Gems & Gemology

VOLUME XXV SUMMER 1989

The quarterly journal of the Gemological Institute of America

SUMMER 1989
Volume 25 No. 2

Gems & Gemology

TABLE OF CONTENTS

EDITORIAL

FEATURE ARTICLES

NOTES AND NEW TECHNIQUES

REGULAR FEATURES

ABOUT THE COVER: Fine diamonds in fine jewelry—like this superb necklace and matching earclips—represent the heart of the jewelry industry. Because of the premier importance of diamonds, however, the rewards of making a diamond "better" are potentially very great. Although historically there have been numerous diamond substitutes, modern technology has led to new industries devoted to the treatment of natural diamonds. Three of the articles in this issue deal with some of the most important—or potentially important—diamond treatments. The fourth deals with one of the world's most notorious untreated diamonds: the Hope.

The necklace (97.75 ct total weight) and earclips (24.63 ct total weight) are courtesy of Van Cleef & Arpels.

Photo © Harold & Erica Van Pelt—Photographers, Los Angeles, CA.

Typesetting for Gems & Gemology *is by Scientific Composition, Los Angeles, CA. Color separations are by Effective Graphics, Compton, CA. Printing is by Waverly Press, Easton, MD.*

ISSN 0016-626X

Gems & Gemology

EDITORIAL STAFF

Editor-in-Chief
Richard T. Liddicoat

Associate Editors
William E. Boyajian
Peter C. Keller
D. Vincent Manson
John Sinkankas

Technical Editor
Carol M. Stockton

Editorial Asst., Nancy Hays

Editor
Alice S. Keller
1660 Stewart St.
Santa Monica, CA 90404
Telephone: (800) 421-7250 x251

Subscriptions
Lisa Hebenstreit, Manager
Bruce Tucker, Asst. Manager
Telephone: (800) 421-7250 x201

Contributing Editor, John I. Koivula

Editor, Gem Trade Lab Notes
C. W. Fryer

Editor, Gemological Abstracts
Dona M. Dirlam

Editors, Book Reviews
Elise B. Misiorowski
Loretta Bauchiero

Editors, Gem News
John I. Koivula
Robert C. Kammerling

PRODUCTION STAFF

Linda Manion, **Art Director**
Jennifer Brosious
Susan Kingsbury
Ruth Patchick
Peter Johnston
Julie Matz
Robin Teraoka

SUBSCRIPTIONS

Subscriptions in the U.S.A. are priced as follows: $39.95 for one year (4 issues), $94.95 for three years (12 issues). Subscriptions sent elsewhere are $49.00 for one year, $124.00 for three years.

Special annual subscription rates are available for all students actively involved in a GIA program: $32.95 U.S.A., $42.00 elsewhere. Your student number *must* be listed at the time your subscription is entered.

Single issues may be purchased for $10.00 in the U.S.A., $13.00 elsewhere. Discounts are given for bulk orders of 10 or more of any one issue. A limited number of back issues of G&G are also available for purchase.

Please address all inquiries regarding subscriptions and the purchase of single copies or back issues to the Subscriptions Manager.

For subscriptions and back issues in Italy, please contact Istituto Gemmologico Mediterraneo, Via Marmolaia #14, I-38033, Cavalese TN, Italy.

To obtain a Japanese translation of *Gems & Gemology*, contact the Association of Japan Gem Trust, Okachimachi Cy Bldg, 5-15-14 Ueno, Taito-ku, Tokyo 110, Japan.

MANUSCRIPT SUBMISSIONS

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

Gems & Gemology is published quarterly by the Gemological Institute of America, a nonprofit educational organization for the jewelry industry, 1660 Stewart St., Santa Monica, CA 90404.

Postmaster: Return undeliverable copies of *Gems & Gemology* to 1660 Stewart St., Santa Monica, CA 90404.

New Challenges for the Diamond Industry

We think every issue of *Gems & Gemology* is special. But this one is particularly significant. Notwithstanding previous articles in the journal on diamond synthesis, this issue addresses some of the most critical scientific challenges facing the diamond industry today.

One of the immediate concerns to all who deal with diamonds is the enhancement procedure first introduced by Zvi Yehuda in Israel and now available in New York. Like the oiling of emeralds, the filling of diamonds results in an apparent improvement in clarity. Also like the oil in emeralds, however, this filling material cannot withstand all jewelry manufacturing and repair techniques.

The lead article in this issue, the result of months of research, provides a comprehensive review of filled diamonds, including before and after photographs and grading information, techniques for detecting the treatment, analysis of the filling material, and a report on the reaction of the filling to routine jewelry cleaning and repair procedures. It is must reading for everyone in the diamond community and the retail jewelry trade.

Today, the practical applications for synthetic diamond thin films lie primarily in electronics and other industries. Yet the technological advances in this field have been so rapid in recent years that the potential implications for gemology—synthetic diamond thin films over softer materials to protect them, over diamond simulants to disguise them from the thermal probe—cannot be ignored. The article by Fritsch et al. in this issue addresses this new technology as it applies to the gemologist.

Still one of the greatest challenges to the practice and science of gemology is the identification of colored diamonds that have been treated by irradiation. The examination of hundreds of colored diamonds has produced another indicator that a stone has been irradiated by man: the presence of unusual color-zoned pavilions in some yellow and blue-to-green diamonds.

Gemology continues to be caught up in the rapid advancements in technology that are propelling us into the 21st century. The science of gemology must secure the knowledge necessary to insure stability in the marketplace. Support of scientific work is vital to meet these challenges.

Richard T. Liddicoat
Editor-in-Chief

THE CHARACTERISTICS AND IDENTIFICATION OF FILLED DIAMONDS

By John I. Koivula, Robert C. Kammerling, Emmanuel Fritsch, C. W. Fryer, David Hargett, and Robert E. Kane

The filling of surface-reaching cleavages, fractures, and other separations in diamonds has generated a great deal of concern during the last two years. This article reports on the study of six diamonds both before and after a filling treatment and the examination of 12 additional filled stones. Microscopy provides the best means of identifying that a stone has been filled. Chemical and other analyses indicate that the filling material is a type of glass. The filling will not withstand all standard jewelry manufacturing and repair procedures.

ABOUT THE AUTHORS

Mr. Koivula is chief gemologist, Mr. Kammerling is general manager of the Technical Development Department, and Dr. Fritsch is research scientist at the Gemological Institute of America, Santa Monica, CA. Mr. Fryer is director of gem identification, Santa Monica and New York, Mr. Hargett is manager of gem identification, New York, and Mr. Kane is senior staff gemologist, Santa Monica, at the GIA Gem Trade Laboratory, Inc.

Acknowledgments: The authors thank Dr. James E. Shigley, Bob Crowningshield, Tom Moses, Karin Hurwit, Loretta Bauchiero, James Lucey, Mark Mann, Duane Pebworth, and James Morton for their help in this project. John Armstrong and Mary Johnson, of the California Institute of Technology, helped with the chemical analyses. The assistance of Eli Haas and Martin Rapaport was invaluable. Unless otherwise noted, all photomicrographs are by John I. Koivula. This study was supported in part by the Dr. Byron C. Butler Fund for Inclusion Research.

Gems & Gemology, Vol. 25, No. 2, pp. 68–83

Few would argue that the sale of loose diamonds and diamond-set jewelry is vital to most jewelers. The introduction of a new diamond enhancement process, then, is likely to generate concern at all levels of the diamond trade, from the small retail store to the boardrooms of the International Diamond Manufacturers Association and the World Federation of Diamond Bourses. The filling of surface-reaching cleavages and fractures has had just such an effect throughout the industry.

Developed by Mr. Zvi Yehuda, of Ramat Gan, Israel, this enhancement can alter the apparent clarity of many faceted diamonds. By decreasing the visibility of cleavages, fractures, and other separations that reach the surface of a stone, this treatment not only can potentially change the perceived clarity from SI to VS, but it can also give diamonds in the low-clarity "imperfect" range a much more desirable—and, therefore, salable—appearance overall (figure 1).

Since September 1987, there has been ongoing discussion in the trade press concerning such filled diamonds. According to a recent announcement (Everhart, 1989), this topic drew "major attention at the recent (24th) World Diamond Congress in Singapore." In addition, members of the International Diamond Manufacturers Association and of the World Federation of Diamond Bourses have just passed resolutions declaring that "knowingly selling diamonds treated by this method without disclosing that fact is a fraud and conduct not becoming to a member" (Everhart, 1989; Maillard, 1989b).

This form of diamond enhancement was first encountered by GIA in January 1987, when a colleague submitted a few of these treated diamonds for examination. On August 14, 1987, GIA issued a press release to alert the trade to the existence of this filling procedure; just one day earlier, Mr. Nubuo Horiuchi, of the Central Gem Laboratory in Japan, had issued International Colored Stone

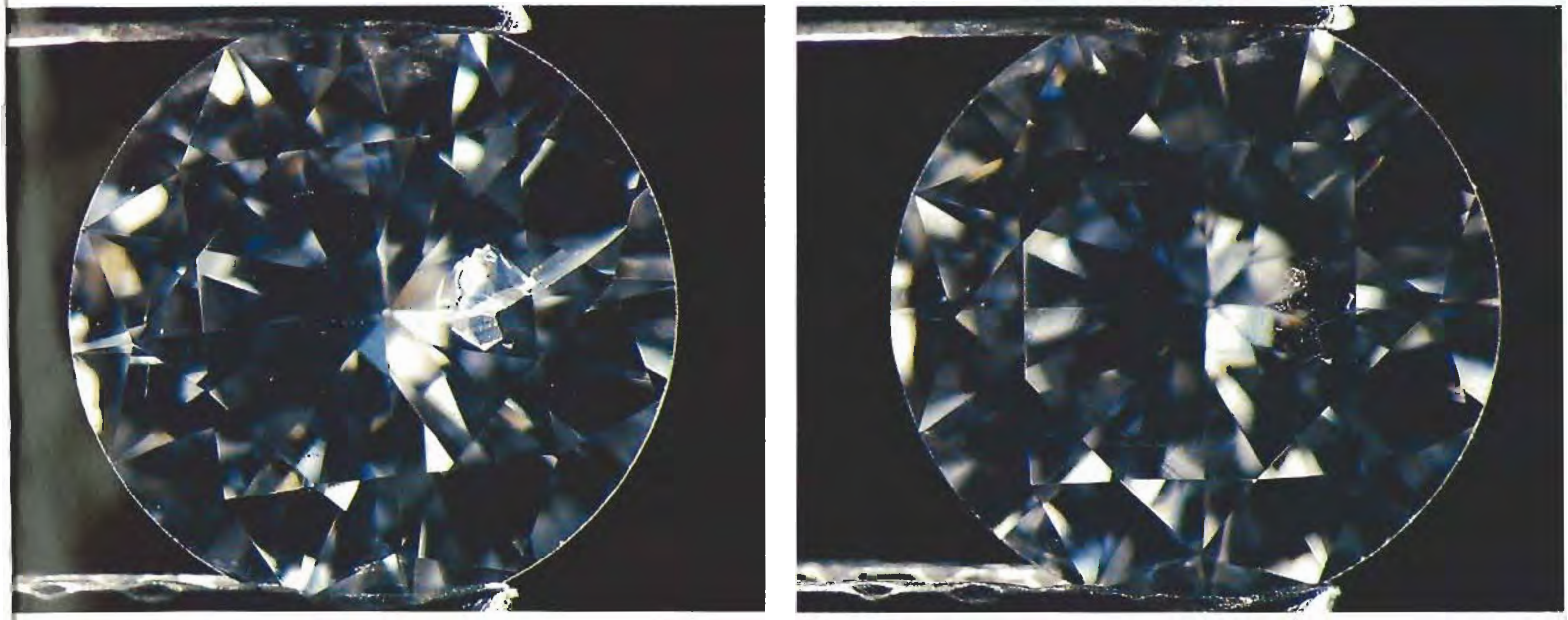


Figure 1. The filling of fractures, cleavages, and other separations in a diamond can have a significant effect on the apparent clarity of the stone. Before enhancement (left), this 0.25-ct diamond, with its eye-visible inclusion under the table, was clarity graded as an I_1. After the stone was treated by the Yehuda filling method at Dialase Inc., the apparent clarity (right) had risen to a grade of SI_2.

Association Lab Alert No. 7 on this treatment. Both reports described the effectiveness of the treatment in enhancing apparent clarity, with the GIA statement indicating that stones that would have originally graded I_2 and I_3 might be improved to the equivalent of an I_1. Both notices also stated that the stones examined thus far were reportedly treated in Israel; Mr. Horiuchi suggested that the filling material might be silicone oil.

In September 1987, GIA's Research Department acquired a 1.22-ct round brilliant-cut diamond that had been treated, reportedly by the filling process, and subsequently boiled in sulfuric acid in a diamond boiling kit. This cleaning procedure had partially removed the filler to a uniform depth from the system of intersecting cleavages reaching the table and crown facets of the stone, which resulted in an obvious white cruciform pattern just below the surface (figure 2). A close examination of this diamond provided some visual clues to the microscope-aided identification of filled diamonds (Koivula, 1987). More recently, with the opening of a diamond-filling operation in New York City (Maillard, 1989a), a number of articles have appeared in the trade press regarding these and other clues to identifying diamonds enhanced in this manner (see, e.g., Koivula et al., 1989; Shor, 1989).

To more accurately evaluate the effectiveness of this filling procedure, and to thoroughly characterize these fracture and cleavage fillings for identification purposes, we documented six diamonds both before and after filling and an additional 12 diamonds that were known to be filled. Tests not only included microscopic examination of these stones, but also analysis of the filling material and

Figure 2. A white cruciform pattern appeared in this diamond after an acid bath removed part of the filling compound that lay near the surface of the stone. A close examination of this 1.22-ct diamond provided the first visual clues to the microscope-aided identification of filled diamonds. Magnified 10×.

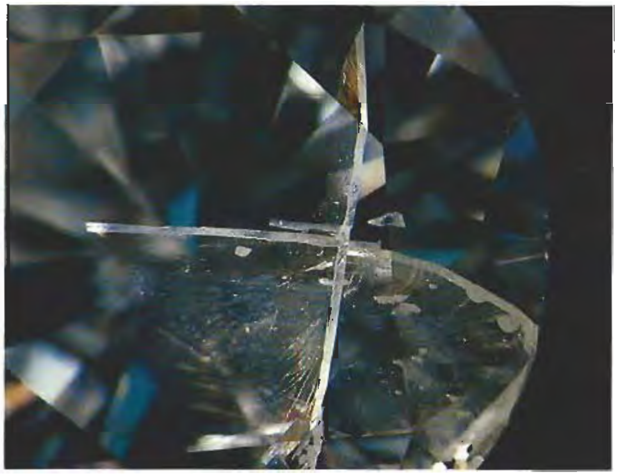


TABLE 1. Color and clarity of six round brilliant-cut diamonds before and after filling by the Yehuda method.[a]

No.	Measurements (mm)	Weight (ct)	Before		After	
			Color	Clarity	Color	Clarity
1	6.21–6.28 × 3.72	0.92	**L**	**Below I_3**	**M**	**I_3**
2	3.76–3.81 × 2.43	0.22	K	I_1	K	I_1
3	6.21–6.28 × 3.74	0.90	**K**	I_3	**L**	I_3
4	5.24–5.31 × 3.09	0.51	I	**SI_1**	I	**VS_2**
5	4.22–4.28 × 2.34	0.25	**E**	**I_1**	**F**	**SI_2**
6	4.06–4.18 × 2.39	0.25	**I**	I_1	**J**	I_1

[a] *All stones were graded independently at the GIA Gem Trade Laboratory for research purposes only. The laboratory does not offer grading reports on filled diamonds.*

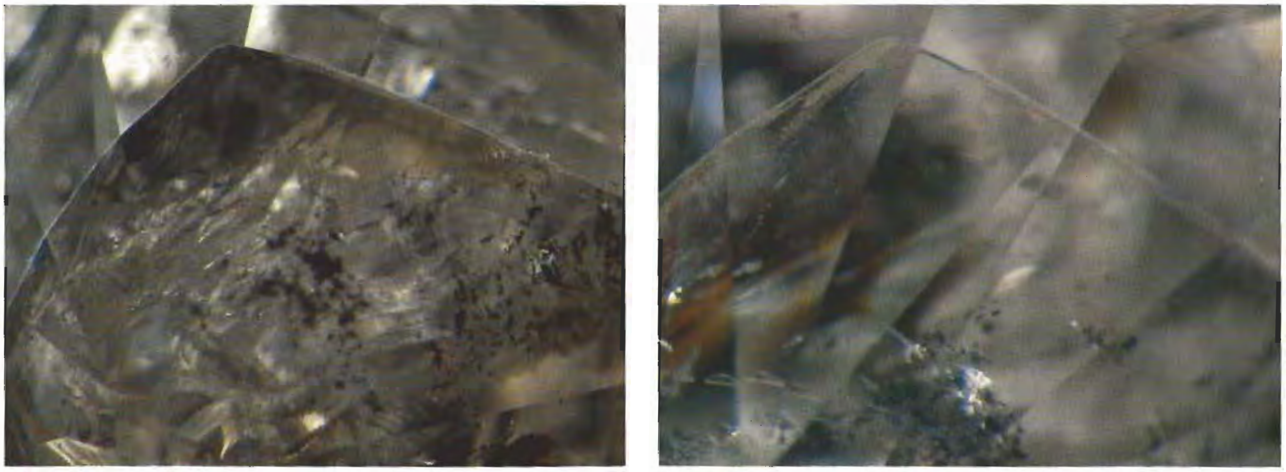
evaluation of the durability of the treatment when a filled stone is exposed to routine cleaning and jewelry manufacturing and repair procedures.

EFFECTIVENESS OF THE FILLING PROCEDURE

The stated purpose of this treatment is to improve the clarity of a diamond. In reality, this treatment has its roots in the oiling of emeralds, a practice that dates back to the ancient Roman Empire (Nassau, 1984). According to Ringsrud (1983), "The principle of oiling is simply that while air-filled fractures in gemstones are highly visible, a fracture filled with a transparent oil or some other suitable material will be much less apparent." The principle of the diamond-filling procedure is the same: replace the air that normally fills such breaks with a transparent substance that has an index of refraction close to that of diamond. The result is a much less visible separation that improves the overall appearance of a diamond to the unaided eye and, according to the trade press, greatly enhances the apparent value of the stone (Everhart, 1987; "U.S. Diamond Dealers . . . ," 1987; Weil, 1988; "Filler Must Be Disclosed," 1988). The GIA Gem Trade Laboratory in New York has even examined samples of laser-drilled diamonds that have been treated in an attempt to fill fractures reached by the laser.

According to the *Rapaport Diamond Report* (September 4, 1987), the filling compound developed by Yehuda is introduced into the diamonds at relatively high pressures (in the range of 50 atmospheres) and a temperature of 400°C. This procedure has not, however, been confirmed; and it may actually involve the use of a vacuum rather than the more technically difficult high-pressure environment suggested. The precise composition

Figure 3. A large cleavage system reduced the transparency of this 0.92-ct diamond (no. 1 in table 1) before treatment (left). After treatment (right), there was a dramatic reduction in the visibility of the cleavage, with a significant improvement in the apparent clarity. Magnified 15×.



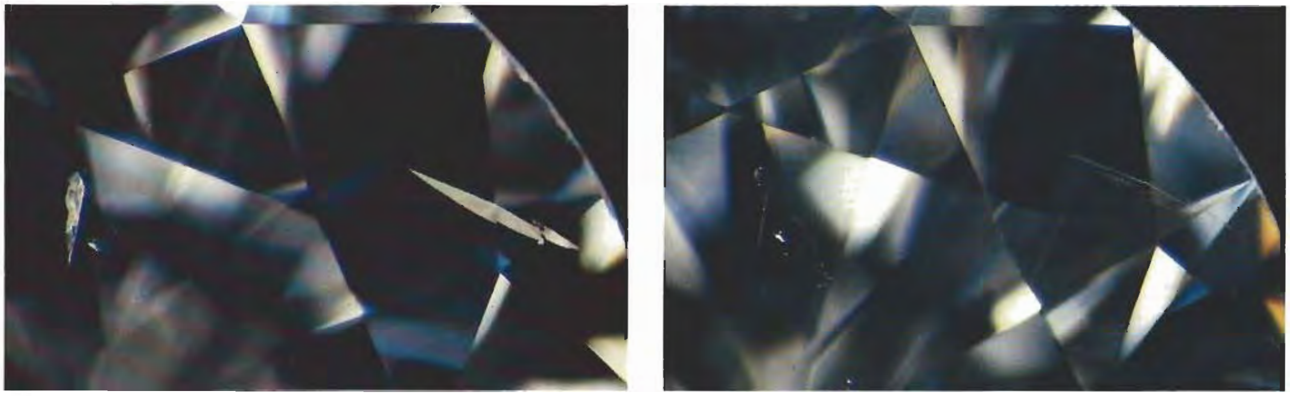


Figure 4. The small cleavages shown here contributed to the SI_1 clarity grade in this 0.51-ct diamond (no. 4 in table 1) before treatment (left). After treatment (right), the clarity was graded as VS_2. Magnified 15×.

of the filling material has not been disclosed by Mr. Yehuda; in fact, he reportedly denies that a filler is used in his process (Everhart, 1989).

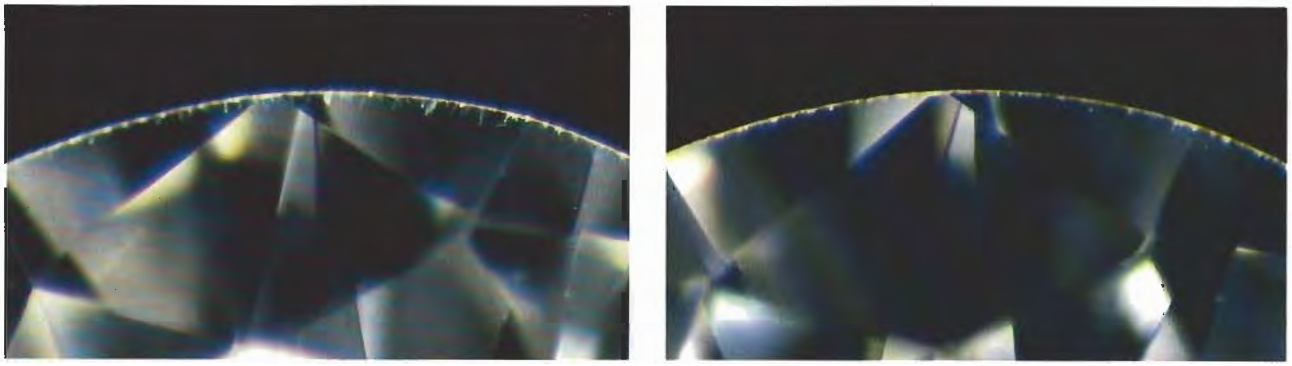
The six round brilliant-cut diamonds that served as the core of our test sample were selected from GIA's collection based on the position and appearance of the breaks that reached the surface of each. Prior to undergoing the filling procedure, all six stones were thoroughly documented photographically, weighed on an electronic balance, and independently graded for color and clarity by GIA Gem Trade Laboratory diamond graders (table 1). The six stones were then submitted by members of the trade for enhancement in New York at Dialase Inc., which purports to use the filling procedure developed by Mr. Yehuda in Israel (Maillard, 1989b).

After treatment, the stones were thoroughly re-examined and then photographed, weighed, and regraded for clarity and color. It is important to emphasize that this "before-and-after" color and clarity grading was performed by GIA Gem Trade Laboratory graders for research purposes only; it is *not* a GTL service offered on filled diamonds (as is discussed later in this article).

The results of the examination after treatment are also reported in table 1. They indicate that the treatment appeared to be very effective in some stones (figure 1; stone 5 in table 1), while in others there was no significant change. In the cases that showed significant clarity improvement, the specific changes were often dramatic. As evident in figure 3, the appearance of large cleavages was improved radically. Figure 4 illustrates an equally impressive degree of clarity enhancement of much smaller features once they have been filled. Even the general appearance of bearded girdles was improved by the filling procedure (figure 5).

One of the diamonds selected for this experiment was chosen because it contained a large diamond crystal (knot) under the table from which a large cleavage extended into the crown (figure 1).

Figure 5. Before treatment (left), the slight bearding along the girdle of this 0.25-ct diamond (no. 6 in table 1) is relatively easy to see. After treatment (right), the visibility of the bearding appears to be significantly reduced. Magnified 20×.



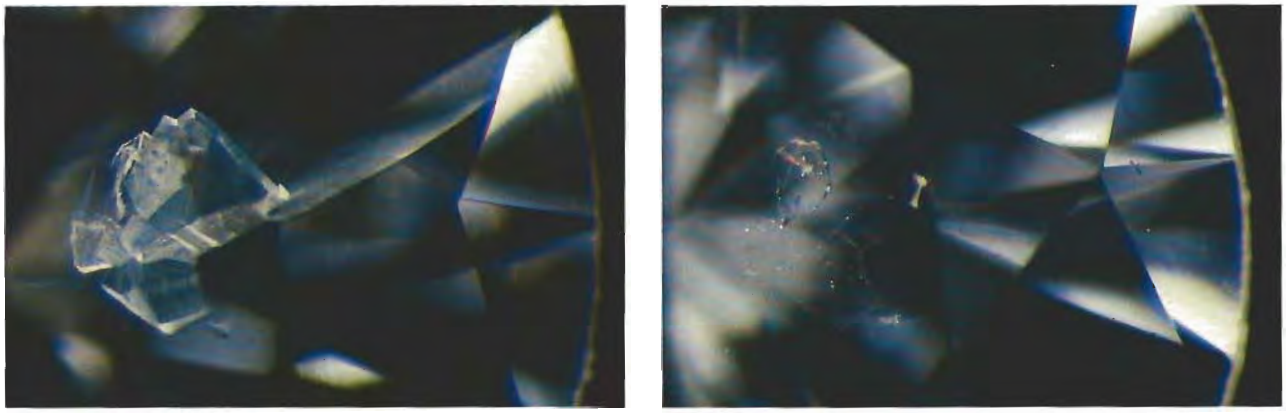


Figure 6. The white-appearing interface around the diamond crystal inclusion (knot) in the diamond shown in figure 1 (stone 5 in table 1) is readily visible before filling (left). After filling (right), the interface and knot-associated cleavage both seem to have virtually disappeared. Magnified 20×.

The crystal was surrounded by a white interface that made the inclusion highly visible when the stone was viewed table-up (figure 6, left). We had already established that the visibility of surface-reaching cleavages and fractures could be reduced by the filling treatment, but could the visibility of a knot be reduced by filling the interface between the host diamond and the knot? The answer to this question is dramatically provided in figure 6, right. Thus, it seems likely that virtually *any* separation reaching the surface of a diamond can be filled by this process.

Another factor considered was weight. Could the filling compound also increase the weight of the original stone? The six stones treated for this report did not show any evidence of weight gain after the enhancement. This is undoubtedly because the filler incorporated is essentially a thin film, so in even the most badly cleaved and fractured diamonds its weight is negligible.

A somewhat surprising finding was a generally poorer color after treatment: Four of the six stones showed a drop of one full color grade (again, see table 1). Even two of the stones that showed no significant clarity improvement graded lower in color after treatment.

The enhancement appears, then, to be very effective in improving the apparent clarity of most diamonds with appropriate inclusions. There was no effect on the weight of the diamonds tested. However, the treatment may have a negative impact on the overall color of the stone. The next question was: How can the presence of a filling best be detected? We looked to microscopy for the answer.

For the purposes of microscopic and other testing, we also examined an additional 12 diamonds known to have cleavages and fractures filled by this or a similar process. These stones ranged in weight from 0.22 ct to almost 2 ct, and represented a variety of cutting styles, including pear shapes, marquises, emerald cuts, and round brilliants. In apparent color—again, graded for research purposes only—they ranged from colorless (E, on the GIA color grading system) to fancy brownish yellow. During the course of this study, more than 50 diamonds found to be filled were received at the GIA Gem Trade Laboratory, Los Angeles, and examined by several of the authors. Information obtained from these stones has also been included as appropriate.

VISUAL IDENTIFICATION: MICROSCOPIC EXAMINATION PROVIDES PROOF

At first glance with the unaided eye, a filled diamond may appear slightly greasy or oily with a very slight yellowish overtone. The yellowish overtone is most apparent in stones with many treated areas, and may be due to the color of the filling compound.

A person experienced with diamonds is likely to feel that something is "not quite right" when encountering one of these filled stones. This is particularly true if there are a large number of treated eye-visible breaks. To follow up on these "first suspicions," we found that examination of the fractures and cleavages with a microscope is the single best means of quickly and positively recognizing this new form of diamond enhancement. Careful study of the 18 filled diamonds used for this report revealed a number of micro-

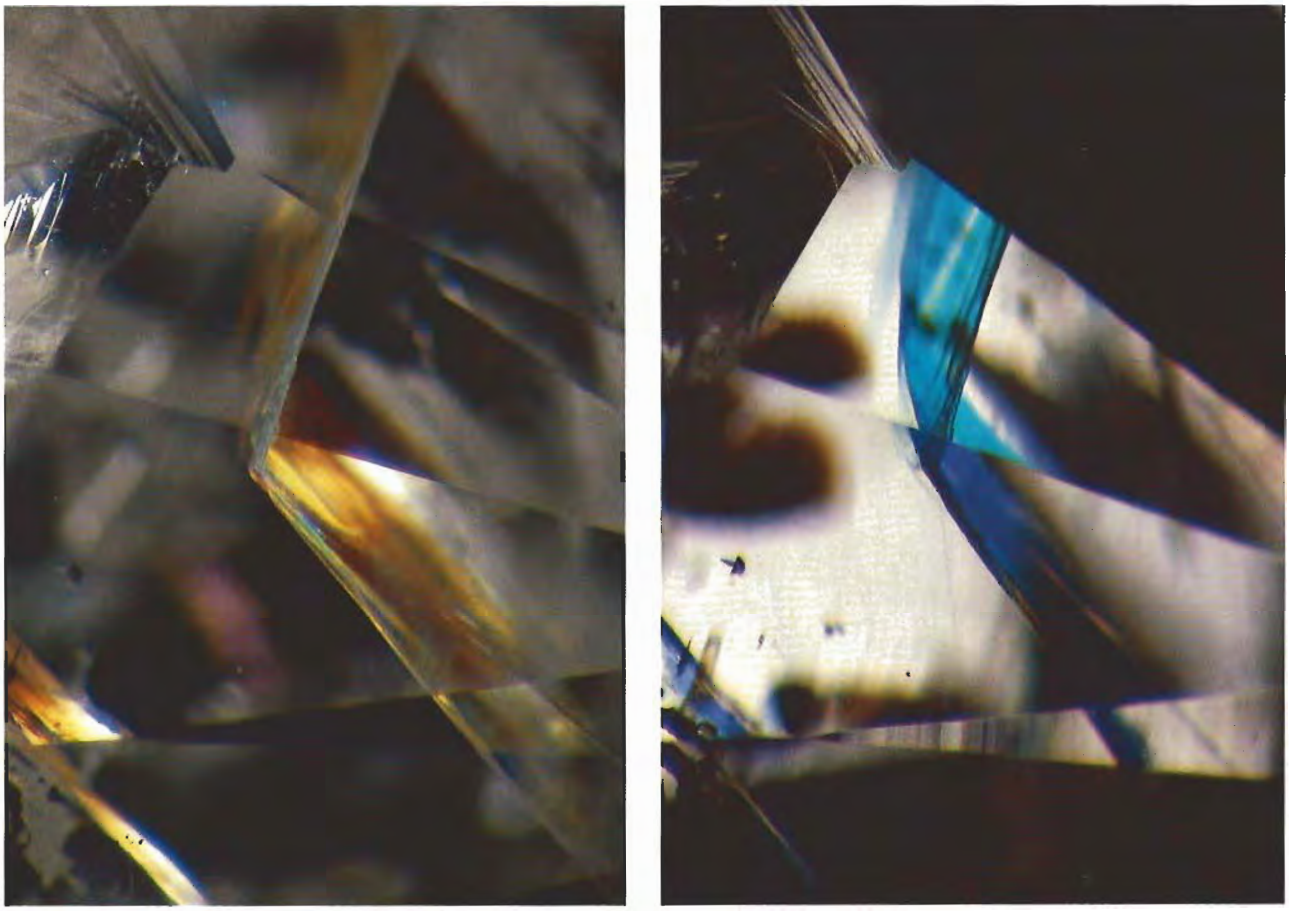


Figure 7. A "flash effect" is one of the most important visual features of filled breaks in a diamond. In darkfield illumination (left), this effect is a very characteristic yellowish orange; it changes to a distinctive blue when the stone (here, no. 1 in table 1) is rotated slightly to a position where the background becomes bright (right). Magnified 20×.

scopically resolvable features that indicate that a stone has been enhanced in this manner. Although no one feature has been seen in all of the stones examined to date, the presence of one or more of these features in a diamond can provide evidence that the stone has been filled.

