

# GEMS & GEMOLOGY

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FALL 1995



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# GEMS & GEMOLOGY

FALL 1995

VOLUME 31 NO. 3

## T A B L E O F C O N T E N T S



p. 153

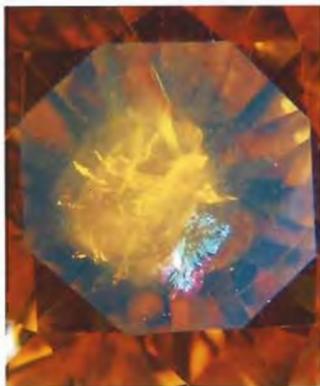


p. 169



p. 198

p. 189



### EDITORIAL

149 1995 Challenge Winners

150 LETTERS

### FEATURE ARTICLES

152 Gem-Quality Grossular-Andradite: A New Garnet from Mali

*Mary L. Johnson, Edward Boehm, Horst Krupp, Joachim W. Zang, and Robert C. Kammerling*

168 Sapphires from Southern Vietnam

*Christopher P. Smith, Robert C. Kammerling, Alice S. Keller, Adolf Peretti, Kenneth V. Scarratt, Nguyen Dang Khoa, and Saverio Repetto*

### NOTES AND NEW TECHNIQUES

188 "Ti-Sapphire": Czochralski-Pulled Synthetic Pink Sapphire from Union Carbide

*Mary L. Johnson, Meredith E. Mercer, Emmanuel Fritsch, Patricia Maddison, and James E. Shigley*

### REGULAR FEATURES

196 Gem Trade Lab Notes

204 Gem News

217 Book Reviews

218 Gemological Abstracts

**ABOUT THE COVER:** A new find of gem garnets has been made in the Republic of Mali, western Africa. The lead article in this issue characterizes these garnets, which are primarily yellow-green to brown but also (rarely) intense green. They have compositions between grossular and andradite. The brooch contains Mali garnets, in a range of colors, and diamonds. The loose stones range in size from the 1.35-ct yellow triangle cut to the 18.03-ct oval. The largest intense green stone is 2.90 ct.

All stones and jewelry courtesy of Gustav Zang, Lapidary, Idar-Oberstein, Germany. Jewelry design by Monika Leyser, of Kirschweiler, near Idar-Oberstein. Photo © Harold & Erica Van Pelt—Photographers, Los Angeles, CA.

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*Gems & Gemology* welcomes the submission of articles on all aspects of the field. Please see the Suggestions for Authors in the Spring 1995 issue of the journal, or contact the editor for a copy. Letters on articles published in *Gems & Gemology* and other relevant matters are also welcome.

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# 1995 C·H·A·L·L·E·N·G·E WINNERS

*The Gems & Gemology Challenge has been one of our most popular annual features since its introduction nine years ago. This year was no exception. Hundreds of readers from all over the world took this demanding test, which appeared in the Spring 1995 issue. Our heartfelt congratulations go to all who participated. Those who earned a score of 75% or better received a GIA Continuing Education Certificate recognizing their achievement. Those listed below received a perfect 100% score.*

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Answers (see pages 74–75 of the Spring 1995 issue for the questions): (1) a, (2) d, (3) a, (4) b, (5) c, (6) c, (7) b, (8) a, (9) b, (10) a, (11) b, (12) c, (13) d, (14) c, (15) c, (16) b, (17) b, (18) d, (19) a, (20) b, (21) a, (22) d, (23) d, (24) c, (25) b.

Our thanks to Warli Latumena of Jakarta for suggesting that we list the winners geographically.

# LETTERS

## MORE ON RUSSIAN EMERALDS, FANCY-COLOR DIAMONDS

I was very impressed with the quality and broad coverage of the Summer issue of *Gems & Gemology*. However, there are two items in that issue that I would like to address by relating: (1) some recent experiences I have had with emeralds from the Ural mountains (the topic of the Laskovenkov and Zhernakov article), and (2) some additional remarks about the book *Fancy-Color Diamonds*, which was written by Harvey Harris and reviewed by Sharon Wakefield.

**Superb Russian Emeralds Seen.** In August 1994, I visited the emerald-producing region around Malysheva with Dr. Adolf Peretti. At that time, gems could be purchased legally only through three officially recognized gem suppliers: AO Mining Co., the joint venture Emural, and MRU (Malischewskoe Rudouprawlenie Ural). We toured these facilities and were shown thousands of carats of rough and lesser quantities of mostly small faceted samples, including alexandrites, yellow to brown andradite garnets, and a few demantoid garnets, in addition to emeralds and green beryls. One lot consisted of approximately 22 grams (110 ct) of top-quality, richly colored rough emeralds, although most weighed no more than 1–1.5 ct.

A few months after this visit, a Swiss businessman with close connections in the former Soviet Union brought several lots of Uralian emeralds to the Gübelin Gem-

mological Laboratory. These lots consisted of several dozen faceted samples between 0.50 and 1.50 ct, with some larger stones of 2–3 ct (figure 1), as well as some high-quality euhedral crystals. As most *Gems & Gemology* readers are aware, Uralian emeralds typically are pale, and many would be more properly described as green beryls. However, these gems were comparable in quality to fine, highly saturated Colombian stones. Nevertheless, when the Gübelin Laboratory team tested a randomly selected sample of 21 stones, they found them to be consistent with Uralian emeralds described by other researchers (e.g., Schmetzer et al., "Emeralds from the Ural Mountains," *Gems & Gemology*, Summer 1991, pp. 86–99) as well as samples that the laboratory's Dr. Dietmar Schwarz (in 1991) and I had collected at the mines. Particularly noteworthy were the characteristic basal-oriented, thin film, "fingerprint" inclusions.

I had never before seen such a collection of truly fine emeralds, with such highly saturated colors, from the Ural Mountains. Our client informed us that this region has always produced a small quantity of fine emeralds, but they usually were smuggled out illegally and subsequently lost their Uralian origin on entering the gem market. Our client echoed the view of Drs. Laskovenkov and Zhernakov that the Urals will once again take their place as one of the world's major emerald-producing localities.

**Comments on the Review of *Fancy-Color Diamonds*.** To begin, I do not disagree with some of Mrs. Wakefield's comments in her review of *Fancy-Color Diamonds*. Certain corrections do need to be made in the text, and clarification in other areas would be well advised. However, I do feel that appropriate credit has not been given to Mr. Harris for the work that this book represents.

Mr. Harris is not simply a reporter or a researcher. As he states in his book, he has 25 years of experience as a diamond wholesaler, dealing primarily with fancy-color diamonds. He is one of the few diamond dealers I have met who has taken the time and effort to study the many technical aspects that play such an integral role with fancy-color diamonds. He brings this unique knowledge and background to a subject that is largely unfamiliar to most gemologists, giving the reader the benefit of his personal experiences and an insight that is not readily found elsewhere.

In addition, whereas dozens of books have been written on near-colorless diamonds, *Fancy-Color Diamonds* is the first to focus solely on colored diamonds. Nowhere else can a reader find so much information on all the colors and aspects of each color group in a single source. Although some may find certain of his views or opinions controversial, this should not diminish the overall contribution of his work and its appeal to readers from many different backgrounds.

Figure 1. These emeralds from the Ural Mountains (0.50–3.03 ct) are comparable to top-quality Colombian stones. Photo courtesy of the Gübelin Gemmological Laboratory.



As for the photos, I have seen many of the actual diamonds that are pictured and feel that Tino Hammid superbly captured the subtleties in the colors of these exceptional stones. These photos give the reader a rare opportunity to view some of the finest colored diamonds ever found.

Christopher P. Smith  
Manager of Laboratory Services  
Gübelin Gemmological Laboratory,  
Lucerne, Switzerland

#### CAUTION NEEDED IN MACHINE MEASUREMENT OF COLOR

In his book, *Fancy-Color Diamonds* (reviewed on p. 141 of the Summer 1995 issue), Harvey Harris creates some expectations concerning the issuance of a new type of laboratory report. Because he mentions me in this context, I wish to make some additional comments and warnings regarding the use of numerical data based on photometric measurements. (For further information on this technique, see A. Peretti and W. Boguth, "Color Measurement of Fancy Diamonds Applying Computer-Based Multichannel Spectroscopy," in *Proceedings of the International Gemological Symposium 1991*, GIA, Santa Monica, pp. 160-161.)

Although "MCS color machine" measurements are quite useful in some situations, I have three main concerns about their use in laboratory reports for fancy-color diamonds. First, the machine's readings are influenced by the shape, proportion, and size of the stone. This means that all the color values Mr. Harris illustrates can only be used to compare stones of the same shape, proportions, and size. Second, the color values given are not absolute: The geometry of the MCS machine's measuring head creates a shift in the diamonds' spectra that also shifts the calculated color values. As a result, one cannot use these measurements to discuss the percentage of gray in a stone; only saturation/toner ratios can be used. Third, the color measurements do not take into consideration the color reflections seen in a fancy-color diamond face up.

Given these limitations, the individual experience of the practicing gemologist will ultimately determine the usefulness of such a report for communicating with the buying public. Based on my personal experience, the numbers generated by the MCS machine for colored diamonds are most useful within a laboratory, as internal back-up, or for a sophisticated dealer. Further improvements in technology are needed before a report using numerical color values is issued.

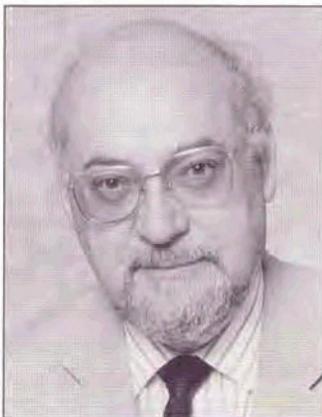
A. Peretti, Ph.D.  
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## IN MEMORIAM

### HENRY O. A. MEYER, Ph.D

The staff of *Gems & Gemology* were greatly saddened to learn of the June 15 death from cancer of Henry O. A. Meyer, a valuable member of the journal's Editorial Review Board for more than 10 years. Professor Meyer was an expert in those areas of diamond science that relate to how diamond formed in the Earth, how it reached the surface, the nature of the deposits in which it has been found, and where such sources might be located in the future. Dr. Meyer brought this broad knowledge and experience to his reviews of papers submitted to *Gems & Gemology*, combining an exceptional ability to render the arcane eminently readable with a willingness to devote great time and energy to ensure that the information was accurate.

Henry Meyer received his Bachelor of Science degree from University College London in 1959 and his Ph.D. from London University in 1961. After teaching in London for some years, in 1966 he moved to Washington, DC, as a fellow of the Carnegie Institute of Washington. Later he was associated with NASA, at the Goddard Space Center, before he joined the Department of Geosciences at Purdue



University, West Lafayette, Indiana, in 1971. At the time of his death, at 58, he was Professor of Mineralogy in the Department of Earth and Atmospheric Sciences at Purdue. Dr. Meyer served as a consultant for many different companies, including gem-industry organizations such as Harry Winston Inc., Ocean Diamond Mining, Cominco American, and Adamas Minerals Inc. His resumé and publications list fill several pages.

Although he often traveled for months at a time, all over the world, Henry Meyer was a dedicated reviewer for *Gems & Gemology*. Once when we had left a message at his office asking if he could review a complex

but important paper on diamond sources in a matter of days, he returned the call from his hospital bed: Although he had just undergone an emergency surgical procedure, he insisted that we send the paper to his home by express mail so he could start working on it as soon as he was released. The detailed review was back in our hands within a week.

Henry Meyer is survived by his wife, Helen, five children and two grandchildren. Charming, energetic, and intelligent, he will be sorely missed.

# GEM-QUALITY GROSSULAR-ANDRADITE: A NEW GARNET FROM MALI

By Mary L. Johnson, Edward Boehm, Horst Krupp, Joachim W. Zang, and Robert C. Kammerling

*A find of new gem garnets has been made in contact metamorphic deposits in the Republic of Mali, western Africa. These garnets, primarily yellow-green to brown but also (rarely) intense green, have compositions between grossular and andradite. Although garnets of similar composition are relatively well known, this is the first documented occurrence of gem-quality material in commercial quantities. Because this gem variety is not represented by any of the gem garnet terms previously in use, it is described as grossular-andradite by the GIA Gem Trade Laboratory. It can be distinguished from grossular by its absorption spectrum and (usually) higher refractive index; it can be distinguished from andradite by its lower R.I. The stacked parallel planes of growth zoning, always visible between crossed polarizers, are diagnostic of grossular-andradite.*

## ABOUT THE AUTHORS

*Dr. Johnson is a research scientist at the GIA Gem Trade Laboratory, Santa Monica, California. Mr. Boehm is a geologist and Graduate Gemologist with Pala International, Fallbrook, California. Dr. Krupp is a physicist and president of Firegems, La Costa, California. Dr. Zang is vice president of Gustav Zang Lapidary in Idar-Oberstein and a researcher at the Institute for Gemstone Research, Department of Geosciences, University of Mainz, Mainz, Germany. Mr. Kammerling is vice president of Research & Development in the GIA Gem Trade Laboratory, Santa Monica.*

*See acknowledgments at the end of the article.  
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Garnets have been prized as gems since at least 3200 B.C. (Andrews, 1991). Today, gem garnets are found in almost any color. They exhibit broad chemical variability between the known end-members, the most common of which are pyrope, almandine, spessartine, grossular, and andradite. (A useful overview of gem garnets was given by Stockton and Manson, 1985; see also Manson and Stockton, 1982, and Stockton and Manson, 1982, 1983, for specific color ranges). Garnets are also used as ornamental gem materials in their massive forms: Examples include hydrogrossular and grossular.

In spring 1994, a new type of gem-quality garnet (figure 1) first appeared on the market in Idar-Oberstein (one of the authors—Dr. Krupp—was first offered rough material at this time; see also Frazier and Frazier, 1995a and b). This was a transparent, facetable material in the yellow-to-green-to-brown range, with properties close, but not identical, to those of grossular. One version of the discovery was that the material was found by a West African who had once lived in Idar-Oberstein (Frazier and Frazier, 1995b). In the gem trade, the material is typically called “Mali garnet” or “grandite garnet.”

Among discussions of Mali garnet in the trade press are reports on their appearance at Intergem in Munich in September of 1994 (Frazier and Frazier, 1995a and b; “Impressions of Intergem ‘94,” 1994), and mention in the 1995 International Colored Gemstone Association (ICA) world gemstone mining report (Eliezri and Kremkow, 1994). Four technical reports have been published in German (Zang, 1994; Henn et al., 1994; Lind and Bank, 1994; Lind et al., 1995). One stone reportedly from this locality was examined in the GIA Gem Trade Laboratory in September of 1994 (Hurwit et al., 1994). Since we began work on this report in September 1994, a short article in English appeared in the *Australian Gemmologist* (Brightman, 1995).

Figure 1. One of the most recent additions to the gem marketplace are gem garnets from Mali. These grossular-andradites, from the first-known commercial gem occurrence of this material, range in color from yellow to green to brown. Although most of the stones faceted to date are smaller than 5 ct, some are quite large, as indicated by this loose 33.29-ct stone. The stones in the rings are 4.03, 4.57, and 5.53 ct. Courtesy of M. Fabrikant & Sons, New York City; photo © Harold & Erica Van Pelt.



### LOCATION AND ACCESS

The garnets are being recovered from various localities in the "Zone of Sangafé," near the village of Diakon (about 100 km northeast of Bafoulabé, 110 km southwest of Nioro, and 130 km east of Kayes; air miles in all cases), in the Kayes Region of Mali (figure 2). The Zone of Sangafé is in the Sahel region (a semiarid area between the Sahara Desert to the north and the savannas to the south). William Dameron, former U.S. Ambassador to Mali, stated that many garnets come from Sibirindi, "about 20–30 km south of Sandaré" (pers. comm., 1995), in the vicinity of Diakon. One of our contacts in Mali states that the intense green Mali garnets come from the village of Duvalé.

Access to the mining area is difficult. The closest major town, Kayes, can be reached by train from either Bamako, the capital of Mali, which is about 400 km to the southeast, or Dakar, the capi-

tal of Senegal, which is about 620 km due west, on the Atlantic Coast. From Kayes, one must travel by jeep, or *bashé* (the local term for bush wagon or taxi), to cover the remaining 170 km of partially paved roads to the town of Sandaré. From there, another 20–30 km of unpaved roads lead to the mining areas around the villages of Sibirindi and Diakon.

It is possible that some material has been transported out of Mali via Dakar because of its coastal access. Despite the difficulty in reaching the mining areas, there has been such a rush to the region that extra railroad cars were added to the trains going to Kayes. The rough is carried in flour or rice sacks and transported by any available vehicle to the train station at Sandaré.

