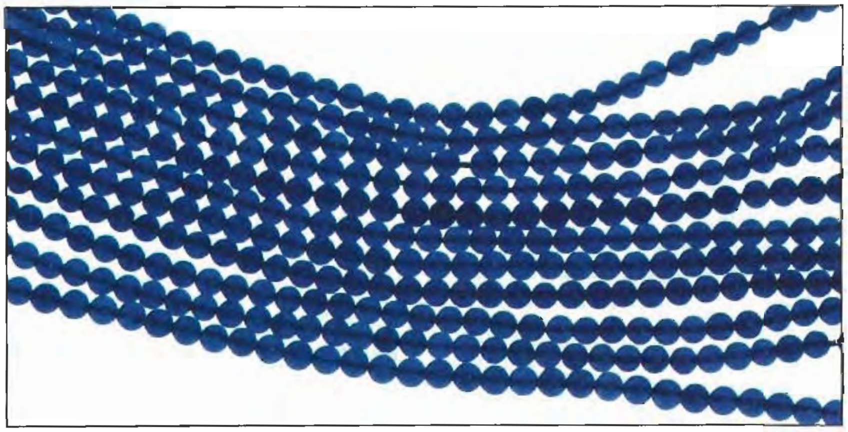
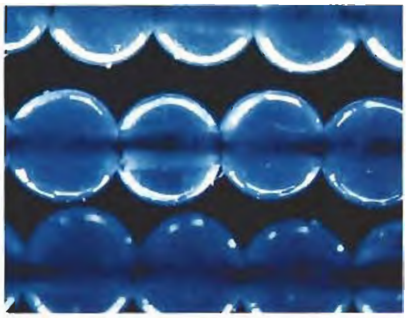


Figure 13. The transparency and fine polish of the sodalite beads shown in figure 12 are evident even at 10× magnification.



SPINEL from Tanzania

The West Coast laboratory recently received for identification the 2.28-ct purplish pink faceted pear shape illustrated in figure 14. Subsequent testing revealed that it was a natural

Figure 14. This 2.28-ct purplish pink spinel is reportedly from Tanzania.

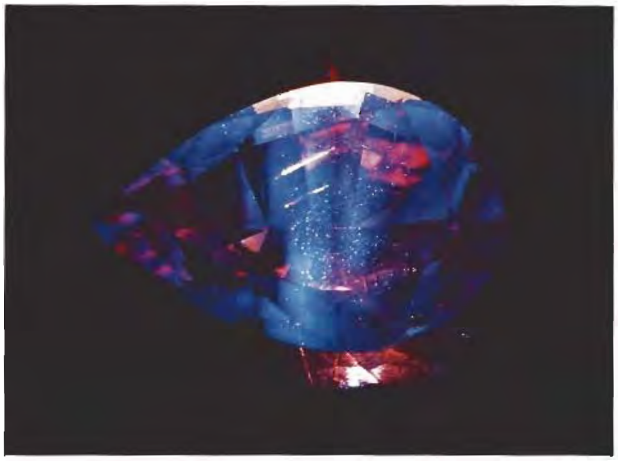


Figure 15. With intense light, the spinel showed a strong blue transmission-type effect.

spinel (R.I. 1.714; singly refractive with very weak anomalous double refraction; S.G. by hydrostatic method of approximately 3.60; strong and very weak red fluorescence to long- and short-wave U.V. radiation, respectively; characteristic absorption spectrum). An interesting feature was noted, however: When the spinel was placed over the intense light emitted through a small opening of the iris diaphragm on the spectroscope unit, a moderate to strong whitish blue transmission-type effect was very evident (see figure 15). This phenomenon was also apparent to the unaided eye when the stone was held a few inches from either an incandescent or fluorescent light source. A faint bluish hazy cast was seen when the spinel was held at "arm's length" in sunlight. This is probably a scattering effect caused by minute inclusions, or dislocations, similar to the reaction seen in some other gem materials.

With the microscope, we observed that although the stone was slightly included, the parallel rows of tiny octahedra that are so frequently encountered in spinels from the classic localities of Burma and Sri Lanka were conspicuously absent. In addition to the "cloudy" transmission effect discussed above, the most prominent internal features were numerous "sheets" of polysynthetic twinning planes. These planes intersected in two directions throughout the gem, and in several areas they were associated with coarse needles or growth tubes. Immersion of the stone in methylene iodide revealed faint color zoning, which appeared to be in alignment with some of the twinning features discussed above. Also dispersed through most areas were densely packed clouds of what appeared to be exsolutions of tiny particles and needles oriented in three directions. A few small, thin, transparent, near-colorless tabular euhedral crystals were present.

The physical and optical properties, as well as color and visual appearance, of this spinel match those of spinels from a "new" deposit in Tanzania that were shown to the writer by Mrs. Eckehard Petsch during a recent visit to Idar-Oberstein. Tanzanian spinel was also available at the 1990 Tucson Show. The owner of the spinel described here reported that the stone was indeed from Tanzania. *RK*

SYNTHETICS and SIMULANTS in Period Jewelry

The East Coast laboratory again had the opportunity to examine some interesting period pieces. The blue stone in the pierced earring shown in figure 16 certainly appeared to be in good company, set in a silver top/gold back earring with near-colorless old-mine brilliants and Swiss cuts—a combination that was common before the turn of the century. The blue stone proved to be glass, with a refractive index of 1.57. It could well be the replacement for a stone lost from an original near-antique piece. However, an even greater mystery is in the markings on the gold (figure 17): the number 583, a quality stamp, and a symbol consisting of a five-pointed star within which is a hammer and sickle. The style was recognized as Russian by a member of our staff who is of Russian extraction. However, we have been unable to determine if this symbol was in use in pre-

Figure 16. This faceted blue glass, surrounded by old-mine- and Swiss-cut diamonds, probably replaced the original center stone in this period earring.

Figure 17. The unusual hallmarks on the gold post of the earring in figure 16 raise some questions as to when and where it was fashioned. Magnified 10×.

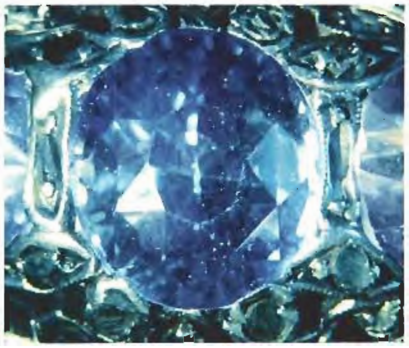


Figure 18. Since synthetic blue sapphires were not made before 1910, this ring may be a reproduction of an earlier piece, with diamond chips used to suggest the earlier dating.

revolutionary Russia, or even if the piece is indeed Russian. If the hammer and sickle came into use only after the 1917 revolution, then the piece would have to be considered a reproduction.

The ring shown in figure 18 contains three very deeply cut synthetic sapphires that resemble some Sri Lankan sapphires we have seen. The silver top and gold shank again suggest a turn-of-the-century dating for the ring. Of particular interest, and to us a rarity, is the fact that the near-colorless accent stones are completely unpolished diamond chips (again, see figure 18). The blue stones appear to be undisturbed in the setting and therefore are probably original. The earliest date for these synthetics would be 1910, so the piece could not have been made before then. *RC*

FIGURE CREDITS

The photomicrographs in figures 1, 2 and 8 are the work of John I. Koivula. Figures 3, 14, and 15 are by Robert Weldon. Dave Hargett is responsible for figure 4. Vincent Cracco took the photo for figure 5. The I.R. spectrum in figure 6 was produced by Ilene Reinitz. Nicholas DelRe provided figures 7, 9, 11–13, and 16–18. The X-radiographs reproduced in figure 10 were taken by Robert Crowningshield.

A HISTORICAL NOTE

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

SUMMER 1965

The New York lab commented on seeing for the first time a gray-blue kornerupine set in jewelry. They also mentioned a color-change sapphire, two cat's-eye apatites, and a number of painted diamonds that were being fraudulently sold as natural color by a 47th-Street jeweler.

The Los Angeles lab reported on a beautiful aquamarine that was faceted on the pavilion but had a buff top carved with the head of a lady who was wearing a heavy bead necklace and a hair ornament. They also described and illustrated a badly damaged diamond ring. The owner remembered hitting the side of the swimming pool a few times with it, but didn't realize the damage caused. The stone had chips extending from the girdle to the culet on all four sides between the prongs of the setting.

SUMMER 1975

Several examples of very beautiful scrimshaw work on sperm whale teeth were examined and illustrated by the Los Angeles laboratory. An unusual occurrence of corundum in pinite was discussed and shown by reflected and transmitted light, with the difference in hardness of the two materials readily apparent from the difference in luster. Another rare item was a snuff bottle carved from the beak of a hornbill. The red color of the casque on the bill was evident as a darker rim on the edges of the bottle.

The New York lab saw first-hand the effects of too much heat on a diamond. The ring in which the stone was set had been repronged with the stone in place and no effort made to protect it. As a result, the diamond was burned beyond recognition, with all of the facets destroyed.

The color changes that can occur in GGG (gadolinium gallium garnet) when it is exposed to ultraviolet radiation and then heated were covered in detail. The stones turn brown when exposed to U.V. radiation but return to their original color on heating. A "Mood Stone" was examined and found to be a quartz cabochon backed with an unknown material that changes color as the temperature changes. The color-change effect is very similar to that of the liquid crystal thermometers that change color with variations in temperature.