"Flash Effect." One of the most obvious and most common characteristics of the filled fractures and cleavages is what we call a "flash effect." Filled breaks in most of the treated diamonds examined to date, and in all six that we had treated by Dialase Inc., have revealed a very characteristic yellowish orange interference color in darkfield illumination that changes to an intense vivid "electric" blue when the stone is rotated very slightly to a position where the background turns bright through secondary reflection (figure 7). As a treated diamond is tilted back and forth, these interference colors will change from orange to blue and back to orange again in a flashing manner—hence, the "flash effect" designation. These "flash effect" colors are seen when the viewing angle is very steep, approaching a direction parallel to the plane of the treated fracture or cleavage (i.e., edge-on with the separation).

Provided the proper illumination is used, the "flash effect" can be so obvious that it is easily seen even at low magnification (figure 8); in some cases a standard 10× loupe is sufficient. In fact, stones with fractures or cleavages in the table-to-culet direction probably are not good candidates for filling, as the "flash effect" will be too readily visible through the table. The yellowish orange "flash effect" may be difficult to see in dark brownish yellow to orange diamonds, although, as is evident in figure 9, the vivid "electric" blue is still quite apparent. It must be noted, though, that in extremely small separations—a bearded girdle, for example—the "flash effect" may not be visible

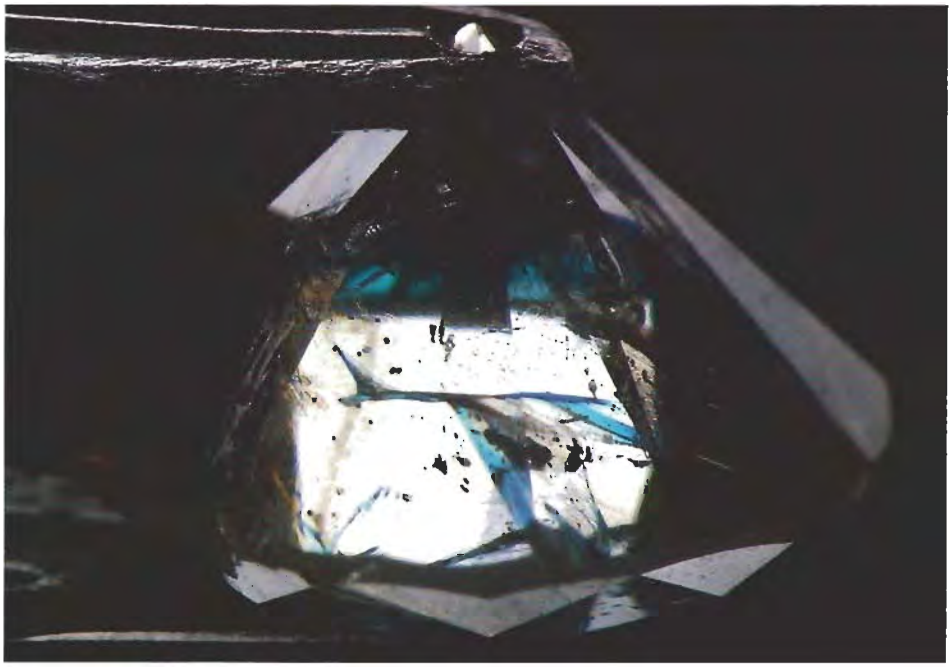


Figure 8. Even at 10× magnification, "flash effects" may be seen in some filled diamonds.

at all. Nor was it visible even in some larger breaks in some of the filled diamonds recently examined at the West Coast GIA Gem Trade Laboratory.

Cleavages and fractures that reach the surface of an *untreated* diamond may be decorated with a rusty orange-colored stain of iron-containing naturally derived epigenetic compounds (figure 10) that could at first be mistaken for the yellowish orange "flash effect." In addition, *unfilled* fractures in untreated diamonds sometimes behave as thin films and display bright iridescent colors when viewed in certain directions (figure 11). However, neither the rainbow-like arrangement of the colors nor the "feathery" appearance of the cleavage itself has been observed to date in an artificially filled fracture or cleavage. These iridescent colors in an unfilled separation are most likely to be seen at an angle nearly perpendicular to the plane of the break. Again, the best viewing angle for a "flash effect" is near-parallel (edge-on) to the break.

Flow Structure. Another very distinctive and relatively common feature of this enhancement process is the flow structure of the filling material (figure 12). Apparently the compound is intro-

Figure 9. Even though the orange "flash effect" is difficult to see in this 1.32-ct brownish yellow diamond, the blue "flash" is clearly visible. Magnified 15×.

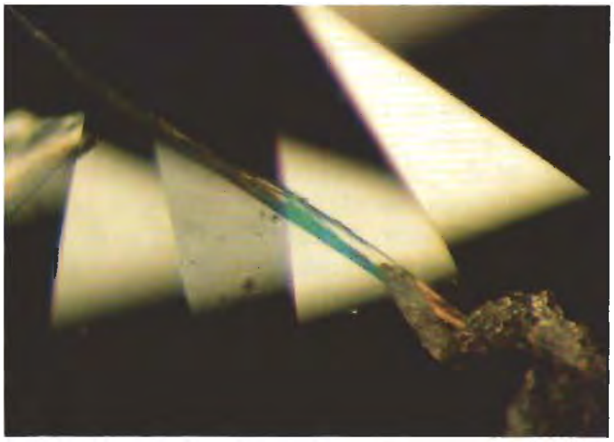
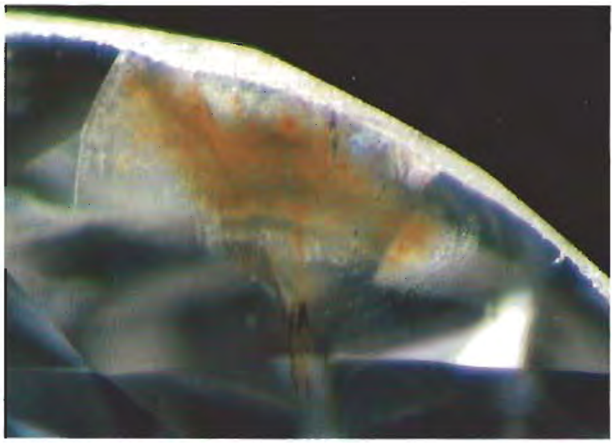


Figure 10. Epigenetic iron stains, such as the one decorating this cleavage, should not be mistaken for the yellowish orange "flash effect" observed in filled breaks. Diamond courtesy of Gregg Lyell. Magnified 40×.



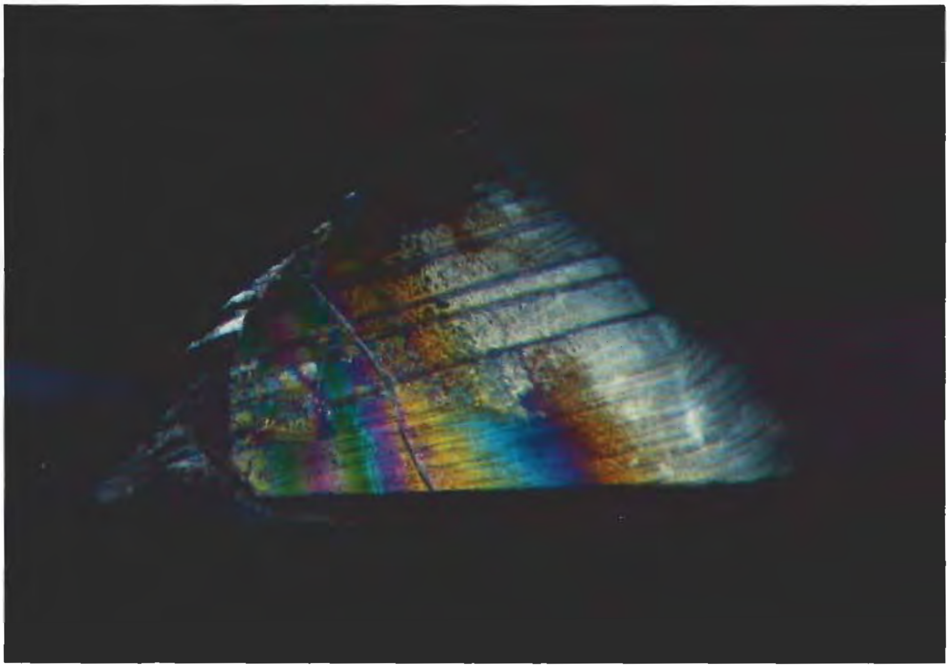


Figure 11. The "feathery" appearance and rainbow-like interference colors shown here are typical of an untreated *fracture in diamond. Similar texture and intense iridescence are not seen in filled cleavages or fractures. Magnified 35×.*

duced into the exposed separations at a high temperature in a molten state (a relatively high vacuum is probably used as well, which would then be followed by increasing pressure as the vacuum is released). The compound flows by capillary action into any open areas in the diamond, obscuring the normal feathery appearance (again, see figure 11) that is associated with breaks in *untreated* gems. Under magnification, the resulting flow structures generated by this enhancement look as if a glassy substance has been melted into the separations, creating a texture not seen in untreated diamonds.

Trapped Bubbles. Careful microscopic examination revealed at least a few flattened gas bubbles trapped within the filling material in a number of stones. Most of the bubbles observed are quite small, and in some areas they are rather plentiful, forming a fingerprint-like inclusion (figure 13). Some, however, were comparatively large and conspicuous (figure 14). Bubbles probably result from shrinkage of the filling material during cooling and/or from air trapped in the breaks by the liquified filling material.

Crackled Texture. Although encountered in only three stones in our investigation, a crackled or web-like texture in a separation provides conclusive proof that it has been filled (figure 15). Somewhat akin to the mud cracks seen in dry lake beds, this feature was observed in only the thickest portions of the filled areas. Such a crackled texture may result from a combination of a partial crystallization of the filling material and uncontrollable or rapid shrinkage as it cools.

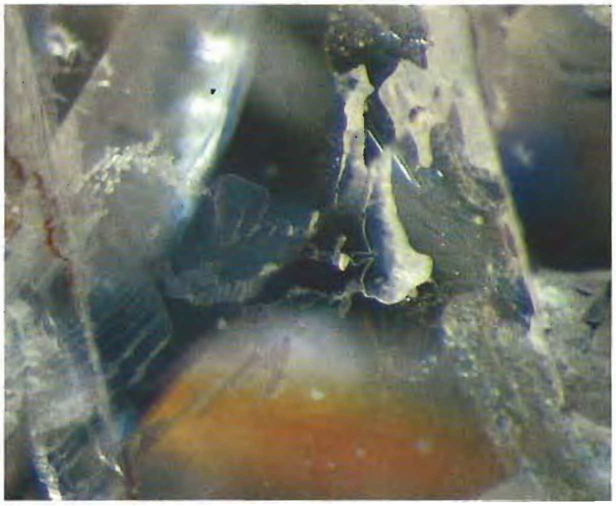


Figure 12. The melted appearance of the flow structure in a filled cleavage (here, in stone 1 from table 1) is very different from the distinctive pattern of an untreated break shown in figure 11. Magnified 35×.

Apparent Color of the Compound. The filling agent is rarely thick enough for its true color to be judged, but when it is, as shown in figure 15, it seems to be light brown to brownish yellow or orangy yellow. This may explain the lowering of

Figure 13. These numerous small trapped bubbles form a fingerprint-like inclusion in the filled cleavage plane of this diamond (stone 3 in table 1). Magnified 35×.

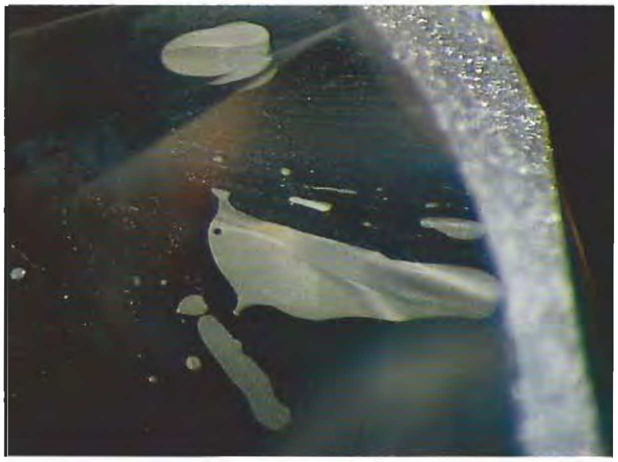
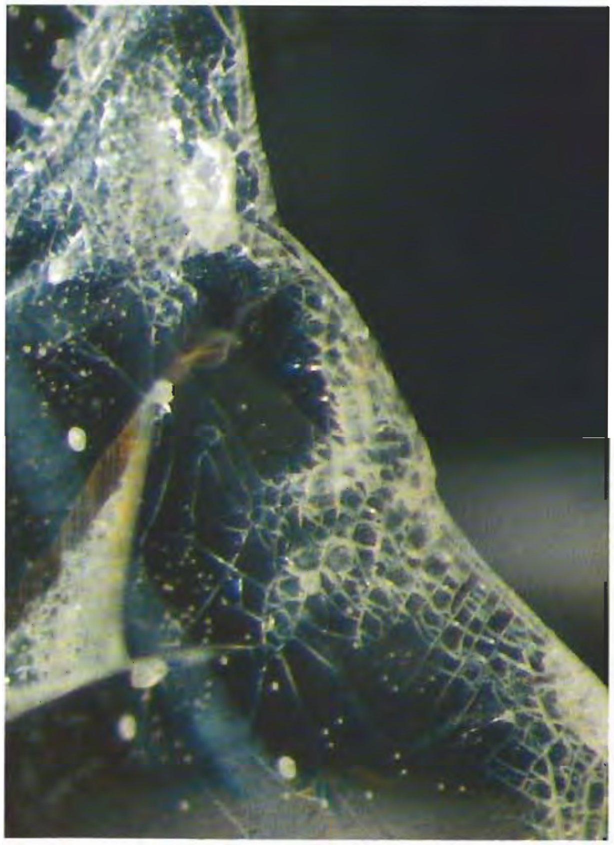


Figure 14. Large trapped gas bubbles such as those shown here probably result from the incomplete filling of the fracture in this diamond. Magnified 35×.

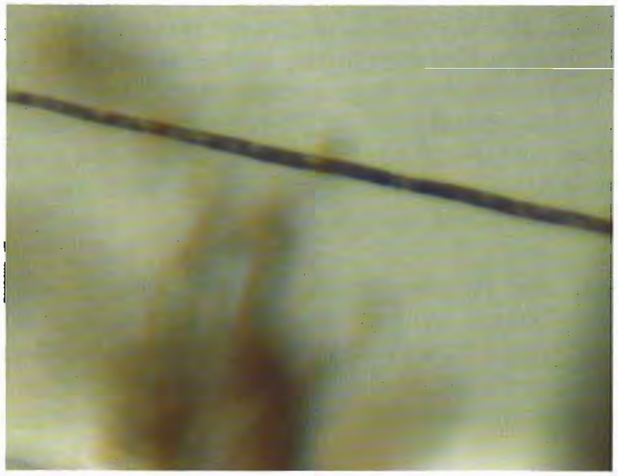
the graded color in four of the six stones examined before and after treatment. One of the diamonds examined contained a thin void 0.5 mm long that was partially filled with the treatment compound, which appeared as a light brownish yellow irregular mass in direct association with a network of cleavages. We also observed a brownish compound in the laser drill hole of a diamond that was found to be filled (figure 16).

Figure 15. Although not as common as other identifying features, a crackled texture is additional evidence that a break has been filled. Note also the color of the filling revealed here. Magnified 30×.



Estimating the Refractive Index of the Filling. Where the filling agent is in direct contact with the diamond, and there is no interfacial separation, it is possible to do a crude form of the Becke line test to determine which of the two—diamond or filler—has the higher refractive index. The results of such observational testing revealed that diamond, with a refractive index of 2.417, is the higher of the two. However, the bright-line appearance, together with the extremely low relative

Figure 16. The yellowish to brown color of the filling material is also evident in this filled laser drill hole. Photomicrograph by David Hargett; magnified 60×.



relief between the diamond and the filler, suggests that the refractive index of the filler is very close to that of diamond.

X-RADIOGRAPHY

X-radiography can also help identify filled diamonds. Working together in the New York GIA Gem Trade Laboratory, Bob Crowningshield and Tom Moses have had considerable success using X-radiography to separate diamond from many of its simulants, especially when dealing with melee-size stones (Tom Moses, pers. comm., 1989). Therefore, they decided to see if X-radiography could also be useful in determining the presence of filled cleavages and fractures in a diamond. Using a technique similar to that used for pearls, but with a lower voltage and current because of the high transparency of diamond, they took an X-radiograph of three diamonds that were known to have been filled. On the processed film, the filled areas appeared much more opaque to X-rays than did the surrounding diamond (Koivula and Kammerling, 1988; Koivula et al., 1989). This same test has since been done several times in the GIA Gem Trade Laboratory. Although in most cases the lab has observed the same positive results, in some stones fillings that had been observed with microscopy did *not* show up as opaque on the developed X-ray film. In addition, certain mineral inclusions have also proved to be much more X-ray opaque than diamond. Thus, while this test may be particularly helpful for a preliminary assessment on large lots of diamonds, we recommend that it always be used in conjunction with microscopy.

Inasmuch as Mr. Horiuchi's August 1987 ICA Lab Alert had suggested that the filling material might be a silicone oil, Messrs. Crowningshield and Moses decided to coat an untreated diamond with silicone grease to see if this coating would be less transparent to X-rays than the underlying diamond. There was no difference in transparency between the coating and the stone, so silicone was ruled out as the filling agent in the Dialase process.

On the X-ray film, the filled areas appear as distinct white, underexposed patches and zones on the diamonds, as illustrated in the stone shown in figure 17. On the basis of this appearance, it was evident that one or more atomically heavy, X-ray-opaque elements was present in the filling material. Further work was now necessary to determine its precise nature. For this purpose, a number of filled diamonds were studied using a variety of techniques to identify the presence and the composition of the filling material.

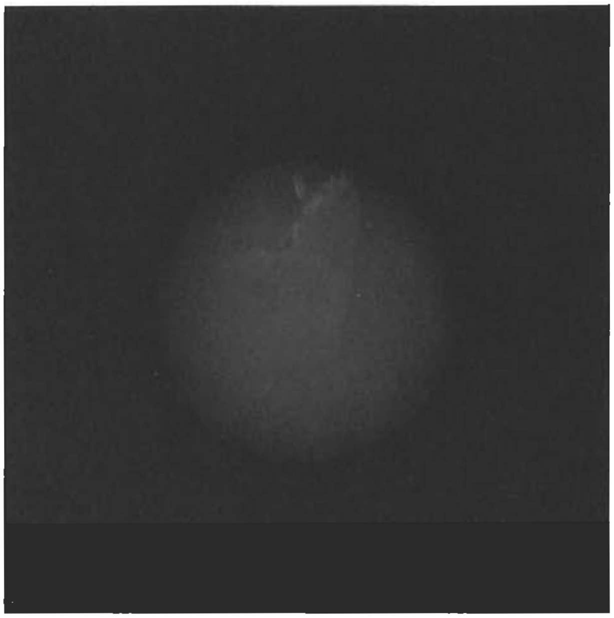


Figure 17. This X-radiograph of the 0.90-ct Yehuda-treated stone (no. 3 in table 1) shows the filled areas as opaque, unexposed white patches. X-radiograph by Karin Hurwit.

ANALYSIS OF THE FILLING MATERIAL

Impregnation with an organic substance in other gem materials can usually be detected using infrared absorption spectroscopy in the mid-infrared range (400–4000 cm^{-1}). Therefore, five known filled diamonds were run on a Nicolet 60SX Fourier Transform spectrometer (Fritsch and Stockton, 1987) to determine whether the filling was organic or inorganic in nature. To visualize the material in the fractures and obtain a local semiquantitative chemical analysis, a Camscan scanning electron microscope (SEM) in the Division of Earth and Planetary Sciences at the California Institute of Technology was used (analysts: John Armstrong and Mary Johnson) on stone 1 of table 1. For a precise chemical analysis and measurement of the concentration of light elements (oxygen in particular), a Jeol Superprobe 733 in the same laboratory was used (analyst: John Armstrong) on the same stone. Additional semiquantitative chemical analysis was performed on the six Dialase-treated stones and more than 25 additional filled diamonds with a Tracor X-ray Spectrace 5000 X-ray fluorescence spectrometer in GIA's Research Department.

Infrared Spectroscopy. None of the stones tested exhibited any noticeable additional absorption in the mid-infrared range, even when microscopic inspection had proved the presence of numerous filled breaks. This suggests that the filling material is not organic.

Scanning Electron Microscopy. Using a scanning electron microscope with the appropriate detectors (Stockton and Manson, 1981), one can obtain both a visual representation of the surface shape of the filling and a map of the spatial distribution of chemical elements in the near-surface layer of the material. The higher the atomic number (the heavier the element) is, the brighter this area of the black-and-white image will appear. Figure 18 clearly shows how at relatively low magnification (30×) the filled fractures stand out because of their very high contrast (almost white versus the very dark gray of the remainder of the stone). The fact that the tone of the material in the fractures is different from that of the bulk of the diamond confirms the presence of a foreign (noncarbon) material in the cracks. The very light tone of the filling also proves the presence of high-atomic-number elements.

Higher magnification (180×) reveals patches of various tones within the foreign material, although most of it appears white (figure 19). This means that the filling is not homogeneous.

Using the SEM's energy dispersive spectrometer (EDS) attachment, the analyst performed semi-quantitative analysis on eight spots along the fracture illustrated in figure 19. All eight showed the presence of lead and chlorine as major constituents. Six also showed significant amounts of bismuth. Various other elements (e.g., sodium, potassium, calcium, aluminum, and silicon) were detected, but in negligible amounts. Similar results were obtained on other filled areas analyzed.

When both lead and bismuth were present in a filling, the lead-to-bismuth concentration ratio was generally around 2:1, although it dropped to 1:1 in one spot. The chlorine concentration consistently seemed to approximate the sum of the lead and bismuth concentrations.

Electron Microprobe. The presence of oxygen as a major constituent in the filling material was ascertained with the electron microprobe. The exact values of oxygen concentration could not be obtained because our gem specimens did not conform to the precise technical conditions required for this type of analysis.

X-Ray Fluorescence. This technique provides the overall bulk composition of the material under study. Because the instrument does not detect carbon, the bulk composition of the diamond itself is ignored, and the XRF spectrum obtained represents the composition of the inclusions, primarily the filling agent. This technique is very fast and does not require any preparation of the sample, so it also provides a rapid means of identifying filled diamonds. The diamonds were run in conditions appropriate for the detection of heavy elements. Only three of the samples examined by XRF contained lead and bismuth. The remaining stones had only lead, indicating a variable chemistry of the filling material from one stone to the next, similar to the inhomogeneities seen with the SEM in a single fracture from one spot to the next.

X-Ray Diffraction. To determine whether the filling agent has a definite structure, we decided to crush the 0.92-ct diamond (no. 1 in table 1) because it contained the greatest number of comparatively large filled areas.

To minimize contamination, the diamond was first broken with a pair of steel pliers and then crushed between two thick slabs of chalcedony. The largest of these fragments with the greatest number of freshly exposed surfaces was selected for the X-ray study. An iron scraper instead of diamond (again, to minimize contamination) was used to scrape the freshly exposed surfaces. The minute amount of powder obtained in this manner was mounted on a spindle in a Debye-Scherrer camera and exposed to X-rays from a copper target tube powered at 46 kV and 26 mA for 18 hours.

The X-ray pattern generated was very weak. The only two visible lines in the pattern could be identified as coming from the diamond (probably loosened cleavage fragments) and the iron scraper. No evidence of additional crystalline structure from the filling agent was present. This suggests that the filler is amorphous, and probably a glass.

Subsequent to this examination, we received a filled stone that had three readily discernable droplets adhering to the surface. X-radiography indicated that these droplets had the same opacity

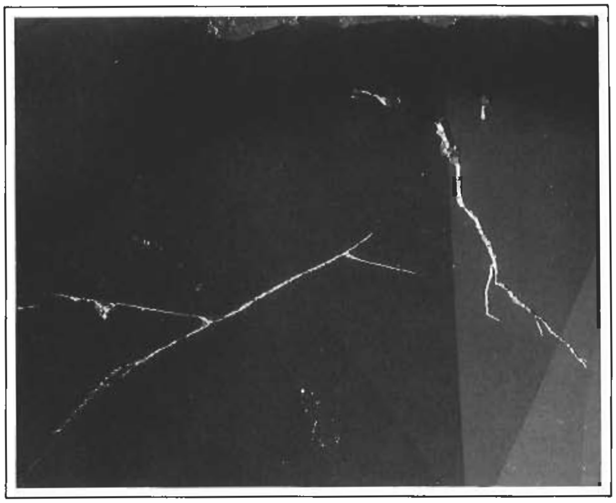


Figure 18. A scanning electron micrograph of filled breaks shows the very high contrast between the separation and the diamond. This indicates the presence of a foreign (noncarbon) material containing elements of high atomic number. Electron micrograph by John Armstrong; magnified 30×.

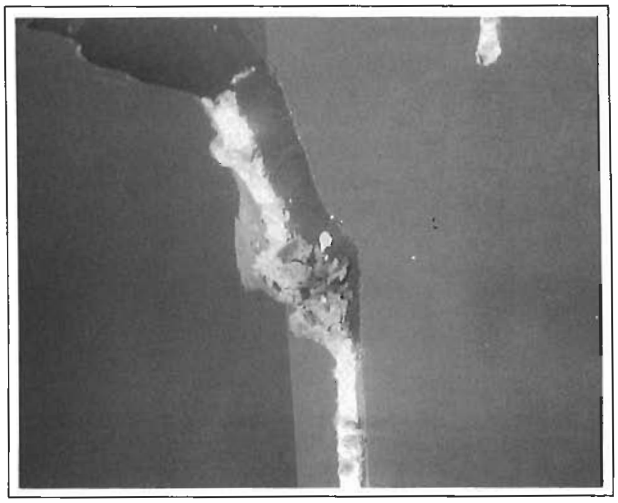


Figure 19. Higher magnification shows three different tones in the breaks illustrated in figure 18. These different tones indicate that the filling material is not homogeneous. Electron micrograph by John Armstrong; Magnified 180×.

as the filling material in the fractures of this stone. A scraping was easily made of the material from one of these droplets which X-ray diffraction proved to be amorphous, thus confirming our earlier findings.

Discussion. Chemical analysis showed that the filling material is a compound of lead, chlorine, and oxygen, with variable amounts of bismuth. (Boron is another possible component, but we do not have the means to detect its presence.) X-ray diffraction analysis proved that it is amorphous. Therefore, this particular filling material is undoubtedly a lead-containing glass-like material.

One can estimate what the optical and physical properties of this material might be by looking at materials of similar composition. There is only one natural lead-bismuth oxychloride, the very rare mineral perite, of formula $PbBiO_2Cl$. It is "sulfur" yellow in color (Gillberg, 1960), and its refractive index has been estimated to be over 2.4, very close to that of diamond (2.417). There are also various man-made "solder glasses" with high lead and bismuth contents that have low melting points and refractive indices in the 2-plus range. Because chlorides or oxychlorides of lead or bismuth typically have a high index of refraction (BiOCl: 2.15; $PbCl_2$: 2.199, 2.217, 2.260; Weast, 1980), their presence in the cleavages and fractures of a diamond would make these defects much less noticeable. In addition, such compounds are usually infrared transparent, which is consistent with our results.

Many materials belonging to this class also have low to moderate melting temperatures: $Pb(ClO_3)$ decomposes at 230°C, $PbCl_2$ melts at 501°C, $BiCl_4$ and $BiCl_3$ melt at about 230°C, and BiOCl melts at "red heat" (Weast, 1980). This characteristic would be particularly attractive for a process that requires that the filling material be drawn into the breaks while it is in liquid form.

Finally, some of the compounds mentioned above have an intrinsic yellow to red coloration. This could account for the slightly yellowish additional component (and consequent drop in apparent color grade) observed in some of the test stones after treatment.

DURABILITY AND STABILITY OF THE FILLING

One of the most important issues that surrounds any new enhancement is durability. Therefore, we conducted several tests using one of the six diamonds we had filled (stone 3, table 1) to determine the durability and stability of this treatment under a wide range of conditions to which a diamond might be routinely subjected (see table 2).

The first of these was ultrasonic cleaning,

TABLE 2. Durability and stability of the treatment in a diamond filled by the Yehuda method.[a]

Test	Procedure	Result
Ultrasonic cleaning	Stone placed in solution of commercial jewelry cleaner in ultrasonic cleaner for 30 minutes	No effect on treatment
Steam cleaning	Used two steam cleaners with pressure between 40 and 70 PSI, stone placed one inch from nozzle for 10 minutes	No effect on treatment
Boiling in detergent solution	Stone boiled in solution of water and dish-washing liquid for 30 minutes	No effect on treatment
Boiling in acid[b]	N/A	Filling damaged
Repolishing[c]	N/A	Filling damaged
Low temperature and thermal shock	Stone covered with 1/4 inch of liquid nitrogen to cool to −185°C	No effect on treatment
Stress	Stone set in four-prong head, with no prongs touching a filled area	No effect on treatment
Heat from jewelry repair	Prongs retipped with stone in place; 14K gold beads and 18K gold solder, flow point of 810°C, used with MECO midget torch with no. 40 tip; diamond heated a total of nine times	Beads of filling agent sweated out and appeared on surface of gap

[a] *All tests performed by the authors and other GIA staff members used one of the six stones submitted for treatment by the Yehuda method to Dialase Inc., New York.*
[b] *Test not performed by present authors; see Everhart (1987), Rapaport (1987), Koivula (1987), and Weil (1988).*
[c] *Test not performed by present authors; see Maillard (1989a).*

using a solution of commercially available jewelry cleaner. The stone, in the solution, was placed in an ultrasonic cleaner for 30 minutes. Microscopic examination confirmed that the enhancement was completely unaffected by this cleaning procedure.