### GEOLOGY AND OCCURRENCE

Western Mali is underlain by the Precambrian West African Craton. The craton has been warped

into a broad bowl—the Taoudeni Basin—with edges at the Western Sahara/Mauritania border and from Sierra Leone and Guinea to southeast Mali. Cambrian sediments fill the western part of the basin and are overlain by Mesozoic deposits to the east. In the region of interest, the sediments include magnesian limestones and dolomitic limestones (Furon, 1963). These sediments have been intruded in various places by dikes primarily of diabase (that is, fine-grained gabbroic rocks mainly consisting of plagioclase and pyroxene), which extend from the border with Guinea to Mauritania (figure 3); these dikes vary from basalt to albite-quartz pegmatites (Furon, 1963; Bessoles, 1977). Southwest of the town of Nioro, these diabases are Jurassic in age (Cahen et al., 1984) and form a massif known as the Kaarta, a zone of rugged relief ranging up to 300 m in altitude (Furon, 1963).

According to reports on the regional geology of Mali, garnets formed in contact metamorphic zones along the boundaries where the widely scattered diabase dikes intruded into limestones (among other rocks). Besides garnet, the minerals that formed in the contact zone between diabase and limestone include epidote, (titaniferous) magnetite, prehnite, fluorite, and occasionally chrysoberyl (Hubert, 1914, as reported in Bessoles, 1977; Furon, 1963; Ministère des Mines [no date]). This information is consistent with statements that have been made elsewhere concerning the geologic occurrence of gem garnets in Mali. Both Lind and Bank (1994) and Henn et al. (1994) state that the garnets come from contact metamorphosed deposits, which, according to Henn et al. (1994), consist of clay and feldspar-bearing sandstones and marbles that have been intruded by a diabase. Garnet, epi-

Figure 2. The grossular-andradite garnets studied for this article were all reportedly from deposits near the village of Diakon, in the Kayes Region of the Republic of Mali, western Africa. (Adapted from: Institut Géographique National—France, 1993.)

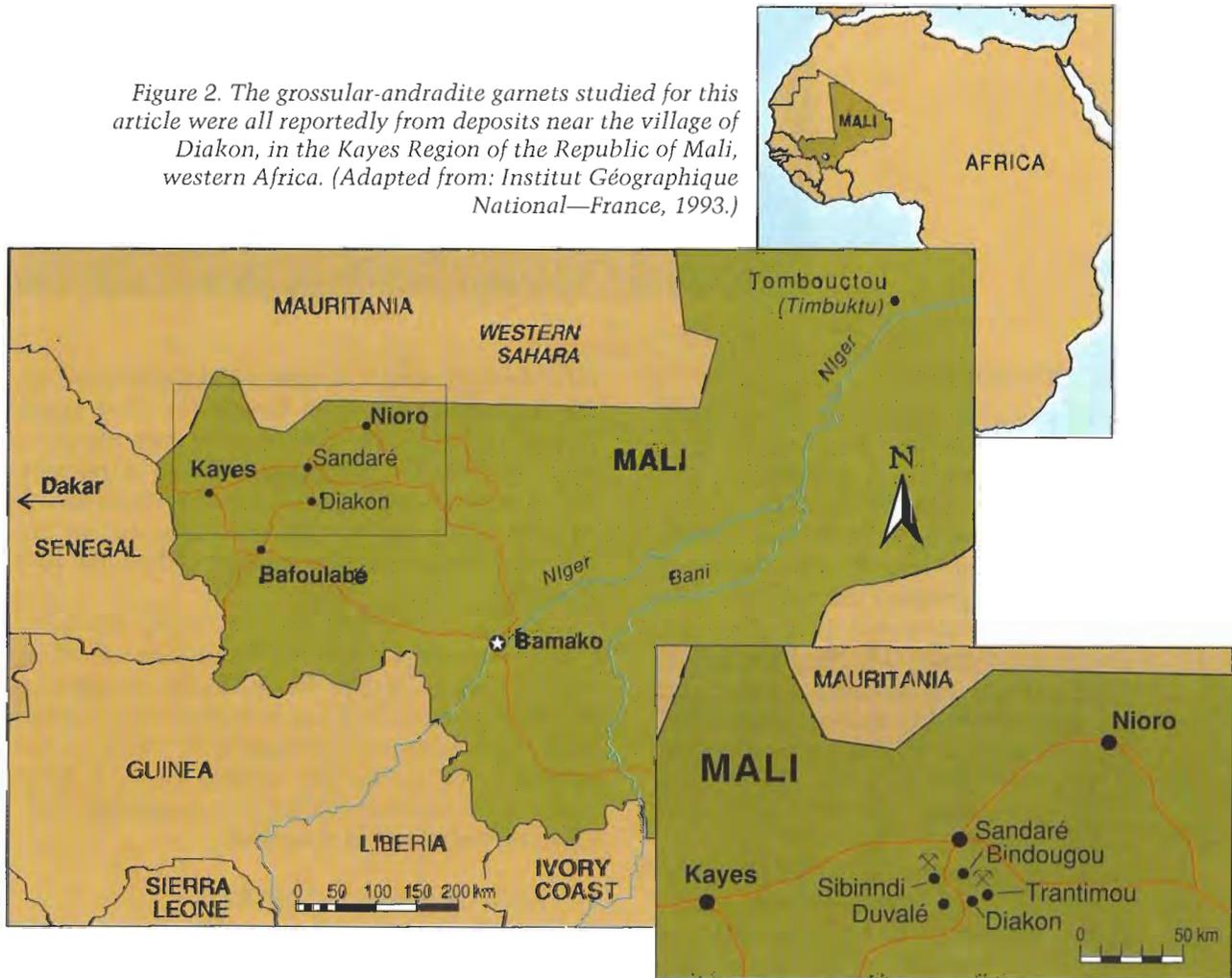


Figure 3. This geologic sketch map of western Mali, as well as parts of Senegal and Mauritania, shows the large diabase intrusions. Contact metamorphic bodies, including some that contain gem-quality garnets, are found along the boundaries of the diabase intrusives. Figure adapted from Furon, 1963.



dote, prehnite, and vesuvianite mineral specimens from Mali were marketed in Tucson, Arizona, in spring 1995 by Dave Bunk Minerals of Wheat Ridge, Colorado (with the locality given as "Sandaré, Nioro du Sahel, Mali"); also, "bright green" garnets as large as 4 cm—some with chalcedony overgrowths—have been found growing on some vesuvianites mined in Mali (W. Dameron, pers. comm., 1995).

In addition to the garnets mined near Sibinndi and Diakon, well-formed opaque brownish red crystals have been found in the village of Bindougou, a few kilometers north of Diakon. Black garnets have been found a few kilometers east of Diakon, in the village of Trantimou (W. Dameron, pers. comm., 1995). Thus far, only a few intense green stones have been found, including two in this study and a recently discovered crystal that produced a 2.9-ct cut stone.

The garnets also occur as waterworn nodules, reportedly from alluvial sources near the contact metamorphic deposits (Eliezri and Kremkow, 1994; Hurwit et al., 1994).

### MINING AND PRODUCTION

Although garnets from this region have been known since 1914, the recent discoveries represent the first gem-quality stones found in any significant quantities. We have seen crystals larger than 5.5 kg (Zang, 1994); for the most part, however, the facetable areas in each stone are relatively small.

The largest faceted stone seen to date is a brown 57.5-ct round brilliant (figure 4). Only gemmy cores—generally, nodules—are suitable for faceting (figure 5), although cabochons are being cut from other parts of the rough. Considerable manual labor is required to break up these crystals, and most dealers now insist on purchasing only nodules, so relatively few euhedral crystals are available for mineral collectors and crystallographic study.

The authors calculate, from personal experience, that a parcel of 400–500 crystals, weighing about 200 kg, yields 160 grams of nodules, from which only 60 grams would be facet grade. Of these 60 grams (300 ct) of facet-grade rough, perhaps 150 ct of faceted gems result: a total yield of 0.015%.

Some dealers are believed to have large stockpiles of rough Mali garnets in Idar-Oberstein, with substantial quantities also in North America and Australia. We estimate that, as of September 1995, these stockpiles totaled several dozen kilos of facet-grade material and several hundred kilos of cabochon-quality rough. According to Joe Freilich of M. Fabrikant & Sons in New York, their stock of faceted Mali garnets exceeds 5,000 ct, primarily in sizes up to 5 ct, but with a few larger "collector pieces" (again, see figure 1).

### MATERIALS AND METHODS

For our gemological investigation, we examined 23 faceted stones (some are shown in figure 6), 20



Figure 4. This 57.5-ct round brilliant-cut stone is the largest faceted grossular-andradite garnet from Mali seen by the authors to date. Courtesy of Gustav Zang, Lapidary, Idar-Oberstein; photo © Harold and Erica Van Pelt.

rough crystals and crystal sections, and eight rough nodules (see, e.g., figure 7). The faceted stones ranged from 0.34 to 15.67 ct, and the rough crystals weighed from 8 grams to greater than 2.1 kg. The gem nodules weighed from 3.11 to 9.32 ct; the nodule examined by Hurwit et al. (1994), which

Figure 5. Although most of the Mali garnet crystals seen to date appear to be opaque (right, 61.02 ct), many have large areas of transparent material (left, 106.29 ct). Courtesy of Firegems; photo © GIA and Tino Hammid.



will sometimes be mentioned for comparison purposes, weighed 25.35 ct.

Face-up colors were viewed using both fluorescent and incandescent light sources. Refractive indices were measured with a Duplex II refractometer and a near-monochromatic, Na-equivalent light source. We determined specific gravity hydrostatically as an average of three sets of measurements. Fluorescence to ultraviolet radiation was observed in a darkened room using a short-wave/long-wave ultraviolet lamp. We noted polarization behavior using a GIA GEM Illuminator polariscope, and observed absorption spectra using a Beck prism-type spectroscope. The Chelsea filter reaction was determined with illumination from a spectroscope base unit. We examined internal features using a standard gemological microscope in conjunction with brightfield, darkfield, and oblique fiber-optic illumination, as well as polarizing filters.

Chemical compositions for five stones (a mix of faceted and rough) were determined quantitatively using a CAMEBAX electron microprobe at the University of Mainz, in Mainz, Germany. Three additional faceted stones were studied with a Camscan Series II analytical scanning electron microscope (SEM) at the California Institute of Technology, in Pasadena, California. Back-scattered electron imaging was also performed to look for fine compositional details in these garnets. Eleven stones of various colors were also examined with energy-dispersive X-ray fluorescence (EDXRF) spectroscopy, using a Tracor Xray Spectrace 5000 with a rhodium-target X-ray tube.

We obtained visible spectra on two stones, one yellowish green and one intense green, using a Perkin-Elmer Lambda 3 UV/VIS spectrophotometer, with a 0.2-nm step width and 15 nm/min. scanning speed. The two faceted stones were embedded in BaSO<sub>4</sub> and measured in reflection mode using an integration sphere. A few additional stones were run in absorption mode using a Hitachi UV/VIS spectrophotometer.

X-ray powder diffraction images were taken from minute amounts of powder scraped from nine stones (representing both faceted and rough), with a Debye-Scherrer camera mounted on a Siemens Kristalloflex diffractometer. The unit-cell edge of an additional stone was measured with the more precise Guinier technique (see, for example, Taylor, 1961).

We calculated garnet end-member components as follows: All magnesium was apportioned

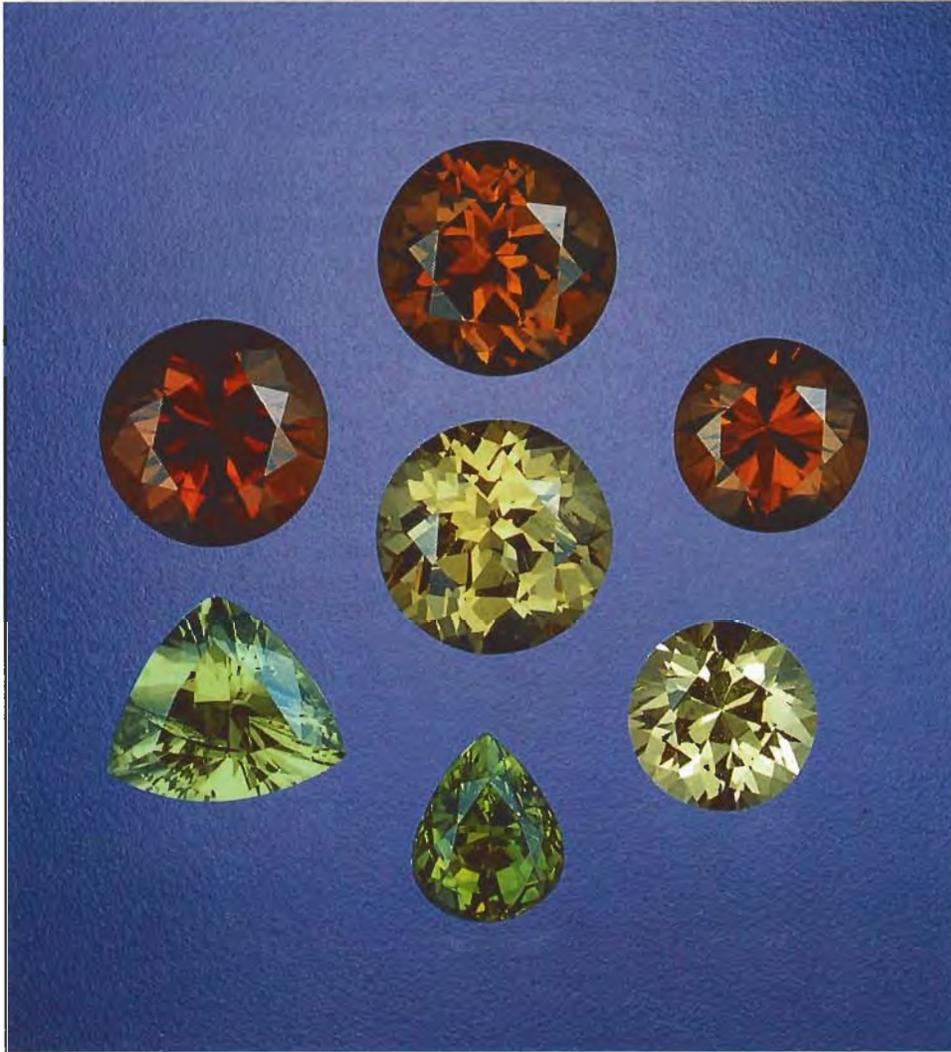


Figure 6. These seven faceted brown, yellow-green, and green grossular-andradite garnets from Mali (ranging from 0.85 to 2.39 ct) are part of the study sample. Stones courtesy of Pala Properties International and Thomas M. Schneider; photo © GIA and Tino Hammid.

to the pyrope component, *Py*; all manganese to the spessartine component, *Sp*; all chromium to the uvarovite component, *Uv*; and all iron ( $\text{Fe}^{3+}$ ) to the andradite component, *And*. Assignment of all iron as  $\text{Fe}^{3+}$  is supported by our spectra, which revealed no evidence of  $\text{Fe}^{2+}$  (as in almandine). Calcium, aluminum, and silicon were distributed according to stoichiometry; remaining aluminum was apportioned to the grossular component, *Gr*. Because none of the stones revealed a significant titanium content, Ti was ignored in calculating end members. Components were normalized to 100% (e.g.,  $\text{Gr}_{78}\text{And}_{20}\text{Py}_1\text{Sp}_1$ ).

### CRYSTAL MORPHOLOGY

The rough samples we examined (again, see figure 7) occurred in two forms: as crystals, often nearly complete, and as rounded nodules. Most of the

crystals showed dodecahedral  $d\{110\}$  faces; some also showed minor trapezohedral  $n\{211\}$  faces; and, in at least one case, the trapezohedron was the major form shown. Most crystals showed regular shapes, but a few were distorted; distorted crystals are flattened in a variety of directions.

All the crystals appeared to have dodecahedral core zones, and some very large crystals showed only the dodecahedral habit (that is, not all crystals have trapezohedral faces). In some cases, gemmy yellowish green or green cores were found in crystals with dull, nearly opaque, brown surface "skins" (again, see figure 5). The surface regions were less transparent than the cores. At least one crystal was so dark brown as to appear nearly black, and one showed a bright green surface region (figure 8).