SUMMER 1985

Different cat's-eyes were discussed and illustrated, with the various gemological properties listed. These included specimens of zircon, quartz, a 52.97-ct green-brown scapolite, and a rare 1.86-ct hexagonite (the pink variety of tremolite, found in St. Lawrence county, New York). Also illustrated was the damage incurred when a fluorite carving was placed in dilute sulfuric acid to remove traces of soldering flux and tarnish from a gold bail. An unusual synthetic opal and a radioactive natural opal from Mexico were discussed and illustrated.

GEM NEWS

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

DIAMONDS

Scientists research material as hard as diamond. Using principles based on the calculated compressibility of a hypothetical solid composed of carbon and nitrogen, scientists at the Lawrence Berkeley Laboratory investigated the possibility of synthesizing new materials with a hardness comparable to diamond. Physicist Marvin Cohen and Berkeley graduate student Amy Liu used a combination of a simple empirical model and a quantum-mechanical "first principals" computer calculation to test their hypothesis. Experiments were performed on silicon-nitride, in which the silicon was substituted with carbon. Results found that a carbon-nitrogen compound would have a bulk modulus of 4.3 megabars, compared to the 4.4 megabars of a diamond. (A megabar is one million times atmospheric pressure at sea level.)

A material with a hardness comparable to diamond would be valued in industry for use in cutting tools and as a wear-resistant protective coating.

Malaysia diamond plant. According to the Bernama news agency, a new diamond-processing plant opened this past March at Ipoh, 190 km north of Kuala Lumpur in Malaysia. The plant, a joint venture between two Belgian companies (Schongut and Tache), is said to have an annual capacity of 900,000 processed diamonds, with a work force of 250.

Botswana beats target. Botswana produced 13 million carats of diamonds in the first three quarters of 1989, which betters the production target of 12.6 million carats, according to the minister of Finance Development Planning. The minister added that an $87 million crushing plant was scheduled for completion in April at Debswana's Jwaneng diamond mine near the city of Kanye, about 100 km southwest of Gaberone. He speculated that diamonds produced at Jwaneng in the future would be smaller and of lower value than those presently mined, although total carat output would remain at the current level. (*Mining Journal*, March 23, 1990)

Soviet-Singapore joint venture. Intraco of Singapore, a government-linked trading firm, announced plans for a joint trading venture with Almazjuvelirexport (Almaz), which is currently the exclusive producer and exporter of diamonds for the Soviet Union. The joint venture, which began operations in April 1990, is called Russalmaz Asia, and has started with an authorized capital of $500,000. Almaz would take a 50% stake, with the remainder divided equally between Intraco and Agrochem Investment of Singapore. The intention of the newly formed venture is to deal not only in diamonds, but also in colored stones, jewelry, precious metals, and industry-related equipment and machinery.

New area in Angola to be mined. A new area in and around Lucapa, in the province of Lunda-Norte, is a prospecting target for the Sociedade Portuguesa de Empreendimentos. SPE signed a two-year agreement that allows it to prospect the area, for which target production is 400,000 ct of diamond a year, according to SPE's chairman. At the end of the two-year contract, SPE and Endiama (Angola's national diamond enterprise) might consider a joint mining venture. (*Diamond International*, March/April 1990)

Argyle cutting school near Beijing. The Australian government has funded a school to train diamond cutters to boost the cutting of Australian rough in China and encourage competition with India in the manufacture of Australian goods. According to Beijing officials, the school, managed by Argyle Diamond Sales, was scheduled to begin operations in April. On staff are five Chinese training managers from the Pearl, Diamond, Gem and Jewelry Import and Export Corporation (CPDGJIEC). Students for the school—which hopes to train 850 cutters over the three-year duration of the project—will be recruited from CPDGJIEC factories in Beijing and the provinces. Argyle will supply the rough to be cut and polished; the finished stones will be returned to Argyle. (*Diamond International*, January/February 1990)

Kimberlite find in the U.S. The Upper Peninsula region of Michigan was targeted for drilling by Crystal Exploration, Inc., to determine the diamond potential of a kimberlite pipe found there. Out of 10 holes drilled in that area, seven intersected kimberlite.

Crystal Exploration has acquired the diamond exploration assets of Dow Chemical Co., which had been exploring for diamonds in Michigan for almost five years. During this time, they discovered six pipes, two of which require further processing to assess their potential. (*Mining Journal*, April 13, 1990)

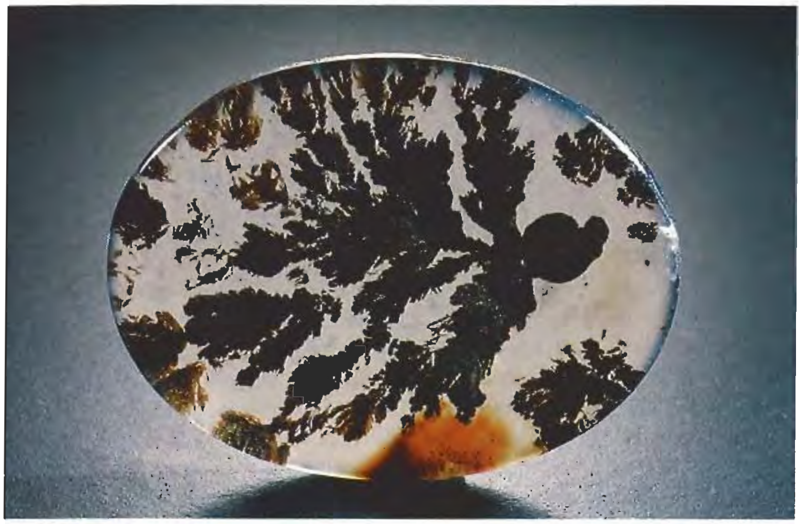


Figure 1. This 39.00 × 30.45 × 6.42 "plume" agate is actually an assembled stone. Photo by Robert Weldon.

Diamond-cutting industry in Sri Lanka. Switzerland and Sri Lanka are setting up a joint venture in the Katunayake area of Sri Lanka to cut and polish diamonds and colored stones. The project is expected to employ about 150 people. Sri Lanka had three approved diamond-cutting units in 1986, and now has 13, most of which are joint ventures with Belgian, Israeli, and Japanese interests. The Sri Lankan government has offered outside investors incentives such as duty-free import of machinery and accessories and tax exemptions on export profits.

Future industry proposals include the establishment of an exclusive diamond zone within the Katunayake Free Trade Zone as well as the establishment of a special Diamond Guild. (*Mining Journal,* April 27, 1990)

Tanzania intensifies mineral search. Apparently because of radical reductions in the production of gold and diamonds (the latter is reportedly only 50% of what it was in the mid-1970s), the Tanzanian government has intensified its search for mineral deposits. The Mwadui diamond mine is expected to be exhausted in approximately nine years. (*Diamond Intelligence Briefs,* May 8, 1990)

Prospecting in Botswana. The firm Molopo Australia is currently exploring for diamonds in Botswana in a large tract to the south and southwest of Debswana's Jwaneng diamond mine. The firm reports "significant advances" in its evaluation of one of the kimberlite pipes discovered in the prospect area. Molopo will carry out aeromagnetic surveys in parts of the concession as well as continue to evaluate the economic potential of already-discovered kimberlite pipes. (*Diamond Intelligence Briefs,* May 8, 1990)

COLORED STONES

Assembled "plume" agate. From time to time, we see gem materials that have been treated to fabricate, alter, or induce inclusions. We have seen transparent quartz crystals with man-made "three-phase" inclusions, topaz with stained etch channels that were heat treated to alter the color of the iron-based staining, and agates with dendritic inclusions produced through electrically stimulated chemical precipitation.

Recently, Pieter Bennett, a student at GIA in Santa Monica, donated an interesting assembled stone to the Institute. The stone, a very low-domed oval cabochon (figure 1), had been purchased at the February Tucson Show, where it was represented to be "natural" dendritic agate. The 61.39-ct specimen is essentially colorless and almost transparent where inclusions are not present. It exhibits an attractive "plume"-type pattern of dark reddish to greenish brown dendrites. One small, irregular area is a dark yellowish brown color with wavy, agate-like banding.

When examined from the side, the assembled nature of the piece becomes obvious: The top consists of a transparent, colorless, convex cap joined to a flat, light gray, semitransparent to translucent base. With magnification, the cap appears inclusion-free. Between the cap and the base is a fairly thick (approximately 0.5 mm), transparent, colorless layer that contains many minute spherical gas bubbles. Using a straight pin and very little pressure, we easily scratched and indented this layer, which we believe to consist of an epoxy or similar synthetic resin. Irregular drops of this material were found on the cap near the separation plane, and the entire base—which showed several scratches—was coated with it. In addition to the dendritic inclusions mentioned above, the approximately 1.2-mm-thick base section contained some irregular, wispy, milky-white areas, some of which showed typical "botryoidal" or "fortification agate" structure.

A spot R.I. taken on the apex of the cap revealed a reading of 1.51; the 1.56 flat-facet reading taken on the base was believed to represent the thick coating rather than the underlying material. No birefringence or pleochroism was noted, and no absorption features could be detected with a desk-model prism spectroscope unit. When examined face-up in the polariscope, the stone exhibited an aggregate reaction; when examined through the side, parallel to the separation plane, the cap gave a singly refractive reaction, while the base gave an aggregate reaction. Using hardness points, we determined that the cap had a Mohs hardness of approximately 5 1/2.

Viewed face-up, the piece was inert to long-wave U.V. radiation and fluoresced a moderate chalky yellow to short-wave U.V. When the piece was examined parallel to the girdle plane, however, the epoxy-like layer fluoresced a bright bluish white – and both the base and cap were inert – to long-wave U.V.; to short-wave U.V., the cap fluoresced a strong chalky yellow, the epoxy-like layer fluoresced a moderate chalky bluish white, and the base was inert. Interestingly, when the stone was viewed through its base while exposed to short-wave U.V. radiation, the yellow fluorescence of the cap was masked.