Jewelers commonly steam clean diamond-set jewelry to remove gold-polishing compound and other debris that has been trapped in the mounting during manufacture or repair. To test the effect of steam cleaning on filled diamonds, GIA's Mark Mann and Jim Lucey used two steam cleaners so that steam pressure could be maintained between 40 and 70 pounds per square inch (PSI). Because the filled areas in the test diamond (the same one used for the ultrasonic cleaning test) were open to the surface on the table and crown, the stone was held in the steam jet in the table-up position approximately one inch from the steamer's nozzle. As the pressure dropped in one steam cleaner to near 40 PSI, the stone was placed under the nozzle of the other unit. Alternating between cleaners, the treated diamond was subjected to a jet of pressurized steam almost continuously for approximately 10 minutes. Again, microscopic examination showed that the treatment was completely unaffected.

Because jewelers will sometimes clean diamonds by boiling them in a solution of water and a detergent, we decided to boil the test diamond for 30 minutes in a solution of 100 ml of distilled water containing 10 drops of commercially available dishwashing liquid. Again, there was no effect on the treated areas.

Occasionally, diamonds are boiled in sulfuric acid to remove dop, prong, and tweezer metal from the surfaces of rough girdles and to clean out laser-drilled inclusions. We did not perform this test, however, because several sources (Koivula, 1987; Everhart, 1987; *Rapaport Diamond Report*, 1987; Weil, 1988) had already reported that acid boiling attacks the treatment (again, see figure 2). Likewise, we did not test the effect of the heat generated during a repolishing procedure, which Maillard (1989a) has already reported will undo the treatment.

To determine the effect of extreme cold on the test stone, we placed the diamond in a styrofoam cup and covered it with about one-quarter inch of liquid nitrogen; this almost instantaneously lowered the temperature of the diamond to −185°C (a temperature likely to be reached if the stone was cryogenically cooled for spectrophotometric examination). This not only tested the effects of extreme cold but, in the rapid way the cooling was done, it also subjected both the diamond and the filling agent to extreme thermal shock. Again, though, there were no signs of damage.

A diamond undoubtedly undergoes great stress during setting and, even more so, during the retipping of setting prongs. So, as a final step in durability testing, we turned the same test diamond over to Duane Pebworth and James Morton, of GIA's Jewelry Manufacturing Arts Department, to determine how it would hold up under the pressure generated during setting and the heat required for normal prong retipping.

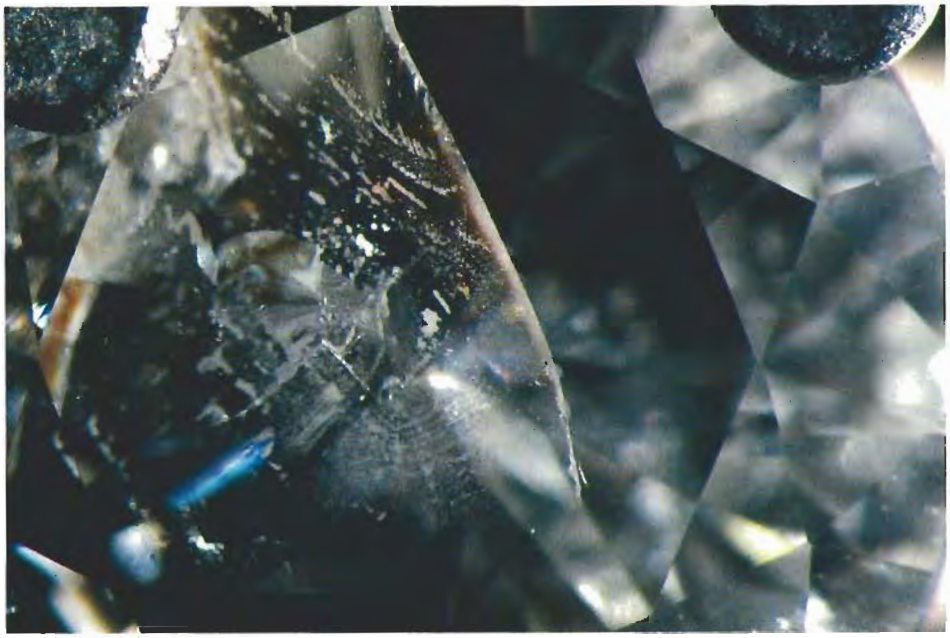


Figure 20. Damage to the filling (the same one illustrated undamaged in figure 13), became evident after the stone was exposed to the heat required in normal prong retipping. Magnified 15×.

The filled diamond, the same one illustrated in figure 13, was first set in a 14K white gold cast four-prong head. Care was taken not to place a prong directly on the filled area. There was no evidence of damage to the stone or the filling from the pressure required for the setting procedure. After ultrasonic and steam cleaning, the prongs were retipped using 14K white gold beads and 18K white gold solder with a flow point of approximately 1490°F (810°C). A MECO Midget torch with no. 40 tip was used with natural gas and oxygen. Following standard practice, the stone was fire coated first and then preheated slowly to bring it up to soldering temperature. During this step, the diamond began to turn a light yellow and, as retipping progressed, it became a dark, bright yellowish green. (This color change was totally unexpected. We do not know if it was caused by the presence of the filling material.) The diamond was heated a total of nine times: once for preheating, four times for tinning the solder, and four times for soldering the gold beads to create new tips on the prongs. As the stone was allowed to air cool, it reverted to its original color.

Examination of the diamond after retipping immediately showed that the filling had been damaged (figure 20); beads of the filling agent had sweated out of the separation and were visible as tiny droplets along the surface edge of the gap (figure 21). Their experience with this stone led Messrs. Pebworth and Morton to conclude that although most filled diamonds could probably withstand the pressure of setting (provided the work was done by an experienced artisan who was

Figure 21. Beads of the filling agent can be seen as tiny droplets along the surface edge of the gap shown in figure 20. They sweated out during the retipping procedure. Magnified 50×.

aware that the stone had been filled), such treated stones should NEVER be subjected to the heat of a jeweler's torch.

GIA GEM TRADE LABORATORY POLICY ON GRADING FILLED DIAMONDS

At the GIA Gem Trade Laboratory, diamonds determined to have cleavages and/or fractures that have been filled are considered in the same category as coated diamonds. Just as one cannot grade a coated diamond accurately without first removing the coating, one cannot grade a filled diamond accurately without first removing the filling material from the cleavages and fractures. In neither case can the true color of the stone be determined while the enhancement is present. Unlike the situation with most coated diamonds, however, there is no practical way to remove all of the filling material.

Laser drilling is a permanent, stable (unless, of course, the drill hole has been filled), and irreversible procedure that attempts to enhance the clarity of a diamond. The filling procedure, however, is not stable, especially when exposed to high temperatures, and cannot be considered a permanent change in clarity. More importantly for grading purposes, laser drilling alone does not affect the color of a diamond, while the filling procedure may produce a significant change (see table 1). The long-range stability of this color change has not been determined. It is, therefore, the present policy of the GIA Gem Trade Laboratory *not* to issue grading reports on any diamonds that contain any form of filling. The only GTL document given on such a stone is an identification report stating that the stone in question is a diamond and that it has been filled.

CONCLUSION

This relatively new process is designed to enhance the clarity of a diamond by filling breaks that reach the surface of the stone with a high R.I. material that, in effect, helps disguise these inclusions. It can improve the apparent clarity the equivalent of one full grade in many, though not all, appropriate stones. The presence of the filling material in a diamond is readily identifiable with a standard darkfield-equipped gemological microscope. The orange and blue "flash effects," flow structures, and flattened, trapped gas bubbles evident in the filled areas of these diamonds are easily detected by the properly trained diamond dealer or gemologist. In some cases, where the filled areas are particularly large, a standard 10× loupe may be adequate. Although not all of these characteristics were evident in all of the diamonds studied, at least one was present in each. In addition, the opacity to X-rays of the filling agent in most of the stones examined offers another useful test, provided it is applied in conjunction with microscopy.

The combined results of infrared spectroscopy, chemical analysis, scanning electron microscopy, and X-ray diffraction analysis show that in all probability the filling agent used is a lead-containing glass-like material.

This enhancement should in no way be confused with a repair process, although it has been referred to as such incorrectly, as evidenced by the title of an article in a recent trade publication: "Diamond Treatment that Removes Flaws Hits U.S. Market" (Everhart, 1989). The most recent advertising used to promote this enhancement process also uses the word *removed* in reference to "white gletzes" in its clarity improvement claims. This suggests that surface-reaching cleavages and fractures present before treatment are "removed" from the stone by the procedure and are no longer present after treatment. In fact, like the oiled fractures in emeralds, the cleavages and fractures in diamonds subjected to this form of filling still exist; they are just more difficult to see, thereby improving the apparent clarity of the stone.

There is nothing inherently wrong with this or any other enhancement process provided it is *always* disclosed at every level of sale. This filling process does improve the appearance of diamonds that, before treatment, were perhaps not marketable as jewelry-quality stones, although the GIA Gem Trade Laboratory has seen evidence of fillings in stones that might have graded in the VS range before treatment. In effect, this treatment also acts as a sealant, preventing dirt or other unsightly debris from entering laser drill holes and other open fissures in a stone.

The process does, however, appear to have a negative impact on the overall color of the stone. In addition, it is not durable in all normal manufacturing and repair situations. The filled breaks in these diamonds cannot take the heat required to repolish the stones or to retip the prongs on the mountings in which they are set. It therefore follows that filled diamonds that are sold without full disclosure may in time be discovered by the diamond cutter or bench jeweler who must work with them.

There has been continuous speculation that there is more than one vendor offering this type of filling service. One such rumor states that a similar procedure, using a molten, lead-based glass, is now being routinely done in India on low-quality goods. The slight variation in chemical composition noticed during scientific analysis supports the claim that there could be more than one filling material in the trade, or at least variability in the material used by the Yehuda operations. In addition, many of the filled diamonds seen recently in the GIA Gem Trade Laboratory show evidence of a filling procedure that is far less sophisticated (i.e., fractures are not completely filled, or have not been thoroughly cleaned before enhancement and thus show considerable dirt) than the one to which our 18 core test stones had been subjected.

It appears that the filling of diamonds is becoming more prevalent. Members of the trade have informed GIA that they have seen large parcels of filled diamonds. The more than 50 such stones examined at the West Coast GIA Gem Trade Laboratory in late May and early June lends support to these reports. Although most of these stones were from a single client, almost all of the several clients who have submitted diamonds found to be filled thus far indicated that they did not know their stones had been filled. With careful examination, however, most diamonds enhanced in this manner should be readily identifiable.

REFERENCES

Everhart J. (1987) Diamond dealers balk at disclosure of new treatment. *National Jeweler*, October 1, pp. 1, 86.

Everhart J. (1989) Diamond treatment that removes flaws hits U.S. market. *National Jeweler*, January 16, pp. 1, 33.

Filler must be disclosed (1988) *Jewellery News Asia*, No. 49, pp. 172–173.

Fritsch E., Stockton C.M. (1987) Infrared spectroscopy in gem identification. *Gems & Gemology*, Vol. 23, No. 1, pp. 18–26.

Gillberg M. (1960) Perite, a new oxyhalide from Langban, Sweden. *Arkiv Mineralogi och Geologi*, Vol. 2, No. 44, pp. 565–570. As abstracted by M. Fleischer in *American Mineralogist*, Vol. 46, Nos. 5 and 6, 1961, p. 765.

Koivula J.I. (1987) Gem news: "Filled" diamonds. *Gems & Gemology*, Vol. 23, No. 3, pp. 172–173.

Koivula J.I., Kammerling R.C. (1988) Gem news: "Filled" diamond update. *Gems & Gemology*, Vol. 24, No. 4, p. 248.

Koivula J.I., Kammerling R.C., Fryer C.W. (1989) Visual characteristics of Yehuda-treated stones. *New York Diamonds*, No. 4, pp. 72–76.

Maillard P. (1989a) Clarity enhanced diamonds now in New York. *Diamond Intelligence Briefs*, Vol. 4, No. 78, p. 450.

Maillard P. (1989b) Yehuda's treated diamonds arouse controversy in New York. *Diamond Intelligence Briefs*, Vol. 4, No. 79, p. 457.

Nassau K. (1984) *Gemstone Enhancement*. Butterworths, London.

Rapaport M. (1987) Diamond treatment—buyers beware! *Rapaport Diamond Report*, Vol. 10, No. 32, September 4, p. 8.

Ringsrud R. (1983) The oil treatment of emeralds in Bogotá, Colombia. *Gems & Gemology*, Vol. 19, No. 3, pp. 149–156.

Shor R. (1989) Filled diamonds worry dealers. *Jewelers' Circular-Keystone*, Vol. 159, No. 2, February, pp. 394–395.

Stockton C.M., Manson D.V. (1981) Scanning electron microscopy in gemology. *Gems & Gemology*, Vol. 17, No. 2, pp. 72–79.

U.S. diamond dealers fail to endorse mandatory treatment disclosure (1987) *Mazal U'Bracha*, Vol. 3, No. 16, p. 51.

Weast R.C. (1980) *CRC Handbook of Chemistry and Physics*, 61st ed. CRC Press, Boca Raton, FL.

Weil A. (1988) Yehuda process stirs controversy. *Diamond News and S. A. Jeweler*, No. 7, p. 8.

NOTES
· AND ·
NEW TECHNIQUES

A PRELIMINARY GEMOLOGICAL STUDY OF SYNTHETIC DIAMOND THIN FILMS

By Emmanuel Fritsch, Laurie Conner, and John I. Koivula

To evaluate possible problems in separating gem materials coated with a synthetic diamond thin film from their uncoated equivalents, we examined one sample of a free-standing, polycrystalline diamond film about one micron (0.001 mm) thick. This film could be easily recognized by standard microscopic examination, especially in surface-reflected and polarized light. The potential problems related to detecting thicker, monocrystalline, or colored synthetic diamond thin films and coatings that might be encountered in the future on faceted stones are also briefly discussed.

One of the most significant developments in gemology in the 1980s has been the commercial growth and production of gem-quality synthetic diamonds. All of the samples—both commercially grown and those for research only—described in the gemological literature to date, however, have been synthesized using high pressure and temperature. Because of this mode of formation, they exhibit characteristic features that allow a skilled gemologist to separate them from natural diamond by means of conventional testing techniques (Crowningshield, 1971; Koivula and Fryer, 1984; Shigley et al., 1986 and 1987).

Within the past few years, a completely different type of process has been developed to grow a thin layer of synthetic diamond on a substrate at low pressure and moderate temperature. Based on the well-known technique of chemical vapor deposition (CVD), this new technology involves the deposition of tetrahedrally bonded carbon atoms from a carbon-containing, hydrogen-rich gas (Angus and Hayman, 1988). Variations of this technique have been used successfully to grow both synthetic diamond films and a new class of materials called diamond-like carbon (DLC), in which the carbon atoms are present in both diamond-type and graphite-type bonding arrangements. Although the physical and chemical properties of the diamond-like materials can be noticeably different from those of diamond, they seem to be easier to manufacture than synthetic diamond and yet offer many of its advantages. This new growth technique suggests the possibility that a synthetic diamond or DLC coating several microns thick could be placed on various materials to improve their resistance to wear, enhance some other property of the material, or even create new types of devices for many useful technological applications.

ABOUT THE AUTHORS

Dr. Fritsch is research scientist, and Mr. Koivula is chief gemologist, at the Gemological Institute of America, Santa Monica, California. Ms. Conner, who has advanced degrees in both civil engineering and business, is director of marketing and sales for Crystallume, Menlo Park, California.

Acknowledgments: The authors thank Dr. Michael Pinneo, Crystallume's co-founder, vice-president, and chief scientist, for providing extensive technical data and sharing his personal experience. Dr. G. R. Rossman helped take the total reflectance infrared absorption spectra of the synthetic diamond film and explain the origin of the coloration. Dr. James Shigley's constructive comments are much appreciated. This work was supported in part by a grant from the Harry Winston Research Foundation.

Gems & Gemology, *Vol. 25, No. 2, pp. 84–90*

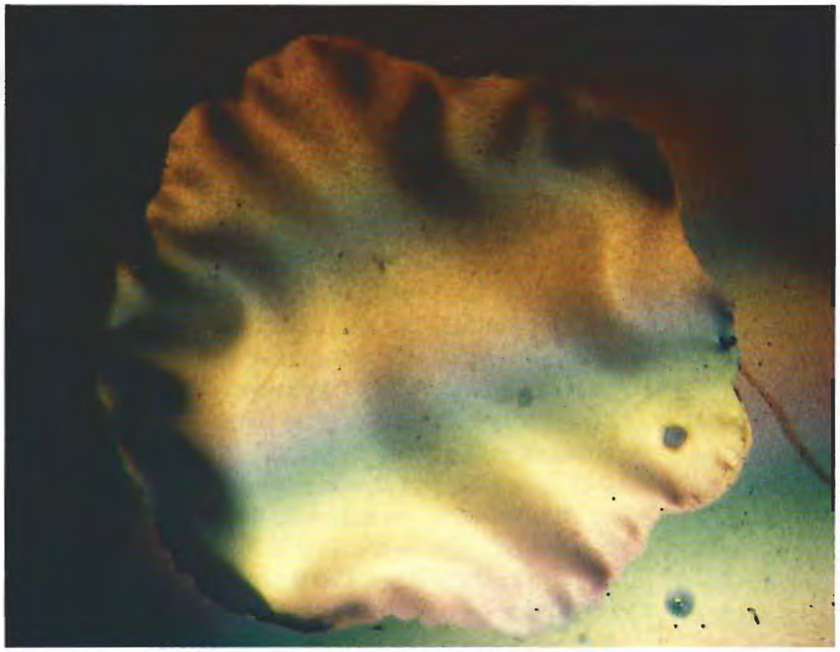


Figure 1. The synthetic diamond thin film studied measures approximately 6.8 × 6.8 mm. One of the reasons interference colors are evident here is the fact that the thickness (1 μ) of this film is of the same order of magnitude as the wavelengths of visible light. Note the warped aspect of the free-standing part of the film, which measures about 4 mm in diameter. Without the tension imposed by the silicon base, the film relaxes and wrinkles. Photomicrograph by John I. Koivula; magnified 6×.

With few exceptions, the synthetic diamond and DLC films grown today are polycrystalline; that is, they are made up of many tiny crystallites. To date, only limited experimental work has been done (e.g., by Sumitomo Electric Industries) to deposit single-crystal synthetic diamond films on a substrate of a crystal of synthetic diamond (Hara and Fujimori, 1989).

Even so, there has been some concern that this technique could be used in the jewelry industry, for example to coat faceted stones of various diamond simulants so that they would show a high thermal conductivity and might then test as diamond on a thermal inertia probe. These films might also show some other gemological properties that would make the simulant behave more like a diamond. One jeweler has already reported encountering a diamond simulant that was allegedly coated in this manner (Koivula, 1987).

To investigate the potential problems that such a product might pose, we examined a polycrystalline synthetic diamond thin film, about one micron (1 μ) thick, that had been deposited on a silicon substrate (figure 1). The particular technique used to grow this thin film, plasma-enhanced chemical vapor deposition (PECVD; see figure 2), is one of the most common methods currently used to grow such materials. The sample we studied was manufactured by Crystallume of Menlo Park, California. The center part of the silicon square was chemically etched away, so that part of the thin film would be free standing. This allowed us to examine the film by transmitted light, as would be done if it were deposited on a transparent substrate such as a diamond simulant.

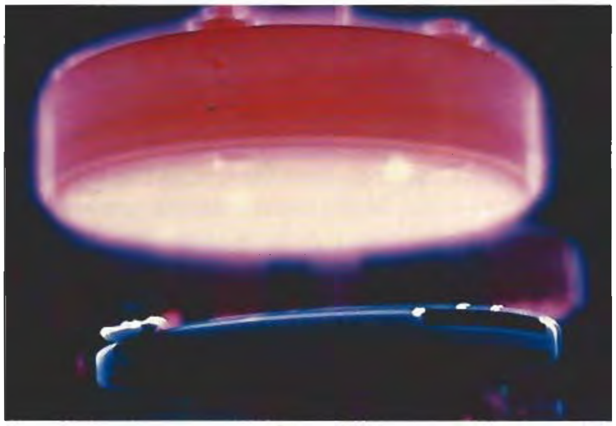


Figure 2. The thin film studied was grown from this gas plasma, using a technique known as plasma-enhanced chemical vapor deposition (PECVD). Photo courtesy of Crystallume.

This thin film was tested by classic gemological methods and instrumentation to document ways by which it could be detected. The results are reported below. Although some background on the history of synthetic diamond thin films is provided, this article will not present a detailed explanation of the various and sometimes complex growth processes used to produce such films. Readers interested in learning more about this technology and its expected industrial applications outside of gemology are referred to DeVries (1987), Spear (1987), Angus and Hayman (1988), and Bachmann and Messier (1989).

HISTORY OF DIAMOND THIN FILMS

It is difficult to tell from the published scientific literature who was first to grow synthetic diamond at low pressure. W. Eversole received a patent in 1962 to produce diamond by a low-pressure process, but his methodology is very different from the techniques used presently (Eversole, 1962). The low-pressure CVD diamond technology in greatest use today got its start in the Soviet Union in the early 1960s. Not until 1968, however, did crystal growth scientist Boris Derjaguin and his coworkers report their success in depositing synthetic diamond at low pressure (Derjaguin et al., 1968). Although many Western scientists were aware at that time of Derjaguin's work, they questioned the validity of the material's identification as diamond.

In the late 1970s and early 1980s, however, Japanese researchers indicated that they had duplicated Derjaguin's earlier work, and proved that the deposition of a synthetic diamond thin film at low pressure was technically feasible (see, e.g., Matsumoto et al., 1982 a and b; Kamo et al., 1983). These reports made a major impact in the world of materials science. Many organizations worldwide, such as the Royal Signal & Radar Establishment in the United Kingdom (Lettington, 1988) and companies like Sumitomo, Kobe Steel, Fujitsu, and Toshiba in Japan, started research and then production of synthetic diamond or DLC thin films. In 1988, for example, approximately US$20 million was spent on CVD synthetic diamond research in Japan (M. Yoder, pers. comm., 1989).

Individual researchers in the U.S. began work on growing tiny synthetic diamond crystals by the CVD method in the 1960s (Eversole, 1962; Angus et al., 1968). Not until the early 1980s, however, was a major collective effort directed toward the growth of synthetic diamond and DLC thin films. Prominent organizations such as General Electric, IBM, Pennsylvania State University, the Massachusetts Institute of Technology, and the Naval Research Laboratory, among others, began significant research programs in this area, supported for the most part by grants from the Department of Defense Strategic Defense Initiative ("Star Wars"). One company, Crystallume, was created in 1984 for the sole purpose of developing "engineered" products coated with synthetic diamond or diamond-like thin films.

Although most of the interest in diamond thin film production to date has focused on the many industrial, scientific, and military applications, organizations with significant interest in the gem market worldwide are following this new technology closely. Kyocera, a Japanese company well known for the many synthetic gem materials grown by its subsidiary Inamori, has submitted several patents on the manufacture of synthetic diamond by CVD, including one claiming the production of a 1.2-ct "inclusion-free, flawless and blemish-free" single crystal (Hiroshi, 1986). When contacted, Kyocera admitted that "work in this area is still in the developmental stage." De Beers is also "closely monitoring developments in the CVD area" (De Beers, 1988).

Why all the fuss? Until now, diamond's unique combination of superior hardness, very high thermal conductivity, and optical transparency was unavailable in the form of a film or coating over large surface areas on a three-dimensional object with good adherence to the substrate. Although adherence problems have not been solved completely, this new CVD process does allow synthetic diamond to be deposited on a variety of surfaces in thin coatings, thereby opening up a wide variety of applications, including the possibility of a synthetic diamond coating on diamond simulants or other gem materials.

A BRIEF DESCRIPTION OF THE CVD PROCESS

A schematic illustration of a typical CVD diamond reactor is given in figure 3. Quite simply, the process involves the use of hydrocarbon (typically methane) and hydrogen gases and a source of energy. The energy is most commonly derived from microwave, radio frequency (RF), or direct current (dc) sources, or from a heated tungsten filament. This energy serves to ionize the input gases, creating a carbon-rich gas "plasma" of charged particles. Typically, a pressure of 50 to 150 Torr and a temperature of 700° to 1000°C are needed for a gas composition of 0.1 to 1 vol.% methane (CH_4) in hydrogen. Under these conditions, the hydrocarbon gas breaks down, and carbon atoms are deposited on the substrate material as a thin film of synthetic diamond. Atomic hydrogen is believed to be necessary near the deposition area to maintain the carbon atoms in the proper type of tetrahedral bonding and thereby minimize the formation of graphite. The resulting coated surface can have all the inherent properties

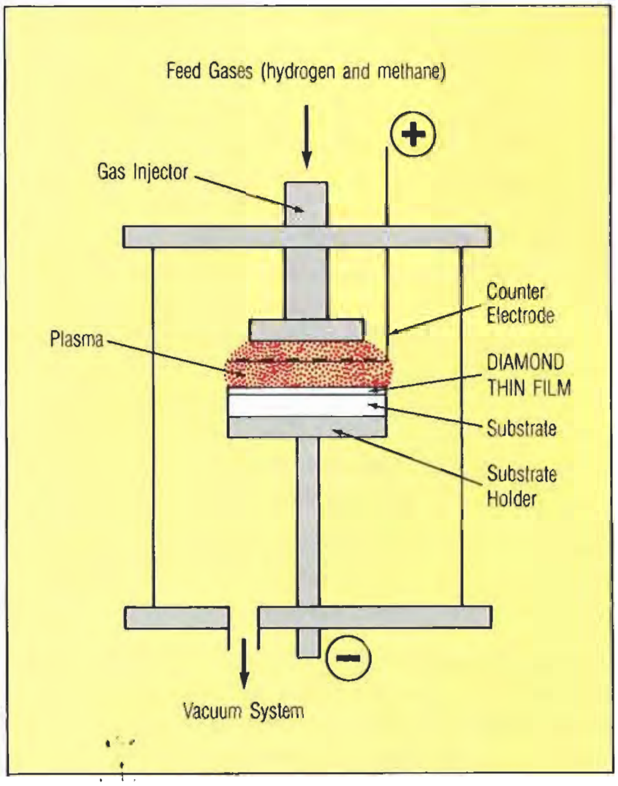


Figure 3. This schematic diagram illustrates the PECVD process used to grow synthetic diamond thin films similar to that studied by the authors. Drawing by Robin Teraoka.

of diamond. DLC films are produced with variations of CVD technology that use a higher methane concentration in the gas, a much lower temperature (down to room temperature), or ion beam sputtering.

GEMOLOGICAL EXAMINATION OF THE DIAMOND THIN FILM

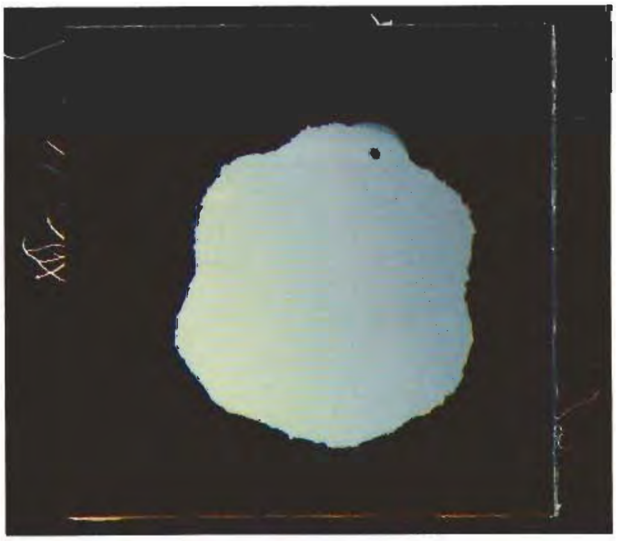
The film we examined was deposited on a square silicon substrate that is 6.8 mm on each edge and 0.55 mm thick. The central free-standing portion is about 4 mm in diameter (again, see figure 1). This film (Crystallume sample EASI 23K), approximately 1 μ thick, was determined by Raman spectroscopy to be crystalline diamond with one part per thousand of a "graphitic" component. It would, therefore, be readily considered a synthetic diamond film rather than a diamond-like carbon film (see Williams and Glass, 1989).

General Appearance. The film can be easily recognized either on the silicon substrate or free standing in air because it gives rise to interference colors (like an oil slick on water—again, see figure 1). This results from factors such as the contrast in index of refraction between diamond and the underlying silicon (or air, for the free-standing part) and a film thickness close to the wavelengths of visible light. Also, the smoothness of the silicon-diamond film interface might have an influence.

Haziness. In darkfield illumination, the thin film appears to be hazy rather than transparent (figure 4). Because the film is polycrystalline and the individual synthetic diamond crystallites are uniformly approximately 1 μ (again, comparable in size to wavelengths in the visible range), the material scatters visible light. This scattering results in a hazy appearance.

Color. When viewed against a white background in diffused light, this film has a brownish appearance that is barely visible to the naked eye (figure 5). We could not detect any absorption features with a hand-held spectroscope. However, the optical absorption spectrum obtained by transmission mode with a Pye Unicam 8800 spectrophotometer shows a gradual rise in absorption toward the ultraviolet, which is what would be expected from a brownish material. For the most part, this color is probably due to an intrinsic absorption of the film material,

Figure 4. In darkfield illumination, this synthetic diamond film is not transparent but somewhat hazy. This is due to light scattering at the grain boundaries of this polycrystalline material. Photomicrograph by John I. Koivula; magnified 3×.



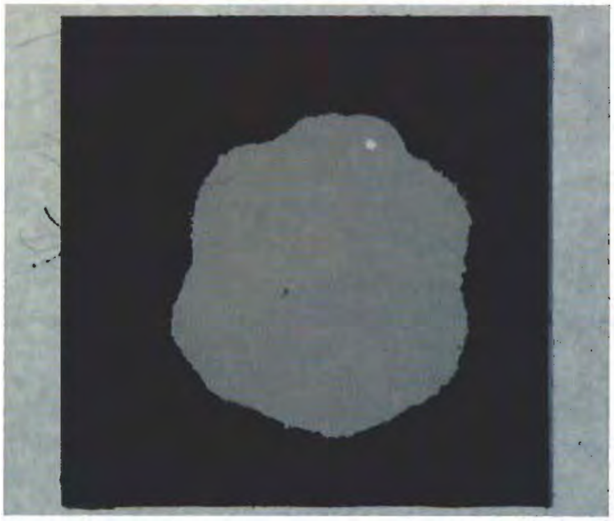


Figure 5. When viewed against a white background in diffused light, this synthetic diamond thin film appears light brown. Photomicrograph by John I. Koivula; magnified 3×.

resulting from the peculiar electronic structure of the minor "graphitic" component (Koidl, 1989). Also, a thin-film interference phenomenon could give rise to a brown interference color evenly distributed on the film (as is commonly observed on camera lenses with optical coatings).

Reaction to Polarized Light. When examined between crossed polarizers, the thin film is not extinct. Although diamond is singly refractive, an aggregate reaction is shown by polycrystalline thin films because of light scattering at the grain boundaries and also possibly strain.