Most crystal faces on the predominantly dodecahedral crystals were sharply reflective, although



Figure 7. Also in the study sample were these seven rough crystals and eight nodules of Mali garnet. From top left down: approximately 126-gram dodecahedron, 24-gram trapezohedron/dodecahedron, 16- and 8-gram dodecahedra. From top right down: approximately 780 gram (94 × 71 × 66 cm) dodecahedron, and 22- and 13-gram distorted dodecahedra/trapezohedra. The eight nodules in the center weigh from 3.11 to 9.32 ct. Courtesy of Pala Properties International, Firegems, and the authors; photo by Shane F. McClure.

some had rough surfaces (figure 9), which may be due to intergrowth with other minerals. Some dodecahedral internal surfaces (and all faces on those crystals that were predominantly trapezohedral) had a rough or stepped appearance. This appearance may be due to the dissolution of intergrown minerals, especially calcite, during either weathering or processing of the mined material.

In contrast to these crystals, the “nodules” we examined—actually cobbled rough material, rather than alluvial nodules—had rounded surfaces and no crystal faces. The curved surfaces were probably caused by fracturing along curved fluid-filled

inclusions (see “Appearance with Magnification and in Polarized Light,” below).

#### PHYSICAL APPEARANCE AND GEMOLOGICAL PROPERTIES

Gemological properties of the 23 faceted stones examined are given in table 1 and described below, with additional reference to the results for the eight gem nodules examined, as appropriate.

**Color.** The 23 faceted stones ranged from slightly greenish yellow to dark orangy brown and from greenish yellow to yellowish green and intense green (again, see figure 6). The most common colors appear to be greenish yellow to yellow-green (figure 10). The brownish colors include brownish greenish yellow, brown-orange, and dark orangy brown. The colors of two green samples resembled those typically associated with tsavorite garnet.

Yellow-green Mali garnets typically are of medium tone, with a stronger yellow component than tsavorites from East Africa and transparent green chromium-bearing grossulars from Quebec (see, for

Figure 8. The bright green surface on the top of this 28.0 × 26.3 × 25.4 mm bicolored crystal from Mali was found to have a composition slightly different from the yellowish green regions. Courtesy of William Dameron; photo by Maha DeMaggio.



**TABLE 1.** Gemological properties of yellowish green, green, and orange-to-brown grossular-andradite garnet from Mali.

Property	Yellowish green (18) <sup>a</sup>	Green (2)	Orange to brown (3)
Color	Slightly greenish yellow to light yellowish green	Green	Brown-orange to dark orangy brown
Color distribution	Even	Even	Even to uneven
Refractive index	1.752–1.769	1.762–1.764	1.773–1.779
Optic character <sup>b</sup>	SR, often ADR	Moderate ADR	Moderate to strong ADR
Color filter reaction	Negative (appears green)	Red (1), negative (1)	Negative (appears green)
Absorption spectrum	Weak 415, 440 band, sometimes faint 465, 495 lines	Weak 415 band or 440 cutoff, moderate 445 band, and 600 line	440 cutoff and/or 445 band
Fluorescence to long- and short-wave UV	Inert	Inert	Inert
Specific gravity	3.64–3.68	3.65–3.67	3.67–3.68
Growth zoning	Dodecahedral	Dodecahedral	Dodecahedral or trapezohedral
Inclusions	Fingerprints, sometimes small crystals	Fingerprints, sometimes small crystals	Fingerprints, sometimes small crystals

<sup>a</sup> Numbers in parentheses represent number of samples studied. All data are from this study.

<sup>b</sup> SR = Singly refractive; ADR = anomalously doubly refractive.

instance, Anderson, 1966; Dunn, 1978; Schmetzer and Bank, 1982). Intense green and orangy brown stones from Mali cannot be distinguished from other types of garnets on the basis of color.

**Refractive Indices.** We recorded R.I. ranges of 1.752–1.769 for the yellowish green and green stones we examined; and 1.773–1.779 for the orangy brown stones. These are consistent with R.I. values of 1.755–1.782 reported in the literature for Mali garnets (Zang, 1994; Henn et al., 1994; Lind and Bank, 1994; Brightman, 1995). Grossular is usually reported as having a refractive index between 1.73 and 1.76, and the R.I. of andradite is in the 1.880–1.895 range (Stockton and Manson, 1985).

**Polariscope Reaction.** Seventeen of the 23 faceted stones showed moderate-to-strong anomalous double refraction (ADR) when viewed in a polariscope. All showed anomalous birefringent colors when examined microscopically between crossed polarizing filters. Strong ADR was also observed in all of the rough nodules that were sufficiently transparent to be so examined.

**Optical Absorption Spectroscopy.** All 31 nodules and faceted stones that we examined with the handheld spectroscope showed a band centered about 440 nm (with the center ranging from 435 to 450 nm). We also noted a 415-nm line in the 17 faceted stones and nodules with the lightest colors. We saw two faint lines in the 460–470

nm and 495–500 nm regions in six of these 17 stones. In the stone with the most intense green color, we also saw a line at 600 nm (which we tentatively attributed to chromium). The spectra for the darkest toned (orangy brown and green) stones had a cutoff at about 440 nm. In general, the strongest feature—the cutoff or 440-nm band—was consistent with the typical spectrum for andradite (figure 11; see also Payne, 1981).

*Figure 9. This surface on a 13-gram garnet crystal from Mali shows evidence that additional minerals, possibly blades of epidote, had grown adjacent to it. Courtesy of Firegems. Photograph by John I. Koivula; magnified 2×.*





Figure 10. Most of the Mali garnets seen to date have been in the greenish yellow to yellow-green range. These six faceted yellow-green grossular-andradite garnets (1.76 to 2.55 ct) from Mali are part of the test sample. Most stones courtesy of Pala Properties International; photo © GIA and Tino Hammid.

**Specific Gravity.** Values determined for our samples are consistent with ranges reported by Zang (1994), Lind and Bank (1994), and Brightman (1995): 3.63 to 3.70. Henn et al. (1994) report the much larger range of 3.58 to 4.19; the highest value is anomalous. Our faceted stones showed a general increase in specific gravity with increase in refractive index, although there was considerable variability from one stone to the next.

**Appearance with Magnification and in Polarized Light.** For the cleanest stones we examined, inclusions were very rare or nonexistent. However, all stones showed pronounced dodecahedral growth

zoning (sometimes only visible as parallel layers). Although these layers were frequently visible (as color zoning) with standard illumination (figure 12, left), they were especially distinct when the stones were examined between crossed polarizers, showing up as dull-to-bright-gray birefringent layers (anomalous birefringence; figure 12, right). Such growth zoning took on an unusual appearance in the darkest brown stone: It consisted of darker orange trapezoids, which we suspect are trapezohedral {211} growth zones (figure 13).

The most common inclusions were curved, partially healed fractures, or "fingerprint" inclusions (figure 14), seen in nine faceted stones and near the surfaces of all the nodules (figure 15). In fact, the rounded surfaces of the (cobbed) nodules could be seen to be made up of material etched or broken along the curved fingerprints. Two-phase fluid inclusions were seen in a healed fracture in one stone.

Five of the faceted stones contained tiny included crystals, which were too small and too far from the surface to identify. Although the stone described by Hurwit et al. (1994) showed a very fine, wispy, "horsetail" (visible at 50× magnification), we did not detect this feature in any of the sample nodules or faceted stones.

## CHEMICAL COMPOSITION

**Electron Microprobe Analysis.** Results of quantitative chemical analyses for five stones are given in table 2. Two yellowish green faceted stones, analyses MA01 and MA02 (previously described by one of the authors: Zang, 1994), are typical in color and gemological properties of most grossular-andradites coming from Mali, with compositions of approximately  $Gr_{80}And_{18}Py_2$ . An 11-point traverse (figure 16) was made across a portion of sample MA19, which had a green core (average composi-

Figure 11. The absorption spectrum seen with a handheld spectroscope in most grossular-andradite garnets from Mali resembles this spectrum for typical yellowish green demantoid andradite garnet. Figure © GIA.

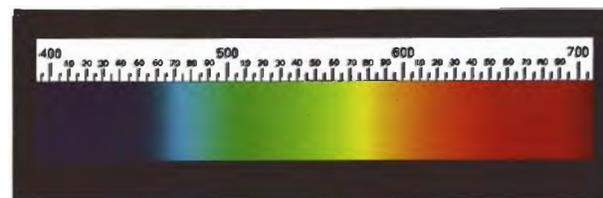




Figure 12. Straight growth zoning parallel to two dodecahedral faces was commonly seen in the test sample of grossular-andradite garnet from Mali (left). This feature appears particularly sharp when viewed between crossed polarizers (right). Photomicrographs by John I. Koivula; magnified 20 $\times$ .

tion  $\text{Gr}_{73}\text{And}_{25}\text{Py}_2$ ) and a 0.5-mm-thick brown rim (average composition  $\text{Gr}_{33.5}\text{And}_{65}\text{Py}_{1.5}$ ). Sample MA93, an intense green stone, contained chromium (0.63 wt.%  $\text{Cr}_2\text{O}_3$ ), but no vanadium was detected (approximate composition  $\text{Gr}_{79}\text{And}_{16}\text{Py}_3\text{Uv}_2$ ). Sample MA23, a brown rhombohedral crystal about 1.5 cm in diameter, was found to have a relatively homogeneous composition (about  $\text{Gr}_{30}\text{And}_{68}\text{Py}_2$ ) that included 0.04 wt.%  $\text{V}_2\text{O}_3$ .

**Scanning Electron Microscopy.** With the scanning electron microscope, analyses can be made of individual submicron spots, and of rectangular areas up to the size of the (magnified) field of view. Both techniques were used in this study. The results are also given in table 2; two faceted stones had compositions similar to those seen in the microprobe analyses of Mali garnets. (Unfortunately, we were not able to run both electron microprobe and SEM analyses on the same stones.) A third faceted greenish yellow stone, R-2596, contained significantly more magnesium (about 1 wt.%  $\text{MgO}$ ; pyrope content about 4 mole %). This stone also had a significantly lower R.I. (1.752) than the other greenish yellow stones in our sample.

These faceted samples were imaged in back-scattered electron (BSE) mode. In two stones, no compositional detail was seen using BSE imaging. However, R-2596 showed brighter stripes against an evenly toned background (figure 17). A bright region in BSE imaging corresponds to a higher average atomic weight (see, e.g., Newbury, 1975), and these stripes represent linear regions of lower magnesium content. For this stone, we successfully obtained analyses from one point on a BSE-bright stripe and two spots (plus a regional average)

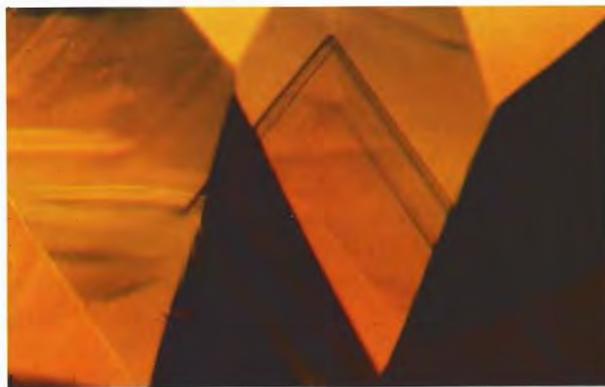
in BSE-darker regions. There was no appreciable difference in iron (calculated as andradite) content between light and dark regions, but there was significantly more magnesium (pyrope component) in the darker regions than in the bright stripe.

EDXRF analyses of 11 additional samples gave results that were consistent with those reported above.

**Composition Determined by Indirect Methods.**

Properties such as refractive index, specific gravity, and unit-cell-edge length vary linearly between end-member compositions in the garnet mineral group (Deer et al., 1982). For some garnets in our study with measured compositions, we checked whether these properties can be used to predict garnet compositions. Our samples fit chemically

Figure 13. The growth zoning seen here in a 15.67-ct dark orangy brown garnet from Mali appears to parallel trapezohedral growth faces. Photomicrograph by John I. Koivula; magnified 20 $\times$ .



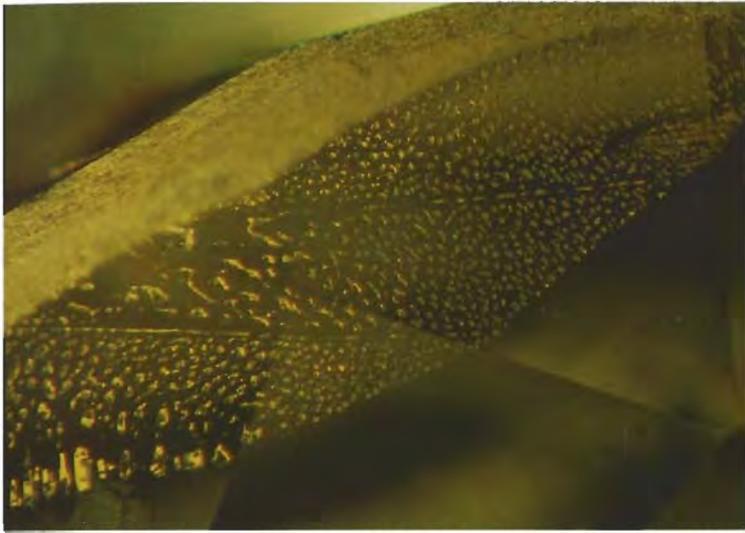


Figure 14. Partially healed fractures were among the most common internal features seen in the Mali garnets examined. Photomicrograph by John I. Koivula; magnified 30 $\times$ .

between the end members grossular and andradite, with minor deviations caused by small amounts of other end members such as pyrope, spessartine, uvarovite and, possibly, hydrogrossular. A good estimate of a given stone's composition can be made by measuring its refractive index and interpolating between 1.734 (pure grossular) and 1.887 (pure andradite); the other indirect measurements, especially specific gravity, have lower certainties and are less useful for this determination.

**Spectrophotometry and Causes of Color.** The two faceted stones for which optical absorption spectra were studied in detail—yellowish green sample MA02 and intense green sample MA93—were very similar in chemical composition (as determined by electron microprobe analysis), about  $\text{Gr}_{81}\text{And}_{15.5}$ . Intense green sample MA93 contained 0.63 wt.%  $\text{Cr}_2\text{O}_3$ , but no chromium was detected in sample MA02.

The spectrum of yellowish green sample MA02 shows a small peak at 408 nm, a broad band centered at 432 nm, and a weaker, still broader band centered at 585 nm (figure 18). The color-inducing element in this sample is trivalent (ferric) iron, which has absorption bands with maxima at about 432 and 585 nm (see Moore and White, 1972; Amthauer, 1976; Rossman, 1988; Burns, 1993). The weak manganese peak at 408 nm has

no appreciable influence on the color (Moore and White, 1972; Duffy, 1990).

The absorption spectrum of intense green sample MA93 shows a maximum at 478 nm, followed by a minimum near 526 nm (i.e., maximum transmission in the green part of the spectrum) and a strong band in the 550–650 nm range that has a maximum intensity at about 608 nm. Two sharp lines are evident at about 696 nm and 700 nm (again, see figure 18). In this spectrum, chromium is the most important color-inducing element, as indicated by the two wide bands with maxima at about 478 and 608 nm; the sharp lines are also due to chromium (Moore and White, 1972; Amthauer, 1972; Burns, 1993). The color is intensified by the influence of ferric iron, similar to those bands seen in sample MA02: The 435-nm band can be easily seen in the spectrum, and the  $\text{Fe}^{3+}$  peak around 585 nm—although less prominent—is also observed.

For some orangy brown stones on which spectra were also run, the 435-nm band was visible as a shoulder on a strong background absorption that increased toward the blue and violet region of the spectrum. In lighter-toned orangy brown stones, the 585-nm band could also be seen; however, in general the strong absorption edge dominated the spectrum.

## DISCUSSION

**Classification of Garnet Type.** For the yellow-green, intense green, and orangy brown garnets from

Figure 15. The curved surfaces of the nodules appear to be broken along healed fractures. This fracture is barely under the surface of a 3.11-ct yellowish green garnet nodule from Mali. Photomicrograph by John I. Koivula; magnified 15 $\times$ .