On the basis of these test results, we determined that the specimen was a glass and dendritic ("plume") agate doublet, the two components being joined by a colorless cement layer. One might ask why anyone would go to the trouble of producing such an assembled stone. Dr. Emmanuel Fritsch, of the GIA Research Department, suggested that only in a relatively thin section might the agate base exhibit the desired "plume" effect; the assemblage allowed this effect to be seen in a larger (and perhaps more durable) stone.

Apatite "from Paraíba" and apatite purchased as emerald. Among the colors seen in the Paraíba tourmaline that has recently emerged from Brazil is a saturated bluish green similar in appearance to what some in the trade call "light emerald." Also seen at the February Tucson Show were parcels of greenish blue to bluish green apatite that reportedly came from Madagascar; at least one exhibitor was offering apatite in this color range as "Paraíba apatite," while another was selling virtually identical material labeled simply "Paraíba." To our knowledge, no apatite comes from Paraíba.

Interestingly, about a month after the Tucson Show, we received International Colored Gemstone Association (ICA) Laboratory Alert No. 35, "Bluish Green Apatite Rough as Emerald." The report, which originated with Yehuda Yacar of the Gemological Institute for Precious Stones and Diamonds Ltd. in Ramat-Gan, Israel, documented the gemological properties of a 230-gram parcel of bluish green apatite that was purchased in Kenya as emerald and was said to have come from Madagascar.

Brazilian chrysoprase. Chrysoprase is one of the more popular gem varieties of chalcedony. The best known locality for this yellowish green material is Australia, and it is often given the misnomer "Queensland jade."

Recently, Douglas M. Henrique of Huntington Park, California, showed us some rough specimens of an attractive light yellowish green material that he described as Brazilian chrysoprase. According to Afranio Moreira, of Brasil Comercio de Pedras Preciosas, in Governador Valadares, the material is found in a galena mine near Niquelandia, in the Brazilian state of Goiás. According to Mr. Moreira, only 30% of the material recovered is green, with the rest white.

We subsequently had two oval single cabochons and a preform cut from one of the pieces of rough (donated by Mr. Moreira) and subjected these to testing to confirm the identity. One of the cabochons, together with a piece of strongly color zoned rough, is shown in figure 2. The pieces are all light, slightly yellowish green and semitranslucent. A refractive index of 1.539 was obtained from the flat, well-polished base of one specimen, and thin sections of the cabochons gave aggregate reactions in the polariscope. When viewed through a Chelsea color filter, the stones appeared grayish green. Specific gravity (taken with heavy liquids) was approximately 2.64. Magnification revealed yellowish, possibly limonitic, staining in some surface-reaching fractures.

Figure 2. Chrysoprase, like this 11.18-ct cabochon and accompanying rough, is being mined in Goiás, Brazil. Photo by Robert Weldon.

X-ray fluorescence spectrometry, performed by Dr. Emmanuel Fritsch, demonstrated the presence of both silicon and nickel in a test sample. Meredith Mercer, also of the GIA Research Department, compared the U.V.–visible absorption spectrum of this material to that of a reference sample of Australian chrysoprase from the GIA collection and found the features of the two to be essentially identical. This testing confirmed the identity of the material as chrysoprase chalcedony.

One interesting feature noted during the gemological investigation was the reaction to ultraviolet radiation of this Brazilian material: It fluoresced a moderate greenish blue to long-wave, and a weaker greenish blue to short-wave, U.V., and did not phosphoresce to either wavelength. Chrysoprase from other localities is typically inert to both wavelengths.

Major jade deposits in Japan. Commercial mining of jade is very limited in Japan, although large deposits of good-quality jadeite exist. In addition to the green variety, blue, purple, black, and white jadeite has been found.

Deposits in Kotaki, near Itoigawa and Oomi in Niigata prefecture, are under snow six months of the year, and even in the warmer months strong river currents and

Figure 3. This "cat's-eye" opal triplet measures 7.78 × 9.85 × 4.80 mm. Photo by Robert Weldon.

landslides make it difficult to get men and equipment into the area. Following the rainy season, however, jadeite pebbles of good color and quality are found on the banks of the Kotaki and Himekawa rivers, in Niigata prefecture, and on the seashore at Asahi, in nearby Toyama prefecture. A deposit of fine jadeite was recently discovered in Hashidate, close to Itoigawa, but the snow, rough terrain, and dangerous insects make commercial mining possible only in September.

In Ooya, in Hyogo prefecture, good-quality white jadeite with splashes of bright green has been discovered, but the deposits are protected. Deposits recently discovered in Kanto and Gunma are yet to be mined. Other jadeite deposits in Japan are: Kamuikotan in Hokkaido; the northern mountain area of Nagano prefecture; Wakasa in Tottori prefecture; Oosa in Okayama prefecture; and Nagasaki and Shikoku. (*Jewellery News Asia,* March 1990)

Attractive chatoyant assembled opal. Opal is an essentially noncrystalline, amorphous form of silica that consists of regularly arranged spherical particles which diffract white light into colors of the spectrum.

Some opal, notably material from Idaho, exhibits a play-of-color in the form of a chatoyant band, an effect that has been attributed to planar faults in the stacking of the silica spheres. This chatoyancy can be enhanced by gluing a colorless cabochon cap, which acts as a condensing lens, over the opal; the cap also increases durability. Another piece of material, such as chalcedony, may be glued to the base, thus producing a "cat's-eye opal triplet."

Recently Lorri Dee Rascoe, a staff gemologist in the GIA Gem Trade Laboratory, showed the editors a very attractive opal triplet measuring 7.78 × 9.85 × 4.80 mm. The assembled stone was noteworthy for the strength of its play-of-color chatoyant band (figure 3).

Peridot mining update. Suzanne Kinkade, of Arizona Gems & Crystals, provided the Gem News editors with an update on peridot mining at the San Carlos Apache Indian Reservation in Arizona. According to Ms. Kinkade, monthly production at this important locality is presently about 600 kg of cabochon- and tumbling-quality material and 12–15 kg of facetable rough. Approximately 95% of the latter consists of pieces smaller than 5 ct. Typically, mining is carried out from October

Figure 4. Amethyst scepters such as this 10-cm-long crystal were found recently in the Inyo National Forest, California. Photo by Robert Weldon.

to March, since the heat is unbearable during much of the rest of the year and many of the potential miners are often occupied as firefighters.

California quartz update. In the Winter 1988 Gem News section, we reported on the recovery of good-quality smoky quartz crystals in the Inyo National Forest, Inyo County, California. Continued exploration by Michael and Cora Anderson has led to the discovery of amethyst crystals as long as 4 in. (10 cm) in this area. Some of these crystals show very fine scepter form, as seen in figure 4.

Most of the crystals found thus far can be described as specimen quality, while a few have transparent areas suitable for faceting. The extent of the deposit is not known at the present time.

Unusual pseudomorph. Some of the most unusual unfashioned specimens of gem minerals are silica pseudomorphs after various organic materials. Included among these are petrified wood and silicified coral, as well as opalized wood, shells, and even lizards.

Recently, an unusually fine fossilized cryptocrystalline quartz pine cone (figure 5) that dates back to the Jurassic period was brought to our attention by David Humphrey. The pine cone, *Aura Caria Mirabilis,* was reportedly found in the Cerro Cuadrado Petrified Forest, in Patagonia, Argentina. It measures 55 mm high and 53 mm in diameter, and weighs approximately 125 grams.

Figure 5. This 55-mm-high fossilized pine cone was discovered in Patagonia, Argentina. Courtesy of David Humphrey, Pacific Palisades, CA. Photo by Robert Weldon.

Rubies from Vietnam? Dr. Henry A. Hänni, of the Swiss Foundation for the Research of Gemstones (SSEF), provided the Gem News editors with some very interesting information relating to rubies that he believes to be from a new source in Southeast Asia. On a recent visit to Thailand, Dr. Hänni heard about rubies supposedly coming from either Vietnam or Cambodia; he also noted that Richard Hughes, editor of *Gemmological Digest,* had mentioned rubies from Vietnam in the most recent issue of that journal. While in Chanthaburi, Thailand, Dr. Hänni had an opportunity to see a large number of rubies (figure 6) that were reportedly from this new locality in Vietnam and to purchase samples for preliminary investigation.

Figure 6. This ruby rough is reportedly from a new locality in Vietnam. Photo courtesy of Dr. Henry Hänni, SSEF.

Dr. Hänni believes, based on his study of the inclusions and on trace-element analyses, that the deposit from which these rubies came is similar to the ruby deposits of Burma, Hunza (Pakistan), and Jegdalik (Afghanistan); he postulates that the rubies are derived from a marble occurrence. Samples he examined contained phlogopite mica and intersecting twin lamellae, and had a "certain milkiness." Almost all of the individual stones were waterworn, rolled pebbles, although some exhibited fresh crystal faces and had a tabular habit (figure 7). Dr. Hänni feels that if these stones were heat treated, they might be indistinguishable – except by trace-element analysis – from similar-appearing material from East Africa or Burma.

The largest specimen examined weighed approximately 20 grams (100 ct); like many of the stones, it was not transparent but was believed to be suitable for heat

Figure 7. Note the tabular habit of this ruby crystal, which was reportedly mined in Vietnam. Photo courtesy of Dr. Henry Hänni, SSEF.

treatment. With magnification, Dr. Hänni observed healing fissures as well as "dense patterns of intersecting narrow twin lamellae" in this stone.