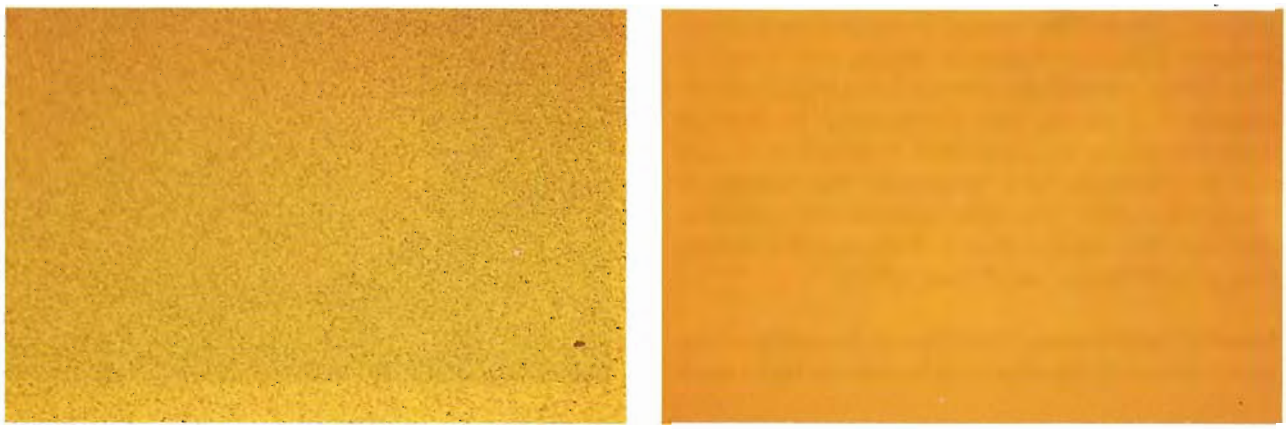
Nomarski Differential Interference Contrast Microscopy. This examination technique (McCrone et al., 1978) highlights very small details on a surface, down to 1 nm or so, by means of different interference colors (thus the orange color of the illustrations in figure 6). Not only is the granular nature of the thin film readily visible with this technique (figure 6, left), but one can actually measure the approximate diameter of the individual grains, 1.25 μ on average.

The surface of the table of a natural polished diamond, examined with the same technique at the same magnification, has a very different appearance (figure 6, right). The few lines visible are surface graining, features inherent to the underlying structure of this particular diamond.

Luminescence. No luminescence to either short-wave or long-wave ultraviolet radiation was observed on this particular film.

Thermal Conductivity. Using a GIA-GEM Duotester, we tested several spots on the synthetic diamond thin film for thermal conductivity. The readings on the diamond tester fell in the range 60 to 80 on the scale, which is at the lower end of the green zone labeled "diamond." However, the silicon substrate gave the exact same readings. Therefore, we believe that the film is too thin to test as diamond with this instrument (on which the value should really be between 90 and 110), and that the measured readings actually correspond to the thermal conductivity of the substrate, since diamond has a higher thermal conductivity than silicon. This film (at this thickness) could not be used to "disguise" a diamond simulant.

Figure 6. With Nomarski differential interference contrast, the graininess of the surface of the synthetic diamond thin film is readily apparent (left). The only observable features on the surface of the table of the natural cut diamond (right) are grain lines. Photomicrographs by John I. Koivula; magnified 80×.



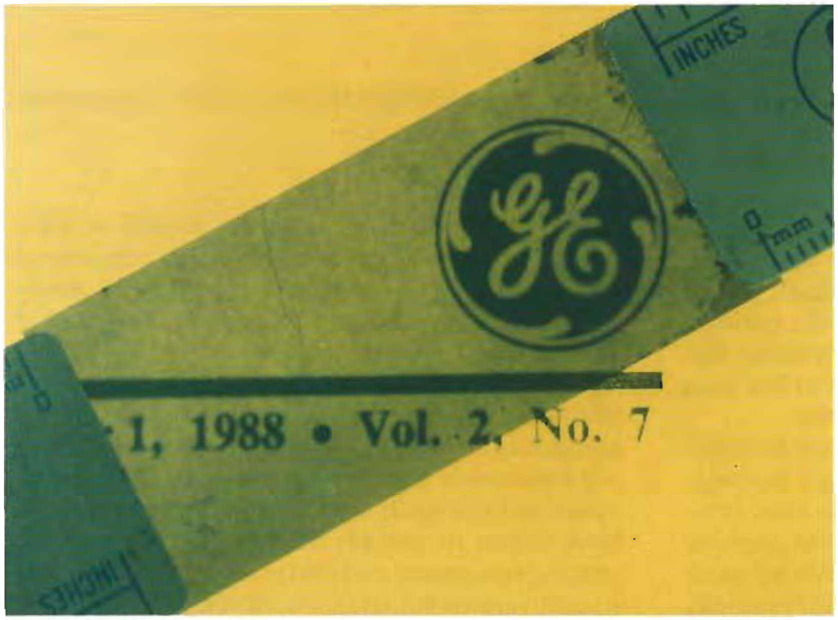


Figure 7. Thin-film technology has advanced to the point of producing this 500-μ (0.5-mm) thick transparent synthetic diamond film. Because this film has been polished on one side only, there is some residual haziness and color caused by impurities from the substrate on the unpolished surface. Photo courtesy of Thomas Anthony, General Electric Co.

Electrical Conductivity. Two steel electrodes were applied to different points of the film still on the substrate to test for electrical conductivity. A very weak conductivity was detected in certain areas (readings around 1 or 2 compared to 130 when the two electrodes are put in contact with each other). This might be due to minute amounts of a more "graphitic" phase at the grain boundaries, as graphite is a good electrical conductor.

DISCUSSION

From this restricted set of observations, one can still predict that as long as a synthetic diamond or DLC film grown by the CVD technique is thin, the thermal tester remains the fastest instrument to separate diamond from a synthetic diamond-coated simulant. According to Michael Pinneo (pers. comm., 1988), the film would have to be at least 5 μ thick to test as diamond with the diamond thermal probe. This thickness requirement could be even greater; the fact that the film is polycrystalline makes its thermal behavior very unpredictable. Currently, this behavior is even more uncertain for DLC.

Interference colors also readily reveal the presence of a very thin film such as that examined for this study, although they disappear on a film 3–4 μ thick (M. Pinneo, pers. comm., 1988). General Electric's Thomas Anthony announced at the April 1989 Materials Research Society Short Course on Diamond and Diamond Thin Films that a transparent, near-colorless polycrystalline synthetic diamond thin film 500 μ thick—one-third the thickness of a Sumitomo synthetic diamond slice—has been grown on a silicon substrate (figure 7). While this material currently is not commercially available, it does indicate the speed with which this technology is progressing.

The most identifiable feature of the synthetic diamond thin film we studied is its granular texture, the result of its polycrystalline nature. What if, one might hypothesize, someone developed a monocrystalline synthetic diamond film thick enough to give the thermal conductivity of diamond that could be deposited on a transparent substrate? There should be no haziness and no aggregate reaction in polarized light. The case most feared by the gem trade would be a monocrystalline film on cubic zirconia. It is highly improbable, however, that such a synthetic diamond film would adhere to this particular substrate, since the crystal structures of the two materials are very different. Although similar adhesion problems also exist with polycrystalline thin films, an intermediate layer of DLC as thin as 10 nm could be used to improve adhesion, as it has in a variety of industrial applications requiring a nonsilicon substrate.

Another possible application of a synthetic diamond thin film would be to modify the apparent color of a faceted diamond. Sumitomo Electric Industries is already able to deposit a blue synthetic diamond coating as thick as 20 μ on a natural near-colorless diamond octahedron (N. Fujimori, pers. comm., 1989). The resulting blue product is electrically conductive. One can imagine that this type of coating might be easy to detect by immersion of the diamond in methylene iodide.

The color in a natural blue diamond is distributed in a slightly nonhomogeneous patchy pattern, whereas the sharp edges of the coating would be readily visible, as they are on a diffusion-treated sapphire with immersion in methylene iodide. Currently, it is unclear whether this technology could provide a new way to balance a small yellow component in a faceted near-colorless diamond by depositing small amounts of blue synthetic diamond in certain areas of the cut stone, as has been done in the past with metallic fluorides.

Many more applications of synthetic diamond and DLC coatings in the gem trade can be imagined. Perhaps the most obvious is to coat gemstones that have a low scratch hardness to improve their resistance to wear. A patent already exists in Germany for this very application on, for example, apophyllite and kyanite (Streckert et al., 1988). Also, DLC thin films could potentially be used to "seal" water in natural opals to prevent crazing. Should diamond coating evolve into a very inexpensive technology, it might even be economical to add a point of weight to push a 0.99-ct stone over the 1.00-ct barrier.

CONCLUSION

The polycrystalline synthetic diamond or DLC films commercially available today, as represented by the sample we examined, appear to be easily detectable and should not be a source of concern at this time to the jewelry industry.

However, even scientists intimately familiar with the subject are in strong disagreement about possible future developments. There is, therefore, a need to closely monitor the progress of this developing technology. It is interesting to note that we have begun to see advertisements for diamond-coating equipment and also for companies offering to coat various substrates with synthetic diamond or DLC thin films (both of which are often—and erroneously—referred to simply as "diamond films"). At this time, however, we are not aware of the commercial availability of any synthetic diamond- or DLC-coated gem material.

REFERENCES

Angus J.C., Hayman C.C. (1988) Low-pressure, metastable growth of diamond and "diamond-like" phases. *Science*, Vol. 241, pp. 913–921.

Angus J.C., Will H.A., Stanko W.S. (1968) Growth of diamond seed crystals by vapor deposition. *Journal of Applied Physics*, Vol. 39, No. 6, pp. 2915–2922.

Bachmann P.K., Messier R. (1989) Emerging technology of diamond thin films. *Chemical and Engineering News*, Vol. 67, No. 20, pp. 24–39.

Crowningshield R. (1971) General Electric's cuttable synthetic diamonds. *Gems & Gemology*, Vol. 13, pp. 302–314.

De Beers Consolidated Mines, Ltd. (1988) *Annual Report 1987*. Kimberley, South Africa.

Derjaguin B.V., Fedoseev D.V., Lukyanovich V.M., Spitzin B.V., Ryabov V.A., Lavrentyev A.V. (1968) Filamentary diamond crystals. *Journal of Crystal Growth*, Vol. 2, pp. 380–384.

DeVries R.C. (1987) Synthesis of diamond under metastable conditions. *Annual Review in Materials Science*, Vol. 17, pp. 161–187.

Eversole W. (1962) Synthesis of diamond. U.S. Patent Office, Nos. 3030187 and 3030188.

Hara A., Fujimori N. (1989) Technological application of CVD diamond. In *Spring Meeting of the Electrochemical Society, Extended Abstracts*, Electrochemical Society, Vol. 89-1, p. 108.

Hiroshi A. (1986) Growth of ornamental diamonds. (Japanese patent) Japan Kokai Tokkyo Koho JP 61/158898 A2, July 18.

Kamo M., Sato Y., Matsumoto S., Setaka N. (1983) Diamond synthesis from gas phase in microwave plasma. *Journal of Crystal Growth*, Vol. 62, pp. 642–644.

Koidl P. (1989) Critical assessment of diamondlike carbon. In *Spring Meeting of the Electrochemical Society, Extended Abstracts*, Electrochemical Society, Vol. 89-1, p. 134.

Koivula J.I. (1987) Gem news: Cubic zirconia coated by synthetic diamond? *Gems & Gemology*, Vol. 23, No. 1, p. 52.

Koivula J.I., Fryer C.W. (1984) Identifying gem-quality synthetic diamonds: An update. *Gems & Gemology*, Vol. 20, No. 3, pp. 146–158.

Lettington A.H. (1988) Optical applications and improved deposition processes for diamondlike carbon coatings. Paper presented at the Society of PhotoOptical Instrumentation Engineers Conference on Diamond Optics, San Diego, CA, August 16 and 17.

McCrone W.C., McCrone L.B., Delly J.G. (1978) *Polarized Light Microscopy*. Ann Arbor Science Publishers, Ann Arbor, MI, pp. 54–57.

Matsumoto S., Sato Y., Kamo M., Setaka N. (1982a) Vapor deposition of diamond particles from methane. *Japanese Journal of Applied Physics*, Vol. 21, No. 4, pp. L183–L185.

Matsumoto S., Sato Y., Tsutsumi M., Setaka N. (1982b) Growth of diamond particles from methane-hydrogen gas. *Journal of Materials Science*, Vol. 17, pp. 3106–3112.

Shigley J.E., Fritsch E., Stockton C.M., Koivula J.I., Fryer C.W., Kane R.E. (1986) The gemological properties of the Sumitomo gem-quality synthetic yellow diamonds. *Gems & Gemology*, Vol. 22, No. 4, pp. 192–208.

Shigley J.E., Fritsch E., Stockton C.M., Koivula J.I., Fryer C.W., Kane R.E., Hargett D.R., Welch C.W. (1987). The gemological properties of the De Beers gem-quality synthetic diamonds. *Gems & Gemology*, Vol. 23, No. 4, pp. 187–206.

Spear K.E. (1987) Growth of crystalline diamond from low-pressure gases. *Earth and Mineral Sciences*, Vol. 56, No. 4, pp. 53–59.

Streckert G.G., Franch H.-G., Collin G. (1988) Schmucksteine und Verfahren zu ihrer Herstellung. Bundesrepublik Deutschland, Deutsches Patentamt Offenlegungsschrift, Nummer DE 3708171A1.

Williams B.E., Glass J.T. (1989) Characterization of diamond thin films: Diamond phase identification, surface morphology, and defect structures. *Journal of Materials Research*, Vol. 4, No. 2, pp. 373–384.

GRADING THE HOPE DIAMOND

By Robert Crowningshield

For the first time ever, the famous Hope diamond has been graded by a widely recognized system. Although the 45.52-ct weight was confirmed, the GIA Gem Trade Laboratory graders found the clarity—recently reported as "apparently flawless"—to be VS_1. Color graded "fancy dark grayish blue," the Hope phosphoresces an exciting red to short-wave U.V. radiation.

Much has been written about the history of the Hope diamond and especially the misfortunes that have supposedly befallen many who have owned it (see, e.g, Patch, 1976; Balfour, 1987; Krashes, 1988). In the more than 30 years since Harry Winston donated it to the Smithsonian Institution in 1958, however, the Hope has been an object of great admiration. One of the most popular exhibits at the Smithsonian, it is probably seen by more people each year than any other diamond.

Although the Hope has been in the United States for most of the 20th century (since its purchase in 1911 by Evalyn Walsh McLean), it had never been formally graded. In December 1988, the opportunity presented itself when GIA learned that the Hope was being removed from its mounting for a number of reasons, including photography (figure 1) and the making of a model. Several representatives of the New York office of the GIA Gem Trade Laboratory traveled to Washington to prepare a complete grading report on the Hope, the first using a widely recognized grading system.

Earlier individual efforts had already provided some of the required information that would only need to be confirmed for the GTL report. For example, in 1960 GIA's Bert Krashes had tested the stone with a conductometer and determined that it was semiconductive, as is characteristic of natural-color type IIb diamonds, which are usually blue. He also remarked on the red phosphorescence to short-wave ultraviolet radiation. In 1975, Herbert Tillander suggested (in a paper presented at the 15th International Gemmological Conference) that since the stone had last been weighed before the metric carat had been accepted worldwide, its weight was undoubtedly greater than had heretofore been reported. He subsequently persuaded then-curator Paul Desautels to have the stone unmounted and weighed: It was indeed found to be 45.52 ct rather than the previously published weight of 44.50 ct.

The mystery of the Hope is further compounded by Dr. Frederick Pough's recent report (Westman, 1988) that the Hope was recut slightly while in the possession of Harry Winston in the

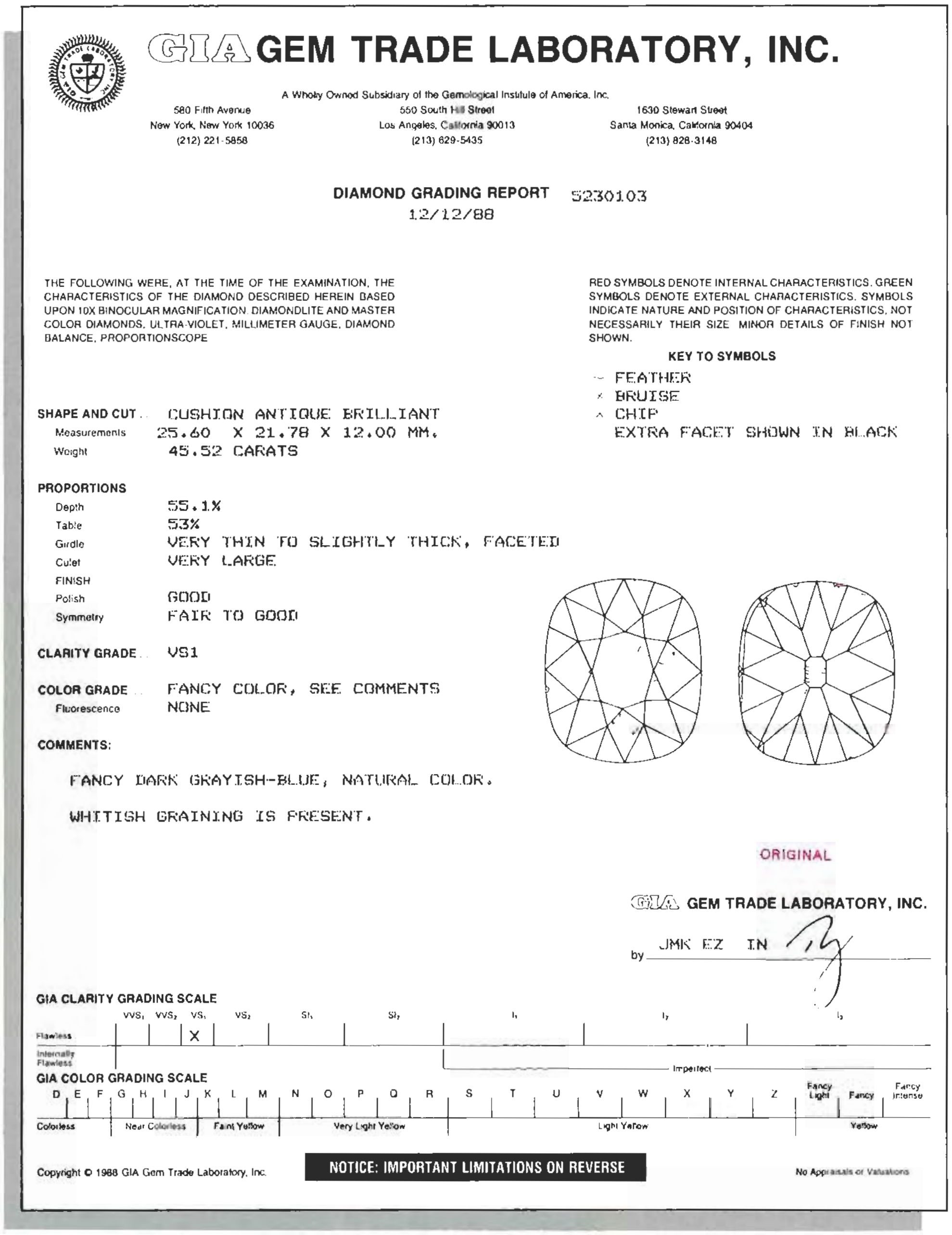
Figure 1. Since the Hope has been removed from its mounting so seldom in modern times, this is one of the few photographs ever taken of the famous 45.52-ct diamond unmounted. Photo © Tino Hammid.

ABOUT THE AUTHORS

Mr. Crowningshield is vice-president of the GIA Gem Trade Laboratory, Inc., Santa Monica and New York.

Acknowledgments: Dave Hargett, John King, Ingrid Nolte, Eddie Schwartz, Tom Yonelunas, and Phil Yurkiewicz, all of the GIA GEM Trade Laboratory, participated in the grading of the Hope. John Sampson White and Russell Feather, of the Smithsonian Institution, were invaluable in making the arrangements for the grading session.

Gems & Gemology, Vol. 25, No. 2, pp. 91–94



GIA GEM TRADE LABORATORY, INC.

A Wholly Owned Subsidiary of the Gemological Institute of America, Inc.

580 Fifth Avenue
New York, New York 10036
(212) 221-5858

550 South Hill Street
Los Angeles, California 90013
(213) 629-5435

1630 Stewart Street
Santa Monica, California 90404
(213) 828-3148

DIAMOND GRADING REPORT 5230103
12/12/88

THE FOLLOWING WERE, AT THE TIME OF THE EXAMINATION, THE CHARACTERISTICS OF THE DIAMOND DESCRIBED HEREIN BASED UPON 10X BINOCULAR MAGNIFICATION, DIAMONDLITE AND MASTER COLOR DIAMONDS, ULTRA-VIOLET, MILLIMETER GAUGE, DIAMOND BALANCE, PROPORTIONSCOPE

RED SYMBOLS DENOTE INTERNAL CHARACTERISTICS. GREEN SYMBOLS DENOTE EXTERNAL CHARACTERISTICS. SYMBOLS INDICATE NATURE AND POSITION OF CHARACTERISTICS, NOT NECESSARILY THEIR SIZE. MINOR DETAILS OF FINISH NOT SHOWN.

KEY TO SYMBOLS

~ FEATHER
× BRUISE
^ CHIP
EXTRA FACET SHOWN IN BLACK

SHAPE AND CUT CUSHION ANTIQUE BRILLIANT
Measurements 25.60 X 21.78 X 12.00 MM.
Weight 45.52 CARATS

PROPORTIONS
Depth 55.1%
Table 53%
Girdle VERY THIN TO SLIGHTLY THICK, FACETED
Culet VERY LARGE
FINISH
Polish GOOD
Symmetry FAIR TO GOOD

CLARITY GRADE VS1

COLOR GRADE FANCY COLOR, SEE COMMENTS
Fluorescence NONE

COMMENTS:

FANCY DARK GRAYISH-BLUE, NATURAL COLOR.

WHITISH GRAINING IS PRESENT.

ORIGINAL

GIA GEM TRADE LABORATORY, INC.

by JMK EZ IN

GIA CLARITY GRADING SCALE

Flawless | Internally Flawless | VVS1 | VVS2 | VS1 X | VS2 | SI1 | SI2 | I1 | I2 | I3 — Imperfect

GIA COLOR GRADING SCALE

D E F G H I J K L M N O P Q R S T U V W X Y Z Fancy Light | Fancy | Fancy Intense

Colorless | Near Colorless | Faint Yellow | Very Light Yellow | Light Yellow | Yellow

Copyright © 1988 GIA Gem Trade Laboratory, Inc.

NOTICE: IMPORTANT LIMITATIONS ON REVERSE

No Appraisals or Valuations

Figure 2. This GIA Gem Trade Laboratory report represents the first time the Hope has been formally graded by a widely recognized system.

1950s. It is puzzling that the actual weight was not reported to the Smithsonian at the time of donation (J. White, pers. comm., 1989).

For the present study, the GTL staff members provided a Mark V Gemolite microscope, Polaroid plates, a long- and short-wave fluorescence unit, a conductometer, a camera for photography of the inclusions, and two ColorMasters with a fluorescent daylight equivalent source. The results of their efforts are shown in figure 2 and reported below.

SHAPE AND CUT

In the presence of the graders, Smithsonian gem collection curator John Sampson White weighed the 25.60 × 21.78 × 12.00 mm cushion antique brilliant on an analytical balance. The 45.52-ct weight reported in 1975 was confirmed.

PROPORTIONS

We calculated depth percentage to be 55.1% and the table 53%. The girdle, which is faceted, ranges from very thin to slightly thick. Although the

Figure 3. Although historically the Hope was believed to be "of the greatest purity," close examination with 10× magnification revealed some wear marks, such as the abraded table edge shown here, in addition to a few small feathers and bruises. Photomicrograph by David Hargett.

Figure 4. Also affecting the clarity of the Hope is the graining shown here at 10× magnification. Because of the graining, the clarity could never be better than VVS_1. Photomicrograph by David Hargett.

culet is very large, symmetry was found to be fair to good. The polish is good.

CLARITY GRADE

The clarity of the Hope has been variously noted as "all perfection without specks or flaws" (Françillon, 1812), "of the greatest purity" (Hertz, 1839), "a perfect brilliant" (Bauer, 1904), and "apparently flawless" (1975 Smithsonian data, as reported in Patch, 1976). The GTL clarity grade of VS_1 was based on the few wear marks that the stone has accumulated during its adventures over the years (figure 3), a few minor feathers, and whitish graining (figure 4). Although whitish graining is characteristic of natural-color blue diamonds, it is not always present to the extent that it will affect the clarity grade, as it does on the Hope. Because of the graining, the highest grade possible for this stone would be a VVS_1.

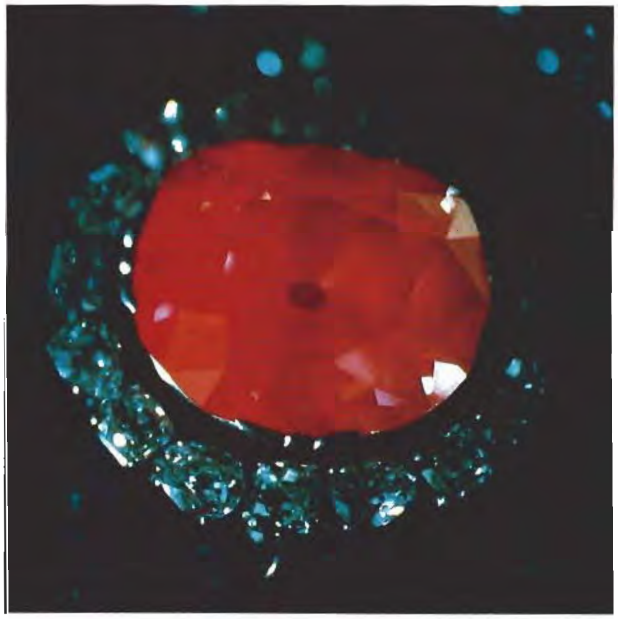
COLOR GRADE

Like the clarity, the color of the Hope has also been described in a number of different ways since the stone in its present form first appeared in the literature in 1812. According to Françillon (1812), the Hope is a "superfine deep blue"; in the Hope catalog (Hertz, 1839), it is described as a "fine deep sapphire blue." The 1975 Smithsonian description (as reported in Patch, 1976) is "dark blue, often described as steel blue."

Our graders determined the color to be a "fancy dark grayish blue." The ColorMaster description and notations are: Blue 7.5/1.5 (D 02/25/53). It should be noted here that most blue diamonds have a perceptible amount of gray.

Although there was no fluorescence to long-wave ultraviolet radiation, and its presumed red fluorescence to short-wave U.V. appeared to be masked by the visible light from the ultraviolet unit, we were fascinated to see the strong red phosphorescence to short-wave U.V. (figure 5),

Figure 5. One of the most distinctive characteristics of the Hope diamond is its distinct red phosphorescence to short-wave ultraviolet radiation. Photo © John Nels Hatleberg.



which lasted 15–20 seconds. Such red phosphorescence is not unknown in blue diamonds, but it is limited almost exclusively to dark blue stones and is seldom as intense as that seen in the Hope.

CONCLUSION

The Hope diamond is undoubtedly one of the most famous stones in the world. Certainly it is the most famous blue diamond – unusual for its large size, depth of color, and the rich, if often tragic, history that has been attributed to it. The grading of the Hope by the GIA Gem Trade Laboratory is part of an ongoing program to more thoroughly document such notable stones (see, e.g, Fryer and Koivula, 1986) for the benefit of future gemologists.

REFERENCES

Balfour I. (1987) *Famous Diamonds.* Collin, London.

Bauer M. (1904) *Precious Stones.* Reprinted by Charles E. Tuttle Co., Rutland, VT.

Françillon J. (1812) Statement and sketch regarding a 177-grain deep blue diamond. Reproduced in S. S. Patch, *Blue Mystery: The Story of the Hope Diamond,* Smithsonian Institution Press, Washington, DC, 1976.

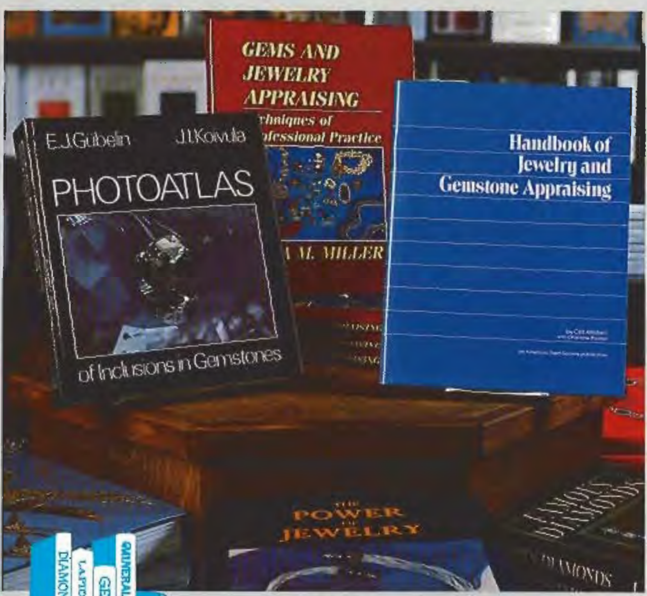
Fryer C.W., Koivula J.I. (1986) An examination of four important gems. *Gems & Gemology,* Vol. 22, No. 2, pp. 99–102.

Hertz B. (1839) *Catalogue of the Collection of Pearls and Precious Stones Formed by Henry Philip Hope, Esq.* William Clowes and Sons, London.

Krashes L. (1988) *Harry Winston: The Ultimate Jeweler,* 3rd ed. Harry Winston, Inc., New York, and the Gemological Institute of America, Santa Monica, CA.

Patch S.S. (1976) *Blue Mystery: The Story of the Hope Diamond.* Smithsonian Institution Press, Washington, DC.

Westman B.J. (1988) The enigmatic Hope. *Lapidary Journal,* Vol. 41, No. 12, pp. 42–45, 105.



CONTRIBUTION TO THE IDENTIFICATION OF TREATED COLORED DIAMONDS: DIAMONDS WITH PECULIAR COLOR-ZONED PAVILIONS

By Emmanuel Fritsch and James E. Shigley

Some treated yellow and blue-to-green diamonds show a peculiar color zoning when viewed through the pavilion. The culet or keel-line area on such stones exhibits a bright yellow or blue color that contrasts with the otherwise lighter (and/or different) body color of the diamond (which does not show any other strong color zoning). Such peculiar color zoning near the culet or keel-line is a strong indication that the stone has been treated by electron irradiation. Although rare, this feature can be useful in identifying irradiated diamonds, especially some green diamonds, for which few criteria are available to separate natural-color from laboratory-treated stones.

To expand the criteria for separating natural from laboratory-treated (i.e., irradiated and, in some cases, annealed) colored diamonds, the GIA Research Department has systematically documented the gemological and spectroscopic properties of more than 1,000 such stones over the last several years. These properties include color and color zonation, ultraviolet- and visible light–excited luminescence, characteristics seen with a microscope, and visible and infrared absorption spectra.

During the course of this study, we have examined a number of colored diamonds that share a peculiar feature: Although their face-up color is either yellow (figure 1) or dark green to blue (figure 2), when viewed perpendicular to the pavilion facets they exhibit a rather striking and unusual color zoning. In these stones, the overall color seen through the pavilion is much lighter than (and/or noticeably different from) the face-up hue, with a narrow area of strong yellow in the yellow stones (figures 3 and 4) or strong blue in the dark green to blue stones (figure 5), that occurs only near the culet or keel-line. In all cases, there is no other strong color zoning in the rest of the stone. We could find no report in the literature of a natural-color diamond with similar zonal coloration; nor have we encountered or heard of such a diamond in the course of our research. Therefore, we suspected that this unusual color zoning might be the result of laboratory treatment.

Our suspicions were further substantiated when we received for examination a similarly color zoned diamond that was known to have been electron irradiated (Saul and Ivin Perlman, pers. comm., 1988). This round brilliant-cut stone, which appeared blue face-up and light brown when viewed through the pavilion (figure 6), was accompanied by a second, untreated, light brown emerald-cut diamond that had been faceted from the same piece of rough. We subsequently submitted the latter stone for electron irradiation. On the basis of the nine stones in which we had observed this peculiar zoning, and the results of our radiation treatment of the 10th, we are able to describe this feature and draw some conclusions regarding its usefulness in separating laboratory-treated from natural-color diamonds.