**TABLE 2.** Quantitative chemical analyses of eight Mali garnets.<sup>a</sup>

Results	Microprobe analyses, by sample number						Analytic SEM analyses, by sample number			
	MA01	MA02	MA93	MA23	MA19		R-2597	R-2594	R-2596	
	Yellowish green	Yellowish green	Intense green	Brown	Green core	Brown rim (3)	Greenish yellow	Yellow-green	Greenish yellow BSE dark (3) <sup>b</sup>	Greenish yellow BSE light (1) <sup>b</sup>
<b>Wt. % oxides</b>										
MgO	0.49	0.47	0.67	0.34	0.48	0.33	0.78	0.70	1.06	0.80
Al <sub>2</sub> O <sub>3</sub>	17.26	18.09	17.55	6.29	15.67	6.97	17.70	17.51	18.25	18.47
SiO <sub>2</sub>	38.80	38.97	39.11	36.43	39.02	36.67	40.23	40.01	38.58	39.15
CaO	36.29	36.63	36.49	34.42	35.94	34.57	34.05	34.59	36.95	36.94
TiO <sub>2</sub>	0.19	0.18	0.65	1.15	0.68	0.87	0.10	0.09	0.13	nd
Cr <sub>2</sub> O <sub>3</sub>	nd	nd	0.63	nd	nd	nd	0.09	0.07	0.12	nd
V <sub>2</sub> O <sub>3</sub>	nd	nd	nd	0.04	nd	nd	—	—	—	—
MnO	0.11	0.10	0.13	0.10	0.11	0.14	0.09	0.11	0.10	nd
Fe <sub>2</sub> O <sub>3</sub>	6.88	5.23	5.20	20.91	7.99	20.25	6.96	6.92	4.80	4.64
Sum	100.02	99.67	100.43	99.68	99.89	99.81	(100)	(100)	(100)	(100)
<b>Mole % garnet end-members</b>										
Py	1.91	1.85	2.65	1.46	1.96	1.40	2.93	2.73	4.17	3.1
Sp	0.24	0.22	0.29	0.24	0.26	0.34	0.18	0.23	0.23	nd
Uv	nd	nd	1.98	nd	nd	nd	0.25	0.20	0.37	nd
And	20.29	15.58	15.59	67.97	24.58	64.95	20.00	20.07	14.37	13.9
Gr	77.56	82.34	79.48	30.32	73.20	33.31	76.60	76.77	80.87	83.0
Unit-cell edge	11.8937						11.87	11.88	11.88	
R.I.							1.765	1.765	1.752	
S.G.							3.67	3.66	3.64	

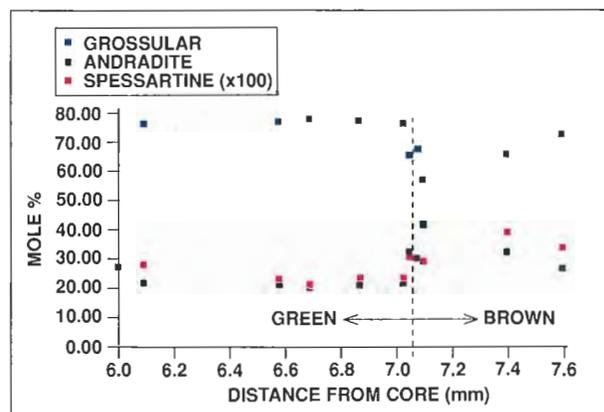
<sup>a</sup>Microprobe analyses were run on a CAMEBAX electron microprobe, and analytical SEM analyses were run on a Camscan Series II SEM. Elemental concentrations below the detection limits of the microprobe are listed as "nd;" vanadium was not looked for with the SEM (as indicated by a dash). Consult the authors for further experimental details.

<sup>b</sup>BSE = Backscattered electron imaging.

Mali, which have more than 50% grossular component, the proper mineralogic name is *grossular garnet* or, since the iron is in the Fe<sup>3+</sup> (ferric) oxidation state, *ferric grossular garnet*. As a gem variety, we are referring to this material as grossular-andradite garnet, since it lies between the two pure end-members. This is analogous to Stockton and Manson's (1985) use of the terms *pyrope-almandine*, *pyrope-spessartine*, and *almandine-spessartine* to describe intermediate garnets in the pyralspite subgroup. For any (probably orange-to-brown) garnets with compositions of 50% (or more) andradite, we propose also using the grossular-andradite designation, although the mineralogic name for such garnets would be (aluminian) andradite. Some gem garnet names currently in use by the GIA Gem Trade Laboratory are given in table 3.

Intermediate grossular-andradite garnets, sometimes called grandite garnets in the petrologic and mineralogic literature, are common as

Figure 16. These calculated garnet end-member components were derived from a microprobe traverse across part of a Mali garnet section (specimen MA19; see table 2) that had a green core and a brown rim. Manganese (spessartine) values are exaggerated by 100x for clarity. Pyrope contents do not vary significantly in this stone.



semi-translucent to opaque dull-colored garnets in contact-metamorphic (skarn) deposits, but they have not been previously documented as facetable gem materials. However, another gem-quality intermediate garnet in the uvarovite-grossular-andradite series was described by Burns (1973): "lime" green crystals from a drill core at Marvel Loch, Western Australia, that were found to have a composition of  $\text{Gr}_{55}\text{And}_{13}\text{Uv}_{32}$ . The largest was reportedly about 5 mm in diameter. The Mali grossular-andradites are extraordinary among the contact-metamorphic ugrandite garnets for their combination of size and transparency.

**Possible Causes of Growth Zoning and Anomalous Birefringence.** The most pronounced visual feature of the grossular-andradite garnets from Mali is linear growth zoning, which we saw when the stones were magnified, sometimes with standard dark-field illumination, but always when viewed between crossed polarizers. This feature is typically found in grandite garnets and has been extensively studied in the mineralogical literature. The possible causes include: variation and ordering between  $\text{Fe}^{3+}$  and Al (Lessing and Standish, 1973; Akizuki, 1984; Akizuki et al., 1984; Hirai and

Figure 17. Compositional variation in a 1.86-ct greenish yellow grossular-andradite garnet from Mali (R-2596) can be seen as variations in brightness in this back-scattered electron image taken with a scanning electron microscope. Bright bands are lower in pyrope than the dark bands. (The dark band to the left is the edge of the table facet; the dark spots are dust particles on the stone's surface.) Electronmicrograph by Mary L. Johnson; magnified 88x.

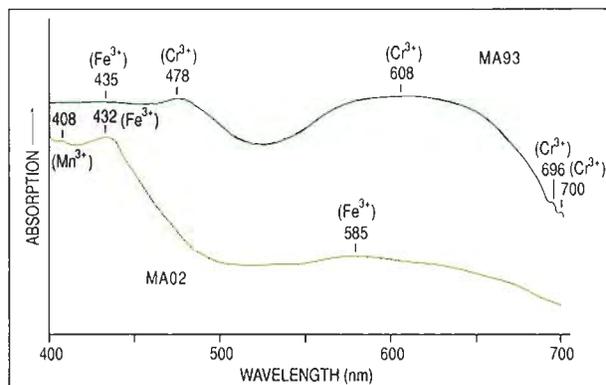
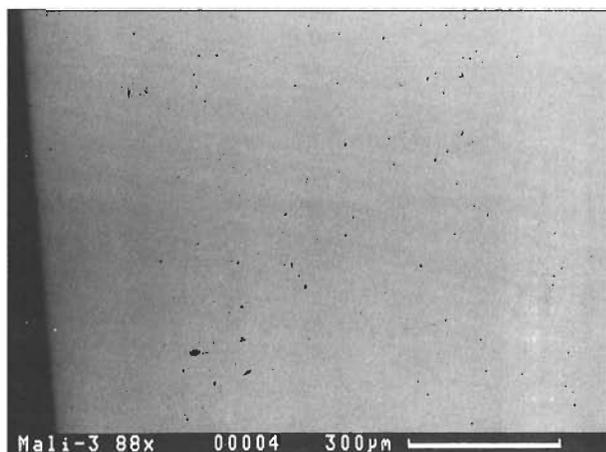


Figure 18. Ultraviolet-visible absorption spectra for yellowish green (MA02) and intense green (MA93) grossular-andradite garnets from Mali show peaks associated with trivalent iron ( $\text{Fe}^{3+}$ ), the principal cause of color in sample MA02, and chromium (Cr), another important color-inducing element in sample MA93.

Nakazawa, 1986; Soós et al., 1991; Jamtveit, 1991); strain (Foord and Mills, 1978; McAloon and Hofmeister, 1993); orientational variation of OH groups (Rossman and Aines, 1986; Allen and Buseck, 1988); and twinning within individual layers (Hirai and Nakazawa, 1982). Another possible cause for the zoning may be immiscibility unmixing between components in the grandite and pyralite subgroups (Bosenick et al., 1995).

TABLE 3. Chemical compositions and refractive index ranges for gem garnets.<sup>a</sup>

Gem garnet	Chemical composition	Refractive indices
Pyrope	$\text{Mg}_3\text{Al}_2(\text{SiO}_4)_3$	1.714 – <1.742
Pyrope-almandine	$(\text{Mg}, \text{Fe})_3\text{Al}_2(\text{SiO}_4)_3$	1.742 – <1.785
Almandine	$\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$	1.785 – 1.830
Almandine-spessartine	$(\text{Fe}, \text{Mn})_3\text{Al}_2(\text{SiO}_4)_3$	1.810 – 1.820
Spessartine	$\text{Mn}_3\text{Al}_2(\text{SiO}_4)_3$	1.780 – <1.810
Pyrope-spessartine	$(\text{Mg}, \text{Mn})_3\text{Al}_2(\text{SiO}_4)_3$	1.742 – <1.780
Grossular	$\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$	1.730 – 1.760
<b>Grossular-andradite</b>	<b><math>(\text{Ca}, \text{Fe})_3\text{Al}_2(\text{SiO}_4)_3</math></b>	<b>1.752 – 1.782</b>
Andradite	$\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$	1.880 – 1.895

<sup>a</sup> Derived from Stockton and Manson (1985) and present study.

## CONCLUSIONS

**Gem Nomenclature and the Distinguishing Features.** Mali garnets examined to date were greenish yellow-

low to green or greenish yellow to orangy brown, with an R.I. range between 1.752 and 1.782, and S.G.'s between 3.63 and 3.70 (disregarding the single 4.19 value of Henn et al., 1994). The absorption spectra and chemistry of these garnets agreed with those of garnets colored primarily by trivalent iron (with the exception of the intense green stones, which also contained chromium and possibly vanadium). The most common internal features seen were parallel growth planes, sometimes showing dodecahedral or trapezohedral angular boundaries (again, see figures 12 and 13) that are related to the anomalous birefringence of the material. *These growth features are ubiquitous in, and may be considered diagnostic for, grossular-andradite garnets.* "Fingerprint" inclusions, small white and dark anhedral crystals, and (one) very wispy horsetail inclusion have also been seen in stones from Mali. All these properties are consistent with the material from Mali being an intermediate garnet in the grossular-andradite series of the ugrandite (*uvarovite-grossular-andradite*) subgroup, with less than 10% pyrope plus [possibly] *almandite plus spessartine* components.

At the moment, the gem trade seems to be calling this material "Mali garnet," or "Mali grossular garnet." It is also being sold as "grandite garnet," a short-hand term used by petrologists but not a name accepted by the International Mineralogical Association (IMA). The GIA Gem Trade Laboratory calls this material *grossular-andradite* (as opposed to simply *grossular*) because its properties lie between the two gem species. To wit: (1) the range of refractive indices extends beyond, and barely overlaps, that which is traditionally considered to be grossular, and does not reach the andradite range; (2) the yellow-green, green, and orangy brown colors and absorption spectra are consistent with andradite (pure grossular is colorless); and (3) the absorption spectrum (440 band) is consistent with andradite (pure grossular has no absorption spectrum). The composition extends from grossular toward andradite, far beyond the most Fe-rich transparent grossulars reported by Manson and Stockton (1982). Transparent stones on both sides of the 50/50 split between grossular and andradite should have gem properties consistent with this classification.

**Effect on the Gem Market.** Most gem-quality grossular-andradite garnets from Mali seen thus far

are reminiscent of pale greenish yellow to yellow-green grossulars from Tanzania, and are similar in appearance to faceted chrysoberyl from Sri Lanka and Brazil. Some rare stones resemble peridot. There are also numerous brown to brownish orange stones which can be quite brilliant, due to their (andradite-derived) higher R.I.'s and dispersions. These may serve as inexpensive substitutes for "cognac" diamonds. Although only a few intense green stones have been found so far, Mali is a promising source for these garnets. In light of the current low supply of tsavorite from Kenya and Tanzania, and the extreme rarity of fine demantoids, this potential new source would be a welcome alternative.

This new gem variety of garnet will undoubtedly reach mass-marketing channels soon. Stockpiles of rough, rumored to total several tons, await processing in Idar-Oberstein, Australia, and America. Also ready for cutting as of early September 1995 were several dozen kilograms of facet-grade nodules and several hundred kilos of cabochon-grade material. Already, thousands of carats of fashioned gems are poised to enter the marketplace.

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# SAPPHIRES FROM SOUTHERN VIETNAM

By Christopher P. Smith, Robert C. Kammerling, Alice S. Keller, Adolf Peretti, Kenneth V. Scarratt, Nguyen Dang Khoa, and Saverio Repetto

*Gem-quality blue to bluish green sapphires from basaltic terrains in southern provinces of Vietnam have been entering the gemstone market since the late 1980s. Visits to two of the sapphire-producing areas—Phan Thiet and Di Linh—confirmed that the sapphires occur in association with alkali basalts. Mining was done by hand at the Phan Thiet localities and with relatively sophisticated equipment at Di Linh. Investigation of 250 faceted samples revealed gemological, spectroscopic, and chemical properties similar to those of other basaltic sapphires. Notable internal features are prominent growth structures, distinctive color zoning, various cross-hatch to lath-like “cloud” patterns, and several mineral inclusions.*

## ABOUT THE AUTHORS

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In recent years, considerable attention has been focused on the deposits of ruby and fancy-colored sapphires in northern Vietnam (see, e.g., Kane et al., 1991; Kammerling et al., 1994). Yet, significant corundum deposits have also been found in southern Vietnam. Since the late 1980s, blue to bluish green gem-quality sapphires (figure 1) have been recovered from secondary deposits in basaltic terrains in the provinces of Binh Thuan (formerly Thuanh Hai), Lam Dong, Dong Nai, and Dac Lac (figure 2). With the start of both organized and wide-scale independent mining in approximately 1990, thousands of carats of these sapphires began to enter the gem market through Thailand and elsewhere. To date, mining activity has been erratic, although periods of intense activity marked the first half of the 1990s. In fact, a spring 1995 report stated that more than 10,000 people had gone to central “Darlac” [Dac Lac] Province in search of sapphires (“Sapphire Fever Strikes . . .,” 1995). Because the blue sapphire deposits of southern Vietnam appear to cover a fairly wide area, and they are easily mined from secondary gravels, future prospects appear promising.

In late 1992 and early 1993, several of the authors (RCK, SR, AP, KVS, ASK) visited the deposits at Phan Thiet (Binh Thuan Province) and Di Linh (Lam Dong Province) and collected firsthand information and samples. Additional samples were obtained through various marketing channels within Vietnam. At the time of our visits, there was no formal mining in Dong Nai Province, although we were told that sapphire had been found in the area of Gia Kiem, in central Dong Nai. Nor was there organized activity at Dac Lac. This report focuses on the geologic occurrence of these blue to bluish green sapphires, the mining methods used to extract them, and their gemological properties (especially their distinctive internal structure and other internal features).

Figure 1. Commercial quantities of blue sapphire have been mined from various regions in southern Vietnam. These Vietnamese sapphires range from 0.50 to 1.58 ct. Jewelry courtesy of The Gold Rush, Northridge, California; photo by Shane F. McClure.



## GEOLOGY AND OCCURRENCE

In northern Vietnam, the gem corundums (primarily rubies and fancy sapphires, although some blue sapphires have been reported) occur in metamorphic rocks, specifically marbles (see, e.g., Kane et al., 1991). In contrast, the blue to bluish green gem corundums in southern Vietnam are found in alkali basalts (volcanic igneous rocks). Like the first gem corundums discovered in northern Vietnam, however, those in the south are recovered from secondary deposits, mainly alluvials (placers).

The geologic setting of these southern Vietnam sapphires is similar to that of alkali basalts elsewhere in Southeast Asia and China, such as Mingxi in Fujian Province (Keller and Keller, 1986), Penglai on Hainan Island (Wang, 1988), and Changle in Shandong Province, China (Guo et al., 1992b); Chanthaburi-Trat and Kanchanaburi, Thailand (Vichit et al., 1978); Pailin, Cambodia (Jobbins and Berrangé, 1981); and Monghkak, Myanmar (Hlaing, 1993). At these localities, the alluvial and eluvial deposits result from concentration of the gem corundums by weathering and mechanical processes; zircon, spinel, and garnet may also be recovered.

The volcanic activity in Southeast Asia that brought the corundum-bearing alkali basalts to the surface began at least 13 million years (My) ago and has continued to the present (see, e.g., Barr and Macdonald, 1981). During Middle and Late Cenozoic time (since about 37 My ago), Southeast Asia experienced block faulting as a result of regional tension, with the subsequent formation of grabens (long, narrow troughs, such as those in East Africa and the Rhine Valley, bounded by normal faults). Thus, topographically, this part of southern Vietnam may be viewed as consisting of numerous partly eroded plateaus separated by trough-like valleys. Volcanic activity along the rifts resulted in a broad basalt cover over much of the area. The depressions were filled not only with basalts but also with sediments, including corundum, derived from the weathering of rock formations at higher elevations (i.e., the upraised fault blocks; Barr and Macdonald, 1981).