Rock-like material with play-of-color. At a Santa Monica gem show, one of the Gem News editors recently examined an interesting semitranslucent gem material, fashioned *en cabochon*, that ranged from gray to yellow-brown in body color and exhibited a speckled play-of-color (figure 8). Magnification revealed transparent colorless grains surrounded, and cemented together, by what appeared to be a whitish opal exhibiting diffraction colors. Some specimens exhibited a range of spectral colors, while others showed only green.

According to the vendor, Ajith K. Senanayake of Sri Gems, Baton Rouge, Louisiana, the material is recovered from swampy areas within a 30- to 40-mi. (48–64 km) radius of the city of Lafayette, Louisiana. It is found in association with what Mr. Senanayake describes as a "sandstone-like" rock. Slabs as large as 1 m across have been recovered.

Figure 8. These 3- to 5-ct cabochons of a rock-like material from Louisiana display a speckled play-of-color. Photo by Robert Weldon.

The GIA Gem Trade Laboratory has examined similar material in the past, and found it to be a rock composed primarily of quartz sand grains, opal, and pyrite, with the opal being the cementing agent.

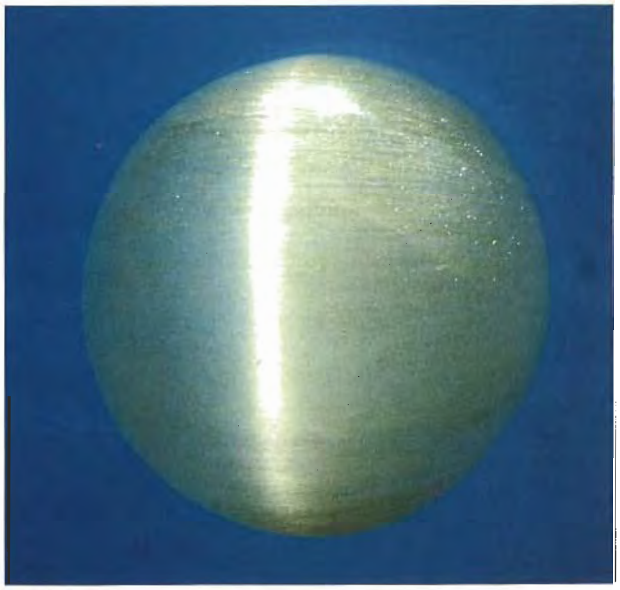
Cat's-eye topaz. Recently, Charles Carmona of Guild Laboratories, Inc., Los Angeles, showed us an interesting, very light yellowish brown, almost round double cabochon that he had identified as topaz. The 3.53-ct stone (8.63 × 8.36 × 5.01 mm) was translucent and exhibited a very strong chatoyant band (figure 9), which was apparent even under the diffused illumination of overhead fluorescent lighting.

Magnification revealed a dense pattern of very fine, parallel etch ribbons that were stained with a light yellow material (possibly limonite). When the stone was examined in transmitted light down the length of the ribbons, a transmission effect similar to that seen with the mineral ulexite (sometimes sold as "TV stone" because of the fiber-optic effect it exhibits) was noted. Secondary partially healed fractures in fingerprint patterns were also noted.

This is the first example of cat's-eye topaz that either of the Gem News editors has seen.

The discovery of the Paraíba tourmaline mine. The introduction of the "electric" blue and green tourmalines known as "Paraíba" to the colored stone market was one of the more notable industry events of recent years. Heitor Barbosa, who claims to have first discov-

Figure 9. This 3.53-ct cat's-eye topaz exhibits strong chatoyancy. Photo by Robert Weldon.



ered the Paraíba tourmalines, provided the following report on the history and development of this mine.

The sole source of the material, Mina da Batalha a Nova Era (Mine of the Battle of the New Era) is located in the state of Paraíba, Brazil, south of the mountain range Serra da Borborema on the north flank of Serra da Frade. It is 4.5 km northeast of Salgadinho, near the village of São Jose da Batalha. The mine is operated by COGASBRA, Cooperativa de Garimpeiros de São Jose da Batalha, municipality of Salgadinho, registered by the National Department of Minerals, DNPM, alvara no. 7.432, on March 13, 1990. Because the ongoing dispute over mining rights could become violent, the mine is not open to outsiders at the present time.

Barbosa, who previously had mined green tourmaline from the Golconda mine in Minas Gerais, was traveling through northeast Brazil's rugged *sertão* outback region in 1982 when he met Jose Pereira of Patos, Paraíba, an old *garimpeiro* who dealt in industrial "black mineral"—tantalite-columbite—which is found almost exclusively in pegmatites. When Barbosa examined some samples of the black mineral, he noticed tiny grains of a material resembling colored sugar that no one had identified but he suspected was a gem material. Barbosa then decided to explore for gem prospects with Pereira as his guide. They searched the mine dumps and tailings of the region's tiny industrial pegmatites, exploited for tantalite, beryl, mica, phosphate, and quartz, among other minerals. In 1983, while investigating the tailings of a small manganotantalite pit at the base of a hill, Barbosa spotted colorful fragments and began to dig.

Over the course of two and a half years, with a crew of 10 to 16 men, Barbosa laboriously dug two shafts up to 50 m deep, the second with 15-m galleries at several levels. The slow and cumbersome process involved two-kilo sledge hammers, chisels, pry bars, shovels, picks, and dynamite. The shafts followed vertical pegmatite dikes, with narrow (1.8 × 0.6 m) galleries carved where they intersected a horizontal finger of the dike. (Tourmaline is usually found here in pencil-thick veinlets enveloped in white kaolin clay.) Debris was moved back out of the galleries by shoveling across the length of the shaft and into a rubber bucket, which was then hauled to the top of the shaft by a hand-turned winch.

During 1985–87, Barbosa relates, miners encountered several varieties of tourmaline, ranging from bright "lettuce" green to blue green, near-emerald color, and drab green stones with indicolite tips large enough for faceting. In August 1988, at a depth of 50 m, Barbosa found five different types of blue tourmaline, including the "electric" blue stone he calls "Heitorita" (figures 10 and 11). He tells how he had to "bring [the beautiful tourmaline] out again and again to look at it. . . . After five and a half years, this was not just a good surprise but a present beyond imagination." In late 1988, the first examples of Paraíba blue tourmaline found their way into the Brazilian markets.

Figure 10. Heitor Dimas Barbosa holds some of the exciting tourmalines that he has mined from the Batalha a Nova Era mine, in Paraíba, Brazil.

Since the emergence of significant amounts of this fine material, a second claim has been made on exploration rights in the general vicinity. However, Barbosa has already been granted these rights for the area where the tourmaline was found, and he expects the Federal Department of Minerals to grant the mining lease to the COGASBRA mining cooperative, of which he is president, shortly. Currently, COGASBRA is working five different shafts with 14 miners, although Barbosa feels that a greater capacity—up to 25 pits—is feasible.

Tourmaline doublets. Some of the most interesting assembled stones—and potentially the most difficult to identify—are those that are composed partially or completely of the natural gem species being imitated. For example, beryl triplets, composed of two sections of natural beryl joined by a green cement, will give refractive index and birefringence readings consistent with emerald.

ICA Laboratory Alert No. 33, written by Drs. Hermann Bank and Ulrich Henn of the Deutsche Stiftung Edelsteinforschung, Idar-Oberstein, reports on tourmaline doublets. One basic type exhibits a cat's-eye effect, made by cementing a transparent crown to a

Figure 11. The "electric" blue color that appears to be unique to the Paraíba find can be seen here in this 1-cm tourmaline fragment on quartz from the Batalha a Nova Era mine. Specimen courtesy of Nature's Geometry; photo by Robert Weldon.

Figure 12. These two bicolored tourmalines were identified as assembled stones. Photo courtesy of H. Bank and U. Henn, Deutsche Stiftung Edelsteinforschung, Idar-Oberstein, Germany.

fibrous pavilion; the other is a bicolored transparent stone, with the two color components cemented together (figure 12). In either case, the component pieces may or may not be from the same crystal. As the authors note, both types can be identified with magnification, as the cement layer is easily visible.

"Treasure" postage stamp. While reading the article "Emerald and Gold Treasures of the Spanish Galleon *Nuestra Señora de Atocha*" (*Gems & Gemology*, Winter 1989), Nawal Kishore Tatiwala of Bansal Jewellers Gem Identification Laboratory in Jaipur, India, was reminded of a postage stamp in his gems and jewelry stamp collection (figure 13).

The stamp, issued by the Bermuda government in 1969, shows a gold cross that appears to be set with cabochon emeralds in a style very similar to that of the emerald-set cross described in the *G&G* article and pictured on the cover of that issue. The stamp carries the

Figure 13. The emerald-set gold cross pictured on this Bermuda postage stamp is strikingly similar to the cross that appeared on the cover of the Winter 1989 Gems & Gemology. Stamp courtesy of Nawal Kishore Tatiwala; photo by Robert Weldon.

legend "1594 TREASURE FROM THE SEA" and a value of "4d." According to Mr. Tatiwala, four stamps of different values were issued.

SYNTHETICS AND SIMULANTS

Plastic cameo imitations. The Spring 1989 Gem News column reported on two plastic cameo imitations, one resembling a shell cameo and the other mimicking a Wedgwood piece.

At the most recent Tucson Show, the Gem News editors saw a new type of plastic imitation cameo that was quite large and resembled those cut from the reddish brown and white helmet shells. These imitations are particularly effective in that they appear to have been molded in a manner that produces an irregular concave back, similar to that seen on large natural shell cameos (figure 14).

Figure 14. These two plastic imitation shell cameos, which measure 70 × 56 mm, had been molded to imitate the irregular concave backs seen on some natural shell cameos. Photo by Robert Weldon.