BACKGROUND

Color zoning is not uncommon in natural-color diamonds. During our study, we have periodically noted diamonds with lighter and darker zones of the same or a different hue where the zones are sometimes separated by graining (which term is used here in accord with the definition provided in Shigley et al., 1987, pp. 203–204). In addition, yellow, brown, pink, and purple stones can show a concentration of color specifically along the graining which may be planar or very irregular (Kane, 1982).

ABOUT THE AUTHORS

Dr. Fritsch is research scientist, and Dr. Shigley is director of research, at the Gemological Institute of America, Santa Monica, California.

Acknowledgments: The authors are grateful to Roger and Richard Krakowsky of JDR Diamonds for the loan of several stones. Saul and Ivin Perlman of S&I Diamonds provided information on colored diamond treatment. John Fuhrbach of Jonz Fine Jewels loaned a diamond for examination. Robert Weldon and John Koivula kindly photographed the stones used in this study. Chuck Fryer provided constructive comments on the manuscript. This research was funded in part by a grant from the Harry Winston Research Foundation.

Gems & Gemology, *Vol. 25, No. 2, pp. 95–101*

Figure 1. These two treated yellow diamonds (samples 2 and 4) show a homogeneous face-up color. Photo by Robert Weldon.

Figure 2. This treated diamond (sample 9) appears bluish green when viewed through the table. Photo by Robert Weldon.

A very different type of color zoning can be seen in some laboratory-treated colored diamonds. One important example is provided by cyclotron-irradiated diamonds, in which some of the color is concentrated along distinct zones that parallel certain facet junctions; in a round brilliant-cut stone, this color zoning is arranged in a "star- or umbrella-shaped" pattern surrounding the culet (Liddicoat, 1987, pp. 181–183). Although diamonds with a pattern of natural color zoning can be irradiated and annealed, this treatment will change only the color of the various zones, not the pattern of color zoning itself.

MATERIALS AND METHODS

All 10 stones were examined thoroughly with a 10× loupe and a gemological microscope, and then tested for their reaction to long- and short-wave ultraviolet radiation. Optical absorption spectra of all 10 diamonds were recorded at low temperature (80°K) with a Pye-Unicam 8800 UV/VIS spectrophotometer. Infrared absorption data were obtained with a Nicolet 60SX Fourier Transform spectrometer covering the energy range from 400 to 25,000 wavenumbers (cm^{-1}; Fritsch and Stockton, 1987). As reported above, the 10th stone was originally received in its natural state. It was first carefully examined and then submitted for electron irradiation through the same commercial diamond treater (Saul Perlman, pers. comm., 1989) who had previously irradiated its treated counterpart. The irradiation was performed in a linear accelerator (Richard Krakowsky, pers. comm., 1989). No further details of this particular procedure are available due to the proprietary nature of the process. The stone was reexamined after this treatment. The results for all 10 stones are reported in table 1 and discussed below.

OBSERVATIONS

Four of the diamonds (samples 1–4) display a yellow (again, see figure 1) or greenish yellow color when viewed face-up through the table. When viewed through the pavilion, all four appear very light yellow, light brownish green, or light brown-

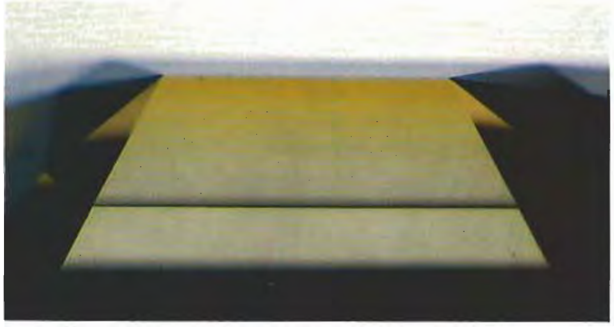


Figure 3. When observed through the pavilion, this treated yellow diamond (sample 2) shows a body color that is much lighter than is evident when the stone is viewed face-up (figure 1), with an obvious zone of a darker, yellow along the keel-line. Photomicrograph by John I. Koivula.

Figure 4. When this treated yellow diamond (sample 4) was viewed through the pavilion, it also revealed a lighter overall body color than its appearance face-up (figure 1), with a deep yellow zone at its culet. Photomicrograph by John I. Koivula.

ish yellow except for a darker and much brighter "lemon" yellow area very near the culet (see figures 3 and 4). The remaining six (samples 5–10) are dark green to blue face-up (figure 2), but appear light brown, light to medium brownish green, or light grayish green when viewed through the pavilion, except for a narrow, bright blue zone at the culet (figures 5 and 6). This unusual color zoning was easily observed with the microscope using diffused transmitted light. It can also be seen with a loupe. In fact, this type of color zoning is first evident to the unaided eye in the dramatic difference in color appearance when the diamond is viewed through the crown and then through the pavilion, for example, as one opens the stone paper.

Figure 5. This treated bluish green diamond (sample 9, see also figure 2) displays a distinct blue zone at the culet. Photomicrograph by John I. Koivula.

Figure 6. This treated blue diamond (sample 5), with a blue culet and light brown body color, is known to be electron irradiated. Photomicrograph by John I. Koivula.

TABLE 1. Physical and optical properties of the 10 "color-zoned" diamonds examined for this study.[a]

Property	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Weight (ct)	2.11	2.18	0.88	1.02	0.87
Cut	Round brilliant	Emerald cut	Round brilliant	Round brilliant	Round brilliant
Face-up color	Yellow	Greenish yellow	Yellow	Greenish yellow	Blue
Color at culet or keel-line	"Lemon" yellow	"Lemon" yellow	"Lemon" yellow	"Lemon" yellow	Blue
Body color (through pavilion)	Very light yellow	Light brownish green	Light brownish yellow	Light brownish yellow	Light brown
Long-wave U.V. luminescence	Moderate yellow	Moderate orangy yellow	Moderate yellow	Weak to mod. orangy yellow	Weak greenish gray
Short-wave U.V. luminescence	Very weak yellow	Very weak yellow	Weak yellow	Very weak orangy yellow	Weak greenish gray
Visible-excited luminescence	Moderate green at culet	Weak green, uneven	Weak to moderate green at culet	Weak green at culet	Weak green
Optical absorption spectrum[b] (nm; band designation, strength of band, sharpness of band)	415 (N3; strong, sharp) 478 (N2; mod., broad) 496 (H3; weak, broad) 503 (H3; weak, sharp)	385 (ND1; mod., medium) 395 (ND1; mod., sharp) 405 (N3; strong, medium) 415 (N3; strong, sharp) 465 (N2; mod., medium) 478 (N2; mod., medium) 496 (H3; mod., medium) 503 (H3; mod., sharp) 563 (weak, sharp) 595 (weak, sharp) 740 (GR1; weak, broad)	415 (N3; strong, sharp) 422 (weak, sharp) 465 (N2; mod., sharp) 478 (N2; mod., sharp) 496 (H4; mod., sharp) 503 (H3; mod., sharp) 595 (weak, sharp)	385 (ND1; mod., sharp) 395 (ND1; mod., sharp) 405 (N3; mod., sharp) 415 (N3; strong, sharp) 454 (weak, broad) 465 (N2; mod., broad) 478 (N2; mod., sharp) 496 (H3; weak, broad) 503 (H3; mod., sharp) 593 (weak, medium) 700 (GR1; weak, broad) 724 (GR1; weak, broad) 742 (GR1; weak, broad)	385 (ND1; mod., broad) 395 (ND1; mod., sharp) 405 (N3; weak, broad) 415 (N3; mod., sharp) 418 (weak, sharp) 428 (GR2-8; weak, sharp) 503 (H3; weak, sharp) 595 (weak, sharp) 620 (GR1; weak, broad) 666 (mod., sharp) 676 (GR1; mod., broad) 700 (GR1; mod., broad) 722 (GR1; mod., sharp) 741 (GR1; strong, sharp)
Near-infrared absorption bands[c]	Weak H1b and H1c	Very weak H1b	Weak H1b and H1c	No H1b and H1c	No H1b and H1c
Diamond type; nitrogen content	Ia; high nitrogen	Ia; high nitrogen	Ia; high nitrogen	Ia; high nitrogen	Ia; moderate nitrogen

[a] *Because of the difficulties in photographing the pavilion area, and the fact that the color zone so strongly affects the rest of the stone, the body color in the photomicrographs may not appear as described in this table. For assignments of the absorption bands in the ultraviolet/visible and infrared regions, see Collins (1982) and Woods and Collins (1986).*

[b] *Optical absorption spectra recorded at low temperature (80°K) with a Pye-Unicam 8800 UV/VIS spectrophotometer.*

[c] *Infrared spectra recorded with a Nicolet 60 SX Fourier transform spectrometer to determine the diamond type and the presence or absence of the H1b and H1c bands. For the energy positions of the H1b and H1c bands, see the text. When present, the H1b and H1c bands are of weak intensity but are sharp.*

Despite the small size of the zone near the culet or keel-line, it influences the color of the remainder of the diamond because of its position directly beneath the table. Such an effect is commonly observed in colored stones, and has been used in faceting to take best advantage of predominantly light-color rough that has some darker areas (see Fryer et al., 1987, p. 107). This bright yellow or blue zone appears to extend about 1 or 2 mm from the culet or keel-line into the stone (when the diamond is viewed parallel to the girdle). Whether this colored zone is only on the surface or actually extends into the culet area is difficult to assess without destructive testing.

In the six diamonds with a blue area at the culet or keel-line, the border separating this zone from the remainder of the diamond appears to be distinct but is not sharp. The border between the two color zones in the four yellow diamonds is slightly less distinct. In both cases, this border appears to be roughly parallel to the table of the stone. No indication of graining could be seen marking the border in either diffused or polarized transmitted light.

In three of the four yellow stones, the small bright yellow area near the culet or keel-line luminesced green when exposed to visible light; the remaining portions of these stones did not luminesce at all. This behavior (referred to as "green transmission") was not noted in the blue-culet diamonds. Green transmission per se is common in both natural and laboratory-treated yellow diamonds; in our experience, it is related to the H3 center (see, e.g., Collins, 1982).

As mentioned above, we knew that one of the blue-culet diamonds (sample 5) had been electron irradiated. The use of electron irradiation for this treatment, where the position of the beam can be focused and thus only a portion of the diamond may be exposed to the radiation, explains why an area of different color may be located only near the culet or keel-line. We suspect that samples 5–9 originally had a light brown or light gray body color and were electron irradiated with a focused

Sample 6	Sample 7	Sample 8	Sample 9	Sample 10[d]
3.31	1.98	1.23	3.06	0.88
Round brilliant	Round brilliant	Round brilliant	Round brilliant	Emerald cut
Dark green	Green-blue	Yellowish green	Bluish green	Greenish blue
Blue	Blue	Blue	Blue	Blue
Light brown	Light grayish green	Light brownish green	Brownish green	Light brown
Inert	Very weak grayish blue	Moderate orangy yellow	Moderate yellowish green	Weak greenish yellow
Inert	Very weak grayish blue	Weak yellowish green	Very weak green	Very weak yellow
None	None	None	None	None
410 (weak, sharp) 417 (weak, sharp) 428 (GR2-8; mod., sharp) 486 (weak, broad) 494 (weak, sharp) 504 (H3; weak, broad) 514 (weak, broad) 620 (GR1; weak, broad) 666 (mod., sharp) 670 (GR1; mod., broad) 700 (GR1; mod., broad) 720 (GR1; mod., broad) 740 (GR1; strong, sharp)	(not recorded; GR1 band present in FTIR spectrum)	405 (N3; mod., sharp) 415 (N3; strong, sharp) 436 (weak, sharp) 441 (weak, sharp) 450 (weak, broad) 475 (mod., sharp) 488 (weak, sharp) 503 (H3; weak, sharp) 545 (weak, broad) 563 (weak, sharp) 592 (weak, broad) 620 (GR1; mod., broad) 648 (weak, sharp) 666 (weak, sharp) 680 (mod., broad) 700 (weak, broad) 722 (GR1; mod., broad) 741 (GR1; mod., sharp)	375 (mod., sharp) 385 (ND1; strong, sharp) 394 (ND1; strong, sharp) 415 (N3; weak, sharp) 429 (weak, sharp) 440 (weak, sharp) 480 (weak, broad) 494 (H3; weak, broad) 503 (H3; weak, broad) 544 (weak, broad) 592 (weak, broad) 620 (GR1; mod., broad) 676 (mod., broad) 700 (GR1; mod., broad) 722 (GR1; mod., broad) 741 (GR1; strong, sharp)	376 (mod., broad) 385 (ND1; strong, sharp) 394 (ND1; strong, sharp) 416 (N3; weak, sharp) 418 (GR2-8; weak, sharp)* 428 (GR2-8; weak, sharp)* 488 (weak, sharp) 496 (H3; weak, broad) 502 (H3; weak, sharp) 524 (weak, sharp)* 554 (weak, broad)* 595 (weak, sharp)* 620 (GR1; mod., broad)* 666 (weak, sharp)* 674 (mod., broad)* 695 (mod., broad)* 722 (GR1; strong, broad)* 741 (GR1; strong, sharp)*
No H1b and H1c	No H1b and H1c	No H1b and H1c	Possible H1b, no H1c	No H1b and H1c
IIa	IIa	Ia; high nitrogen	Ia; high nitrogen	Ia; moderate nitrogen

[d] Data listed for sample 10 were determined after the diamond had been irradiated. In addition to the change of color, the optical absorption bands marked by an asterisk(*) are the result of treatment.

beam, giving the culet area an intense blue color. This would be due to the limited penetration depth of the electrons. Samples 1–4, originally with a light yellow body color, were presumably electron irradiated in the same way; the intense blue color produced at the culet in these stones would have been subsequently converted to an intense yellow by heat treatment (Collins, 1982; Collins et al., 1986).

To better ascertain that this type of color zoning is the result of laboratory irradiation, we submitted the natural-color light brown stone cited above (sample 10, cut from the same rough as sample 5) for electron irradiation, as described earlier. Before irradiation, this emerald-cut diamond exhibited a light brown body color due to brown graining; after irradiation, the face-up color is a medium dark greenish blue (figure 7). When the treated stone is viewed perpendicular to the pavilion, however, the light brown body color in the center of the stone is identical to the overall color of the stone before irradiation. Yet the stone has developed a distinct blue color along both the keelline and the edges of the pavilion (figure 8). Although less pronounced than in sample 5 because of differences in facet shape and possibly conditions of irradiation, the color zoning of this second known treated stone is basically the same as that observed in the other blue-culet diamonds. Development of the blue color is due to formation of the radiation-induced GR1 center at 741 nm. This same color center is responsible for the green color of irradiated diamonds (Collins, 1982).

The near-infrared spectra of diamonds in the yellow-to-brown range are known to provide evidence of irradiation and subsequent heat treatment (Woods and Collins, 1986). Near-infrared spectra of three of the four yellow-culet diamonds exhibit H1b (4935 cm^{-1}) and/or H1c (5165 cm^{-1}) bands (see table 1). In our experience, H1b and H1c bands are never found in natural-color yellow diamonds, but they commonly do occur in those yellow diamonds that have been laboratory irradiated and heat treated. Only one isolated example of

Figure 7. Sample 10, which was cut from the same piece of rough as sample 5, was light brown prior to electron irradiation in a linear accelerator (left); after electron irradiation, it appears greenish blue when viewed face-up (right). Photos by Robert Weldon.

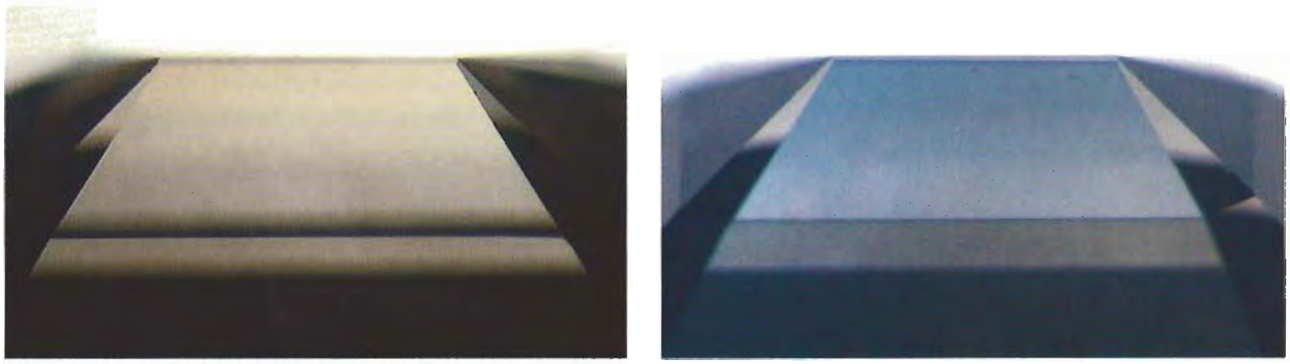


Figure 8. The keel-line of sample 10 before (left) and after (right) electron irradiation illustrates how the blue color produced by this treatment is concentrated in this area of the stone. The blue body color apparent here is the result of reflection from the keel-line within the stone; the overall body color after irradiation was light brown when the stone was viewed perpendicular to the pavilion. Photomicrographs by John I. Koivula.

a natural stone exhibiting H1b and H1c bands has been reported in the literature thus far (Woods and Collins, 1986). Therefore, the presence of the H1b/H1c bands in most of these yellow diamonds is considered further evidence that they were treated. The near-infrared spectra of the blue-culet diamonds revealed no evidence of these absorption bands. This is not particularly surprising since these bands are the result of the heat treatment of laboratory-irradiated type Ia diamonds (Collins et al., 1986), and blue to green diamonds are generally not annealed.

Although treated diamonds with the kind of color zoning described here do not seem to be common, this color-zoning criterion is helpful for stones in the greenish blue to green range, for which the problem of the origin of the body color has not been completely solved (see, e.g., Fritsch et al., 1988).

CONCLUSION

Yellow diamonds that have a darker, brighter "lemon" yellow zone at the culet or keel-line, and dark green to blue diamonds with a bright blue zone in the same area, should be viewed with suspicion if no other strong color zoning is present. We have summarized here the properties of 10 diamonds that display this rather remarkable appearance. A survey of the information presented in table 1 regarding the dark green-to-blue treated diamonds reveals that there are no features common to all six of these diamonds that are indicative of treatment except for this unusual color zoning. In the case of three of the four yellow stones, the H1b/H1c bands in the near-infrared spectrum confirms that the stones had been treated.

There is no report in the literature of a natural-color diamond with this appearance; nor have we ever encountered or heard of such a stone. We conclude, therefore, that a brightly colored area at the culet or keel-line in a colored diamond of different body color (and no other prominent color zoning) is a strong indication of treatment. Although this type of color zoning may not often be encountered, it does provide an important clue to the origin of color and can be checked easily by the jeweler-gemologist with a loupe or conventional gemological microscope.

REFERENCES

Collins A.T. (1982) Colour centres in diamond. *Journal of Gemmology*, Vol. 18, No. 1, pp. 37–75.

Collins A.T., Davies G., Woods G.S. (1986) Spectroscopic studies of the H1b and H1c absorption lines in irradiated, annealed type-Ia diamonds. *Journal of Physics C, Solid State Physics*, Vol. 19, pp. 3933–3944.

Fritsch E., Shigley J.E., Stockton C.M., Koivula J.I. (1988) Detection of treatment in two unusual green diamonds. *Gems & Gemology*, Vol. 24, No. 3, pp. 165–168.

Fritsch E., Stockton C.M. (1987) Infrared spectroscopy in gem identification. *Gems & Gemology*, Vol. 23, No. 1, pp. 18–26.

Fryer C.W., Crowningshield R., Hurwit K.N., Kane R.E. (1987) Gem Trade Lab Notes. *Gems & Gemology*, Vol. 23, No. 2, pp. 104–110.

Kane R.E. (1982) Graining in diamond. In D.M. Eash, Ed., *International Gemological Symposium Proceedings 1982*, Gemological Institute of America, Santa Monica, CA, pp. 219–235.

Liddicoat R.T. Jr. (1987) *Handbook of Gem Identification*, 12th ed. Gemological Institute of America, Santa Monica, CA.

Shigley J.E., Fritsch E., Stockton C.M., Koivula J.I., Fryer C.M., Kane R.E., Hargett D.M., Welch C.W. (1987) The gemological properties of the De Beers gem-quality synthetic diamonds. *Gems & Gemology*, Vol. 23, No. 4, pp. 187–206.

Woods G.S., Collins A.T. (1986) New developments in spectroscopic methods for detecting artificially coloured diamonds. *Journal of Gemmology*, Vol. 20, No. 2, pp. 75–82.

Gem Trade LAB NOTES

EDITOR
C. W. Fryer
Gem Trade Laboratory, West Coast
CONTRIBUTING EDITORS
Robert Crowningshield
Gem Trade Laboratory, East Coast
Karin N. Hurwit
Gem Trade Laboratory, West Coast
Robert E. Kane
Gem Trade Laboratory, West Coast
David Hargett
Gem Trade Laboratory, East Coast

Phenomenal CHRYSOBERYL

The West Coast laboratory recently identified a 20.12-ct dark greenish brown cat's-eye chrysoberyl that displayed unusual phenomena. The gemological properties of this gemstone were typical of cat's-eye chrysoberyl: 1.75 spot refractive index, inert to long- and short-wave ultraviolet radiation, and the strong absorption spectrum typical of a "rich brown" chrysoberyl. Characteristic chrysoberyl inclusions were also observed.

The phenomena displayed by this stone, however, were not typical. When the cabochon was placed flat on its base and viewed from directly above, illuminated by a single overhead light source, a strong chatoyant band (cat's-eye effect) was observed. Yet, when the stone was viewed at an oblique angle from the apex, an additional weaker ray could be seen crossing the chatoyant band to form a four-ray star (figure 1). *RK*

Figure 1. This 20.12-ct cat's-eye chrysoberyl shows a very unusual four-ray star when viewed at an oblique angle.

DIAMOND

"Coated" Diamond

A jeweler asked the East Coast laboratory to determine why his customer's very light pink diamond, set in a ring, had apparently turned brown. Using magnification with an overhead light source, we observed a brownish residue (figure 2) on the diamond.

The jeweler mentioned that neither steam nor ultrasonic cleaning would remove the offending material. In fact, this diamond had changed color once before and had been sent to a diamond cutter to be repolished. We recognized that this "coating" was the result of the ring being worn in an area that has hard water.

Concentrated sulfuric acid will remove the coating. A similar case was reported in the Summer 1976 issue of *Gems & Gemology* (p. 182). *DH*

Figure 2. Exposure to hard water has resulted in brown chemical deposits on the surface of this pink diamond that cannot be removed by either steam or ultrasonic cleaning. Magnified 45×.

Diamond Cube with Cloud-like Inclusion

The Summer 1976 issue also showed a polished cube of diamond with a central symmetrical cloud (p. 181). At the time, we were disappointed that the photo did not reproduce clearly the cross that could be seen within the cloud. However, it did suggest the fact that the cross could be seen in every face of the cube.

We are indebted to the owner for allowing our East Coast laboratory to rephotograph the cube. Figure 3, taken directly through one of the faces, also clearly shows the ghostly frame around the cloud, which the original photograph failed to record. A more magnified view of the cross (figure 4) illustrates its needle-like composition. Note, too, that the weight was reported incorrectly in the earlier article; the cube actually weighs 8.70 ct. *RC*

Fancy Intense Yellow Diamond with a Green Irradiation Stain

The East Coast laboratory recently examined a 1.68-ct fancy intense yellow, natural color, cushion octagon-shaped modified brilliant-cut diamond. The green irradiation stain on the pavilion (figure 5) is the first such

---

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

Figure 3. A cross can be clearly seen in this unusual cloud inclusion observed in an 8.70-ct diamond cube.

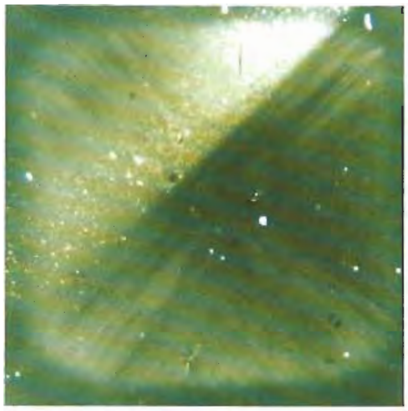


Figure 4. Magnification (here, at 45×) reveals the needle-like composition of the cross shown in figure 3.

Figure 5. A green irradiation stain visible at 60× magnification on this facet junction is a good indication that the color of this fancy yellow diamond is natural.

stain this lab has seen on a naturally colored fancy yellow diamond.

With the Beck "hand-held" spectroscope unit, the diamond displayed a rich cape series spectrum. It also displayed a fine absorption line at about 520 nm. This line is occasionally observed in intense yellow cape-series diamonds. The diamond showed no evidence of irradiation in its spectrum, and the fact that the irradiation patch was still green is another indication of natural color. If irradiation patches were present on a treated yellow diamond, the heat from the annealing process that must be used to create an artificial yellow color would cause them to turn brown. Brown irradiation stains also occur, if rarely, on natural yellow diamonds. *DH*

Naturally(?) Irradiated Diamond Rough

From time to time, dealers will submit unusual rough diamonds to the laboratory for examination. One such diamond, seen recently by the East Coast staff, is an irradiated cubic crystal that had been sawed into two pieces. The larger, 24.45-ct piece of the crystal is still green, while the smaller, 4.85-ct piece is now near colorless (figure 6).

Both pieces of rough had brown irradiation stains (figure 7). Such irradiation stains occur on natural diamond rough; however, subsequent laboratory irradiation is always possible. Figure 7 also shows the irregular coloration of the larger stone. *DH*

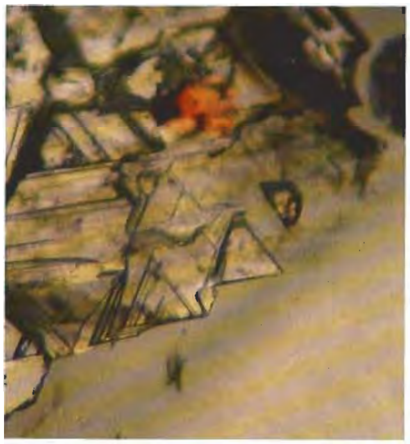


Figure 7. Brown irradiation stains, as seen here in the larger diamond in figure 6, were present in both stones. Note also the irregular green color zoning. Magnified 60×.

Figure 6. The larger (16.7 × 16.1 × 11.6 mm) of these two sawed sections from the same diamond crystal is still green, while the smaller one (15.7 × 10.8 × 4.2 mm) is near colorless.

EMERALD, with Plastic-like Filling

A number of items have been published on natural rubies—and, rarely, sapphires—with glass-like fillings. Recently, we identified an approximately 33-ct natural emerald that showed a similar type of "repair" (figure 8). Even though the emerald was heavily included, a group of small gas bubbles became visible under low magnification in a small area close to the pavilion, showing where the cavity had been filled. When the stone was exposed to long-wave U.V. radiation, the same area fluoresced a strong bluish white. Although we did not determine the exact identity of the filling, the fact that it could be indented easily with a pin probe suggests that the filler is a plastic-like substance. Strong yellow fluorescence in all the fractures indicated that the emerald was also heavily oiled. *KH*

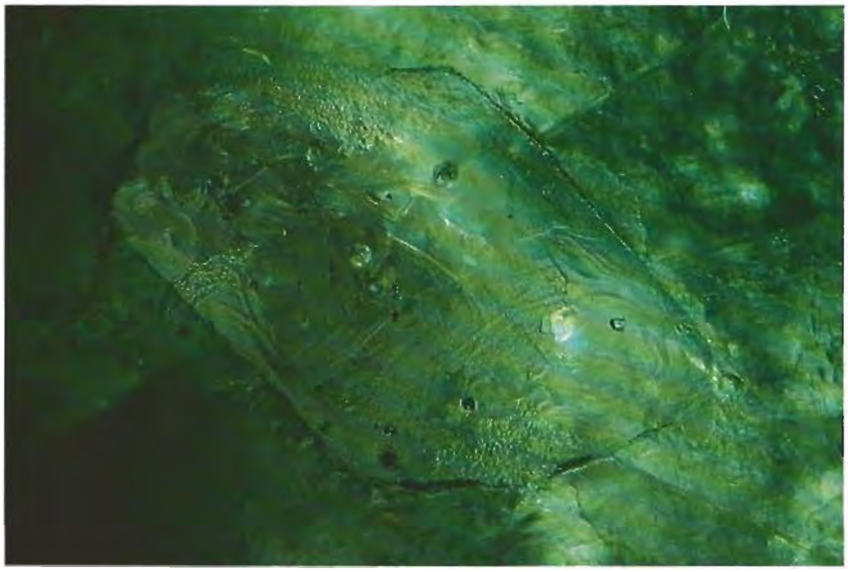


Figure 8. Bubbles are evident in this soft, plastic-like filling in a 33-ct emerald. Magnified 10×.

Imitation LAPIS LAZULI

Dyed Blue Calcite Marble

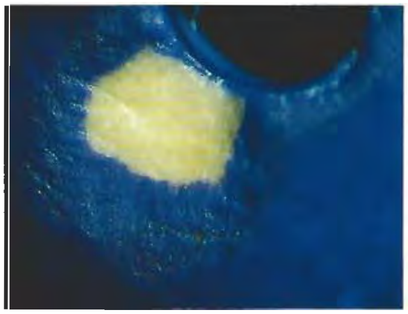
The West Coast laboratory was asked to identify a single-strand necklace with uniform beads that were purported to be lapis lazuli. The 68 opaque blue round drilled beads averaged approximately 10.4 mm in diameter (figure 9). There was no reaction to long- or short-wave U.V. radiation. With the microscope, we noted a slightly mottled appearance. Using the refractometer for a spot test on several beads, we obtained vague R.I.'s from around 1.4 to 1.6, with a blink suggesting a carbonate.

Care must be taken when testing for a carbonate reaction with a weak HCl solution. Because this is a destructive test, it should be performed only in an inconspicuous area, under magnification. Effervescence did occur when a tiny droplet of 10% HCl solution was applied to one of the beads, thus confirming that the material is a carbonate.

Magnesite was ruled out here because it does not react to room-temperature 10% HCl solution. However, one of the beads had a chip near the drill hole that not only revealed the shallow penetration of blue dye, but also showed the true pale yellow color of the material and its structure (figure 10). Incidentally, when we tested this bead for dye with an acetone-soaked cotton swab, no stain was produced, but when a 10% HCl solution was used, a light blue stain appeared on the cotton. The structure appeared to be too fine for dolomite, but did match known samples of dyed calcite marble (see the Fall 1985 issue of *Gems & Gemology*, p. 172). X-ray diffraction analysis provided a pattern that matched that of calcite. *RK*

Figure 9. The approximately 10.4-mm beads in this necklace were believed to be lapis lazuli, but proved to be dyed calcite marble.

Figure 10. A chipped area near the drill hole in one of the beads shown in figure 9 reveals the shallow penetration of the dye as well as the internal structure and natural yellow color of the calcite. Magnified 25×.



X-ray Transparency Separates Two Imitations

Only occasionally does the laboratory use X-radiography for a purpose other than pearl determinations. One feature that we occasionally do test for is transparency to X-rays. For example, no transparent stone resembling diamond is as transparent to X-rays as diamond itself is.