*Basalt* is a general term for fine-grained, dark-colored, mafic (high Fe and Mg) igneous rocks composed chiefly of calcium-rich plagioclase and calcium-rich clinopyroxene (mainly augite). There are two major types of basalt: tholeiite and alkali. In

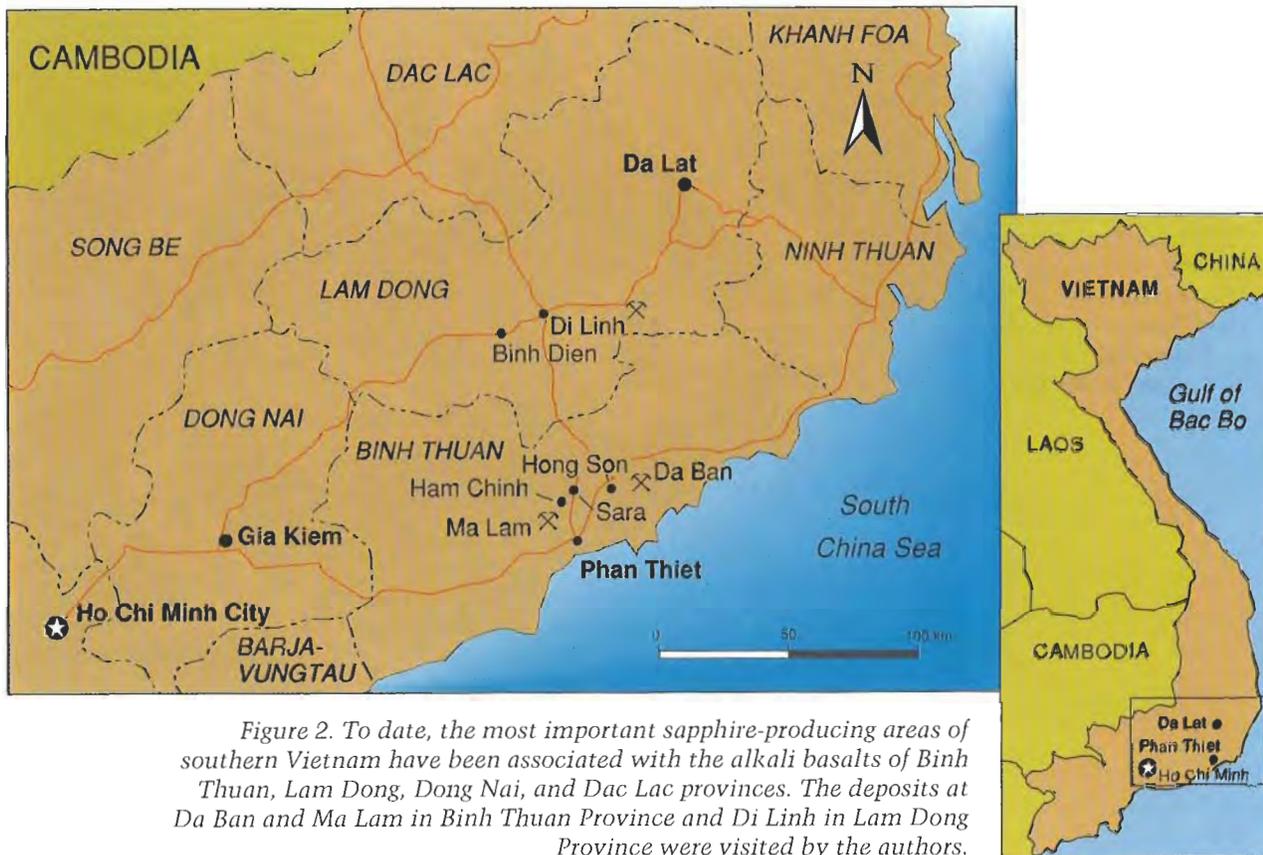


Figure 2. To date, the most important sapphire-producing areas of southern Vietnam have been associated with the alkali basalts of Binh Thuan, Lam Dong, Dong Nai, and Dac Lac provinces. The deposits at Da Ban and Ma Lam in Binh Thuan Province and Di Linh in Lam Dong Province were visited by the authors.

areas where more than one type of basalt occurs, as in southern Vietnam and elsewhere in Southeast Asia, usually the older flows are tholeiites and the younger flows alkali basalts. Corundum is found only in association with alkali basalts, which con-

Figure 3. At Da Ban, most of the mining is done with simple hand tools, like the pick used by these miners to remove the potentially gem-bearing gravels. Photo by R. C. Kammerling.



stitute a small percentage of all basalts; they are characterized by higher alkali (>3–5 wt.% Na<sub>2</sub>O + K<sub>2</sub>O) and lower silica (40–50 wt.% SiO<sub>2</sub>) contents compared to the more common tholeiitic basalts (see, e.g., Levinson and Cook, 1994).

Basaltic magmas form within the upper mantle (that part of the Earth below the crust) by a process known as partial melting (i.e., melting of selective components—about 5–10%—of mantle peridotite). Of the two major types of basalts, alkali basalts typically form at greater depths (about 60–120 km) than tholeiites (about 20–80 km). In addition, alkali basalts frequently contain abundant xenoliths and xenocrysts (rocks and crystals, respectively, included in a magma but not formed from the magma itself), which were picked up from the mantle as the magmas rose to the surface. Among these xenocrysts are sapphire and other varieties of corundum (see, e.g., Levinson and Cook, 1994).

To date, sapphires have been found in basaltic alluvials in four provinces in southern Vietnam: Binh Thuan, Lam Dong, Dong Nai, and Dac Lac. The authors gained access to mining operations in Binh Thuan (the Phan Thiet District) and Lam Dong (the Di Linh District).

## THE PHAN THIET DISTRICT

The Phan Thiet sapphire-mining district in Binh Thuan Province lies near the coastal city of Phan Thiet, about 200 km (124 miles) due east of Ho Chi Minh City (again, see figure 2). At the time of our visits, travel into the mining areas by non-Vietnamese nationals required special permits, which were checked at police posts throughout the region. The authors were accompanied by local government officials when they went into the Phan Thiet mining district, which included two large areas: Da Ban and Ma Lam.

**Da Ban Mining Area.** *Access.* Da Ban is located near Hong Son Village, about 28 km (17 miles) northeast of Phan Thiet City. We reached the mining area by driving a combination of paved and winding dirt roads and then walking the last 1 km northwest through a shallow valley. Unlike the lush tropical vegetation we had encountered in the ruby-mining areas in northern Vietnam, the vegetation in this hot, dry region was mostly scrub.

*Mining.* The mining area was a field of small, irregularly shaped pits typically about 1–2 m deep; local miners told us that the sapphires were found relatively close to the surface. We could not discern a distinct gravel layer in any of the pits. Although most were very small and shallow, barely holes in the ground, some of the pits were as large as 3 × 4 m (as shown in Koivula et al., 1992).

In November 1992, the area was being worked by several small groups of local villagers. They used agricultural hand tools—hoes and shovels—first to remove the vegetation and topsoil, and then to dig down to and through the gem-bearing zone (figure 3). They shoveled the gravels into wood-framed sieves and then washed them using water that had accumulated in their or another pit. The miners examined the gravels and removed any gem material by hand on site.

Local villagers told the authors that at the very height of activity only a few weeks earlier, 2,000–3,000 people had worked about a 7-km<sup>2</sup> of this mining district. They said that mining activity had decreased recently because (1) local government officials had made concerted efforts to curb illegal digging, and (2) much of the material was relatively low quality and so brought low prices.

At one house in the area, miners showed us a small lot (about 100 ct) of rough stones that ranged from light to very dark blue to greenish blue. They



Figure 4. This miner throws gravel into a simple metal sieve for washing at Ma Lam. As at Da Ban, many miners work in the hot sun, shoveling dirt and gravels, and then carrying the heavy sieves to nearby ponds. Photo by R. C. Kammerling.

said that this material, much of which did not appear to be cuttable, was recovered over four days by seven people. This seemed to confirm the assessment that generally only poor-quality material was being found at that time.

**Ma Lam Mining Area.** *Access.* We reached Ma Lam from Phan Thiet City by driving a circuitous route north-northwest about 20 km (12 miles), through Sara and Ham Chinh villages. The final kilometer or so was on a poorly delineated dirt road.

*Mining.* This field of mining pits extended over a larger area—several square kilometers—than that at Da Ban. Here, the pits ranged from about 0.5 to 2 m deep. Miners used shovels to excavate the sandy soil until they reached the gravel-bearing zone. They threw the gravels (figure 4) into crude metal



Figure 5. Most of the ponds used for washing the gravels at Ma Lam appeared to be old pits that had been filled with groundwater. Here a young boy searches for pieces of gem rough. Photo by A. S. Keller.

sieves that they took to nearby flooded, previously excavated pits for washing (figure 5). As at Da Ban, there were no distinct boundaries to the gravel layer.

We encountered several dozen men, women, and children mining in the area, singly and in groups of up to about 10. We were told that, in November 1992, about 400 people were mining in the region, compared to about 1,000 only a few months previously. The miners reported an average total yield for Ma Lam of about 100 stones a day.

**Marketing.** Some of the sapphires recovered by local miners in Binh Thuan Province were marketed in Phan Thiet City through a government selling office, actually a branch of the Vietnam National Gold, Silver, and Precious Stones Corporation (figure 6). Here, we saw several lots (about 2,000

carats total) of rough sapphires. The best of these were nearly euhedral to slightly rounded subhedral crystals displaying strong green and blue dichroism. Most of the stones were small—less than 3 ct—although a few were over 10 ct. The larger pieces were nearly opaque. In many of the stones, we noted distinct color banding as well as what appeared to be epigenetic iron-based staining.

Only about 5% of the material we saw was of cutting quality. However, Donato Cremaschi, an experienced gem cutter working in Ho Chi Minh City at the time, told us that about 10% of the sapphires brought into his offices were cuttable. Because of the fees charged by the government selling office, and the desire to control distribution themselves, miners and dealers typically sold as much as 95% of their production through channels other than the official government market.

#### DI LINH DISTRICT

**Location and Access.** The Di Linh District, encompassing the Di Linh and Binh Dien mining areas, is located in Lam Dong Province, adjacent to and north of Binh Thuan Province. Although the mining areas can be reached by driving from Ho Chi Minh City to Phan Thiet and then traveling almost due north, a more direct route is to drive northeast from Ho Chi Minh City to Da Lat City, which can be used as a base from which to visit Di Linh City. From Ho Chi Minh City, which is near sea level, to

Figure 6. Lots of rough sapphire were brought to the Phan Thiet branch of the Vietnam National Gold, Silver, and Precious Stones Corporation by local miners and dealers at the time of the authors' visit. Photo by R. C. Kammerling.



Da Lat, the road climbs to an elevation of about 1,500 m; it passes through rubber tree and eucalyptus plantations, and then tea and coffee plantations closer to Da Lat. The Summer Palace of the former imperial families is located in the resort city of Da Lat. Locals regularly pan for gold in the river that runs through the city.

Two of the authors (AP, KS) visited the mining operation of the Vietnam National Gems Company (Vinagemco) at Di Linh in October 1992. (Vinagemco had a joint venture with the Thai firm BH Mining to mine rubies and sapphires in Luc Yen.) They reached the mining area by traveling about 40 km (24 miles) southwest from Da Lat, then leaving the main road and traveling southeast about 2 km through hilly country on a rough, winding trail. During the rainy season (approximately May through August), only a large four-wheel-drive vehicle can negotiate the road. The topography of the mine area is typical of that at many other basaltic regions: undulating, with numerous flat-topped hills.

**Mining.** Unlike the rudimentary independent mining seen in the Phan Thiet district, Vinagemco had mechanized much of their sapphire-recovery operation at Di Linh (figure 7). A backhoe removed the overburden and then the sapphire-bearing gravels. A dump truck took the gravels to a processing plant about 100 m from the mining site for washing. The gravels were sent through a wooden hopper, into a rotating trommel, and then onto a wooden jig. At the time of our visit, however, this process had produced a potentially deadly environment in and around the washing plant: Large areas of quicksand, some 3 m deep, had formed from the run-off water.

There was also considerable independent mining in the Di Linh area. Miners worked the hills surrounding the Vinagemco plant, and then brought the excavated gravels to nearby streams for washing.

### GEMOLOGICAL CHARACTERISTICS OF SOUTHERN VIETNAM SAPPHIRES

**Materials and Methods.** The test sample for this study consisted of more than 250 faceted, non-heat-treated gem-quality sapphires ranging from 0.14 to 3.44 ct, and six rough crystals ranging from 3.54 to 7.32 ct. All were obtained from various marketing channels in Vietnam and represented to be from southern Vietnam. This entire collection was exam-



Figure 7. At Di Linh, in Lam Dong Province, the joint venture Vinagemco uses a backhoe to remove the overburden and reach the gem gravels. A dump truck then carries the gravels to a nearby washing plant. Photo by K. V. Scarratt.

ined to document the range of color, diaphaneity, reaction to ultraviolet luminescence, and microscopic features.

For more detailed analyses, a subset of roughly 100 of the faceted stones was selected to represent the full range of colors, including tone and saturation as well as hue variations, of the complete test sample. The gemstones in this group were examined by the senior author (CPS) to produce the broader scope of data presented in this article. Of this subset, 50 samples were also examined to record their refractive indices, birefringence, optic character, pleochroism, and optical absorption spectra (desk-model spectroscope), all with standard gemological instrumentation. Specific gravity was determined on 25 faceted stones and five of the rough crystals by the hydrostatic weighing method.

Approximately 50 stones were selected from the above 100 samples for spectroscopic and chemical analysis, as well as for examination of growth structure. A Perkin Elmer Lambda 9 spectrometer was used to perform polarized ultraviolet-visible through near-infrared spectroscopy (slit opening 0.5 nm, interval 0.2, response 1.0, and scanning speed 120 nm/min.) on two groups of stones: 49 in the region 200–900 nm, with a beam condenser and polarizing filters; and six in the region 300–2000 nm, with a calcite polarizer and beam condenser. We performed infrared analyses on 39 samples with

a Pye-Unicam FTIR 9624 spectrometer, using a diffused reflectance unit for sample measurement. Semi-quantitative chemical analyses were conducted on 53 specimens by means of energy-dispersive X-ray fluorescence (EDXRF) analysis. This was performed on a Tracor Northern Spectrace 5000 system, using a program specially developed by Prof. W. B. Stern, Institute of Mineralogy and Petrography, University of Basel.

The internal growth structures of 80 faceted stones were analyzed with the use of a horizontal microscope, a specially designed stoneholder, and a mini-goniometer attached to one of the oculars on the microscope, employing the methods described by Schmetzer (1986a and b) and Kiefert and Schmetzer (1991a). Inclusion analysis was performed on almost 40 mineral inclusions in 32 stones. Some were analyzed with a scanning electron microscope-energy dispersive spectrometer (SEM-EDS), others with X-ray diffraction analysis, and some with both techniques. Some of the stones were polished to expose specific inclusions.

**Visual Appearance.** Most of the *crystals* studied appeared rounded or tumbled, with no indication of the original crystal form. Some, however, showed less evidence of weathering and revealed overall forms (i.e., crystal habits) that were either oblong or blocky. Clearly displayed on the surfaces of these crystals were severely etched or dissolved features typical of rough sapphires from basaltic deposits (figure 8); these result from contact with the highly

Figure 8. The rough crystal surfaces of the southern Vietnam sapphires displayed the heavy dissolution effects typical of corundums that have been brought to the surface by alkali basalts. Overhead illumination.



corrosive alkaline basalt magmas (Tombs, 1991; Coenraads, 1992a and b). Consequently, at best there was only an approximate indication of the original crystal habit. We also noted chipped or broken areas, and parting along basal planes. See the "Growth Characteristics" section for specific details about crystal habit.

Face up, the *faceted samples* were predominantly blue to greenish blue to bluish green, with tones from medium-light to very dark (figure 9). Many were so dark that they appeared black in standard daylight. A common trait was strong, eye-visible color zoning (again, see "Growth Characteristics" below).

In diaphaneity, the faceted samples ranged from transparent to translucent, depending on the nature and number of inclusions as well as on color saturation and tone. Much of the sample material was essentially devoid of eye-visible inclusions, although most displayed an overall "sleepy" appearance.