Imitation emeralds from southern Africa. Jim Lewis of Kaiser Gems, Los Angeles, has provided more information on imitation emerald crystals similar to those described by Dr. Henry A. Hänni in the Spring 1989 Gem News section.

On a buying trip to Zambia in May and June of 1989, Messrs. Lewis and Caesar Habib (co-owner of Kaiser Gems) were shown what appeared to be a large emerald crystal by a local man not involved in the gemstone industry. In Malawi, they were shown a similar-appearing specimen. In Los Angeles some months later, Kaiser Gems was visited by the man from Zambia who brought with him the original specimen plus another similar "crystal." These were examined with magnification and immediately determined to be composite imitations. Mr. Lewis subsequently loaned them to GIA for examination.

The two "crystals" have a distorted hexagonal habit (figure 15). The larger weighs 63.35 ct and measures 31.96 × 17.60 × 16.37 mm; the smaller weighs 26.96 ct and measures 28.30 × 15.49 × 12.05 mm. They are both medium dark green with rather rough surfaces that are partially coated with a light orangy brown limonitic staining and tiny flakes of mica. The smaller one has an area of distinctly lighter color and lower transparency. Some relatively clean, smooth surface areas on both reveal highly transparent interiors; neither of the specimens has a termination.

The larger piece had one relatively smooth surface that allowed determination of refractive index readings of approximately 1.54–1.55, although the condition of the surface did not allow for an accurate birefringence. The smaller "crystal" had a smooth, partially polished face which gave R.I. readings of 1.545–1.553 and a birefringence of 0.008; a flat surface on the lighter green area gave a vague R.I. reading of 1.57. Both "crystals" gave doubly refractive reactions in the polariscope and appeared grayish green through the Chelsea color filter. Both showed a strong, chalky, slightly greenish white reaction to long-wave U.V. radiation in some areas, with a similar but distinctly weaker reaction to short-wave U.V. There was no phosphorescence to either wavelength. When the specimens were examined with a DISCAN diffraction-grating spectroscope unit, a dark absorption band at 662–689 nm was observed; this is similar to the main absorption feature noted in jadeite and some other gem materials that have been dyed green, including quench-crackled quartz.

Magnification revealed the true nature of the deception. Both specimens consisted of fairly thick green seams holding together irregular fragments of a transparent colorless material, the individual fragments exhibit-

Figure 15. These two imitation emerald crystals, the larger weighing 63.35 ct, are composed primarily of quartz fragments held together by a green binding agent. Photo by Robert Weldon.

ing parallel striations that were randomly oriented from one fragment to another. The green binding material contained numerous gas bubbles and was easily indented with a needle probe; the mica flakes appeared to be glued onto the surfaces of the specimens. Doubling could be seen through the smoothest face of the smaller specimen.

On the basis of this examination, the editors concluded that these imitation emerald "crystals" were composed primarily of quartz fragments that were held together with a green epoxy resin or other plastic. The lighter green area on the smaller crystal is believed to be a piece of low-quality natural emerald. These two specimens appear to be quite similar to the two imitation emerald crystals from southern Africa described by Dr. Hänni in his earlier report.

Figure 16. The 10-mm beads in this necklace resemble rhodochrosite but were determined to be dyed massive calcite. Photo by Robert Weldon.

Imitation rhodochrosite beads. Massive calcite has been dyed various colors and used to imitate a wide variety of other ornamental gem materials such as jade ("Mexican jade"), lapis lazuli, and coral. GIA instructor Mary Fitzgerald recently showed the Gem News editors a continuous strand of approximately 10-mm beads that at first glance resembled rhodochrosite. The beads, which she purchased in Mexico, have an overall pinkish body color; many of them showed prominent banding ranging from very light pink to slightly orange-red (figure 16). With routine gemological testing, the beads were found to be massive banded calcite ("onyx marble"). Magnification showed obvious dye concentrations in surface-reaching fractures and around the drill holes, while vigorous rubbing produced a pink discoloration on an acetone-dipped cotton swap.

ANNOUNCEMENTS

Tiffany & Co. has donated a large kunzite necklace to the Smithsonian Institution's National Museum of Natural History. The necklace, which features a 396.30-ct kunzite on a necklace of South Sea baroque pearls, was designed by Paloma Picasso in 1986. It appeared on the cover of the Summer 1987 issue of *Gems & Gemology.* The donation coincided with the opening of a branch store of Tiffany & Co. in Tysons Corner, Virginia.

The National Museum of Natural History also recently received a donation from the Independent Jewelers Organization of a 120-lb. (54.5-kg) specimen of transparent smoky citrine consisting of two pencil-like, six-sided crystals that are joined at the base. The longer section is 26 in. tall and 7 in. in diameter. Both crystals are so transparent that it is possible to read newsprint through them. The specimen was found at a mine in Minas Gerais.

The Cleveland Museum of Natural History has announced the opening of its new 7,000 square-foot exhibition gallery with an inaugural exhibit from its permanent collection of gems, jewelry, and precious metals. The show, titled GemFire, will run from April 7, 1990, to February 17, 1991. On display are over 2,000 gems, minerals, and metals, including fancy-colored diamonds, black opals from Australia, a 122.08-ct kunzite, and a 22.18-ct emerald from the Muzo mine in Colombia. Also in the hall will be several educational exhibits on geology, the lapidary arts, and mining.

Erratum: The Gem News entry regarding the Pamir spinel in the Winter 1989 issue of *Gems & Gemology* should have called the stone a cushion cut. It was faceted by Justina Wright of Fallbrook, California, but is owned by Marius Van Dyk.

BOOK REVIEWS

Elise B. Misiorowski and Loretta B. Loeb, Editors

ENCYCLOPEDIA OF MINERALS

2nd Edition, December 1989

*By Willard L. Roberts, Thomas J. Campbell, and George R. Rapp, Jr., 979 pp., illus., publ. by Van Nostrand Reinhold, New York, 1989. US$99.95**

Prior to the publication of the first edition of the *Encyclopedia of Minerals* in 1974, it had been a long time since any major compendium of minerals had been released, the last being volumes I and II of *Dana's System of Mineralogy* (1944 and 1951, respectively). During the interval (1951–1974), new species were being introduced at an average rate of more than 50 per year, with some 65 being acknowledged in the year just before the first *Encyclopedia* was published. Moreover, many long-familiar species had been discredited, families of related species were being recognized, and basic data relating to many established minerals had been refined. There thus existed a great thirst for a contemporary book combining the vast accumulation of data on new species that had blossomed over the previous 24 or more years.

The first edition of the *Encyclopedia of Minerals* brought existing and new information together in a praiseworthy fashion. No one had ever tackled such a compilation, and it was bound to have some problems. The problems were minor, however, and in no way diminished the grandeur of that monumental accomplishment. It was, in fact, such a prodigious effort that few ever dreamed that it would be followed by a second edition.

The second edition is of enormous size, with 979 pages, 286 more than the first edition, for a total weight of just over seven pounds. The 240 color photographs are presented in a center section of the book, while another 104 black-and-white illustrations are interspersed throughout the text, as are 45 crystal drawings. The book's primary objective is to present tens of thousands of hard facts accurately. There is no better method to measure accuracy than to select a big block of these facts and check them against their original sources. When one does this (as I did with a random sampling), a measure of the authors' dedication, thoroughness of proofreading, and care taken in data gathering quickly becomes evident. The authors have done a remarkable job; the number of errors was far below what I was prepared to accept as tolerable.

The format is essentially the same as the first edition, with the minerals arranged in alphabetical order. Under the mineral for which a group is named, one finds a general entry (apatite group, for example), followed by a brief statement of some of the parameters the members share (e.g., crystal system), the elements that may substitute in specific sites (thus creating the various members), and then a list of these members. This convention informs the reader that a group of related minerals exists. Under the data for each of the group members, the group association is again identified.

The information provided under each individual entry includes: chemical formula, crystal system and class, space group, lattice constants, three strongest diffraction lines, optical constants, hardness, density, cleavage, habit, color/luster, mode of occurrence, and at least one selected reference.

The quality of the references provided is vastly improved over the first edition, as many new and better ones have been added. Many now include JCPDS X-ray data file numbers, which is a nice addition. Although one continues to hear complaints about reference inadequacies, this reviewer feels that these complaints are unjustified. The only totally new feature is the inclusion of reflected-light data for opaque minerals.

This reviewer would like to extoll the high level of accuracy that obviously characterized the data entries. It is heartening to find such editorial integrity in an age when books are carelessly researched and thrown together with little or no concern about accuracy or adherence to a specific objective.

One negative aspect about the text was that it may have failed slightly in its cataloguing of important contemporary mineral localities; some very important ones were omitted or overlooked. There also appears to have been poor coordination between the authors and the photo editor, as several localities of specimens illustrated are not given in the text. For example, the authors failed to cite Nasik (India) as the locality for the world's finest powellite, even though a color photograph of a Nasik powellite is used in the book.

Overall, the photographs are excellent, substantially better than those of the first edition. For the most part, the printing is also excellent, although the color is badly off on a couple of specimens (microcline and scorodite). This reviewer feels that, if the purpose of the color photographs was to aid the reader in mineral identification, then there should have been more photographs of very rare species. However, the scanning electron micrographs and the crystal drawings are very helpful in identification.

This book may seem expensive, but a comparable volume probably could not be published for much less. Those who work with minerals can

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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.*

ill afford to be without their own copy—no competing reference stands alone as effectively as this one. While every book about minerals is deficient in some important area, the *Encyclopedia of Minerals* comes closer than any other to satisfying all of the needs of professional mineralogists and amateur collectors in just one volume. This book is a wonderful legacy to have been left by lead author Willard Lincoln Roberts, who did not live to see its publication.