Recently, the East Coast laboratory decided to use this X-ray comparison test on a handsome necklace of opaque blue beads with yellow metal spacers. The jeweler's client had complained that the necklace was staining her skin, so dyed lapis was suspected. The lack of U.V. fluorescence suggested dye, but the R.I. and overall appearance of the beads eliminated lapis. In fact, the beads did not all have the same appearance. Twenty-one proved to be dyed calcite, and 43 were so-called "Swiss lapis" (dyed jasper). With the X-ray transparency test, it was possible to separate the two types of beads quickly. As figure 11 demonstrates, the dyed calcite shows up whiter (less transparent) than the dyed jasper. This transparency to X-rays of different gem materials and gem simulants is discussed briefly in R. Webster, *Gems*, 4th ed., 1983, pp. 865–867. *RC*

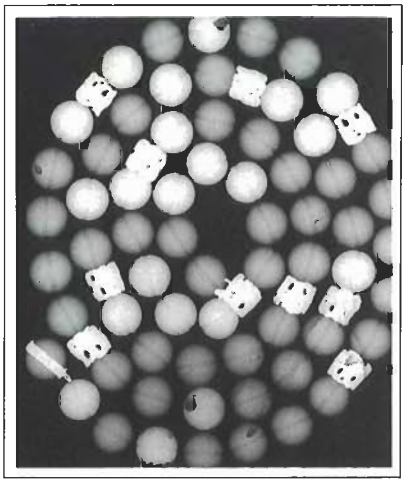


Figure 11. With an X-ray transparency test, calcite (the whiter beads in the photo) can be separated from jasper, which is less opaque.

Figure 12. The color of this attractive 15-mm button-shaped pearl is one indication that it originated in a cherrystone clam.

Cherrystone Clam "PEARL"

Our West Coast laboratory recently examined a very attractive 15-mm button-shaped pinkish purple calcareous concretion that was set in a yellow metal lady's ring (figure 12). With magnification we noticed a faint, but distinct, alveolar (pitted, honeycomb-like) structure. The color and this structure indicate that the concretion had been formed in a cherrystone clam rather than in a Conch or Tridacna. Concretions formed in either of these mollusks would show a characteristic flame-like pattern, as has been described in earlier *G&G* Lab Notes, Fall 1982 and Winter 1987. *KH*

RUBY, Natural Color

The West Coast laboratory recently received for identification a beautiful 3.02-ct natural-color ruby, reported to be of Burmese origin. The refractive indices were typical of ruby, 1.762 and 1.770, with a corresponding birefringence of 0.008. The chromium-rich nature of this ruby was evident not only in the magnificent color, but also in the characteristic absorption spectrum and the strong red fluorescence when exposed to long-wave U.V. radiation.

When examining this stone under the microscope, we observed a classic inclusion scene. In this day and age when heat-treated rubies and sapphires are the rule rather than the exception, it is a rare treat for the gemologist to see the unaltered characteristic inclusions that indicate a natural-color Burma ruby. Easily visible with darkfield illumination were several euhedral calcite crystals entangled within a dense concentration of color swirls, commonly referred to as the "treacle effect" (figure 13). When oblique illumination was added via a fiber-optic light unit, a small "nest" of intersecting short, thin rutile needles was observed (figure 14). *RK*

Figure 13. Euhedral calcite crystals in a dense concentration of color swirls represent a characteristic inclusion scene for rubies from Burma. Darkfield illumination, magnified 30×.

Figure 14. With fiber-optic illumination, a characteristic "nest" of short rutile needles can be seen in the same 3.02-ct ruby shown in figure 13. Magnified 30×.

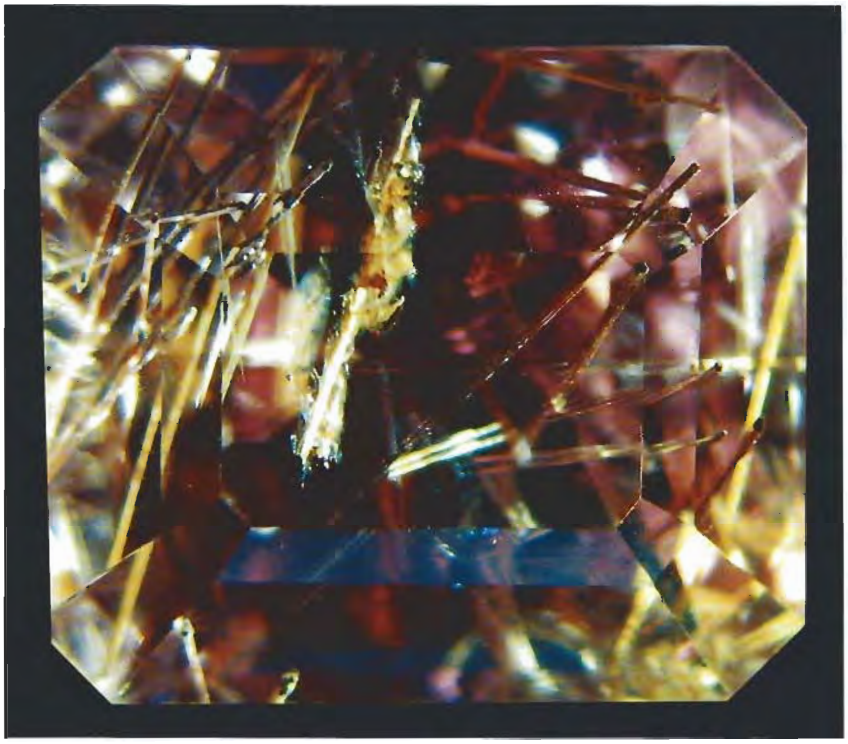


Figure 15. These inclusions in a zircon from Orissa, India, appear to be intermixed rutile-hematite. Darkfield and oblique illumination; magnified 3.5×.

An Unusual ZIRCON

A zircon recently sent to us for examination in Santa Monica proved to contain some rather interesting inclusions of a type we had not encountered in zircon before. The gem itself was a transparent pinkish purple emerald cut that weighed 3.50 ct and measured approximately 8.00 × 6.70 × 5.55 mm. It was reported to have come from Orissa State, in India, and was interlaced with a number of eye-visible acicular inclusions with a dark brown to orangy yellow color (figure 15). With the microscope, we observed that the needle-like inclusions were actually an almost black, submetallic brown, and the yellow color, wherever it was present, was a thin surface coating that apparently resulted from alteration of the underlying inclusion. In cross-section, the inclusions had either an almost circular, or a stretched pseudohexagonal, habit that made them appear to be either tetragonal or possibly orthorhombic.

Several of these inclusions reached the surface of the stone, so they were ideally suited for X-ray diffraction analysis. A diamond-tipped scraper was used to remove a minute amount of powder from one of the inclusions. This powder was mounted on a glass spindle, placed in a Debye-Scherrer powder camera, and run for seven hours in an X-ray beam generated from a copper target tube at 46 kV and 26 mA. The results showed the presence of three different mineral compounds: rutile, hematite, and zircon.

The zircon was undoubtedly from contamination by the host. This left the rutile and hematite. The yellowish iron staining observed on the inclusions indicates the presence of iron. Iron is a necessary component of hematite, and rutile can also contain significant amounts of iron. If a polishing compound containing any iron oxide had been used on the stone, this might account for the hematite, leaving only rutile. It is more likely, however, that the acicular inclusion tested is an intermixed crystal of both hematite and rutile.

John I. Koivula

FIGURE CREDITS

Figures 1, 9, 12, and the Historical Note photo are the work of Shane McClure. Figures 2-7 were taken by Dave Hargett. The photomicrograph in figure 8 is by John I. Koivula. Figure 11 is by Robert Crowningshield. Robert E. Kane supplied figures 10, 13, and 14. Figure 15 is © Anthony de Goutière.

A HISTORICAL NOTE

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

SUMMER 1964

The New York laboratory reported seeing synthetic emerald overgrowth on beryl. There also was some discussion regarding chrysoprase versus dyed green chalcedony, including the mention of a ruling by a New York City court that two retail jewelers were guilty of misrepresentation in the sale of dyed green chalcedony as chrysoprase. Other items of interest were dumortierite in quartz, a beautiful green enstatite, and some diamond doublets set in a pin.

Two items of particular importance were seen in Los Angeles. The first was a rope consisting of nine interwoven strands of small natural pearls. The rope was over 50 in. (125 cm) long and probably contained 7,500 to 8,000 individual pearls. Since an X-radiograph could not be taken without disassembly of the piece, a qualified identification of natural origin was made based on the lack of fluorescence to X-rays and the appearance of the pearls under magnification.

The second item was a pleasant surprise: Four small pieces of rough submitted as diamonds by the person who found them actually were diamonds. Most such pieces found by clients and thought to be (actually hoped to be) diamonds usually turn out to be quartz. These stones ranged in size from 0.06 to 0.22 ct. The owner reported that they were from an area (which he would not name) that was not known to have previously produced diamonds.

SUMMER 1974

A number of emerald imitations were discussed by New York lab personnel, including some clever imitation crystals in fake matrix. The opportunity to examine the largest taaffeite then known was an exciting one, as was the chance to see the 12.42-ct Uncle Sam diamond, the largest from the Arkansas diamond pipe.

Differences in ultraviolet fluorescence and phosphorescence between Gilson synthetic opal and natural opal were discussed by the Los Angeles lab. The lack of phosphorescence in the Gilson product is indicative of its synthetic nature. An expanding movable gas bubble in a natural ruby was photographed in three different stages of expansion caused by heat from the substage light in a Gemolite microscope.

SUMMER 1984

Several types of pearls—imitation, mabe, and cultured—were mentioned in this issue. X-radiographs illustrated the use of lenticular nuclei to produce flattened cultured pearls. Dimples in another cultured pearl suggested that a drilled bead might have been used as the nucleus; the X-radiograph proved that this was indeed the case.

An asteriated quartz with multiple stars was illustrated with photos showing the appearance of a single star when the stone was viewed from the top and multiple stars when the stone was viewed from an oblique angle. A large nephrite carving (see photo) illustrated the use of artistic staining. No attempt was made to alter the main body color of the jade, only to highlight the details in the carving.

This 23.4 × 7.2 × 9.5 cm nephrite carving has been artistically stained to enhance the detail.

Back Issues of Gems & Gemology

Limited quantities of the following back issues of *Gems & Gemology* are still available.

Winter 1983
Engraved Gems: A Historical Perspective
Gem Andradite Garnets
The Rubies of Burma: The Mogok Stone Tract
Induced Fingerprints
Cobalt Glass as a Lapis-Lazuli Imitation

Summer 1984
Gem-Bearing Pegmatites: A Review
Gem Pegmatites of Minas Gerais, Brazil: Exploration, Occurrence, and Aquamarine Deposits
The First-Order Red Compensator

Fall 1984
Freshwater Pearls of North America
The Chemical Distinction of Natural from Synthetic Emeralds
Identifying Gem-Quality Synthetic Diamonds: An Update
Inclusions in Taaffeites from Sri Lanka
Magnetic Properties of Gem-Quality Synthetic Diamonds

Winter 1984
Natural Rubies with Glass-Filled Cavities
Pyrope-Spessartine Garnets with Unusual Color Behavior
Gem-Quality Red Beryl from Utah
An Extraordinary Calcite Gemstone
Green Opal from East Africa

Spring 1985
Gem Pegmatites of Minas Gerais, Brazil: The Tourmalines of the Araçuaí Districts
Sapphire from Cauca, Colombia
Altering the Color of Topaz
A Preliminary Report on the New Lechleitner Synthetic Ruby and Synthetic Blue Sapphire
Interesting Red Tourmaline from Zambia

Summer 1985
Pearl Fashion Through the Ages
Russian Flux-Grown Synthetic Emeralds
Gem Pegmatites of Minas Gerais, Brazil: The Tourmalines of the Governador Valadares District
The Eyepiece Pointer

Winter 1985
A Status Report on Gemstones from Afghanistan
A Proposed New Classification for Gem-Quality Garnets
Amethystine Chalcedony
The Pearl in the Chicken

Spring 1986
A Survey of the Gemstone Resources of China
The Changma Diamond District, Mengyin, Shandong Province, China
Gemstone Carving in China: Winds of Change
A Gemological Study of Turquoise in China
The Gemological Characteristics of Chinese Peridot
The Sapphires of Mingxi, Fujian Province, China

Summer 1986
The Coscuez Mine: A Major Source of Colombian Emeralds
The Elahera Gem Field in Central Sri Lanka
Some Unusual Sillimanite Cat's-Eyes
An Examination of Four Important Gems
Green Glass Made of Mount Saint Helens Ash?

Fall 1986
A Simple Procedure to Separate Natural from Synthetic Amethyst on the Basis of Twinning
Pink Topaz from Pakistan
Carbon Dioxide Fluid Inclusions as Proof of Natural-Colored Corundum
Contributions to a History of Gemology: Specific Gravity
Colombage-Ara Scheelite

Winter 1986
The Gemological Properties of the Sumitomo Gem-Quality Synthetic Yellow Diamonds
Art Nouveau: Jewels and Jewelers
Contemporary Intarsia: The Medvedev Approach

Also Available

Spring 1987
"Modern" Jewelry: Retro to Abstract
Infrared Spectroscopy in Gem Identification
A Study of the General Electric Synthetic Jadeite
A New Gem Material from Greenland: Iridescent Orthoamphibole

Summer 1987
Gemstone Durability: Design to Display
The Occurrence and Gemological Properties of Wessels Mine Sugilite
Three Notable Fancy-Color Diamonds
The Separation of Natural from Synthetic Emeralds by Infrared Spectroscopy
The Rutilated Topaz Misnomer

Fall 1987
An Update on Color in Gems. Part 1
The Lennix Synthetic Emerald
An Investigation of the Products of Kyocera Corp. that Show Play-of-Color
Man-Made Jewelry Malachite
Inamori Synthetic Cat's-Eye Alexandrite

Winter 1987
The Gemological Properties of the De Beers Gem-Quality Synthetic Diamonds
The History and Gemology of Queen Conch "Pearls"
The Seven Types of Yellow Sapphire and Their Stability to Light

Spring 1988
An Update on Color in Gems. Part 2
Chrysoberyl and Alexandrite from the Pegmatite Districts of Minas Gerais, Brazil
Faceting Large Gemstones
The Distinction of Natural from Synthetic Alexandrite by Infrared Spectroscopy

Summer 1988
The Diamond Deposits of Kalimantan, Borneo
An Update on Color in Gems. Part 3
Pastel Pyropes
Examination of Three-Phase Inclusions in Colorless, Yellow, and Blue Sapphires from Sri Lanka

Fall 1988
An Economic Review of the Past Decade in Diamonds
The Sapphires of Penglai, Hainan Island, China
A Gem-Quality Iridescent Orthoamphibole from Wyoming
Detection of Treatment in Two Unusual Green Diamonds

Winter 1988
Gemstone Irradiation and Radioactivity
Amethyst from Brazil
Opal from Opal Butte, Oregon
A Gemological Look at Kyocera's Synthetic Star Ruby

TO ORDER: Call: toll free **(800) 421-7250, ext. 201**
OR WRITE: GIA, 1660 Stewart Street, Santa Monica, CA 90404,
Attn: G&G Subscriptions

Spring 1981 (sold out)

Winter 1981 (sold out)

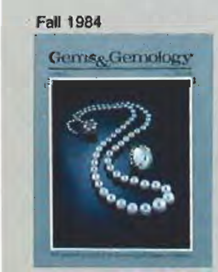
Spring 1983 (sold out)

Fall 1983 (sold out)

Winter 1983

Summer 1984

Fall 1984



Winter 1984

Spring 1985

Summer 1985

Fall 1985 (sold out)

Winter 1985

Spring 1986

Summer 1986

Fall 1986

Winter 1986

Complete your back issues of Gems & Gemology NOW!

Single Issues:*	**$ 8.00** ea. U.S. **$11.50** ea. Elsewhere
Complete Volumes:* 1986 full set 1987 full set 1988 full set	**$26.50** ea. U.S. **$36.50** ea. Elsewhere
1986, 1987, and 1988 full set	**$65.00** U.S. **$95.00** Elsewhere

*10% discount for GIA Alumni Association members

ORDER NOW!

Editorial Forum

ALL GEMSTONE RADIOACTIVITY SHOULD BE DISCLOSED

Gems & Gemology and GIA are to be congratulated for bringing the gem irradiation issue to the industry (i.e., Ashbaugh, "Gemstone Irradiation and Radioactivity," Winter 1988). To learn that 30 million carats of blue topaz are irradiated annually worldwide, 40% of this in the USA alone, is astounding!

There are two factors that concern me with regard to radiation. First, no matter what the source and no matter what the level, the amount of radiation a person receives is *cumulative*. That is, if a person gets a chest X-ray *and* wears a gem that "releases" a tiny amount of radiation, that individual has received a *total exposure* of one X-ray *plus* whatever the gem is releasing. Second, radiation, regardless of level, is most intense when a person is close to the radiation source. For example, when a clerical worker sits 12 inches away from a fluorescent desk lamp, he/she will receive more ultraviolet radiation to the face than if the fluorescent lamp were on the ceiling. Gems are worn very close to the body.

Surely, in general, just because we exist in an environment of natural background radiation does not mean we must accept the *addition* of man-made irradiated objects. And since the safety of even natural background radioactivity is still being studied and is not fully understood (witness the radon gas situation), why should we accept the addition of man-made irradiation of gem minerals?

It is imperative that disclosure of gem irradiation be mandatory at all levels of distribution in the jewelry industry. In this way, at least the buyer of a gem is made aware that the gem releases "some" radioactivity. It should also be mandatory that the names of *all* gems emitting radioactivity (however "low" the levels) should be disclosed to the public. If this is not "enforceable," then efficient instruments should be developed, so that gemologists, wholesalers, and retailers can determine the level of natural or man-made radioactivity in a gem.

Henry Segal
Somerled Jewellery
Montreal, Quebec, Canada

IN REPLY: The tiny amount of radiation received from just about any irradiated gemstone is insignificant when compared to other sources of radiation in nature. The radiation doses from individual gemstones are given only to small and relatively insensitive areas of the body. The dose rates also decrease in time due to radioactive decay. Therefore, it makes no difference biologically whether one wears these gemstones or not. It becomes only a matter of personal choice. Note, too, that efficient instruments already exist for the detection of radiation. An inexpensive Geiger counter will be more than adequate to meet the needs of the jeweler.

Charles E. Ashbaugh III

ERRATA

In David Epstein's Winter 1988 article on amethyst, some confusion could arise from the first paragraph in the "Gemological Description" box on page 216. Although a "bull's-eye" optic figure is unique to quartz, it is found in natural amethyst only when the stone has been cut from an untwinned area of the crystal. A stone cut from a twinned portion of the natural crystal, as is most common, would show a standard uniaxial optic figure, where the cross meets in the center—not a "bull's eye." If the optic figure were resolved over an area at the interface between twinned and untwinned portions of the natural crystal, it would be an Airy's spiral. Thus, natural amethyst can show any one of these three optic figures.

In the Ashbaugh article on gemstone irradiation and radioactivity (Winter 1988), a number of changes should be noted. On page 198: "There are over 2500 *different nuclides known to date." On page 199: "This nuclide decays by the emission of a beta particle* 89% of the time and by electron capture followed by a high-energy gamma ray 11% of the time. *The result is the stable, nonradioactive daughters calcium-40* and argon-40.*" On page 200: The thorianite tested was "more than 1,500 times the stated legal limit for manufactured goods containing* thorium and *uranium."*

GEM NEWS

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

DIAMOND

Companies vie for Angola diamond rights. Several companies are negotiating with the government of Angola for rights to develop the kimberlite pipe recently discovered at Catoca, which reportedly has production potential comparable to that of De Beers's Premier mine in South Africa. Central Selling Organization Chairman Nicholas Oppenheimer has met with Angolan President Eduardo dos Santos to discuss the possibility of Angola rejoining the CSO, which it left in 1987. Along with Botswana and the USSR, Angola is expected to be the major producer of gem-quality diamonds in the 21st century.

Australian diamonds. An offshore diamond project in the Kimberley region of Western Australia has recovered four gem-quality diamonds averaging 0.275 ct each. This has led the owners of the project, Capricorn Resources Australia NL, to expand their exploration activities. Inland, Belray Diamond Tours is now conducting one-day tours of the world's largest diamond mine, the Argyle, that begin with a 90-minute flight from Kununurra and include a first-hand look at the entire mining process, including the grading and sorting of rough.

Diamonds from China. Ashton Mining Ltd. of Australia has been granted exclusive rights to the exploration, mining, and sale of diamonds in China's Hunan Province. The Hunan provincial government will share equally with the company in any profits and will also provide at least half the labor force. In Laioning Province, the Wafandian diamond deposit, potentially one of China's largest, is being developed for mining and is expected to be operational by late 1990. The mine's total projected output of 118,000 ct per year would increase by nearly 60% China's current total diamond output. Most of the current production comes from Chang Ma, Tao Cheng, and Linshu in Shandong Province. The Wafandian mine will join the Bin-Hai, which is already operating in Laioning Province. We do not know, at present, how the recent political unrest in China will affect diamond production.

Deep space diamonds. Roy Lewis and his colleagues at the University of Chicago have reported the discovery of billions of micro-sized diamonds, each measuring no more than a few billionths of an inch across. The discovery was made when fragments of primitive meteorites were dissolved in hydrochloric acid and the residue was analyzed; it was found to consist, in part, of these tiny diamonds. The scientists believe that these diamonds originated on distant stars that subsequently exploded.

COLORED STONES

Visual representation of amethyst to citrine alteration. A great deal has been written on the heat treatment of amethyst to create citrine. However, although verbal descriptions and technical data are readily available, color illustrations of the actual change that occurs, together with practiced procedures, are much less common in the literature.

To get top-quality citrine for his gem carvings, Bart Curren, of Glyptic Illusions in Topanga, California, often does his own heat treatment. The 89.26-ct amethyst and 76.17-ct citrine shown in figure 1 were both carved from identically colored amethyst crystal tips from Marabá, Brazil. To change the one piece to citrine, Mr. Curren packed the amethyst in crushed glass as a temperature buffer, and heated it in air for approximately six hours at 525°C; he then turned off the heat and allowed the stone to cool slowly to room temperature in the crushed glass. Over the course of his heating experiments, Mr. Curren has found that amethysts with slightly grayish and brownish sections turn the best orange color when heated.

Aquamarine found in Wyoming. Transparent gem-quality aquamarine was recently found at the Boston mine in the Big Horn Mountains, Wyoming. According to Kraft's Fine Jewelry and Art of Sheridan, Wyoming, the aquamarine was found in a discard pile of pegmatitic rocks near a pegmatite composed primarily of plagioclase and microcline feldspars, quartz, and mica.

Two faceted gems from this find were studied at GIA. The 2.06-ct pleasing light blue trapezoidal step cut had refractive indices of 1.572–1.579. The smaller,

---

Acknowledgments: The editors would like to thank the following individuals for their assistance in the preparation of this column: Andrew Christie, Emmanuel Fritsch, Robert E. Kane, Richard T. Liddicoat, Robert Middleton, and James E. Shigley.

Gems & Gemology, *Vol. 25, No. 2, pp. 110–118*

Figure 1. The 76.17-ct citrine on the right was originally the same color as its companion 89.26-ct amethyst. The color was changed by heat treatment. Photo by Bart Curren.

elongated octagonal step cut was a light, very slightly bluish green with refractive indices of 1.573–1.581. Both gems were transparent, had a specific gravity of 2.70, and showed weak iron-related absorption in the blue region of the visible-light spectrum.

According to geologists who have studied this deposit, blasting, followed by hand picking of the resulting rubble, may yield additional aquamarines. There is currently no organized mining at the locality.

Colored stone update from China. Dealer D. J. "Doug" Parsons, of Del Mar, California, spent seven weeks traveling throughout China during April and May of this year (his fifth trip to China in 18 months). He provided Gem News with the following report on colored gem production he noted during his visit.

Mr. Parsons was one of the first foreigners to visit the pegmatite region of Altay, in Xinjiang Uygur Autonomous Region, after it was reopened earlier this year. Here he saw commercial quantities of aquamarine (most cutting 1–2 ct stones, with some up to 10–12 ct), citrine, amethyst, light blue and light green tourmaline, and pyrope garnets. Small amounts of emerald and white topaz were also evident. He observed two cutting factories in the town of Altay, which produced beads as well as faceted stones.

In a restricted area of southern Yunnan Province, he saw considerable amounts of topaz, primarily white but some blue. His Chinese hosts informed him that there were operations in China to irradiate and anneal the white topaz to turn it blue. Some of the white topaz crystals were as large as 15 cm (6 in.) in diameter. He also encountered crystals of yellow, dark brown, and dark green tourmaline, but these were suitable primarily for specimens rather than cut stones. He encountered gem-quality topaz and aquamarine in Inner Mongolia, but not in commercial quantities.

One of the most interesting materials he was shown was a lot of more than 200 crystals (ranging in weight from 4.05 to 59.80 grams) of gem-quality diopside from Xinjiang; several of these crystals (figure 2) were submitted to the GIA Gem Trade Laboratory in Santa Monica, where the identification was confirmed. The crystals reportedly came from the Kunlun Mountains, in the

Figure 2. These gem-quality diopside crystals (4.05 to 59.80 grams) came from Xinjiang, China, near the border with Kashmir and Pakistan. Courtesy of D. J. Parsons; photo by Shane McClure.

southwestern portion of Xinjiang Uygur Autonomous Region, near the border with Kashmir and Pakistan.

On the basis of his experience in China, Mr. Parsons is optimistic that in spite of recent events, the opportunities for trade will not dry up totally. Although travel and other activities may be restricted for some period of time, he feels that it is unlikely that the Chinese people will relinquish totally the economic freedoms they have gained during the last 10 years.

Tunnels used to mine emeralds at Muzo. Two major leaseholders at the Muzo emerald mine in Boyacá, Colombia – Tecminas and Coesminas – have begun to use underground shafts and tunnels as an adjunct to the current strip mining with bulldozers. The tunnels give a new direction to the exploitation of what is recognized historically and presently as the world's richest emerald mine.

The relative flatness of many parts of the zone of exploitation at Muzo has resulted in the continual accumulation of mine tailings not only in the Río Itoco riverbed but also in some of the nearby gullies and valleys. This has inevitably covered up access to some of the rich old emerald veins of the past. With the new shafts and tunnels, the leaseholders hope to relocate some of the old veins and follow geologic indicators to new productive areas underground (figure 3).

Figure 3. Tunnels are being used again at the Muzo emerald mine in Colombia. Photo © Peter C. Keller.

Ron Ringsrud, president of Constellation Colombian Emeralds Co. of Los Angeles, spoke to Alvaro Tenjo, engineer in charge of the tunnels at Coesminas. He reports that the tunnels that radiate from the shaft are guided to some extent by geochemical indicators outlined by a joint technical survey and study made by United Nations scientists and Colombian geologists. Samples from the rocks in the tunnels are analyzed and then excavation is directed based on the amounts of sodium, lithium, and lead identified in the black shale. The use of these geochemical guides for exploration has been successful in uncovering emeralds. The rock at 50 m depth, however, is much softer than expected, so all tunnels are being reinforced heavily; the presence of considerable water requires constant pumping as well.

These shafts and tunnels mark the beginning of a new approach to mining at Muzo. Generally, sophisticated geologic mining has been actively pursued there only in the last few years. It is a testimony to the incredible richness of the Muzo region that it has been able to supply fine emeralds for literally hundreds of years with only the most primitive mining and prospecting processes.

Hackmanite: A remarkable variety of sodalite. From a collector's standpoint, one of the most interesting gem materials that we have seen in recent memory was first encountered at the February 1989 Tucson Gem and Mineral Show. This mineral is a very light yellow (near-colorless) transparent single-crystal material that makes excellent faceted stones. Known as hackmanite, it is the sulfur-rich variety of sodalite. Noted cutter Art Grant, of Coast-to-Coast Gemstones, brought the 3.32-ct gemstone to our attention to demonstrate its "color change."

This "color change" was induced by a one-minute exposure to long-wave ultraviolet radiation, during which the stone fluoresced bright orange and then emerged saturated pink (figure 4). This "color change" has been previously reported in the gemological literature, but is quite dramatic to witness.

When the pink hackmanite is exposed to incandescent light, the color fades within a few minutes, and the stone returns to its original light yellow color. This coloring cycle can be repeated again and again, but it is difficult to record on film because the instant the photolights are switched on, the pink color immediately starts to fade.

Hackmanite's remarkable "color change," together with its reported hardness of 5.5 to 6 on the Mohs scale and a cleavage listed as poor, makes this variety of sodalite a most interesting, if rare, gem for jewelry items such as pendants and brooches.

Figure 4. This light yellow 3.32-ct hackmanite (left) becomes bright pink (right) after exposure to long-wave ultraviolet radiation. Courtesy of Art Grant; photo by Robert Weldon.

Australia's opal industry crippled. March flooding has collapsed mine shafts and caused extensive equipment damage and financial losses in the opal fields at Coober Pedy, Mintabie, and Andamooka. A steady downpour during the entire month severely disrupted most of the claims near Coober Pedy, causing flooded shafts to be permanently sealed off and trapping tunneling machinery underground. In low-lying areas, earthmovers and bulldozers in open-cut mines were literally submerged. "Opal production will be down and prices will be up," said Anna Vanajek, of the Coober Pedy Miners Association. "It will take at least six months, and in some cases a year, to get back to full production."

A significant find of Mexican quartz. Well-known mineralogist-gemologist Si Frazier has reported a relatively new find of beautifully formed, gem-quality colorless quartz crystals near Oaxaca, Mexico. According to Mr. Frazier, these crystals closely resemble the nearly perfect quartz crystals from the famous locality in Herkimer County, New York. He reports, however, that in addition to being euhedral, they are "often larger than most Herkimers" and, like most quartz crystals "that grow slowly in solution cavities in calcareous sediments, they are quite lustrous. These features make many of them suitable for use in jewelry in their natural state."

Another significant difference in these Mexican crystals, according to Mr. Frazier, is that "toward the end of their growth, many of them experienced very rapid deposition on the edges and tips, leading to the type of unusual development on some of the larger crystals that is called 'fenster' (window growth) in Europe." This rapid growth on the edges and tips results in the development of cavernous (sunken) rhombohedron and prism faces. In some cases, a sheet of quartz will then grow out from the edges and cover the cavernous opening. These thin sheets of glass-like quartz (the fenster or window) frequently trap clay and/or liquids behind them, resulting in a most unusual quartz-inclusion habit.

These new Mexican quartzes may also have some organic inclusions, again reminiscent of the Herkimer quartzes. So, although the precise locality of these new quartz crystals has not yet been revealed, the matrix rock is probably a calcareous sedimentary rock similar to that from which the New York crystals are mined. The Mexican crystals examined by the Gem News editors ranged up to 5 cm, but the larger specimens were heavily included. Thousands of these crystals were available from a single dealer at the 1989 Tucson Show.

Rose quartz from Connecticut. William Shelton, of Monroe, Connecticut, reports that rose quartz is currently being mined in Fairfield County, Connecticut. Several areas in the state, including this one, have produced rose quartz intermittently for at least 50 years.

The rose quartz occurs in a small pegmatite body that cuts local metamorphic schists of Devonian age. One large vein of rose quartz contains a layer approximately 2.5 cm (1 in.) thick that is composed of very fine faceting-quality gem material. As is typical with gem materials, however, only a small portion of the total amount of rose quartz present is cutting quality.

The finest rose quartz from this locality is transparent and has an unusual optical effect reminiscent of adularescence. Cut gems show a pleasing internal color, with pale rose and yellowish highlights. At this time, there is no organized recovery of gem material.

Blue sapphires from Kenya. According to Dr. N. R. Barot, managing director of the Ruby Center in Nairobi, Kenya, two recently discovered sapphire sources in that country are yielding some blue gems of exceptional quality. One of these deposits, near Kenya's border with Sudan and Ethiopia, is yielding noteworthy quantities of rough crystals. In northeast Kenya, the other new deposit is producing some exceptional star sapphires.