**Gemological Properties.** The standard gemological properties for the sample stones are listed in table 1. They were found to be consistent with corundum in general (see, e.g., Webster, 1983; Liddicoat, 1989) and, in particular, with blue to bluish green sapphires from various other basaltic sources (see, e.g., Keller, 1982; Coldham, 1985; Wang, 1988; Hughes, 1990; Hurlbut and Kammerling, 1991).

**Pleochroism.** All samples exhibited a distinct to strong dichroism when viewed with a calcite dichroscope. Hues ranged from blue to violetish blue parallel to the c-axis, and blue-green to yellow-green perpendicular to the c-axis. It is important to note that all of the blue to bluish green sapphires examined for this study displayed pleochroic colors in these hue ranges. The variations in face-up appearance, with the exception of color zoning, were related to differences in the orientation of the faceted stones with respect to their optic axis.

**Growth Characteristics.** As mentioned previously, the external condition of the rough crystals prevented identification of their growth morphology by standard techniques. We were able to accomplish this only by documenting the internal growth structures and color zoning, which represent a history of the original sapphire crystal as it grew below the earth's surface. Classification of the crystal habits and growth characteristics can help separate natural corundum from its synthetic counter-



Figure 9. The sapphires from southern Vietnam typically range in color from medium-light to very dark blue to bluish green. Less frequently seen are green to yellowish green sapphires, or stones with a violet color. These Vietnamese sapphires range from 0.42 to 3.44 ct. Photo by Shane F. McClure.

parts, as well as help distinguish between corundums from various sources [see, e.g., Peretti et al., 1995].

*Growth Structures.* Prominent growth structures were observed in essentially all of the faceted sapphires examined. These structures consisted of straight and angular sequences of growth planes composed of the basal pinacoid  $c$  (0001), positive rhombohedral  $r$  ( $10\bar{1}1$ ) faces, and different dipyrnidal faces, such as  $n$  ( $22\bar{4}3$ ),  $z$  ( $22\bar{4}1$ ),  $v$  ( $44\bar{8}3$ ), and  $\omega$  ( $14\ 14\ \bar{2}8\ 3$ ) or  $v$  ( $44\bar{8}1$ ). Limitations of the interpretation method do not allow for a separation of these last two dipyrnidal faces, which hereafter are called  $\omega/v$ . Most of the faceted stones examined contained enough internal crystallographic information for us to extrapolate their original crystal habit (figure 10). By far, two dipyrnidal crystal habits, some of which have been modified to barrel

shapes, dominated in the southern Vietnam sapphires. These were composed of  $c$ ,  $r$ ,  $z$  and  $c$ ,  $r$ ,  $n$ , and  $z$  faces (as shown in figure 11). In both cases, the basal pinacoid  $c$  was small and subordinate, while the dipyrnidal  $z$  was the largest and most dominant crystal face. In rare instances, we observed a change between these two crystallographic habits during the growth of a single sapphire crystal.

To a much lesser degree, we were able to reconstruct other crystal habits, including thick tabular habits with  $c$ ,  $r$ , and  $z$  faces, or  $c$ ,  $r$ , and  $\omega/v$ , both of which possessed dominant  $c$  and  $r$  crystal faces. In addition, in rare instances, we also observed these tabular crystal habits with very small and subordinate  $n$  crystal faces present sporadically. A barrel-shaped dipyrnidal habit of  $c$ ,  $r$ ,  $n$ , and  $v$  faces was also observed (again, see figure 11). Some faceted stones only displayed growth structures of  $c$ ,  $r$ , and  $n$  faces; however, such a habit has not been docu-

mented in sapphires from basaltic sources, and these stones may have been cut from fragments of a larger crystal.

**Color Zoning.** Obvious color zoning was present in most of the stones examined (figure 12). This consisted of straight and angular color banding that was parallel to the previously described crystal planes

**TABLE 1.** Gemological characteristics of basaltic sapphires from southern Vietnam.

Properties	No. of samples	Observations
Color	250	Weak to highly saturated colors ranging from blue to bluish green, with tones from light to extremely dark
Clarity	250	Very clean to heavily included, most in the range of slightly to moderately included
Refractive index	50	$n_E = 1.760-1.764$ $n_O = 1.769-1.772$
Birefringence	50	0.008-0.009
Optic character	50	Uniaxial negative
Specific gravity	25 faceted 5 crystals	3.99-4.02
Pleochroism	45	Strong dichroism: blue to violetish blue parallel to the c-axis and mostly green-blue to yellow-green perpendicular to the c-axis
Fluorescence to UV radiation	250	Inert to long- and short-wave
Optical absorption spectrum (nm)	45	450 (strong, broad) 460 (moderate to strong, broad) 469 (weak to moderate, broad)
Internal features <sup>a</sup>	250	Strong color zoning, prominent growth structures, laminated twinning, very fine grained clouds, several types of cloud patterns, various needle-like inclusions, "fingerprints," and negative crystals and crystalline inclusions of: Plagioclase feldspar (Na, Al, Si / K, Ca) Uranpyrochlore (Nb, U, Ca, Ti, Ta, Na / Fe) Columbite (Nb, Fe, Mn / Ta, Ti) <sup>b</sup> Zircon (Zr, Si / Hf) Ilmenite (Fe, Ti / Mn[?]) Pyrrhotite (Fe, S) Magnetite-hercynite (spinel), (Fe, Al / Si, Ti, Mn Zn) Chromite-hercynite (spinel) (Fe, Cr, Al) Goethite (XRD) Kaolinite (IR spectroscopy)

<sup>a</sup> Major/minor elements determined for those crystalline inclusions identified by SEM-EDS are given in parentheses after the inclusions.

<sup>b</sup> Also identified by X-ray diffraction analysis (XRD).



*Figure 10. The internal growth structures seen in many of the sapphires provided enough information to enable the senior author to extrapolate the original crystal habit. This 0.44-ct Vietnamese sapphire shows a combination of crystal planes, composed of: basal pinacoid  $c$  ( $0001$ ), the roughly horizontal growth planes; connected to a more subordinate series of dipyrmaid  $n$  ( $22\bar{4}3$ ) crystal planes, creating an angle of  $118.8^\circ$  with the basal growth planes; and dominant dipyrmaid  $z$  ( $22\bar{4}1$ ) crystal planes, the nearly vertical growth planes, creating an angle of  $100.4^\circ$  with the basal growth planes. Rotating this stone about the vertical axis through  $30^\circ$ , a combination of  $c$  ( $0001$ ) and  $r$  ( $10\bar{1}1$ ) crystal planes were visible, creating an angle of  $122.4^\circ$ . This information permits a crystal habit of  $c$ ,  $r$ ,  $n$ , and  $z$  to be assumed for the original crystal (also refer to figure 11b). Immersion, view perpendicular to the  $c$ -axis, transmitted illumination, magnified  $15\times$ .*

and growth structures. Alternation in color banding between consecutive growth layers was common. This occurred most frequently in two basic forms: (1) strong, sharply bordered blue bands alternating with narrow, colorless bands (figure 13); and (2) strong blue bands alternating with yellowish to brownish bands (figure 14). These two forms of color banding typically occurred parallel to  $r$  and/or  $z$ . Parallel to the basal pinacoid  $c$  crystal planes, zones with very little or no color were observed, or in some instances color banding alternated between light blue and colorless.

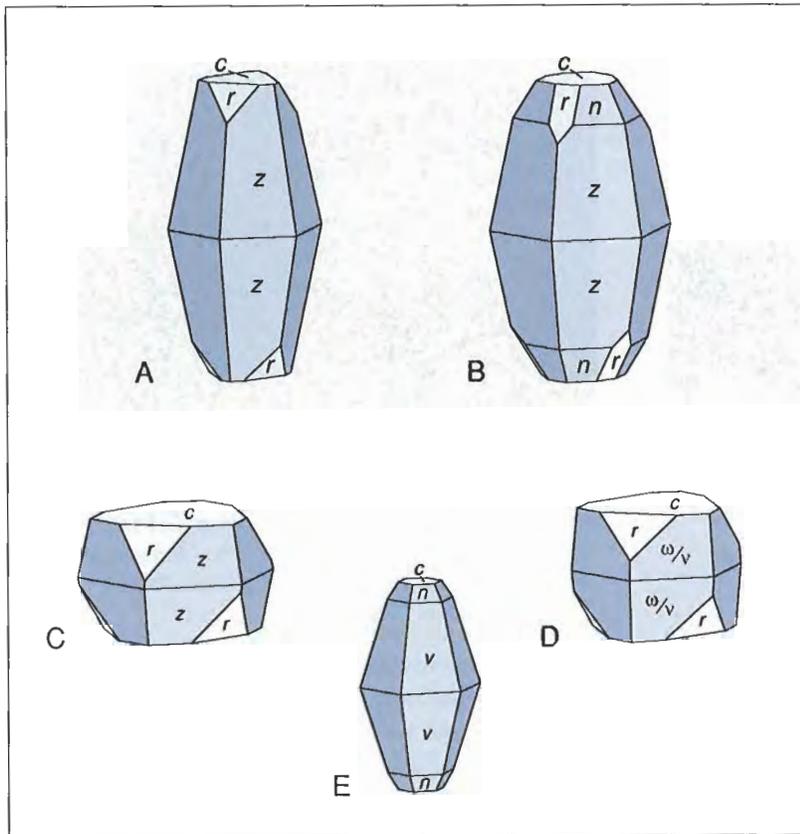


Figure 11. The sapphires from southern Vietnam revealed several different crystal habits. Of these, two oblong to barrel-shaped forms were statistically abundant, composed of: (A) dominant dipyrmaid  $z$  ( $22\bar{4}1$ ) faces, with subordinate basal pinacoid  $c$  ( $0001$ ) and positive rhombohedron  $r$  ( $10\bar{1}1$ ) faces; (B) dominant  $z$  faces, in addition to more subordinate dipyrmaid  $n$  ( $22\bar{4}3$ ),  $c$ , and  $r$  faces. Additionally, tabular crystal habits were also indicated, composed of: (C) dominant  $c$  and  $r$  faces, with intermediate to subordinate  $z$  faces; (D) dominant  $c$  and  $r$  faces, with intermediate dipyrmaid  $\omega$  ( $14\ 14\ \bar{2}8\ 3$ ) or  $v$  ( $44\bar{8}1$ ) faces. To a lesser extent, another barrel-shaped crystal form was identified, composed of: (E) dominant dipyrmaid  $v$  ( $44\bar{8}3$ ) faces, in addition to subordinate  $n$ ,  $c$ , and  $r$  faces.

One of the more intriguing types of color zoning consisted of a colorless "core" through the center of the original crystal. These "cores" represent crystal growth by one of two distinct methods: (1) a colorless sapphire crystal (core) formed during initial crystal growth and was subsequently overgrown by a sapphire with a strong blue color; or (2) the sapphire grew with a crystallographically preferred color orientation, where the basal planes are colorless while the positive rhombohedra and dipyrmaid faces are strong blue. Often these colorless "cores" had interesting geometric forms (figure 15), with blue outlines created by a combination of positive rhombohedra and dipyrmaid forms. In faceted stones, these "cores" commonly looked like colorless "holes" in otherwise blue stones, or they were merely colorless zones of various shapes and sizes (again, see figure 12).

**Twinning.** Twinning parallel to the  $r$  faces was seen in several of the stones examined (figure 16). They usually had only one direction of laminated twinning, parallel to a single positive rhombohedron  $r$  crystal face; occasionally, however, there were two or three twinning systems, parallel to additional positive rhombohedral planes.

**Inclusions.** The most prominent inclusion feature consisted of whitish, very fine-grained "clouds" of minute inclusions confined to growth planes; at

Figure 12. Distinct color zoning is readily seen in the southern Vietnam sapphires when they are immersed in methylene iodide. Also note the remainders of the colorless "cores." Immersion, photo by Shane F. McClure.

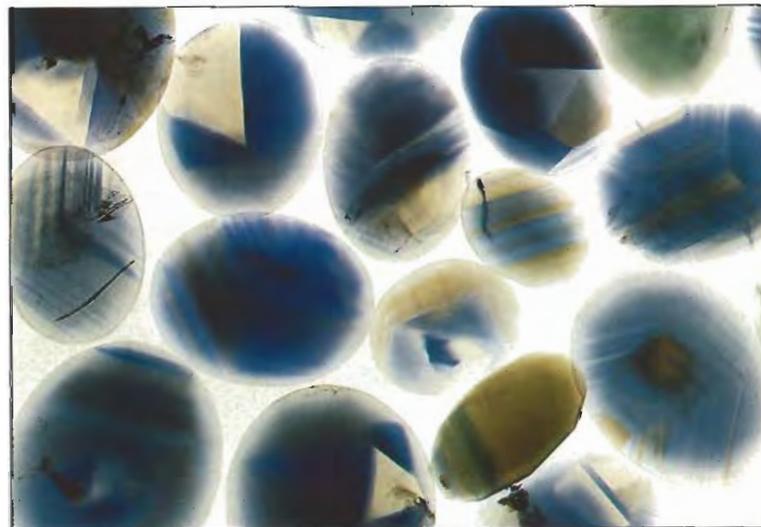




Figure 13. Strong, sharply bordered blue color bands alternating with narrow colorless bands was one type of distinctive color zoning noted in the sapphires from southern Vietnam. Photomicrograph by Dr. Eduard J. Gübelin; magnified 50 $\times$ .

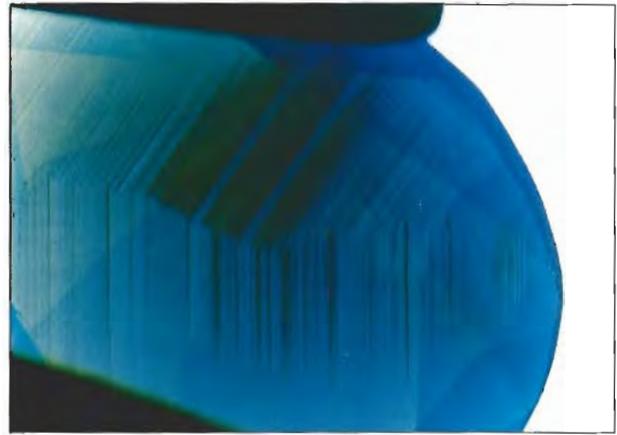


Figure 14. Additional distinctive color zoning, alternating between strong blue and light brown to yellow, tended to concentrate parallel to  $r$  (vertical) and/or  $z$  (diagonal) planes. Immersion, transmitted illumination, magnified 16 $\times$ .

lower magnification, they look like whitish zonal bands (figure 17). EDXRF analysis indicated that generally the particles in these clouds were not related to  $TiO_2$  (i.e., rutile) content. In a couple of instances, however, we recorded a higher level of  $TiO_2$  in areas where these clouds were present (up to 0.24 wt.%; also refer to table 2) as compared to other, more transparent areas in the stone.

Less commonly, concentrations of white particles were seen to occur in other forms, such as fine, narrow, planar clusters grouped together to create cross-hatch or lath-like patterns (figure 18). The individual particles resembled thin blades or very

fine, acicular crystals that are crystallographically oriented. Also noteworthy were dust-like clusters reminiscent of snowflakes (figure 19). Stringers of pinpoint inclusions were often seen in curved wisps following no particular crystallographic orientation, or extending in a straight line perpendicular to growth planes.

Needle-like inclusions were also noted in a small number of samples, along the intersection of two or three laminated twin planes. Typically

Figure 15. Colorless cores were frequently seen in the southern Vietnam sapphires, oriented parallel to the  $c$ -axis of the original rough sapphire crystal. This triangular image results from strongly colored  $r$  planes surrounding colorless  $c$  planes. Immersion, transmitted illumination, magnified 15 $\times$ .



Figure 16. Laminated twinning (shown here as bright vertical planes) was relatively common in the sample sapphires, generally following only one direction, parallel to a single  $r$  ( $10\bar{1}1$ ) face. However, occasionally two or three systems were observed, parallel to additional rhombohedral faces. Immersion, transmitted illumination between crossed Polaroids; photomicrograph by Karl Schmetzer.