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BLACK PEARLS OF TAHITI

*By Dr. Jean-Paul Lintilhac, photographs by Alain Durand, 116 pp., illus., publ. by Royal Tahitian Pearl Book, Papeete, Tahiti, 1987. US$39.95**

The subject of black pearls is of growing interest worldwide, and this book has something for everyone, from the casual tourist to the serious pearl dealer. The information is well ordered, beginning with a data sheet on the islands of paradise to whet the appetite of any traveler. This is followed by a brief but concise history of the discovery of the many islands comprising French Polynesia and the politics involved in their development.

While dispelling the myth of glamour surrounding the South Seas pearl diver, the narrative provides an instructive description of the pearling industry, from the production of mother-of-pearl with the pearl as a by-product to the eventual creation and production of the cultured black pearl. Dr. Lintilhac then describes the locations and culturing methods used by many of the farmers to bring this product to the world market. He also relates the rigors of the work and the many and sometimes devastating problems encountered along the way. He includes a description of the characteristics that set these black pearls apart as a desirable commodity in the jewelry trade.

Calling on the experiences of his deeply personal involvement in pearl production, which sometimes approached the status of a full-fledged apprenticeship, he is able to give a meaningful overview of the procedures used in evaluating the *poe rava* (Tahitian for black pearl) for beauty and price. The last few pages are devoted to a photographic essay illustrating the use of the black pearl in jewelry for the world market.

The illustrations are meaningful and the exquisite photography adequately supplies the text material with the necessary visual interest. Although not a voluminous publication, the book is spectacular without being pretentious.

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GEM IDENTIFICATION MADE EASY: A HANDS-ON GUIDE TO MORE CONFIDENT BUYING AND SELLING

*By Antoinette L. Matlins and A. C. Bonanno, 270 pp., illus., publ. by Gemstone Press, South Woodstock, VT, 1989. US$29.95**

This book serves as an introduction to gem identification for readers with little or no gemological background. Matlins and Bonanno begin by recommending gemological instruments they feel are essential to setting up a small identification lab, with emphasis placed on the loupe, dichroscope, Chelsea filter, refractometer, ultraviolet lamp, and microscope. The function, proper use, and limitations of each piece of equipment are discussed in a comprehensible manner using informative illustrations. The authors focus on observations that can be made with the various instruments, rather than on scientific explanations, and supply numerous examples of separations and identifications that can be accomplished with each. The examples, however, are somewhat limited in their completeness. Grouped at the back of the book are a number of tables of gem properties and lists of sources for further information, including magazines, gemological associations, and gem identification laboratories.

The biggest drawback of this book is that it oversimplifies gem identification. By saying that approximately 85% of the commonly encountered gemstones can be positively identified using a loupe, dichroscope, and Chelsea filter, the authors are making gem identification sound deceptively easy and failing to emphasize and explain how complex an issue it can be. In most cases, a confident separation between yellow sapphire and citrine or yellow beryl could not be made using only those three instruments. In addition, several commonly encountered gems have sophisticated synthetic counterparts. If one were to make natural vs. synthetic separations using only a loupe, dichroscope, and Chelsea filter, costly errors could result. However, the authors do acknowledge that it is important for a person to recognize his or her limitations and employ the services of a professional gemologist or laboratory for verified identifications. Overall, although they fall short of discussing the more complex identifications, Matlins and Bonanno have assembled a good introductory guide to gem identification.

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GEMOLOGICAL ABSTRACTS

Dona M. Dirlam, Editor

COLORED STONES AND ORGANIC MATERIALS

Ein Beitrag zur Farbe niederschlesischer Chrysoprase (A contribution concerning color in Lower Silesian chrysoprase). L. Natkaniec-Nowak, W. Heflik, N. Sobczak, and T. Sobczak, *Zeitschrift der Deutschen Gemmologischen Gesellschaft,* Vol. 38, No. 1, 1989, pp. 31–36.

Lower Silesia has produced chrysoprase since the early 1400s; in fact, the Silesian material remained unsurpassed in quality until the discovery in 1960 of Australia's exceptional Marlborough Creek deposits. Fine table surfaces, mosaics, and ceremonial objects fashioned from Lower Silesian chrysoprase can be found in many European castles and chapels, and one fine collection of armbands and rings is held in the Kremlin treasury in Moscow.

Geologic and mineralogic literature on the Lower Silesian deposits is abundant, some of it dating back to the 17th century. Yet the exact cause of chrysoprase's translucent green color has remained scientific conjecture.

Responding to the challenge of finding the cause of color, the authors used Beckman U.V.-visible spectrophotometry, infrared spectroscopy, and electron-spin resonance testing. Their evaluation of structural chemistry concludes that color in Lower Silesian chrysoprase is caused by the presence of nickel silicates in the cryptocrystalline framework. *Paris A. Walker*

Orangefarbene Korunde aus Malawi (Orange corundums from Malawi). U. Henn, H. Bank, and F. H. Bank, *Zeitschrift der Deutschen Gemmologischen Gesellschaft,* Vol. 38, No. 4, 1989, pp. 164–166.

Blue, bluish green, red, and orange corundums are found in the Chimwadzulu Hills, near the Mozambique border in southern Malawi. The orange corundums have the following gemological characteristics: n_e = 1.763–1.765; n_o = 1.771–1.773; birefringence = 0.008; specific gravity = 3.97–3.98. They contain twin lamellae, healed fractures, and rounded, doubly refractive mineral inclusions.

The orange color is due to the superposition of the absorptions of Fe^{3+} and Cr^{3+}. This sets these stones apart from their Sri Lankan counterparts, which are colored by color centers. *EF*

Red and orange corundum (ruby and padparadscha) from Malawi. U. Henn, H. Bank, and F. H. Bank, *Journal of Gemmology,* Vol. 22, No. 2, 1990, pp. 83–89.

The authors describe red and orange corundum from the Chimwadzulu Hill region of southern Malawi, an *in situ* deposit in an epidotized amphibolite, which was first described in 1958. The eight study samples, acquired by one of the authors at the mine, are crystals up to 15 mm long. Six range in color from pale to dark red; the remaining two are orange. The "rubies" revealed a correlation between increasing Cr (and, to some extent, Fe) content and refractive index, as well as birefringence. R.I. values reached previously unreported high values of n_e = 1.770 and n_o = 1.780. Absorption spectra show corresponding variations. Properties for the orange corundums are comparable to those for similar material from Tanzania.

A variety of mineral, liquid, and growth structure inclusions are described for the Malawi corundums, with 12 useful black-and-white illustrations. Although scientific details of analytic conditions are omitted, this study is especially useful to the gemologist for its expansion of the range of values to be expected for rubies. *CMS*

Role of natural radiation in tourmaline coloration: Discussion. I. Petrov, *American Mineralogist,* Vol. 75, No. 1/2, 1990, pp. 237–239.

By reviewing previously published data on pink tourmaline coloration, the author proposes that this coloration is not simply due to Mn^{2+} turning to Mn^{3+} with irradiation, but rather results from a number of different, more complex processes. He proposes three: (1) metastable O^{1-} centers, stable up to 250°C; (2) $Mn^{4+} \rightarrow Mn^{3+}$ electron centers, stable up to 500° or 600°C; and (3) electronic transitions of transition metal ions, for example Mn^{3+}, stable up to 800°C or higher.

Besides thermal stability, interpretations of electron paramagnetic resonance (EPR) spectra are also used as arguments. *EF*

Spectacular spinel. P. Bancroft, *Lapidary Journal,* Vol. 43, No. 11, February 1990, p. 25.

Dr. Bancroft reports on the acquisition of the Katherina spinel by AGT International (based in the Netherlands). Recovered in the Pamir Mountains of the USSR, the Katherina weighed 532 ct rough, and produced a 146.43-ct cushion step cut described as dark pink. This stone is five times larger than the former record holder for a Pamir Russian spinel (27.81 ct). The stone was faceted by Justina of Mission Viejo, California, and also produced a 30-ct triangle-shaped stone. The article contains two color photographs of the faceted gem and the uncut rough. *WRV*

Star rhodolite garnet from Tanzania. R. C. Kammerling and J. I. Koivula, *Journal of Gemmology,* Vol. 22, No. 1, 1990, pp. 16–18.

The authors describe the first-reported star rhodolite from Tanzania. The 15.6-ct stone displays four- or six-rayed asterism, depending on the angle of observation, with near-transparency and a "slightly brownish purplish red" color. Gemological properties are consistent with those typical of rhodolite. Microscopic examination revealed the source of asterism to be fine acicular rutile crystals with 110/70-degree orientation, running the entire distance through the stone. (Unfortunately, part of the text has been omitted in publication—hopefully no more than the apparent two words.) Four color photographs accompany the article. *CMS*

An unusual agate from Guyana. J. G. Gosling, *Journal of Gemmology,* Vol. 22, No. 2, 1990, pp. 76–79.

This article reports on the discovery of a new form of agate in the Republic of Guyana, which is noted for its occurrences of agate. Mr. Gosling, who was involved with the initial development of a lapidary industry in Guyana, reports that most of the agate deposits are located along the Ireng River that borders Guyana and Brazil, from the Good Hope Mountains in the north to the Blue (Kanuku) Mountains in the south. The agates occur in gullies that are dry for most of the year and drain into the river during the rainy season.

The new type of agate consists of a criss-cross lattice of quartz crystals with banded agate filling the cavities in the lattice. Cutting of the material is similar to that for agates in general except that, because it is difficult to clean residual polishing grit out of the cavities after each polishing step, subsequent polishing with the next finer grade of grit can produce scratches if sufficient care is not taken.