Sapphire in Ontario. Clifford H. Stevens, a gemologist from Gansevoort, New York, recently visited a new locality for blue sapphire near Lake Bap and Bancroft, in Ontario, Canada. He reports seeing numerous corundum crystals in white matrix in a large (approximately 7 m × 1.5 m) hole that had been blasted into the hillside. For the most part, the barrel-shaped crystals averaged 1.5 cm × 5.0 cm, although many were much larger. They were primarily dark gray to a distinct blue-gray in color, with some showing small gemmy areas.

A number of the crystals, both loose and in matrix, were of fine mineral specimen quality. Some gave the appearance of asterism or chatoyancy. In some large (up to 1 m in diameter) chunks of the white matrix, as much as 20% of the mass was made up of terminated translucent crystals of a medium grayish blue (similar to the border color of the Summer 1988 cover of *Gems & Gemology*).

The deposit is on private land and the visit was by invitation only. Also observed at the site were calcite/marble, translucent white feldspar (probably microcline), sphene crystals, and small flakes of common black to dark brown biotite.

Figure 5. The unusual multi-layer color zoning of this 4.23-ct Australian sapphire is clearly seen with immersion and diffused transmitted light. Courtesy of Fred Toth; photo by John I. Koivula.

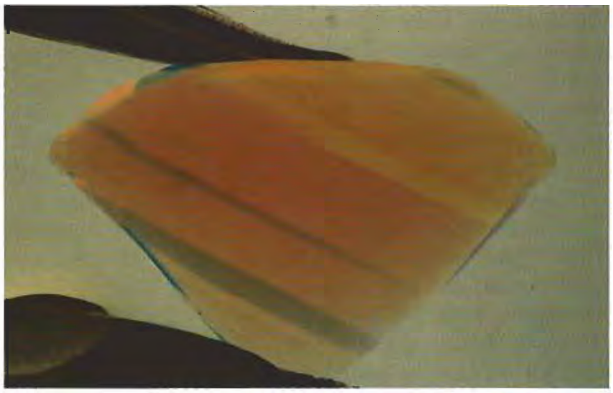


Figure 6. This 10.01-ct Sri Lankan sapphire, set with diamonds in a platinum and yellow gold ring, has classic "padparadscha" coloration. Ring courtesy of Yahiya Farook; photo by Shane McClure.

An interesting zoned Australian sapphire. An unusual 4.23-ct round brilliant-cut Australian sapphire was shown to us recently by Fred Toth of Pacific Palisades, California. Before cutting, the approximately 20-ct rough sapphire was a rounded irregular mass of saturated orangy yellow color with prominent rutile "silk" near its surface that masked the overall transparency. The rough was recovered from alluvial soil at Willows, about 40 km (25 mi.) west of Anakie, a site famous for yellow sapphires. After cutting, it was noticed that, when viewed from the side using immersion and diffused transmitted light, the gem showed an unusual multi-layer color zoning of blue, orangy pink, and yellow (figure 5). Color-zoned or parti-colored Australian sapphires were described in the Fall 1985 *Gems & Gemology* article by Terrence Coldham. In that article, however, no mention was made of parti-colored sapphires showing orangy pink zones together with the more common blue and yellow layers.

"Padparadscha" sapphire. In the Spring 1983 issue of *Gems & Gemology*, Robert Crowningshield traced the history and discussed the use and origin of the color-based trade name "padparadscha." It is rare that a gemologist encounters a natural pinkish orange sapphire that would visually qualify as a "padparadscha," especially one of significant size.

Just such a stone was seen at the 1989 Tucson Show, and later submitted to the Gem News editors for examination. Yahiya Farook, of Sapphire Gem Trading Company, was showing a pleasing "classic" pinkish orange oval mixed-cut sapphire with a stated weight of 10.01 ct that was reportedly from Sri Lanka. It was mounted as the center stone, surrounded by diamonds, in an ornate platinum and yellow gold ring (figure 6). In the mounting, the stone measured approximately 11.8 × 9.7 × 9.88 mm. When examined with a hand-held type of spectroscope, it showed strong chromium-caused absorption in the red. The microscope revealed only one small "fingerprint" inclusion. The gem fluoresced a strong red-orange to long-wave ultraviolet radiation, with a weak fluorescence of the same color to short-wave U.V.

Large tourmaline pocket discovered at the Himalaya mine. Bill Larson, of Pala International, reports the discovery of a large gem pocket at the historic Himalaya mine in the Mesa Grande District of San Diego County, California. First entered on May 7, 1989, the pocket was eventually opened to approximately 0.7 × 1 × 3.7 m deep (2 × 3 × 11 ft.). Large (up to 20 cm) crystals of pink and bicolored tourmaline (figure 7) were found embedded not only in the walls and ceiling of the pocket but also on the floor. At many places throughout the pocket, the host clay was so soft that the crystals could be dug out with one's fingertips.

Five hundred kilos of tourmaline were recovered in the three months following discovery of the pocket. The bulk of the material is suitable for mineral specimens; of particular note are the "matrix" specimens of tourmaline with quartz. Approximately 50% of the production is carving or cabochon grade. Although less than 1% is suitable for faceting, stones as large as 20 ct have been cut. Small cutting-quality crystals of stibiotantalite have also been recovered. This is one of the most important pockets discovered at the Himalaya since it was reopened 12 years ago.

Figure 7. Hundreds of kilograms of bicolored (this crystal is approximately 6 cm high) and pink tourmaline have been recovered from the new pegmatite pocket at the Himalaya mine in San Diego County, California. Courtesy of Pala International; photo © Harold & Erica Van Pelt.

PEARLS

Two remarkable natural freshwater pink pearls from Texas. Boaz Arch, president of Aura America Inc., in Houston, Texas, recently loaned GIA's Dr. Emmanuel Fritsch two unusually large (13.3 and 12.2 mm in diameter) round pink pearls for examination (figure 8). These pearls were stated to be natural freshwater pink pearls from the Concho River, approximately 240 km (150 mi.) northwest of Austin, Texas. The fact that they are natural pearls was confirmed by X-radiography at the GIA Gem Trade Laboratory in New York. These pearls display a "tight" structure with very thin conchiolin layers, as expected. They do not, however, luminesce to X-rays, although freshwater pearls generally show a light orange luminescence which has been attributed to their manganese content. Nevertheless, manganese was easily detected by Dr. Fritsch using X-ray fluorescence spectrometry. Tom Moses, of the New York laboratory, commented that he and his colleagues have observed over the years that the darker the pink color in this type of pearl is, the weaker the X-ray luminescence is. Therefore, the absence of reaction is not totally surprising. Mr. Arch has been told that the color of the pearls from this region seems to lighten as they are found further down the river, closer to Austin.

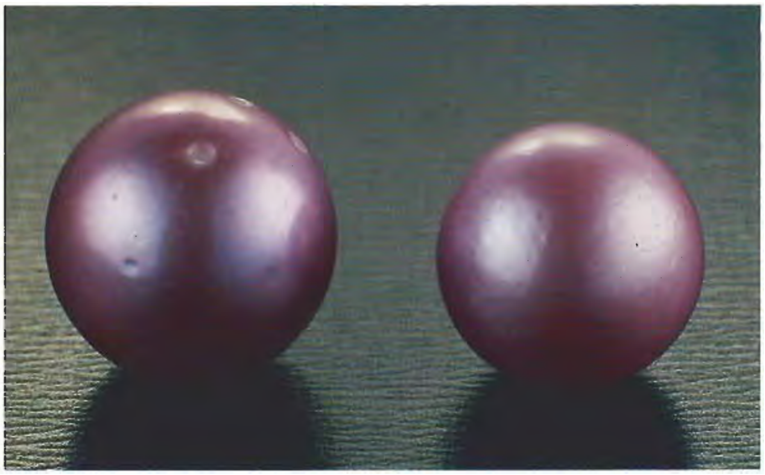


Figure 8. These two pink pearls (13.3 and 12.2 mm in diameter) are reportedly from the Concho River in Texas. Courtesy of Boaz Arch; photo by Robert Weldon.

SYNTHETICS AND SIMULANTS

"Bull's-eye" optic figure in synthetic berlinite. Dr. Emmanuel Fritsch recently received a synthetic berlinite crystal as a donation from Dr. Robert Shannon, of the E. I. Dupont Central Research Laboratory. The crystal was grown by Bruce H. T. Chai, of the University of Central Florida in Orlando.

Berlinite, a naturally occurring aluminum phosphate with the chemical formula $AlPO_4$, is structurally isomorphous with quartz. Both minerals crystallize in the hexagonal (trigonal) crystal system and are optically active (i.e., they have both left- and right-handed varieties). Because of this, when examined between crossed polarizers, untwinned berlinite also shows the "bull's-eye" optic figure (figure 9) described in the gemological literature as being characteristic only of quartz (natural and synthetic). Therefore, it is possible that the "bull's-eye" figure might be characteristic of all optically active uniaxial crystals.

Figure 9. Untwinned berlinite (the crystal illustrated here is synthetic) can show the "bull's-eye" optic figure usually associated only with quartz. Photomicrograph by John I. Koivula.

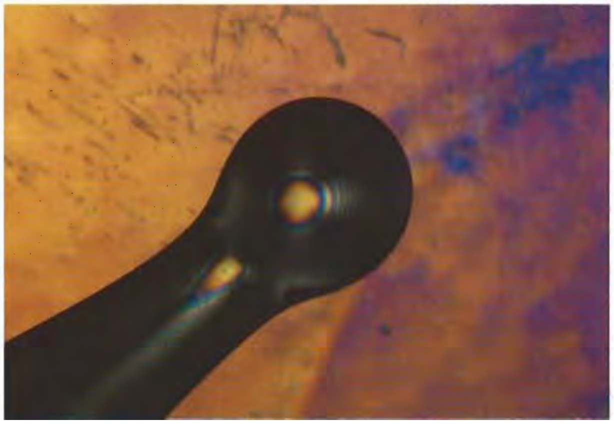


Figure 10. This well-detailed, 35-mm-high cameo is made of ceramic alumina, which has excellent durability. Photo by Robert Weldon.

An unusual ceramic cameo. A particularly fine, non-assembled white-on-blue ceramic cameo (figure 10) was brought to our attention by Masashi Furuya, a gemologist and executive manager of Furuya and Co., of Yamanashi-ken, Japan. The Mohs hardness of the cameo had been stated to be near 9, which suggested that it might be composed of ceramic alumina. The pleasing blue color hinted that the coloring agent could be cobalt. A judiciously applied number 8 (topaz) hardness point failed to produce a scratch on the cameo, thus supporting the reported hardness. An attempt to obtain a refractive index using a Duplex II refractometer and white light yielded a vague reading between 1.75 and 1.76. Qualitative chemical analysis done by GIA's Emmanuel Fritsch and Michael Moon showed that the detectable elements in the cameo were indeed aluminum and cobalt. This is the first time we have seen a cameo of this composition.

The figure on this cameo is very nicely detailed. Because of this, and because of its excellent durability, it appears that such ceramic alumina cameos would work well in a wide variety of jewelry and decorative items.

A clever imitation emerald crystal. During a recent visit to the city of Anapolis, in Goiás, Brazil, GIA's Carl Chilstrom and GIA Gem Trade Laboratory's Caio Maia were shown some unusual "emerald" crystals by Sebastião Domingos de Oliveira and Ronaldo Priori of Metais de Goiás S/A. According to these gentlemen, the crystals had been represented as natural emeralds from the Campos Verdes area, near Santa Terezinha de Goiás. They also stated that manufactured emerald crystals of this type were being seen with some frequency, and they generously donated a sample crystal so that it could be studied in detail.

The 17.51-ct "rough" crystal we examined (figure 11) is a semi-transparent, slightly rounded, doubly terminated hexagonal prism with two of the prism faces polished. Small patches of light brown "matrix" material adhere to the unpolished faces. The crystal is a very convincing slightly bluish green. When held up to a light source, it gives the impression that it could produce one or two excellent faceted emeralds. There is also an obvious, somewhat jagged fracture that superficially circumvents the entire crystal near its middle; this is the actual assembly point. There are no core-hole openings at the surface, as have been present on the assembled crystals we have seen in the past.

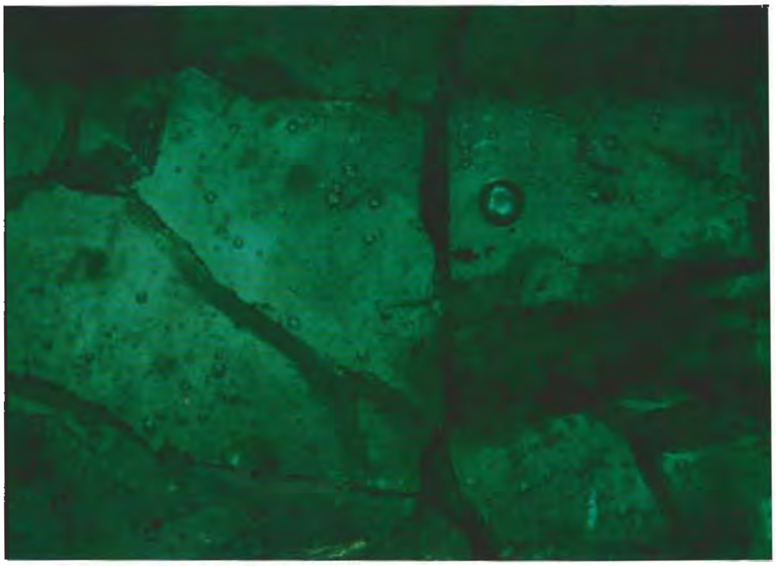
Figure 11: Although this 17.51-ct crystal appears to be emerald, it actually is a clever fake made with near-colorless beryl. Photo by Robert Weldon.

To create this "gem," the pale green to near-colorless beryl crystal was broken in half across its prism faces in a direction essentially perpendicular to the long axis. The cores of the two halves were then drilled out from their freshly broken surfaces, filled with a dyed green epoxy or liquid plastic material, and reassembled. With this method, there are no suspicious openings to the surface other than that provided by the main fracture described above. Once you get by the deceptive outward appearance, however, identification of this imitation emerald crystal is relatively simple.

With a 10× lens or microscope, it was easy to see numerous spherical gas bubbles just beneath the surface of the crystal, visible through any of the six prism faces. Their presence would immediately indicate that something is "wrong." It is also apparent that any fractures in the surface of the crystal only go inward to a uniform depth of about 1 mm or less (figure 12). If specific gravity testing liquids are available, the low S.G. of 2.36±0.01 (compared to the 2.70 typical of natural emeralds) easily reveals that this is an assembled imitation. The bluish green to yellowish green dichroism of emerald is also absent in this imitation. There is no color filter reaction, and the crystal has an absorption spectrum somewhat reminiscent of dyed green jadeite, but not at all like emerald.

Chatham expands. Chatham Created Gems, the world's largest producer of flux-grown synthetic emeralds and rubies, had previously cut all of their stones in Hong

Figure 12. With magnification, fractures confined to near-surface areas and gas bubbles can be seen in the "emerald" crystal shown in figure 11, proving that it is an imitation. Photomicrograph by John I. Koivula; magnified 25×.



Kong, but in fall 1988 they added cutting facilities in Thailand to meet increasing demand.

Chatham also announced that for the first time they will be growing their synthetic gems in an undisclosed overseas location as well as in their U.S. laboratories in San Francisco. At the same time, they will be increasing production in the United States through expansion of their existing laboratories. Chatham's total production and resulting sales amounted to over 10,000 ct of synthetic gems per month at the end of 1988.

Union Carbide growing large synthetic sapphires. GIA's Emmanuel Fritsch recently attended the 11th Conference on Crystal Growth, organized by the American Association for Crystal Growth, which was held in northern California from June 5 to 8. He reports that Union Carbide is now growing colorless synthetic sapphires of excellent quality in sizes up to 15 cm in diameter in an iridium crucible. Union Carbide also produces titanium-doped synthetic sapphire that emerges with a color they refer to as "light ruby" (pink sapphire?). Both materials are grown using variations of the Czochralski-pulling technique. Although both types of synthetics are manufactured principally for industrial applications (electronics and lasers, respectively), representatives of Union Carbide report that "lesser quality" top and bottom portions of the synthetic crystals are sold by a bidding system to the jewelry industry. They indicated that this is a common practice in other companies that grow optical-quality materials.

ANNOUNCEMENTS

The Amsterdam Sauer Gemstone Museum has recently opened in the gem-rich country of Brazil. Located in Rio de Janeiro, this new museum encompasses more than 1,200 specimens of both rough and cut gemstones gathered since 1940 by the museum's founder, Jules R. Sauer. Many of these were used to illustrate his book *Brazil, Paradise of Gemstones.*

The new museum's most recent acquisitions are indeed significant. One is a gigantic, 13,400-gram (67,000-ct), gem-quality aquamarine crystal that was discovered last year in Marambaia, northern Minas Gerais. Another is a very fine cat's-eye chrysoberyl, cut from rough unearthed in the town of Padre Paraíso, also in Minas Gerais. The Sauer Museum is also home to what is said to be the world's largest faceted natural alexandrite, 122.40 ct.

The Gemmological Association of Israel was formed during the May reunion/conference of the Gemmological Institute of Israel. The association's aims include promoting gemology in Israel and providing graduates of the Israeli institute with updates on current technologies. Members must have passed a "recognized" gemology course either in Israel or abroad. Contact Jeremy Graus for more information at 1 Jabotinsky St., Ramat-Gan, 52520, Israel; fax: 972-3-262547.

Gem miners and wholesalers in Zambia have formed a trade association and are collecting information on prices for various grades of rough and faceted amethyst, aquamarine, emerald, malachite, and tourmaline. Assistance from the trade is welcome. For further information, write to Zambia Gemstone and Precious Metals Association, P.O. Box 31099, Room 17, Luangwa House, Cairo Road, Lusaka, Zambia.

The 1989 Santa Fe Symposium in Jewelry Manufacturing Technology will be held September 20–23 in Santa Fe, NM. A variety of speakers will address issues on all aspects of jewelry manufacturing, from rediscovering the technology used in antique jewelry to modern health issues for jewelers. For information, contact the Santa Fe Symposium at 3820 Academy Parkway North N.E., Albuquerque, NM 87109; (505) 344-3357.

KOSIMA '89, an exhibit of jewelry, gem materials, machinery, and equipment, will take place October 20–23, 1989, at the Helexpo's fairgrounds in Thessaloniki, Greece. Helen Lazaridou of Helexpo can be reached at 154, Egnatia Str., Gr 546 21 Thessaloniki, Greece, or via fax at 031-229-116.

The Fashion Institute of Technology will conduct a symposium on "The Romance of the Stone"—diamonds—on Sunday, October 29, 1989. Noted speakers will include François Curiel of Christie's; Peter Schaffer, specialist in Fabergé and Russian jewelry; Diana Scarisbrick, an authority on English jewelry; Benjamin Zucker, historian, collector, and gem dealer; Ken Scarratt of the Gem Testing Laboratory of Great Britain; William Boyajian, president of GIA; Robert Crowningshield of the GIA Gem Trade Laboratory; and Lloyd Jaffe of the American Diamond Industry Association. For information, call Jean Appleton at (212) 760-7254.

The Mineralogical Society of Southern California will be holding their annual show at the Pasadena Center in Pasadena, CA, on November 25 and 26, 1989. The theme will be "Famous Mining Districts." Along with exhibits of gems and minerals, there will be several lectures. For more information, contact Michael T. Evans at 13059 Casa Linda Lane #36H, Garden Grove, CA 92644.

BOOK REVIEWS

Elise B. Misiorowski and Loretta Bauchiero, Editors

GEMSTONES

*By Michael O'Donoghue, 372 pp., illus., publ. by Chapman & Hall, Ltd., London, 1988. US$50.00**

In his preface, O'Donoghue says that "*Gemstones* is the first attempt in English to bring together the geological, mineralogical, and gemmological developments that have taken place during the last 30 years." One wonders, however, if such efforts as Webster's monumental *Gems: Their Sources, Descriptions and Identification,* as updated by the late Basil Anderson in a fourth (1983) edition, would seem to limit that time frame.

In what ways, though, does O'Donoghue's *Gemstones* differ from earlier gemological texts? There are several examples. In his initial chapter, "Formation and Occurrence of Gemstones," there is a heavy emphasis on inclusions from the point of view of formation, followed by a recitation of the inclusions in the major gemstones plus a section on inclusion photography. In the next chapter, on the nature of gemstones, he gives slightly greater emphasis to valency and bonding than in most gemological books. Special attention is given to what he terms "recent developments in gem testing," in which category he includes thermal conductivity, reflectivity, and X-ray topography, as well as the scanning electron microscope and microprobe. Electron paramagnetic resonance, plus X-ray and ultraviolet spectroscopy, are also considered, but not infrared.

Most (more than 200 pages) of the remainder of the book is devoted to the description of inorganic, organic, synthetic, and imitation gem materials. There are also several identification tables. The descriptive sections are clearly aimed more for the collector and the hobbyist than for the jeweler, since many of the materials mentioned would have no possible use in a jewelry environment. For the collector, O'Donoghue does try to cover everything cuttable, including such rarities as linarite, ludlamite, millerite, meliphanite, mellite, mesolite, and serandite. It should be noted that under "millerite," the opaque nickel-sulphide with a metallic luster, he states, "A cloudy yellowish green stone has been recorded in cut form from Rossing, Namibia." This is clearly a reference to milarite, not millerite.

In the specific gravity table, synthetic emerald is listed as 2.66–2.68. This range would not encompass all hydrothermal material. The pale green spodumene from Brazil is labeled "hiddenite" in a color plate. This would not fit the chrome-bearing spodumene originally described as hiddenite. Peridot is described under olivine, suggesting a mineralogic rather than a gemological orientation. Some of his descriptions of various gem materials, however, are exhaustive and would be useful to a student. For example, the corundum section discusses 17 sources, with individual essays on more than half of these.

Overall, this book has some good information and is a useful addition to any library. It leaves the impression, however, that it is a compilation written primarily for the collector of rare and unusual gems.

RICHARD T. LIDDICOAT
Chairman of the Board, GIA
Santa Monica, CA

CHANNEL SETTING DIAMONDS

*By Robert R. Wooding, 136 pp., illus., publ. by Dry Ridge Co., Erlanger, KY, 1987. US$29.95**

The setting of diamonds in a channel is very popular in today's jewelry market. Yet for this, as for most setting styles, there is little written on the specific steps involved in the manufacturing process. In this well-illustrated book, Mr. Wooding provides a detailed description of the techniques he uses for channel setting diamonds. He clearly acknowledges that there are alternate techniques, but offers his for reference or for modification by the individual jeweler.

The contents are divided into two sections. Section one begins with inspection of the diamonds to be set (for size, quality, internal flaws, chips), and then goes into layout of the channel, cutting the channel, burring the seats, and securing the diamonds. The clean-up procedures are explained thoroughly also. The technique of cutting a channel into metal may seem outdated to some, as most channels are now prefabricated. Yet the technique is valid, and the author explains lucidly the requirements for accomplishing a properly cut channel. Readers will find themselves referring to this first section often.

Section two discusses the various types of channels: closed, open, curved, tapered, angular, and inlaid. The inlaid channel uses round diamonds as well as square-cut ones. This section is very helpful, and the illustrations are so good that I found myself following them alone and ignoring the text. Although the author tends to be overly elaborate in his explanations for a simple technique, the in-depth information provided on handling these different types of channels is easily worth the price of the entire book.

Immediately following section two is a discussion of problems and solutions that offers some troubleshooting techniques. I found this feature to be fun reading and would have liked to see it expanded. Finally, an appendix furnishes lists of diamond-setting schools as well as suggested readings, including two other books by Mr. Wooding.

I appreciate the fact that Mr. Wooding has shared some of his techniques (too few bench jewelers do), and use this book as a reference to complete my own projects.

MATTHEW BEZAK
Jeweler-Instructor
GIA, Santa Monica

GEMOLOGICAL ABSTRACTS

Dona M. Dirlam, Editor

COLORED STONES AND ORGANIC MATERIALS

Crystal chemistry of alkali-deficient schorl and tourmaline structural relationships. F. F. Foit, Jr., *American Mineralogist*, Vol. 74, No. 3/4, 1989, pp. 422–431.

The crystal chemistry of the tourmaline group is extremely complex due to the wide variation in composition, multiple atomic sites present in the crystal structure, and range of geologic occurrences of these minerals. On the basis of a survey of the compositions of various natural tourmalines, the author and his colleagues previously reported the existence of both proton- and alkali-deficient tourmalines. In this article, data from a crystal structure refinement of an alkali-deficient schorl are compared with those of 12 other documented tourmalines to better understand the crystal structures of tourmalines of this type. Specific changes in the structure due to the absence of cations or other types of substitutions are described. The article concludes with a discussion of the chemistries of natural and synthetic Na-Mg tourmalines which can be rationalized on the basis of the data reported here. *JES*

Gemmology Study Club lab reports. G. Brown and J. Snow, *Australian Gemmologist*, Vol. 17, No. 1, 1989, pp. 27–33.

Several items of interest are described in these well-illustrated Gemmology Study Club Lab Reports. First is a review of the source and cause of the phenomenal color in spectrolite, a type of labradorite feldspar from Finland. A labradorite cabochon from the Malagasy Republic is described. It displayed a strong greenish blue schiller and a grayish, semitransparent body; had a spot R.I. of 1.56 and an S.G. of 2.7; and was inert to both long- and short-wave radiation. Magnification revealed black exsolved needles of magnetite-ilmenite oriented along polysynthetic twin lamellae, as well as yellowish reflective short needles and tablets of rutile.

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

Inquiries for reprints of articles abstracted must be addressed to the author or publisher of the original material.

The reviewer of each article is identified by his or her initials at the end of each abstract. Guest reviewers are identified by their full names. Opinions expressed in an abstract belong to the abstracter and in no way reflect the position of Gems & Gemology *or GIA.*

A large cabochon of wurtzite, the hexagonal form of zinc sulphide, was found to have brownish agate-like banding, a Mohs hardness of about 4, an S.G. of 4, an R.I. over the limits of the standard refractometer, a slightly waxy to vitreous luster, and orange fluorescence to long-wave U.V. radiation (but was inert to short-wave U.V.).

Also covered are a gold-lipped oyster that illustrates the attachment mechanism used to produce hemispherical blister pearls; a review of the crystal habits of, and flux used to produce, Ramaura synthetic rubies; the properties of Oregon sunstone; two assembled stones that imitate emerald; the stucture of whalebone (used for scrimshaw); and white- to flesh-colored opaque crystals that were first described as scapolite but which X-ray diffraction analysis indicated are alkali feldspar pseudomorphs after scapolite. *RCK*

Greenbushes spodumene-quartz (A new Australian lapidary material). G. Brown and H. Bracewell, *Australian Gemmologist,* Vol. 17, No. 1, 1989, pp. 14–17.

A spodumene-quartz rock of potential lapidary or carving use is being recovered from the Greenbushes pegmatite in southwest Western Australia. Zoning within the pegmatite has effectively segregated its major tin, tantalum, and lithium mineralizations into distinct ore horizons, with the lithium-rich spodumene-quartz unit occurring at depth on the foot wall of the pegmatite. Estimated reserves of spodumene are 42 million tons, albeit of undetermined gem potential.

While commercial mining has occurred sporadically for tin and tantalum ores, commercial mining for lithium did not begin until 1983. Spodumene is currently being recovered from an open-cut operation that involves drilling and blasting.

The spodumene-quartz rock is described as having a variegated pink and gray color. It consists of subangular crystals and crystal aggregates of kunzite within a glassy, transparent grayish quartz matrix, with approximately equal proportions of spodumene and quartz. The spodumene grains exhibit very reflective cleavage surfaces. Other properties of this primarily translucent material include: a uniform Mohs hardness of about 7; an S.G. of 2.81; spot R.I.'s of 1.54 (quartz) and 1.66 (spodumene); and no diagnostic visible-light absorption features or ultraviolet fluorescence. The material can be ground and shaped easily, with its polished surfaces exhibiting a vitreous luster of moderate intensity. *RCK*

Historical notes on mineralogy: On Kunz and kunzite. L. H. Conklin, *Mineralogical Record,* Vol. 18, No. 5, 1987, pp. 369–372.

Lawrence Conklin, author of the 1986 book *Letters to George Frederick Kunz,* reviews the discovery and subsequent naming of kunzite, the pink to lilac variety of spodumene. Conklin first examines the controversy over who discovered this variety of spodumene. Some people credit Frank Salmons of the Pala Chief mine near Pala in San Diego County, California. However, Conklin points out that the first specimens from the White Queen mining claim, also near Pala, were sent to Kunz by Frederick M. Sickler in December 1902. (It should be noted that the H. C. Gordon letter to Kunz describing the discovery and cited on page 369 of this article was written in 1903, not 1902 as stated in the article. This was confirmed by Conklin.) Drawing extracts from the correspondence of the principals involved, Conklin traces the history of the names that were suggested for this variety—from salmonsite to California iris—and describes how, ultimately, *kunzite* prevailed.

The four photographs are delightful, beginning with a black-and-white portrait of Fred Sickler and finishing with a beautiful color photograph of the famous kunzite crystal that Kunz sold to J. P. Morgan in 1903. *DMD*

Oxygen-isotope zonation of agates from Karoo volcanics of the Skeleton Coast, Namibia. C. Harris, *American Mineralogist,* Vol. 74, No. 3/4, 1989, pp. 476–481.

Several mechanisms have been proposed that attribute the formation of agate to various types of silica-rich solutions at a range of crystallization temperatures. In this article, oxygen isotope data are used to estimate the conditions of formation of some banded agates from Namibia. They occur in cavities in rhyodacite volcanic rocks of the Etendeka Formation.

The agates exhibit layered or concentric banding, and consist of both coarsely crystalline and microcrystalline quartz. A systematic difference was noted in the delta oxygen-18 values of the two types of quartz, with the crystalline quartz having lower values on average. This difference is attributed to the crystallization of the crystalline quartz layers from a water vapor, and the microcrystalline quartz layers from a silica solution, at about 120°C. This temperature of formation is lower than the temperature conditions determined in other studies. A model is presented for the formation of agate in the Karoo volcanic rocks based on these oxygen isotope results. *JES*

Proceedings of the First International Amber Symposium. H. Fraquet, *Journal of Gemmology,* Vol. 21, No. 6, 1989, pp. 347–350.

This brief overview of the First International Amber Symposium, which was held in Warsaw in October 1988, points out the importance of this material to collectors and scientists worldwide. Regarded as a somewhat eclectic item by most American gemologists, amber is usually underrated as a gem. Collectors will find Ms. Fraquet's comments on the papers presented—ranging from locality descriptions to paleontological issues and descriptions of unusual related resins—to be mere appetizers. The conference concluded with visits to the amber locality near the city of Gdansk and to the collection of amber at Malbork Castle. *CMS*

DIAMONDS

Famous diamonds of the world XXXII: Kimberley. I. Balfour, *Indiaqua*, Vol. 47, No. 2, 1987, pp. 120–121.

The bulk of this article recounts tales about the Kimberley mine. The remainder describes the Kimberley diamond, allegedly discovered in the South African mine for which it is named. No date is reported for this discovery.

The 490-ct yellowish rough was fashioned into a 70-ct emerald cut in 1921. Baumgold Bros. of New York recut the stone to its current weight of 55.09 ct in 1958. In 1971, they sold the Kimberley to a private collector from Texas. *JLC*

Famous diamonds of the world XXXVII: Little Sancy. I. Balfour, *Indiaqua*, Vol. 52, No. 1, 1989, pp. 147–148.

Balfour writes about the smaller of the two diamonds named after the 14th-century French financier, Nicholas Harlay de Sancy. The pear-shaped Little Sancy weighs approximately 34 old carats or 24.81 metric carats.