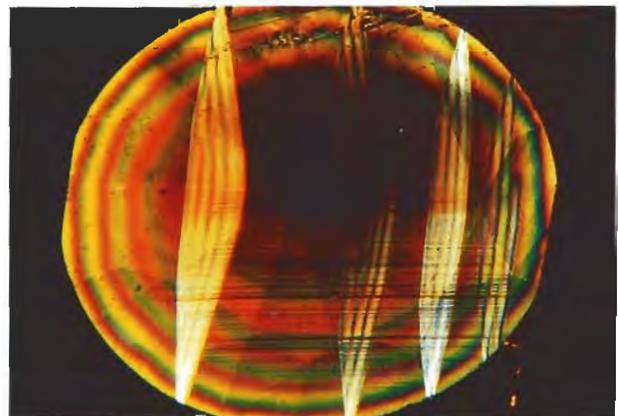




Figure 17. The most commonly observed inclusion feature in the sapphires from southern Vietnam consisted of clouds of fine-grained particles following internal growth planes, and thus appearing as straight and angular whitish bands. Shown here parallel to two dipyramidal  $z$  planes. Oblique fiber-optic illumination, magnified 25 $\times$ .

these needles extended in only one direction (figure 20), but they extended in two or three directions in a small number of stones. Occasionally, these inclusions were orange-brown when penetrated by late-forming minerals that have resulted from weathering, such as kaolinite (refer to the "Infrared Spectrometer" section below).

While not generally found in basaltic sapphires, very fine needles (presumably of rutile or ilmenite) have been documented in corundum from other basaltic sources, such as Thailand (Schlüssel, 1991). We observed similar-appearing inclusions in a small number of the sapphires from southern Vietnam, but we were not able to analyze them to determine their true identity.

Figure 18. Some of the more distinctive inclusion features consisted of unique cross-hatch (left) to lath-like (right) cloud patterns, composed of individual whitish particles which resemble thin "blades" or very fine acicular crystals. Left: Darkfield illumination, magnified 15 $\times$ ; photomicrograph by Dr. Eduard J. Gübelin. Right: Oblique fiber-optic illumination, magnified 25 $\times$ .



**TABLE 2.** Semi-quantitative chemical analyses of trace elements in the blue to bluish green basaltic sapphires from southern Vietnam.<sup>a</sup>

Oxide	Content (wt. %)	Measured in >80% of samples
Fe <sub>2</sub> O <sub>3</sub>	0.43 – 1.82	0.55–1.60
TiO <sub>2</sub>	0.003–0.240	0.01–0.09
Ga <sub>2</sub> O <sub>3</sub>	0.021–0.052	0.02–0.04
V <sub>2</sub> O <sub>5</sub>	0.001–0.017	0.00–0.01
MnO	0.000–0.017	0.00–0.01
Cr <sub>2</sub> O <sub>3</sub>	0.000–0.009	0.00–0.01

<sup>a</sup>Analyses conducted on 53 specimens by EDXRF. See "Materials and Methods" section for details.

Relatively few crystalline inclusions were observed in the sapphires examined. To date, we have identified a total of nine different mineral inclusions by SEM-EDS and/or X-ray diffraction analysis (again, see table 1). Most common were transparent colorless crystals of plagioclase feldspar (figure 21), which appeared in a variety of forms, including flat and tabular, oblong and prismatic, as well as more equidimensional shapes. Curiously, some of these transparent, colorless crystals had their own inclusions (again, refer to figure 21). Prismatic crystals of zircon were accompanied by small stress fractures, and "comet tail" inclusions—caused by growth disturbances within the host sapphire—trailed some crystals. In several sapphires, we identified octahedral crystals of uranpyrochlore, many of which were surrounded by radiation-damage "halos" oriented parallel to the basal crystal planes (fig-

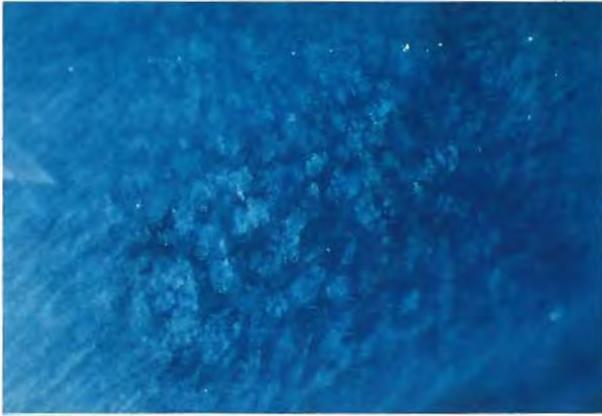
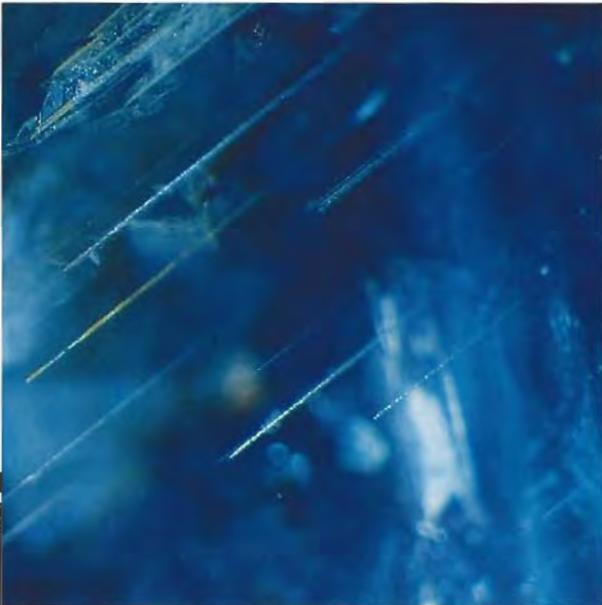


Figure 19. Snowflake-like inclusions were observed in a few of the sapphires from southern Vietnam. Oblique fiber-optic illumination, magnified 30 $\times$ .

ure 22). Some of these crystals appeared bright orange to orange-red, whereas others were essentially black; some were well-formed octahedra, whereas others were slightly rounded or even broken fragments.

Opaque, black-appearing, euhedral-to-subhedral (massive, nondistinct) crystals were commonly observed. These were most frequently identified as

Figure 20. Needle-like inclusions extend in a single direction along the intersection of two systems of twin lamellae. Occasionally these fine tubules appeared yellow to brown when penetrated by kaolinite. Oblique fiber-optic illumination, magnified 25 $\times$ .

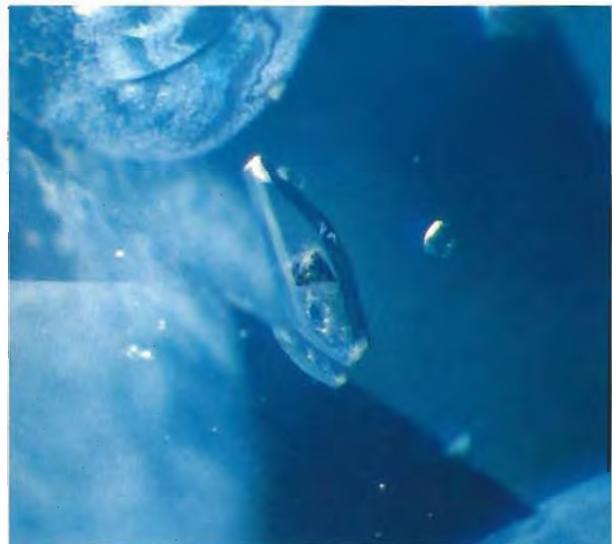


columbite (figure 23) and ilmenite (figure 24), but some were pyrrhotite. Severely corroded crystals of magnetite-hercynite (spinel) had a “brassy” color and strong iridescence when illuminated with an intense fiber-optic light source. Smaller opaque, black, octahedral crystals were identified as chromite-hercynite (spinel). Table 1 gives the major and minor elements found in some of the mineral inclusions identified by SEM-EDS.

A wide variety of negative crystals were also observed. Some looked like translucent yellowish orange to orange-brown solid inclusions, having been completely filled—via associated fractures reaching the surface—by late-forming minerals such as goethite (figure 25). Healed fractures were particularly abundant (figure 26); often they, too, were yellowish orange to orange-brown as a result of epigenetic staining by iron-hydroxides.

**Absorption Spectra.** *Desk-model Spectroscope.* Within the visible range, a general absorption to approximately 425 nm was apparent, together with a series of strong absorption bands centered at about 450, 460, and 469 nm. The first two bands commonly overlapped and merged to form a single broad band. Such strong absorption characteristics

Figure 21. Transparent colorless crystals of plagioclase feldspar were the most frequently observed sizable mineral inclusion. These crystals were present in several shapes, including flat and tabular to more equidimensional forms. Some even had their own inclusions. Oblique fiber-optic illumination, magnified 50 $\times$ .



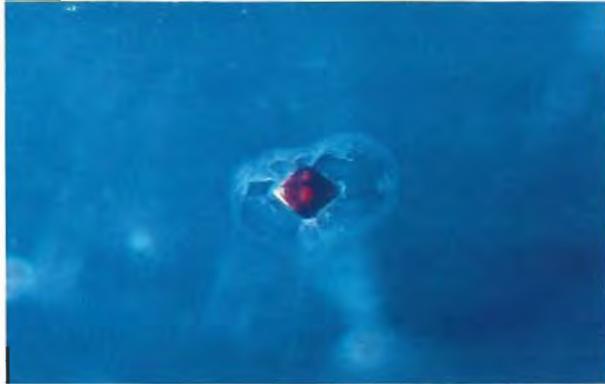


Figure 22. Uranpyrochlore crystals, common in sapphires from other basaltic occurrences, were identified in several of the sapphires from southern Vietnam. Typically, they appeared bright orange to orange-red and black. They were often associated with radiation-damage halos, which extended parallel to the basal growth planes. Oblique fiber-optic illumination, magnified 35 $\times$ .

are typical of blue to bluish green sapphires with high iron contents.

*UV-Vis-NIR Spectrometer.* Because corundum is dichroic, the face-up color appearance of these faceted sapphires is essentially a consequence of the crystallographic orientation during cutting. Therefore, we will address all of the samples mea-

Figure 23. The southern Vietnam sapphires also contained groups of black-appearing acicular columbite crystals. The thinner "rods" displayed a rich red color along the edges when viewed with a pinpoint fiber-optic light source. Magnified 42 $\times$ .



sured (blue to bluish green) as a single group when comparing their polarized spectra.

The spectra recorded had features typical of those seen in blue sapphire, with variations in the relative intensities of the absorption bands associated with the color-causing mechanisms ( $\text{Fe}^{3+}$ ,  $\text{Fe}^{2+} \leftrightarrow \text{Ti}^{4+}$ ,  $\text{Fe}^{2+} \leftrightarrow \text{Fe}^{3+}$ ) observed (figure 27 a-c); however, the spectrum illustrated in figure 27c was by far the most common (seen in almost 80% of the stones examined). All spectra displayed prominent peaks in the ultraviolet region at 375 nm and 387 nm, as well as in the visible region at 450, 460, and 469 nm, which are all related to pairs of trivalent iron ( $\text{Fe}^{3+}$ ; see, e.g., Emmett and Douthit, 1993). Typically, no distinct variation was observed in these bands in the spectra parallel and perpendicular to *c*, although a weak "shoulder" was occasionally seen at the base of the 375-nm peak (at about 380 nm) perpendicular to *c*.

Blue coloration in sapphire is essentially caused by intervalence charge-transfer processes (IVCT) of the ion pairs  $\text{Fe}^{2+} \leftrightarrow \text{Ti}^{4+}$  and  $\text{Fe}^{2+} \leftrightarrow \text{Fe}^{3+}$  (see, e.g., Fritsch and Rossman, 1987, 1988a and b; Fritsch and Mercer, 1993). Because these absorption bands are highly pleochroic, they cause a shift in the position of the absorption maxima perpendicular and parallel to the *c*-axis (see, e.g., Schmetzer and Bank, 1980; Kiefert, 1987; Schmetzer, 1987).

*Infrared Spectrometer.* In addition to showing the dominant absorption characteristics of corundum

Figure 24. Opaque, black crystals of ilmenite—observed in different euhedral to subhedral forms—were another addition to the diverse mineral inclusions found in the southern Vietnam sapphires. Oblique fiber-optic illumination, magnified 35 $\times$ .



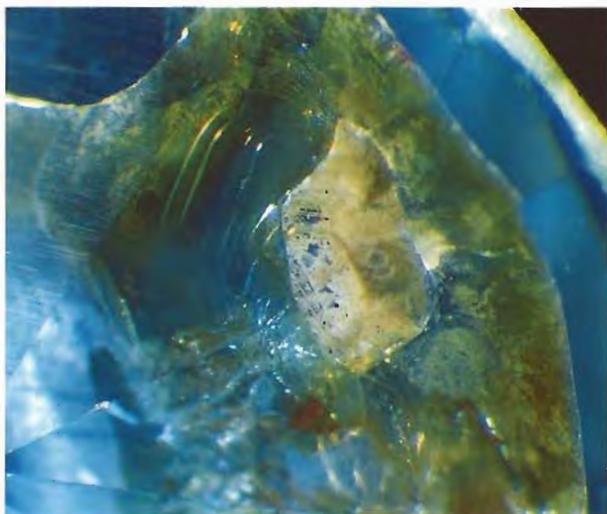


Figure 25. Staining was commonly observed in the fracture systems, as was the filling of negative crystals—a result of the epigenetic penetration by late-forming minerals such as goethite. Oblique fiber-optic illumination, magnified 30 $\times$ .

between approximately 300 and 1000  $\text{cm}^{-1}$  (peak positions at about 760, 642, 602, and 450  $\text{cm}^{-1}$ ; Wefers and Bell, 1972), these (non-heat-treated) sapphires revealed a series of absorption peaks in the 2500–4000  $\text{cm}^{-1}$  region. The strongest was centered at about 3309  $\text{cm}^{-1}$ , typically with a shoulder at about 3293  $\text{cm}^{-1}$ . Additional peaks were seen at about 3232 and 3189  $\text{cm}^{-1}$ , with very minor peaks at about 3367 and 3269  $\text{cm}^{-1}$  (figure 28). Generally, only the 3309 and 3232  $\text{cm}^{-1}$  peaks were present. This region of the spectrum identifies structural OH groups bound to various trace elements (i.e., vanadium, titanium, iron, or magnesium) in the corundum structure (Volynets et al., 1972; Berán, 1991). Additionally, the mineral kaolinite was indicated in fracture systems (again, see figure 20) by the presence of four OH absorption peaks at approximately 3697, 3669, 3652, and 3620  $\text{cm}^{-1}$  (Häger and Greiff, in preparation).

**Chemical Analysis.** EDXRF analysis revealed aluminum (Al) as the sole major element, which is consistent with the chemical formula of corundum ( $\text{Al}_2\text{O}_3$ ). Oxygen (O), with an atomic number of 8 (too low to be detected by this method), is assumed to be stoichiometric. Typical of basaltic sapphires, iron (Fe) was the most significant minor element, present as an impurity. Necessary to the color-

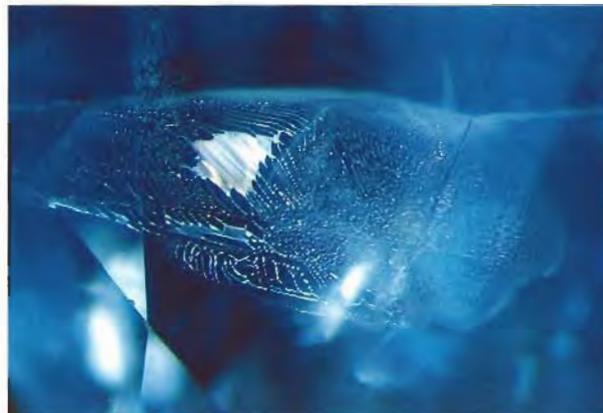


Figure 26. Healed fractures were common in the sapphires from southern Vietnam. Oblique fiber-optic illumination, magnified 35 $\times$ .