This attractive material is illustrated on the cover of the journal as well as in photos that accompany the article, clearly revealing that a visual observation is all that is needed to make an identification. Unfortunately (to this abstractor), the large size of the pattern makes this material—like so many spectacular agates—unsuitable for use in jewelry and limits its application to ornamental objects. *CMS*

DIAMONDS

Brilliance in Tilt. E. S. Love, *Lapidary Journal,* Vol. 43, No. 9, December 1989, pp. 90–94.

This rigorous mathematical exercise explores theoretical aspects of the concept of brilliance-in-tilt. This concept presupposes that a standard round brilliant optimized for combined face-up brilliance and tilt brilliance is preferable to one optimized for face-up brilliance only.

According to Love, brilliance-in-tilt is best achieved through solutions developed for analyzing satellite communications and detections by light rays and optical sensors. Such solutions, known as the L-solutions, embrace single and combined tilting about all three axes.

The body of this article consists of tabulated data illustrating the effects of fluctuating values on brilliance. These data are based on comparative studies, and no examples of successful applications of this theory are included with the article.

Paris A. Walker

How to value irradiated diamonds. C. Altobelli, *Jewelers' Circular-Keystone*, Vol. 161, No. 3, March 1990, p. 130.

This brief but concise article gives pertinent information on how to value irradiated diamonds by using the "market data approach," or the use of comparables. Dealers who have sold treated stones in the past would be good sources of information on the wholesale costs of diamonds that match the cut, color, clarity, and carat weight of your stone.

Altobelli describes a formulaic approach that may be used when determining a broad estimate for insurance replacement cost, and is used when market data are unavailable. First assign an arbitrary GIA color grade as a good representative for the stone. Then set a clarity and cut grade for that weight and shape diamond, and add the cost of treatment to get your wholesale value. If the appraisal is for insurance purposes, add the markup for retail replacement. Also, make note of the type of treatment and method used in determining the markup for retail replacement. When using the formulaic approach, you must state that it was used, why it was used, and any limitations on accuracy that occurred from its use.

The customer should be made aware of the fact that if a replacement is needed, an untreated diamond of the same value may be chosen. In most cases, the insurance company would not object—their main concern is the replacement cost. However, most insurance adjustors deal with replacement companies that offer "at wholesale" prices. If another type of stone is being considered, the insurance company and the customer should have an agreement on the different options available through the specific policy.

Karen B. Stark

Secret of Indian success being emulated by other centers. *New York Diamonds*, No. 7, 1990, pp. 58–64.

India's ever-growing diamond industry has contributed to an expanded world market for diamond jewelry, mainly by manufacturing smaller, lower-quality, low-priced stones. This has caused a reclassification of diamonds (gem, near-gem, and industrial), with more "industrial-grade" diamonds now being cut for the average consumer.

The conditions responsible for India's success—mostly massive pools of cheap, semiskilled labor—also exist in many other countries. Thailand, Sri Lanka, China, and South Africa all have begun to emulate India and encourage investment by foreign manufacturers. In fact, in 1988, Thailand exported 200,000 ct of polished diamonds, more than four times its 1987 production. Often, Belgian and Israeli diamantaires will provide needed expertise and technology.

To maintain its predominance, India must improve both production methods and efficiency. Although it is true that Indian cutters generally receive lower-quality rough, this fact alone cannot explain India's 1988 average yield of only 20.23%, compared to a 40.24% yield by the Israeli industry.

Paris A. Walker

Visual optics. A. Hodgkinson, *Australian Gemmologist*, Vol. 17, No. 4, 1989, pp. 137–138.

Distinguishing between diamond and its various simulants still poses a challenge to jewelers. This brief report describes a simple method that can be useful in such situations. Called visual optics, it is performed by placing the table of a gemstone against partially closed "eyelashes" and looking at a nondiffused light source (e.g., a candle flame or penlight) that is approximately 4 to 6 m away. The patterns and intensities of spectral reflections seen are felt to be indicative of various gem materials, these features being influenced by the gem's refractive index, birefringence, and dispersion.

After discussing the technique, the author proceeds to describe the typical images produced by diamond, zircon, CZ, and strontium titanate. These patterns are also illustrated photographically.

RCK

GEM LOCALITY

Some aspects of pearl production with particular reference to cultivation at Yangxin, China. E. A. Jobbins and K. Scarratt, *Journal of Gemmology*, Vol. 22, No. 1, 1990, pp. 3–15.

This well-illustrated article by Messrs. Jobbins and Scarratt is the result of a recent trip by those authors to a Chinese pearl farm. As background, they describe the major sources of natural and cultured pearls. Historically, the most significant source of natural pearls has been the Persian Gulf. However, changing economics and politics, pollution, and over-fishing have reduced pearl production in this region to a trickle. An interesting discussion of natural pearl fishing in Scotland provides insight into that little-known source.

Since the 1920s, Japan has dominated the pearl market through its production of cultured pearls in enormous quantities and a full range of qualities. The original type of cultured pearl is formed around a mother-of-pearl bead nucleus. The development in the 1950s of "nonnucleated" (mantle-tissue nucleated) freshwater cultured pearls, originally from Japan's Lake Biwa, represented a new phase in both pearl marketing and identification.

The Chinese adopted this technique as suitable for their own freshwater mussels. They began marketing cultured freshwater pearls in the early 1980s. Eventual flooding of the market dropped prices for lower-quality strands radically. However, fine-quality Chinese cultured pearls are also produced.

In May 1989, the authors visited one of the Chinese pearl farms at Yangxin, Hubei Province. The mussels—*Cristaria plicata*—grow as long as 20 cm and are cultivated for about 40 pearls at a time. The farms include nursery ponds, spat sheds, producing ponds, and cultivating sheds. When spats reach 8 cm in length, each is implanted with 40 squares of mantle tissue (from another mussel of the same type) and is placed in a net in a maturing pond.

Nineteen black-and-white and two color illustrations—mostly locality photographs—accompany this very readable and altogether too short article. It is an excellent summary, especially for the jeweler looking for basic information. *CMS*

Wave Hill prehnite. H. Bracewell, *Australian Gemmologist*, Vol. 17, No. 4, 1989, pp. 127–129.

Wave Hill Station, 940 km south of Darwin and 1,230 km northwest of Alice Springs, is located in one of the most isolated regions of Australia's Northern Territory. Here, prehnite is collected from two distinct areas, one that produces opaque greenish material from pebble to small boulder size, while the other yields small, facetable nodules in colors ranging from "whitish to pale green and greenish hues through to a clear yellow."

Four faceted prehnites from the second area, ranging from 7.35 to 31 ct, were examined by the author, with properties determined to be as follows: appearance—semitransparent, slightly grayish green with a slightly fibrous texture; Mohs hardness—6 to 7; mean refractive indices—α = 1.614, β = 1.620, γ = 1.637; mean biregringence—0.023; dichroism—slight, in pale to dark green hues; long-wave U.V. fluorescence—dull brown; absorption spectrum—vague band at 440 nm. Magnification revealed very distinct radiating fibers in the largest specimen, while in the smaller three stones the fibers had a parallel orientation. The author speculates that this latter structure raises the possibility of cat's-eye stones being cut from the material.

The article is nicely illustrated with seven color photographs. *RCK*

INSTRUMENTS AND TECHNIQUES

Mikrospektralphotometrie der Edelstein-Kathodolumineszenz (Microspectrophotometry of gemstone-cathodoluminescence). J. Ponahlo, *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 38, No. 2/3, 1989, pp. 63–84.

This is the latest article by Dr. Ponahlo on gemstone cathodoluminescence, with a focus this time on the emission spectra of various gem materials. After a brief description of the homemade experimental set-up he uses, the author reports on the cathodoluminescence spectra of natural and synthetic rubies, emeralds, padparadscha sapphires, alexandrite chrysoberyls, diamonds, and lapis lazuli. A general rule of thumb valid for the first four is that the cathodoluminescence of natural and synthetic gem materials are mostly similar in spectrum shape, but that the synthetic materials typically luminesce more strongly than their natural counterparts (although there is some overlap.).

For rubies, a slight difference in the shape of the emission spectra of natural and synthetic stones seems to help the separation. Also, it seems that cathodoluminescence could provide an indication of heat treatment, although more research is needed. This technique seems to be helpful, too, in the detection of oiling of emerald. Growth features that help separate natural from synthetic padparadscha sapphires and diamonds are emphasized under the electron beam.

The author pays a great deal of attention to good calibration procedures, and uses a large enough sample size (up to 76 samples for alexandrite) to propose significant results, which are illustrated with numerous color photographs and spectra. Dr. Ponahlo's spectra would be even more useful if he would publish all of them within scale (many spectra are cut off at the top) and provide the curve of his photomultiplier's sensitivity over the maximum range used, as luminescence spectra are known to be instrument-dependent. *EF*

Reconnaissance d'un diamant de synthèse De Beers parmi d'autres gemmes grâce à la cathodoluminescence (Separation of a De Beers synthetic diamond from other gems using cathodoluminescence). C. Bille, R. Chapoulie, J. Dorbes, and M. Schvoerer, *Revue de Gemmologie a.f.g.*, No. 100, 1989, pp. 19–21.

This study provides cathodoluminescence spectra of four groups of samples: small faceted natural diamonds, synthetic diamond powder from De Beers, a YAG crystal, and a zircon crystal from Spain. The purpose of the article and the principles of cathodoluminescence are briefly stated, and the three different instruments used are mentioned. This method is nondestructive only for small samples (less than 1 cm^3).