After Nicholas Sancy's death, the Little Sancy was sold to Prince Fredrick Henry of Orange (1584–1647). It is suspected that his grandson, William III of England, may have given the stone to his consort, Queen Mary II.

Eventually, the diamond came into the possession of Frederick I of Prussia, another grandson of Prince Frederick Henry. For centuries, the Little Sancy was an important part of the crown jewels of Prussia. It was last reported to be on display in the Royal Prussian House in Bremen. *JLC*

Famous diamonds of the world XXXIX: Harlequin. I. Balfour, *Indiaqua*, Vol. 52, No. 1, 1989, p. 149.

A brief discussion of the origin of the word *harlequin* is followed by a note about the 22-ct pear-shaped diamond bearing this name. This diamond was once set in a "golden fleece" for Karl Alexander, Duke of Würtemberg. The Harlequin was removed from this ornament and set as a pendant to a diamond necklace after the duke's death in 1737. Currently, it is on display at the Würtemberg Landesmuseum in Stuttgart, Federal Republic of Germany. *JLC*

Famous diamonds of the world XL: Dresden White. I. Balfour, *Indiaqua*, Vol. 52, No. 1, 1989, p. 149.

Also known as the Saxon White, this colorless square-cut diamond is reported to weigh 49.71 ct (although a photo caption in this article labels it as 40 6/8 ct). Balfour writes that in 1746 the Dresden White replaced the Dresden Green diamond in a setting and was later mounted as the center stone of an elaborate jeweled shoulder knot.

The diamond remained in Dresden until World War II, when Russian forces took the Saxon crown jewels to Moscow. In 1958, the Soviet government returned the jewels to Dresden, where they are on display at the Grünes Gewölbe Museum. *JLC*

Fingerprinting diamonds using ion implantation. R. C. DeVries, R. F. Reihl, and R. E. Tuft, *Journal of Materials Science*, Vol. 24, 1989, pp. 505–509.

At levels that do not impart visible damage, ion implantation can be used both to reveal the growth history of a diamond and to "fingerprint" the stone on the basis of the growth structure unique to each diamond. The characteristic patterns are made visible by subsequent electrostatic charging and dusting, and can be obscured by simply wiping off the dusting powder. Boron, phosphorus, and carbon ions have been used to test this technique on natural and synthetic diamonds. Although the inhomogeneity of natural diamonds and the method's sensitivity to humidity can create some problems, the technique is believed to be generally useful to "fingerprint" gem diamonds. This "fingerprint" does not seem to be affected by "normal wear," although repolishing could remove the surface layer of implantation. A General Electric patent has been issued on this process. *EF*

A study of diamonds of cube and cube-related shape from the Jwaneng mine. C. M. Welbourn, M.-L. T. Rooney, and D. J. F. Evans, *Journal of Crystal Growth*, Vol. 94, 1989, pp. 229–252.

The Jwaneng mine in southwest Botswana is unusual in that about 8% of the diamonds produced there have shapes that could be loosely described as cubes, corresponding to the variety III of cubic shapes described by Orlov. The authors studied in great detail "re-entrant cubes" and "rounded cubes" from this area using X-ray and cathodoluminescence topography. It appears that the shape of "re-entrant cubes" is the result of growth rather than dissolution, and that they have experienced a mixed octahedral and cuboïd growth. Their cores also contain cloud-like light-scattering defects, which might be thin disks, 1 micron in diameter, oriented parallel to the octahedral face. These inclusions correspond to an increased hydrogen concentration (measured using infrared spectroscopy with a microscope attachment) consistent with the presence of C-H bonds at internal interfaces. The clouds also correspond to regions of yellowish green long-wave ultraviolet luminescence within an otherwise blue luminescence.

In contrast, "rounded cubes" possess cores of normal octahedral growth, free of cloud-like defects, that are surrounded by mixed-habit growth zones where the cuboïd growth is largely predominant. Infrared spectroscopy indicates that these cores contain nitrogen in an advanced state of aggregation compared to their rims. The authors favor the theory that the growth of the core

and the overgrowth took place at different times, and that the time interval between the two phases of growth was much longer than the time over which the core originally grew. Twenty-five figures accompany the text.
EF

A look back down The Garden. S. Herbert, *Indiaqua*, Vol. 52, No. 1, 1989, pp. 57–60.

In this article, Herbert brings Victorian Hatton Garden (London's center for the diamond trade) to life in an imaginary trip to the past. Using the post office directories from 100 years ago, Mr. Herbert reconstructs the Garden and its prominent residents, including Anton Dunkelsbuhler, who introduced the young brothers Louis and Ernest Oppenheimer to the diamond world. In 1890, No. 84 Hatton Garden housed the Barnato brothers; the following year, the merger of Barnato's Kimberley Central Mining Co. and Cecil Rhodes's De Beers Mining Company caused the name of Barnato to disappear from The Garden forever.

The balance of the article concentrates on the four generations of the Tom family who have occupied Hatton Garden since late Victorian times. Today, at No. 37, R. H. Tom & Son sorts and grades diamonds for the toolmaking industry. Customers' specific requirements, including wear resistance, are met by careful grading and sorting for size, purity, and color. Weight tolerances have become more precise to meet the requirements of high-tech industries. For top-quality tools, octahedrons, dodecahedrons, macles, flats, and points are used in a broad size range from around 15 ct per stone down to 25 stones per carat. The company is now expanding its international division.
Carol M. Patton

GEM LOCALITIES

L'améthyste au Brésil (2). Classification et localisation des gîtes – Inclusions (Amethyst in Brazil [2]. Classification and localization of the deposits – Inclusions). J. Cassedanne, *Revue de Gemmologie a.f.g.*, No. 95, 1988, pp. 3–9.

This is the second of a two-part article that proposes and illustrates a classification system for amethyst deposits in Brazil. For each deposit, Cassedanne includes location and access, occurrence, mining methods, nature of the rough, its behavior to heat treatment, and a list of typical inclusions. Numerous photographs are provided.

Hydrothermal vein deposits (other than those listed in part 1) are named, and the characteristic inclusions of the amethysts from Xambio (Goiás) are described.

The stockwork deposits consist of a complex network of veinlets, mostly in Precambrian quartzites. The Cabeludos mine, a typical example, produces amethyst that loses and then regains its color with heat treatment under 400°C.

Deposits in massive brecciated zones are also found in Precambrian quartzite, dispersed in a brecciated filling. Most of the amethyst from the Fazenda Serra do Salto is heat treated to citrine. Pale gray-green quartz, or "lambreu," is also found.

Amethyst-bearing cavities as large as several meters occur in cavernous brecciated zones in quartzites. The Grota do Coxo mine is one example, with amethyst crystals that commonly exhibit complex growth features, goethite inclusions, and strong color zoning. The Alto Bonito deposit, best known as Marabá, is also of this type, and currently is the largest amethyst producer in Brazil.

Granitic pegmatite amethyst deposits produce relatively little but are common in the states of Minas Gerais and Bahia. The Boa Vista and Concordia deposits are described in some detail, while others are simply listed.

Deposits in granitoïds, although common, have a negligible production except from Batoque (Ceará). Veinlets or chunks of xenomorphous amethyst crystals fill the spaces between the other granitoïd constituents. The gems were deposited during a hydrothermal phase and lose color when heated.

Secondary amethyst deposits result from the erosion of any of the types of amethyst occurrences previously cited. They are of no economic significance except for the Brejinho conglomerates (Bahia) and the lateritized alluvium at Pau d'Arco (Pará).
EF

The discovery of a new emerald occurrence in Brazil: Capoeirana (Nova Era) Minas Gerais. D. Schwarz, *Australian Gemmologist*, Vol. 17, No. 1, 1989, pp. 4–5.

This brief report begins with a description of the location and overland access to this new emerald deposit, which was discovered in August 1988. Within days, several hundred *garimpeiros*, some from the nearby Hematita alexandrite deposit, began mining in earnest.

The host rock is described as a biotite-phlogopite-schist, with the beryllium being provided by pegmatitic intrusion. The geology of the deposit, along with the color, quality, and inclusions of the emeralds, is reportedly comparable to that of the Belmont mine, only 10 km away.

The author states that while no estimate of the reserves has been made to date, the geologic conditions are favorable for the existence of "extensive emerald mineralization."
RCK

The Anjanabonoina pegmatite, Madagascar. W. E. Wilson, *Mineralogical Record*, Vol. 20, No. 3, 1989, pp. 191–200.

Madagascar has produced some magnificent gem and mineral specimens, many of which have been recovered from a series of pegmatite deposits in the central part of the island. This article describes one of the most famous deposits, the Anjanabonoina pegmatite, located 60 km west of Antsirabe.

Although gemstones were reported from Madagascar as far back as the mid-1500s, the actual deposits were not systematically investigated until early in this century. The pegmatites are of granitic composition and occur in metamorphosed sedimentary rocks of Precambrian age. The mineralogic richness of these pegmatites is extraordinary.

Gem minerals found at Anjanabonoina include morganite beryl, danburite, spessartine garnet, spodumene, and topaz. However, the most important gem mineral is tourmaline, which occurs in magnificent and sometimes large crystals in a wide range of colors. The principal tourmaline species at the pegmatite is liddicoatite. Slabs cut from large crystals showing a complex pattern of colored bands are well known. The article includes several photographs of both the locality and the tourmalines for which it is famous. *JES*

Famous mineral localities: The Ouro Preto topaz mines. J. P. Cassedanne, *Mineralogical Record*, Vol. 20, No. 3, 1989, pp. 221–233.

This article describes the famous topaz localities west of Ouro Preto in Minas Gerais, Brazil. These deposits have been worked intermittently since they were first discovered in the mid-1700s. Because the geology of this area is quite complex, there has been considerable speculation on the origin of the topaz. The current theory is that it formed hydrothermally.

The topaz occurs in a layer of talc-clay rock that outcrops over a large area. The distribution of topaz-rich zones is sporadic, leading to numerous deposits of various sizes. Miners recover the gem rough by removing the overburden and then quarrying and washing the topaz-bearing rock.

Topaz occurs at Ouro Preto as euhedral crystals or crystal fragments in an attractive range of colors: orange, brown, pink, purple, red, and nearly colorless. The orange material is known commonly as "Imperial" topaz. Almost all of the red topaz on the market today is created by the heat treatment of yellow topaz to 450°–500°C. Another gem material from this locality is euclase. *JES*

Les héliodores du Sapucaia (Heliodors of Sapucaia). J. Cassedanne, *Revue de Gemmologie a.f.g.*, No. 96, 1988, pp. 5–6.

The deposit of Fazenda Campo Alegre de Jaime A. Valadares, near Sapucaia, Minas Gerais, Brazil, became famous because of its (sometimes sporadic) production of yellow beryl (heliodor). Cassedanne describes the locality, access, and workings of this pegmatite, in which aquamarine and colorless and green beryl have also been found.

In 1986, the mining of an abandoned pillar produced 2,600 kg of partly gem heliodor. The crystals were corroded hexagonal prisms, commonly reaching 10 cm, with spectacularly flat basal faces. The yellow color, due to Fe^{3+}, is sometimes altered by a brown, greenish, or orangy component. Twenty-five to 30% of the heliodor in that find was of cutting quality. The internal characteristics consist mainly of irregularly shaped two-phase inclusions, numerous milky wispy veils, and fine parallel channels. One map and five photographs (one in color) illustrate this article. *EF*

Mineralogy and paragenesis of the Little Three mine pegmatites, Ramona District, San Diego County, California. E. E. Foord, L. B. Spaulding, Jr., R. A. Mason, and R. F. Martin, *Mineralogical Record*, Vol. 20, No. 2, 1989, pp. 101–127.

The pegmatite mines of San Diego County have been famous for almost a century for their production of both gem-quality and specimen-quality minerals. One of the few mines in this area that is still in active production, the Little Three mine, located just outside the town of Ramona, is world renowned for its production of fine-quality orange spessartine garnet and light blue topaz. This article provides a complete description of this important pegmatite occurrence.

Beginning with a review of the mining history, the authors describe in detail the geology and general features of the several pegmatite dikes that outcrop in the mine area. Information is provided on the numerous minerals found at the mine, including data on their crystallography, chemical composition, and paragenesis. Both black-and-white as well as color photographs illustrate some of the more interesting crystals and mineral specimens that have been found, including the cover photograph of a 4-cm spessartine crystal. The article concludes with a well-written description of the stages of pegmatite formation. *JES*

New East African deposits. T. Themelis, *Lapidary Journal*, Vol. 42, No. 11, February 1989, pp. 34–39.

Themelis reports on preliminary gemological studies done on specimens of prase opal, emerald, and sapphire (both asteriated and nonphenomenal) from various localities in East Africa.

The opal (which shows no play-of-color) is reportedly from an area near Navarera in the Masai Steppe. Two specimens were tested with results similar to prase opal from other localities. One of the specimens showed "iridescent colors" under crossed polarizers (presumed by this abstracter to be strain, which is commonly seen in opal).

The emerald deposit (reportedly new) is near Sumbawanga, in southwest Tanzania. The mine uses heavy equipment in the recovery of the emeralds. Crystals larger than 100 ct have apparently been removed, with a "usual" size of 20 to 30 ct, according to the author. For the most part, the crystals are fine green in color, but at present material is only available in small quantities.

Sapphires are being recovered from a locality 135 km northwest of Lodwar in northern Kenya. Both asteriated and "geuda" rough are found. Heat treatment was done by the author on the "geuda" types with good results.

Two color photos accompany the article. *WRV*

Recent discoveries of hydroxylherderite in Minas Gerais. J. P. Cassedanne, *Mineralogical Record,* Vol. 20, No. 3, 1989, pp. 187–188.

This article summarizes the recent discoveries of crystals of hydroxylherderite at three pegmatite localities in Minas Gerais, Brazil: Boa Esperança and Jove Lauriano, both near Divino das Laranjeiras; and the Urubu pegmatite in the Jequitinhonha river valley near Araçuaí. A brief description of the hydroxylherderite crystals from these three localities is presented. *JES*

INSTRUMENTS AND TECHNIQUES

Analysis of Burmese and Thai rubies by PIXE. S. M. Tang, S. H. Tang, T. S. Tay, and A. T. Retty, *Applied Spectroscopy,* Vol. 42, No. 1, 1988, pp. 44–48.

After a brief summary of the gemological properties and geologic occurrences of Burmese and Thai rubies, the authors report on their trace-element analyses of these stones using PIXE (Proton-Induced X-ray Emission). Sixty rubies were investigated, roughly half of Burmese origin and half of Thai origin. The Burmese rubies were found to contain higher concentrations of all impurities (Cr, Si, S, Cl, K, Ca, Ti, V, and Mn) except iron. In particular, they generally contain significantly higher amounts of chromium, vanadium, and silicon than their Thai counterparts. Burmese rubies have an iron concentration that, on average, is only one-fourth that of Thai stones; however, the two ranges of iron concentration do overlap. Other minor trace elements observed include gallium, nickel, copper, and zinc. The authors conclude by summarizing the advantages of PIXE: It requires minimal sample preparation, is highly sensitive, and produces no damage to the stones, even though it only analyzes a surface layer. *EF*

Identification de micro-inclusions dans des rubis et émeraudes de synthèse par spectroscopie Raman (Identification of microinclusions in synthetic rubies and emeralds by Raman spectroscopy). M.-L. Delé-dubois, J.-P. Poirot, and H.-J. Schubnel, *Revue de Gemmologie a.f.g.,* No. 88, 1986, pp. 15–17.

Raman spectroscopy allows the identification of microinclusions without destroying or grinding down the host gem. Some restrictions apply: The inclusion must be big enough (at least 2 microns or more, depending on the material) and not too shallow (5 mm is a maximum), and fluorescence must be avoided. A list of inclusions studied by Raman spectroscopy in synthetic emeralds and rubies is provided, along with the identifying spectral features. New results include the discovery of sodium ortho-vanadate in Ramaura synthetic rubies and various polymorphs of MoO_3 in Lennix synthetic emeralds. *EF*

Détermination, par microréflectométrie diffuse, de la concentration en Co^{2+} tétraédrique dans les sphalerites (Determination of tetrahedral Co^{2+} concentration in sphalerites by diffuse microreflectance measurements). B. Cervelle, F. Cesbron, and N. Drin, *European Journal of Mineralogy,* Vol. 1, No. 1, 1989, pp. 127–133.

The color of yellowish green to green sphalerites was studied using visible absorption spectroscopy. The green hue is related to the presence of trace amounts of cobalt (0.3 to 405 ppm of Co^{2+}) in tetrahedral coordination in crystals with low iron content (less than 1%). The samples studied came from France, Kenya, Spain, and Mexico. *EF*

Methods for the distinction of natural and synthetic citrine and prasiolite. K. Schmetzer, *Journal of Gemmology,* Vol. 21, No. 6, 1989, pp. 368–391.

In this comprehensive article, Dr. Schmetzer begins with a review of the literature and existing knowledge on the topic, focusing on spectral characteristics and causes of color. He then reports his observations of microscopic and spectral features for a broad range (but unspecified number) of natural and synthetic samples, both irradiated and naturally colored, from a variety of sources. While Dr. Schmetzer provides a wealth of valuable information, the discursive presentation forces one to dig for it. Tables of both the sample localities and sources, as well as the characteristic features, would have been helpful. The author concludes that combined use of ultraviolet and visible spectroscopy and optical microscopy can identify the nature of any citrine or prasiolite sample. Thirty-five illustrations accompany this worthwhile contribution. *CMS*

Optronix® gemmological instruments. J. Snow and G. Brown, *Australian Gemmologist,* Vol. 17, No. 1, 1989, pp. 3–4.

This Instrument Evaluation Committee report covers two multi-purpose light sources manufactured in Thailand.

The Multi View II is described as an all-purpose, variable-intensity fiber-optic light source that incorporates a 100-watt quartz-halogen bulb and an 18-inch light pipe. Evaluators Snow and Brown found that the unit lived up to the manufacturer's claims although it was heavy and "became quite hot with continuous use."

The Omni View is described as an updated version of the other unit, incorporating additional features that allow it to be used for long- and short-wave ultraviolet radiation; determination of optic character and pleochroism, by means of a detachable polariscope; photography, with a 49mm camera adapter; and viewing gems in transmitted light, using an external white plastic viewing panel. One feature rated high by the evaluators is that each function is controlled separately by its own color-coded switch.

Although the evaluators give suggestions for improving the two units, they conclude that they offer "a variety of very useful light sources; at an appropriate cost." *RCK*

Un réfractomètre universel automatique le "Dialsan" (A universal automatic refractometer the "Dialsan"). E. Landais, *Revue de Gemmologie a.f.g.*, No. 96, September 1988, pp. 7–8.

In this article, Landais traces the development of an automatic Brewster angle refractometer that can be used to measure all indices of refraction between 1.50 and 2.90. The original prototype was presented at the International Mineralogical Association meeting in Orleans, France, in 1980. However, this first instrument had two major problems: The estimation of a minimum of illumination required visual observation, and the mechanical parts required high-precision engineering. Therefore, an effort was made to replace the optics and mechanical parts as much as possible with electronics. The second-generation prototype used a more efficient type of lamp, with a photodiode to estimate the minimum amount of illumination. Landais determined that the best sensitivity is achieved at around 800 nm. The polarizing filters were changed from simple Polaroid films to calcite prisms, which polarize light better and are also more transparent. However, this second prototype, with a precision of 0.02, still required manual intervention to look for the minimum of illumination, visualized on a digital voltmeter.

On the third-generation instrument, which is now commercially available, the entire operation is driven by a microprocessor. The index of refraction is now read directly on the digital display, with a precision of ± 0.01 for a flat, clean facet of a gem. *EF*

JEWELRY ARTS

Circa dating. A. M. Miller, *Lapidary Journal*, Vol. 42, No. 11, February 1989, pp. 45–47.

Ms. Miller provides some descriptions of the various motifs of jewelry designs of the past and the general dates of their manufacture. For example: "Retro (1940–1950) jewelry had high drama of design and bold oversize gemstones. . . ." The article offers nice descriptions of general designs and popular stones of each period, but it provides little specific information on the accurate bracketing of dates for appraisals. Two color photos accompany the text. *WRV*

Georg Jensen: Making silver shine. L. Gordon, *Jewelers' Circular-Keystone*, Vol. 159, No. 5, May 1989, pp. 136–142.

This highly readable article is a nicely compact biography of noted Danish jeweler Georg Jensen, whose distinctive jewels of rounded, stylized plant forms were popularized during the first quarter of this century. Jensen usually fabricated his pieces in silver because he preferred the metal's "obstinate character." Silver was also more affordable, as were the cabochon-cut chalcedony, amber, opal, and moonstones that Jensen bezel set in most of his jewelry. Keeping his costs low allowed him to reach a broader range of clients and increased his exposure.

Initially trained as a sculptor, Jensen began making jewelry after seeing the Art Nouveau pieces displayed by René Lalique and others in Paris. Although Jensen was inspired by the Art Nouveau style, his jewelry transcended the period and continued to be popular well into the 1930s, long after the Art Nouveau movement had ended.

Amply illustrated and footnoted (a blessing for researchers), this article is a lucid and scholarly presentation of Georg Jensen's work. *EBM*

Glossary of antique jewelry terms. M. L. Waller, *Jewelers' Circular-Keystone*, Vol. 159, No. 5, May 1989, pp. 145–156.

Compiled originally to help customers understand appraisals, this glossary is also useful for jewelers writing appraisals.

Beginning with *acrostics* and ending with *witches heart*, the author provides succinct definitions for dozens of terms relating to antique and period jewelry. Although many of the defined words will be quite familiar to readers already involved in antique jewelry, several examples are enlightening. This glossary is not encyclopedic, nor does it claim to be; nevertheless, it offers sufficient information to satisfy an immediate need and is a handy quick reference guide for the jeweler-appraiser.

Nine color photos augment the text with interesting and unusual examples of antique jewels. A table showing several gem cuts frequently encountered in antique jewelry concludes this informative compendium. *EBM*

JEWELRY RETAILING

Your next diamond sales frontier: Fancy colors. D. Federman, *Modern Jeweler*, Vol. 88, No. 3, 1989, pp. 50–56.

In this attractively illustrated article, the author tries to help the average retail jeweler expand diamond sales by venturing into the market of fancy-colored diamonds. Attributing the increasing interest in colored diamonds mainly to the greater output of pink, brown, yellow, and even blue diamonds from the Argyle mines in Australia, with special interest placed on the browns, Federman provides some helpful hints on how to become acquainted with buying and selling these stones.

Relying on the experience of a few colored diamond dealers and retail sales managers from New York, Federman gives some specific ideas on how to learn more about colored diamonds (e.g., by visiting the Diamond Dealers Club or talking with knowledgeable independent dealers), and what to look for when buying (such as modifying colors and face-up appeal). He includes a discussion of the value of using fancy cuts rather than a round brilliant for the best concentration of color in a fancy-color diamond. Federman emphasizes that anyone can become successful in the colored diamond market, but the jeweler must first become familiar with all the various factors that dictate the wide range of prices for these unique and exciting stones. *Christopher P. Smith*

SYNTHETICS AND SIMULANTS

Emerging technology of diamond thin films. P. K. Bachmann and R. Messier, *Chemical & Engineering News,* Vol. 67, No. 20, 1989, pp. 24–39.

This is an excellent, detailed review of recent achievements in the technology of diamond thin films. After providing an overview of high-pressure diamond synthesis, the authors detail some key properties of diamond in conjunction with potential applications, from wear-resistant coatings to optical, acoustical, chemical, and electrical devices. A summary of the history of low-pressure diamond synthesis contains some new insights into the very early works in this field.

After describing synthetic diamond and diamond-like films, the authors propose a working definition of diamond films. The most common methods to grow synthetic diamond thin films (microwave-, hot filament-, and plasma-assisted chemical vapor deposition) are illustrated and explained in some detail, including process parameters and the maximum size and quality of the final product. A few applications already or soon to be on the market—such as cutting tools, heat sinks, and tweeters for stereo speakers—illustrate the most recent achievements in this Japanese-dominated research and development area.

The authors conclude that, despite the many problems that remain unsolved at this point, the large number of applications already realized and the exciting possibilities within reasonable reach amply justify a large effort to further develop this new technology. *EF*

Production techniques of commercially available gem rubies. K. Schmetzer, *Australian Gemmologist,* Vol. 16, No. 3, 1986, pp. 95–100.

The author briefly reviews the various production techniques used to grow the commercially available synthetic rubies. Characteristic microscopic features of material from different manufacturers are described. Of particular interest is the disclosure of the composition of the flux that seems to be used in the various flux-growth processes, as determined by electron microprobe, X-ray fluorescence, or X-ray diffraction analysis of the flux residues. The Chatham 2–6, Gilson, and Lechleitner 1–3 rubies studied were found to be grown in a Li_2O-MoO_3-PbF_2 (or PbO) flux. The Kashan samples used cryolite (Na_3AlF_6). Knischka types 1, 2, and 5 (and possibly the other generations) were grown in Li_2O-WO_3-PbF_2 (or PbO) flux. The Ramaura process was found to use Bi_2O_3-La_2O_3-PbF_2 (or PbO) flux. *EF*

Synthèse et imitation de l'opale noble (Synthesis and imitation of precious opal). J.-P. Gauthier, *Revue de Gemmologie a.f.g.,* No. 89, 1986, pp. 16–23.

Gauthier first recounts the early history of opal synthesis and then compares the formation conditions of natural and synthetic opal. One milky white Gilson synthetic opal, exhibiting predominantly green play-of-color, is investigated in detail using transmission electron microscopy (TEM). Several spectacular photomicrographs are provided. The regular stacking of silica spheres is less obvious in the Gilson synthetic than in the natural samples. The most notable feature of the Gilson product is a network of smaller ZrO_2 spherules that seem to fill, in part, the voids between the silica spheres, although the stacking as a whole still has a cubic symmetry. Important microtwinning of this network and the coalescence of silica spherules suggest that compaction was most likely used.

Various simulants that exhibit an opal-like play-of-color are reviewed. *EF*

TREATMENTS

'Aqua Aura' enhanced quartz specimens. R. C. Kammerling and J. I. Koivula, *Journal of Gemmology,* Vol. 21, No. 6, 1989, pp. 364–367.

The authors describe a quartz crystal to which a bluish color and surface iridescence have been imparted by the application of a thin coating of gold. Gemological testing revealed properties characteristic of crystalline quartz, although the coating is visible under magnification. EDXRF analysis revealed the presence of silicon, gold, and titanium (the last, perhaps, as inclusions or impurities in the quartz). Heating and acetone produced no damage to the coating. Color photos illustrate the macro- and micro-features of this material, which is being sold as mineral specimens in the U.S. under the name "Aqua Aura." *CMS*

Imitation pearl coatings. S. J. Kennedy, J. G. Francis, and G. C. Jones, *Journal of Gemmology,* Vol. 21, No. 4, 1988, pp. 211–214.

The authors report on various techniques used to identify the coating on some imitation pearls. First, an X-ray powder diffraction analysis of the coating produced a pattern that resembled but did not match hydrocerussite, a synthetic material that is a lead dihydroxydicarbonate. Further testing by infrared spectroscopy showed a mixture of nitrocellulose and another component. By placing the coating first in dichloroethane and then in acetone, the authors dissolved the nitrocellulose lacquer and identified the insoluble material as a hydrocerussite-like filler. This filler appeared under the optical and scanning electron microscope as minute hexagonal plates. In the electron microprobe, only lead was detected. Since one form of hydrocerussite is the pigment "white lead," a specimen of this material was also subjected to X-ray diffraction analysis and infrared spectroscopy. The patterns obtained matched that of the coating more closely than did the pattern of the mineral hydrocerussite. It was therefore determined that the imitation pearls had been coated with a synthetic basic lead carbonate in the form of minute hexagonal platelets suspended in a transparent nitrocellulose lacquer.

Four photographs illustrate the text. *KNH*

MISCELLANEOUS

A la mémoire de Dina Level, notre presidente d'honneur (To the memory of Dina Level, our honorary president). J.-P. Poirot, *Revue de Gemmologie a.f.g.*, No. 96, 1988, p. 3.

Dina Level, honorary president of the French Gemological Association and a noted figure in French gemology, died at the age of 84 on July 17, 1988. Level first dedicated herself to pearls, but rapidly moved to colored stones, where she developed a pioneering interest in inclusions. Level also helped in the creation of the Laboratory of the Chamber of Commerce of Paris. All through her life she promoted the teaching of gemology and launched many a person's interest in this discipline. Her commitment is expressed by the phrase that became associated with her over the years: "She is married to gems." *EF*

Notes from the Laboratory—14. K. Scarratt, *Journal of Gemmology*, Vol. 21, No. 6, 1989, pp. 339–346.

Mr. Scarratt describes the London laboratory's new FTIR spectrometer and explains how to read absorption curves. He also describes 10 De Beers synthetic yellow diamonds, concentrating on microscopic, ultraviolet, and infrared characteristics. His observations essentially concur with those reported by previous researchers, but are well worth reviewing. Infrared spectroscopy also helped in the identification of a composite that consisted of an orangy artificial coating over a piece of amber that displayed a yellow outer layer (just under the artificial coating) and a colorless interior, which appear to be characteristic of heat treatment. These notes conclude with the description of a gray/green/brown diamond that was identified as type IIb on the basis of reaction to ultraviolet radiation (inert to long-wave and short-wave, but phosphorescing to short-wave), strong electrical conductivity, and characteristic infrared spectrum. Useful color photos and spectral graphs illustrate these notes. *CMS*

The Proctor Collection, Colorado Springs, Colorado. M. I. Jacobson, *Rocks & Minerals*, Vol. 63, No. 1, 1988, pp. 40–56.

This article profiles Keith Proctor, a Colorado-based gem and mineral dealer who travels the world to add to his mineral collection. Profusely illustrated with 59 color photographs of specimens from the collection, the article includes a brief biography and elucidates Mr. Proctor's collecting philosophy. From the photographs and text, it appears that the emphasis of the collection is on aesthetic gem-quality crystals (some having been "saved" in the "nick of time" from cutting). *PASG*

Photographing minerals: Beyond the basics. J. Scovil, *Lapidary Journal*, Vol. 43, No. 2, May 1989, pp. 42–49.

The mineral photographer is often faced with the dilemma of photographing a specimen to either show its intrinsic beauty or represent it with scientific accuracy. In this article, Jeff Scovil suggests some creative approaches and ideas to "solve" this problem. He believes that a compromise can be struck between these conflicting realities, the results of which will please both the hardened scientist and the aesthetic perspective of the artist. He underscores his argument with two stunning photographs. The bibliography provided is also helpful for those photographers seeking additional tips. *RW*

The Van Pelts. J. Culp Zeitner, *Lapidary Journal*, Vol. 43, No. 2, May 1989, pp. 20–32.

If you close your eyes and try to conjure up the vision of a spectacular gemstone or mineral, it is quite likely that the image will be copyrighted. Chances are, you will be thinking of one of the famous photographs of Harold and Erica Van Pelt. For almost 20 years now, their photographs of gemstones and minerals have graced the covers and contents of a myriad of books and publications among which, of course, is *Gems & Gemology.* In an interesting and informative article, Zeitner takes us through the exciting life story of the Van Pelts, including not only their involvement with gemstone photography, but their creative and technical excellence in the lapidary world as well.

Perhaps the most savory section of the article deals with the "Van Pelt Hints for Amateurs," which will no doubt be read and reread assiduously by any aspiring gem photographer. Here, the Van Pelts candidly discuss lighting problems, specimen orientation, and the use of various backgrounds. In a world where quality seems to dwindle before us at an alarming rate, how refreshing and enlightening it is to study the words of such masters of perfection. *RW*