All natural diamonds studied showed a blue cathodoluminescence, centered around 450 nm. The synthetic diamonds showed a yellowish green cathodoluminescence, mostly due to a broad band peaking at about 520 nm. The YAG crystal showed a pink to violet luminescence (depending on the experimental conditions), due to a combination of three main spectral regions of emission. The color of the zircon luminescence is not described, but its complex spectrum is attributed to various rare-earth elements. The authors conclude that this technique could prove useful to characterize gems if a wider, more representative sample could be studied. *EF*

Reflections on reflectivity. P. G. Read, *Journal of Gemmology,* Vol. 22, No. 2, April 1990, pp. 97–102.

For the gemologist interested in why and how things work, Peter Read has provided a discussion of the relationship between reflectivity and refractive index. This relationship has been exploited in recent years by a variety of reflectivity meters, a number of which are described by the author. Generally less accurate than a refractometer, these instruments do, however, have the advantage of a broader range useful in making diamond/simulant separations. The most recent instrument described is the author's own Brewster-angle refractometer, with an R.I. range of 1.4 to 3.3. Photographs and explanatory drawings illustrate the text. *CMS*

Using the spectroscope. S. M. B. Kelly, *Australian Gemmologist,* Vol. 17, No. 4, 1989, pp. 118–119.

This brief article, subtitled "A personal assessment of the contribution to gemmology of J. J. Snow, F.G.A.A., F.G.A.," is printed in a special Memorial Issue of *Australian Gemmologist* dedicated to the late, well-respected gemologist.

The author begins with a reminiscence about her student days and the help Mr. Snow gave her in learning to use the spectroscope. She then goes on to describe a number of personal situations in which an instrument designed by Mr. Snow was especially useful in identifying mounted gems.

The examples are ones to which many gemologists can no doubt relate: identifying orange-brown zircon; separating peridot from sinhalite; distinguishing natural from synthetic sapphire; determining whether small green stones are emerald or demantoid; and separating ruby from almandine garnet. Key absorption lines for the materials described are listed. *RCK*

JEWELRY METALS

Accelerator-based spectroscopy techniques for analysis of archaeological gold jewelry. G. Demortier, *Spectroscopy,* Vol. 4, No. 6, 1989, pp. 35–40.

Demortier describes work in the compositional analysis of archaeological gold jewelry performed at the Laboratory for Analysis by Nuclear Reaction (LARN) in Belgium by particle induced X-ray emission (PIXE), particle induced gamma-ray emission (PIGE), and nuclear reaction analysis (NRA). These are non-destructive, accurate, and sophisticated (but extraordinarily expensive) techniques.

The items discussed include a gold Byzantine cruciform reliquary, a terminal or connecting end from a Roman necklace, and a Byzantine bead shown to have been made with a cadmium-copper solder. The last item supports earlier work of Demortier's showing that the presence of cadmium is not necessarily a sign of modern manufacturing (*Gold Bulletin,* Vol. 17, No. 1, 1984; abstracted in *Gems & Gemology,* Summer 1984). He proposes that the ancient meaning of chrysocolla (a mineral salt used in some ancient soldering techniques) was cadmium sulphide (greenockite). Interestingly, he gives the modern meaning of chrysocolla as copper carbonate, rather than hydrated copper silicate. Other ancient bonding processes, including sintering of the reliquary and solid-state diffusion bonding (the process used in Etruscan granulation work) of the necklace terminal, are also discussed. *Meredith E. Mercer*

Digging a mile deep. L. J. Fisher, *Earth Science,* Vol. 42, No. 1, 1989, pp. 12–13.

The United States uses 2.5 million troy ounces of platinum per year, 93% of which is imported from South Africa, the Soviet Union, and Canada. With the renewed interest in the Stillwater Complex, located in the Beartooth Mountains southwest of Billings, Montana, the percentages of imported platinum and palladium should decrease. Although platinum was found in the complex in the 1920s, at the it time was considered economically unfeasible. Today, more than 780 tons of platinum and palladium ore are mined daily, and yield approximately 20 tons of ore concentrate; after refining, the result is 160 oz. of platinum and 480 oz. of palladium. The expected annual metals yield of the mine is 225,000 oz. The author points out that, although this is a mere fraction of world demand, an advantage is that the mine is "not subject to political problems associated with importing minerals from South Africa and the Soviet Union." *Rose Tozer*

SYNTHETICS AND SIMULANTS

Beauté de l'oulongolite (Beauty of oulongolite). D. Robert, *Revue de Gemmologie a.f.g.,* No. 101, December 1989, pp. 17–18.

This article briefly describes some properties of a new synthetic gem material, oulongolite. The author points out that it is definitely not a YAG; indeed, its composition is "more complex." Among its properties are an R.I. of 1.93–1.99, an S.G. of 7, and a hardness between 7 1/2 and 8. Oulongolite is offered in a wide variety of colors that simulate those of natural gem materials (peridot, sapphire, aquamarine, pink diamond), and can be faceted or carved in "free cuts." Gamma irradiation causes a "ruby-red" coloration, which fades with exposure to light within a few hours. *EF*

Effect of solvent metals upon the morphology of synthetic diamonds. H. Kanda, T. Ohsawa, O. Fukunaga, and I. Sunagawa, *Journal of Crystal Growth,* Vol. 94, 1989, pp. 115–124.

Synthetic diamond crystals up to 3 mm in diameter have been grown in a hydrous environment from various metal solvents to study the effect of those metals on diamond morphology. The growth features were analyzed by etching and various surface microscopy techniques. Only octahedral {111} and cube {100} faces are seen in diamond grown in pure Ni. The dodecahedral {110} and trapezohedral {113} faces appear only when using Ni alloyed with other transition metals. This is attributed to the strong affinity of those metals for nitrogen, which can lead to a modification of the metal-diamond interface conditions during growth, thus producing different crystal faces.

The octahedral and cubic faces grow smoothly in successive layers that are thinner than 30 Å and are persistent throughout the growth, with the octahedral face dominating the morphology. The dodecahedral and trapezohedral faces, which are transient and minor on the final morphology, have a hopper growth, in which growth proceeds from the edges inward, resulting in raised edges. A perturbation in the growth parameters indicates a distinct growth band on the cubic sector.

The presence of cubic faces in synthetic diamonds is attributed to a surface reconstruction of the cubic face, which might be prevented in nature by the silicate magma in which the diamond grows. *EF*

How secret GE recipe for making diamonds may have been stolen. L. Ingrassia, *Wall Street Journal,* Wednesday, February 28, 1990, pp. A1 and A4.

This front-page article relates the circumstances surrounding lawsuits filed by General Electric, a major synthetic diamond producer, and Norton, a major diamond tool manufacturer, against one of their former employees, Mr. Chien-Min Sung. The two companies suggest that Mr. Sung may have sold vital industrial secrets on how to grow high-quality industrial diamonds to China, a South Korean company, and, perhaps, even the USSR. *EF*

Inamori stones' rough (some observations and speculations). J. Snow and G. Brown, *Australian Gemmologist,* Vol. 17, No. 4, 1989, pp. 132–136.

Beginning with a brief review of the Kyocera Corporation's manmade gem products, the authors proceed to describe their examination of unfashioned specimens of several of these materials.

The synthetic corundum examined included rod-shaped single crystals of synthetic ruby, star ruby, and orange-red sapphire. These crystals were oriented with the c-axis parallel to their length and had rounded, machine-ground external surfaces; the authors speculate from the latter that the crystals originally had somewhat irregular external forms. All of the crystals examined contained great numbers of bubbles in basically three configurations: (1) a central mass of bubbles in various sizes and shapes; (2) randomly scattered bubbles; and (3) fine, radially arrayed stringers of bubbles near external surfaces. Based on these observations, the authors hypothesize that the materials may have been grown by a zonal melting technique. Additional features noted were severe surface crazing on the synthetic orange-red sapphire, cloud-like swirls found predominantly toward the periphery of the crystals, and extremely fine exsolved rutile in the synthetic star ruby.

Synthetic chrysoberyl crystals examined included both alexandrite and cat's-eye alexandrite. The former had a distinct purplish red to grayish green color change, were transparent, contained gas bubbles and smoky swirls and, based on their pleochroism, were possibly grown on a seed plate cut at right angles to the a-axis. The chatoyant crystals had a similar but weaker color change, were translucent, had a slightly undulating parallel banding parallel to the c-axis and were possibly grown on a seed plate cut perpendicular to the c-axis.

Kyocera's opaque black and transparent colorless opal products were also studied. The authors observed one previously unrecorded feature: a bronze luster on the base of the black opal rough.

This well-illustrated report provides some very useful information on the visual characteristics of these man-made gems. *RCK*

An investigation of three imitation opalized shells. J. I. Koivula and R. C. Kammerling, *Australian Gemmologist,* Vol. 17, No. 4, 1989, pp. 148–152.

Opal pseudomorphs after shell are an unusual and comparatively rare form of precious opal. This well-illustrated article reports on three imitations that had been represented as natural opalized mollusk shells, including a clam shell, a mussel shell, and a turban snail shell. Each exhibited a patchy play-of-color pattern coming from what appeared to be distinct breccia of white opal. A number of other visual inconsistencies were noted, but magnification revealed the true nature of the deceptions. Each "shell" was seen to be composed of many small chips of white opal, boulder opal, and a limonitic matrix rock, bound together with a transparent, colorless material. The binding agent contained numerous spherical gas bubbles, while flattened bubbles were observed at some interfaces between the binder and opal fragments.

Gemological testing for microhardness, reaction to a thermal probe, R.I., U.V. fluorescence, and hydrophobic reaction led the authors to conclude that the binding agent was a plastic. *RW*