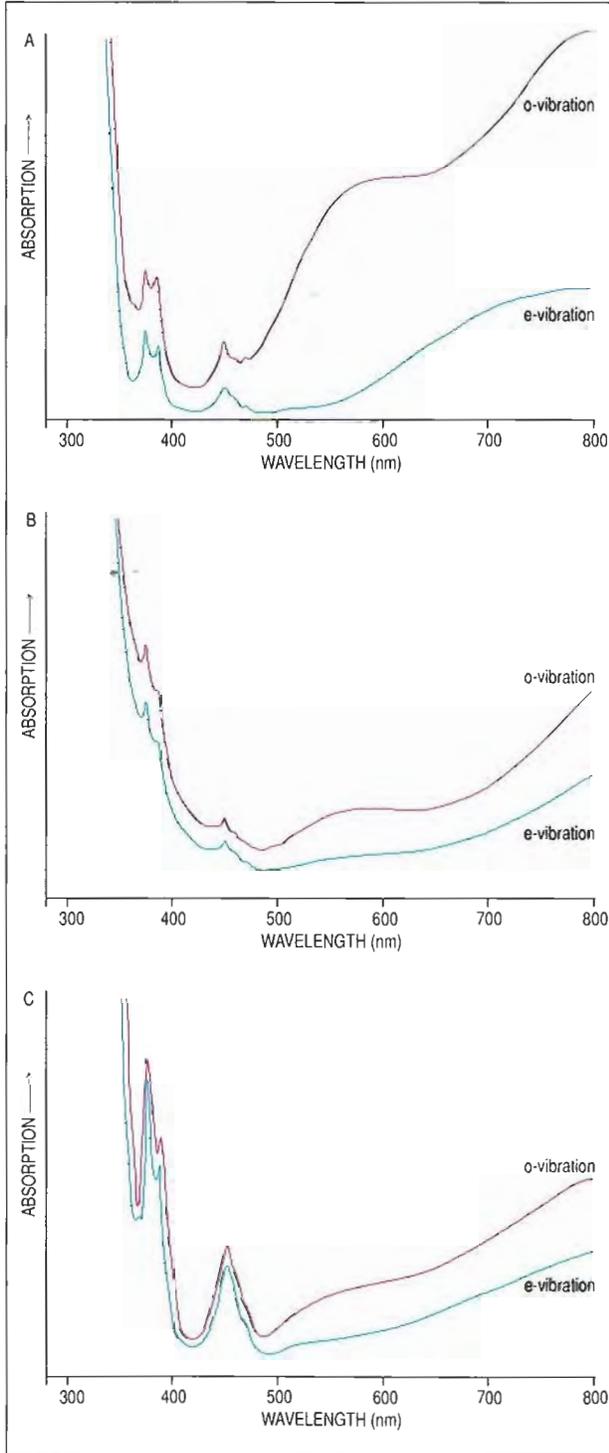
causing mechanism in blue sapphires ( $\text{Fe}^{2+} \leftrightarrow \text{Ti}^{4+}$ ), titanium was the next most important trace element recorded, followed by measurable concentrations of gallium (Ga). Other trace elements were sometimes present in negligible amounts, including V, Cr, and Mn. The complete chemical data are given in table 2.

## DISCUSSION

In general, the blue to bluish green sapphires from southern Vietnam have properties and characteristics similar to those of sapphires from other alkali basalt environments, including Australia (Coldham, 1985), Cambodia (Jobbins and Berrangé, 1981), China (Keller and Keller, 1986; Wang, 1988; Guo et al., 1992b), Nigeria (Kiefert and Schmetzer, 1987), and Thailand (Vichit et al., 1978; Schlüssel, 1991).

Prominent growth structures and color zoning—in parallel, straight, or angular to geometric patterns—established the crystal morphology. The internal growth structures of the southern Vietnam sapphires are similar to those of sapphires from other basaltic deposits around the world (Kiefert and Schmetzer, 1987; Kiefert, 1987; Kiefert and Schmetzer, 1991b). Although a “stepped” occurrence of *c* and *r* faces, as described by Kiefert and Schmetzer (1987) for basaltic sapphires from Nigeria, was also occasionally present in the sapphire from Vietnam, it was not as dominant as that illustrated for Nigerian material. Color zoning in the southern Vietnam sapphires was even more distinctive than the growth structures: strong,

sharply bordered blue color banding that alternated with narrow, colorless bands or yellowish to brownish bands parallel to the crystal planes *r* and *z*. In addition, many of the sapphires revealed a colorless "core."



Various types of "clouds" were the most common inclusions observed. Although the very fine-grained whitish clouds may be seen in sapphires from other sources (e.g. Kashmir, Australia, Cambodia, or Sri Lanka), the cross-hatch or lath-like patterns have not been seen in other sapphires. The dust-like "snowflake" inclusions encountered occasionally appeared similar to those documented for sapphires from Kashmir (Schwieger, 1990).

The very fine, whitish needles (presumably rutile or ilmenite) seen in our samples lacked the well-formed, strongly iridescent appearance of the rutile needles and platelets observed in sapphires from metamorphic environments such as Sri Lanka and Burma (see, e.g., Gübelin and Koivula, 1986).

All of the mineral inclusions identified—plagioclase feldspar, zircon, uranpyrochlore, columbite, ilmenite, pyrrhotite, chromite-hercynite and magnetite-hercynite (solid-solution-series spinels), as well as goethite—have been observed and identified in sapphires from other basaltic sources (see, e.g., Gübelin and Koivula, 1986; Kiefert, 1987; Kiefert and Schmetzer, 1987; Guo et al., 1992a; Guo, 1993).

The UV-Vis-NIR absorption spectra obtained for our samples are typical of sapphires in general and, more specifically, of basaltic sapphires, particularly in relation to the absorption bands toward the near-infrared region resulting from  $Fe^{2+} \leftrightarrow Fe^{3+}$  IVCT. This particular color-causing mechanism is absent in sapphires of metamorphic origin (such as

Figure 27. These three sets of UV-visible spectra are representative for the blue to bluish green sapphires from southern Vietnam. Typical of sapphires from basaltic sources, they are dominated by three essential absorption mechanisms ( $Fe^{3+}$ ,  $Fe^{2+} \leftrightarrow Ti^{4+}$ , and  $Fe^{2+} \leftrightarrow Fe^{3+}$ ). Sharp bands in the ultraviolet at 375 and 387 nm, as well as in the visible region at 450 nm, with bands at 460 and 469 nm, are the result of trivalent iron ( $Fe^{3+}$ ) absorption. Charge-transfer absorption by  $Fe^{2+} \leftrightarrow Ti^{4+}$  is responsible for the absorption maximum between 550 and 600 nm in the ordinary spectrum (vibrational direction perpendicular to the *c*-axis) and approximately 680 to 750 nm in the extraordinary spectrum (parallel to the *c*-axis). ( $Fe^{2+} \leftrightarrow Fe^{3+}$  charge transfers account for maxima in the region between approximately 870 and 890 nm, seen in these spectra as a general trend of increasing absorption toward the near-infrared.)

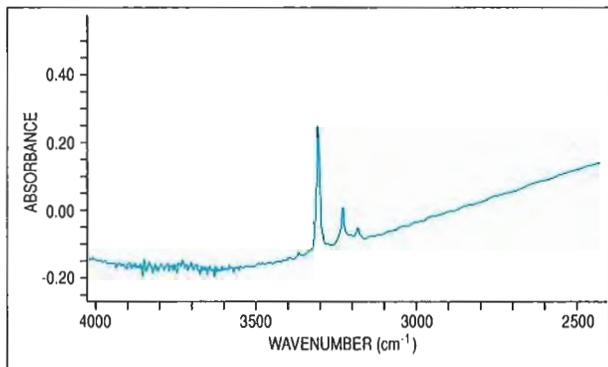


Figure 28. The infrared spectra of the (non-heat-treated) basaltic Vietnamese sapphires typically revealed a series of distinct absorption peaks. These absorption features are related to structural OH groups within the sapphire. Spectra recorded on a Pye-Unicam 9624 FTIR spectrophotometer.

those from Sri Lanka, Myanmar, or Kashmir), although it can be produced to a minor degree in metamorphic sapphires through heat treatment (Schmetzer, 1987). It has been suggested that the trends of certain spectral curves in the region 280–880 nm might aid in identifying sapphires from specific basaltic deposits around the world (see, e.g., Poirot, 1992). The great variability in spectra recorded in this sample, however, is in agreement with Schmetzer (1987,) and strongly suggests the need for care when attempting to use these properties to identify a basaltic sapphire's possible country of origin.

The structural OH groups recorded in the mid-infrared region of the spectrum of the southern Vietnam sapphires are the same as those commonly recorded in sapphires of basaltic origin (e.g., Moon and Philips, 1994). However, these absorption peaks have also been documented in non-basaltic corundums as well as in Verneuil and hydrothermally grown synthetic corundum (for further reference, see Smith, 1995, pp. 326–328).

The EDXRF results are consistent with those chemical analyses reported for sapphires from other basaltic sources (Pearson, 1982; Tombs, 1991; Guo et al., 1992b; Guo, 1993).

At present, many researchers believe that sapphires found in association with alkali basalts did not form from the basalts themselves (e.g., Coenraads et al., 1990; Coenraads, 1992b; Guo et al., 1992a, 1994; Levinson and Cook, 1994). A com-

parison of the internal growth structures and the condition of the external surface features in our sample supports this thesis: that is, that the sapphires did not form in those (highly aggressive) magmas; rather, the basalts merely acted as the transport mechanism by which the sapphires were brought to the surface.

Some blue sapphires are also known to come from the predominantly ruby-producing areas of Luc Yen and Quy Chau in northern and central Vietnam (respectively). However, both of these sources are metamorphic, so the properties of these sapphires are undoubtedly more similar to those from metamorphic sources.

## CONCLUSION

Since their initial discovery in the late 1980s, thousands of carats of blue to bluish green sapphires from southern Vietnam have entered the world gem market. The secondary deposits from alkali basalts in Binh Thuan and Lam Dong provinces were at the height of their production in 1991 and 1992, when virtually thousands of Vietnamese flocked to these areas to mine for the corundums. Largely because miners were not able to realize the same financial returns as in the ruby-producing sources in central and northern Vietnam (Quy Chau and Luc Yen), but also because of government efforts to control the gem-producing regions, most current efforts are by groups of independent miners, usually small scale. The mixing of synthetic gem materials with natural ones has plagued the sapphire-producing regions in Vietnam just as it has the ruby-producing localities: Three of the authors were offered flame-fusion synthetic blue sapphires as natural while at the mining sites.

The combination of absorption spectrum and internal characteristics determined for the southern Vietnam sapphires should provide a clear and ready means of separating them from their synthetic counterparts. This collection includes the various "cloud" patterns and mineral inclusions observed, as well as the internal growth structures and color zoning. In most cases, these sapphires can be readily separated from sapphires of metamorphic (marble-type) sources such as Sri Lanka, Kashmir, and Burma, because of the comparatively higher iron contents present in basaltic sapphires and the properties that high Fe influences (i.e., mineral inclusions, spectra, and chemistry). Separating these sapphires from those of other basaltic sources is more difficult. Nevertheless, there were certain

inclusion features found in our samples—cross-hatch or lath-like “cloud” patterns, the distinctive color zoning, and the colorless “core”—that we have not seen in sapphires from other basaltic sources. These may prove useful for such separations in the future.

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*Gübelin Gemmological Laboratory; Ms. B. Becker, of the Institute for Gemstone Research, Johannes Gutenberg University, Mainz, Germany; and Prof. Guggenheim, Mr. Mathys, and Mr. Duggelin, of the Institute of Mineralogy and Petrography, University of Basel, Switzerland. Prof. S. Graeser, of the Institute of Mineralogy and Petrography, University of Basel, also performed X-ray diffraction analyses. Prof. W. B. Stern, of the Institute of Mineralogy and Petrography, University of Basel, and Nicole Surdez, of the Gübelin Gemmological Laboratory, provided the EDXRF analyses. Nicolas Francfort, of Bunter S.A., Versoix, Switzerland, polished some of the samples for inclusion analysis. George Bosshart, managing director of the Gübelin Gemmological Laboratory, provided useful comments and suggestions; and Ira Kaplan supplied the jewelry shown in figure 1. All photomicrographs are by the senior author except where otherwise noted.*

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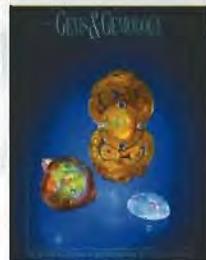
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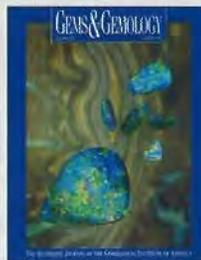
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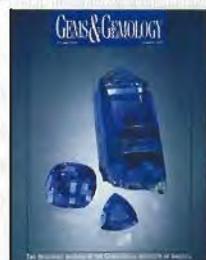
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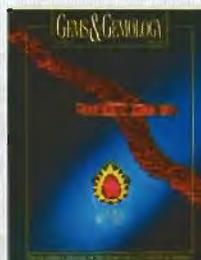
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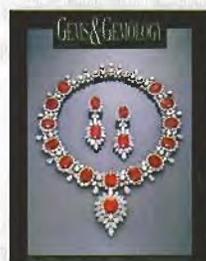
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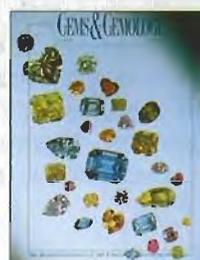
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# “TI-SAPPHIRE”: CZOCHRALSKI-PULLED SYNTHETIC PINK SAPPHIRE FROM UNION CARBIDE

By Mary L. Johnson, Meredith E. Mercer, Emmanuel Fritsch,  
Patricia Maddison, and James E. Shigley

---

*One of the most interesting of the commercially available Czochralski-pulled synthetic corundums is pink “Ti-sapphire.” This material owes its pleasant, somewhat orangy pink color to trivalent titanium, a common trace element in natural sapphires and rubies that occurs here in an unusual oxidation state. Although most of the gemological features are typical of Czochralski-pulled corundum (gas bubbles or small “pinpoint” inclusions, color zoning), these synthetic sapphires have distinctive fluorescence and optical spectra. These properties are also due to the chromophore  $Ti^{3+}$ .*

---

Czochralski-pulled synthetic sapphire was originally grown for technological applications, which require pure crystals with good clarity and even color distribution. Consequently, materials originally intended for such applications can be excellent candidates for use as gems. Czochralski-pulled synthetic rubies have been known for a number of years (see, for instance, Nassau and Crowningshield, 1969, and references cited by

Schmetzer, 1986, pp. 14–15). Major producers of Czochralski-pulled corundum for the gem market include Kyocera (see, e.g., Schmetzer, 1986; Koivula and Kammerling, 1988, 1989); Union Carbide Corporation of Washougal, Washington (Koivula et al., 1992; this article); and Russian sources (Peretti and Smith, 1994). Recently, Czochralski-pulled synthetic ruby and pink sapphire have been in the center of a controversy regarding promotional claims about so-called “recrystallized rubies” (Catalano, 1995a and b; Kammerling et al., 1995b).

Union Carbide is currently using the Czochralski technique to manufacture synthetic sapphires in a variety of colors, specifically for gem applications (figure 1). Although this material has been on the market for a few years (see, e.g., Koivula et al., 1992), we felt that a complete characterization of the various colors of Czochralski-pulled material was desirable, as none has been published to date. We began our study with the

#### ABOUT THE AUTHORS

*Dr. Johnson is a research scientist, and Ms. Maddison is a former senior staff gemologist, in the GIA Gem Trade Laboratory, Santa Monica, California; Ms. Mercer is a former research associate, Dr. Fritsch is former manager, and Dr. Shigley is director of GIA Research, Santa Monica.*

*See acknowledgments at end of article.*

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relatively new pink synthetic Ti-sapphires (figure 2), because—since they are colored by titanium (Ti) rather than chromium (Cr)—identification of this material is more straightforward than for many other colors of Czochralski-pulled corundum. We have adopted the term (synthetic) *Ti-sapphire*, because that is the name by which it is known in the laser field.

Although the material in this study comes from Union Carbide, synthetic Ti-sapphire from other sources may be on the market, including material from China ("Pink synthetic sapphire," 1991).

## BACKGROUND

The Czochralski crystal-growth technique, also known as pulling from the melt, consists of touching a starting-material "seed" to the surface of molten crystal constituents within the hot zone of a furnace, and then withdrawing the seed crystal very slowly, so that only the melt that wets the seed crystal solidifies. The newly solidified material is still in contact with the remaining melt, which continues to solidify as the seed is gradually pulled farther away. This results in a single-crystal rod of high-quality material. Czochralski pulling was originally used to make samples of pure metals (e.g., bismuth); today, it is also used for the production of low-strain, low-defect crystals for technical applications, and for purposes where the growth direction of the resultant boule is important (as in the case of synthetic alexandrite; see, e.g., Kane, 1987). A general introduction to Czochralski pulling is given by Nassau (1980), and more detail can be found in books by Brice (1986), Sloan and McGhie (1988), and Arend and Hulliger (1989); the original publication on this process is by Czochralski (1918). Morita et al. (1993) describe Czochralski growth conditions for synthetic sapphire, especially with regard to the formation of included bubbles in the growing crystal.

Pink synthetic Ti-sapphire is especially useful for laser applications, because its electronic and optical properties allow it to produce high-energy laser light over a wide range of frequencies in and near the visible range (Fletcher and Bischel, 1990). Although it is grown primarily by the Czochralski process, it has also been grown by both the flame-fusion and flux methods (see, e.g., Moncorgé et al., 1988). The coloring agent is trivalent titanium ( $Ti^{3+}$ ), and the quality of this material for laser purposes is determined in part

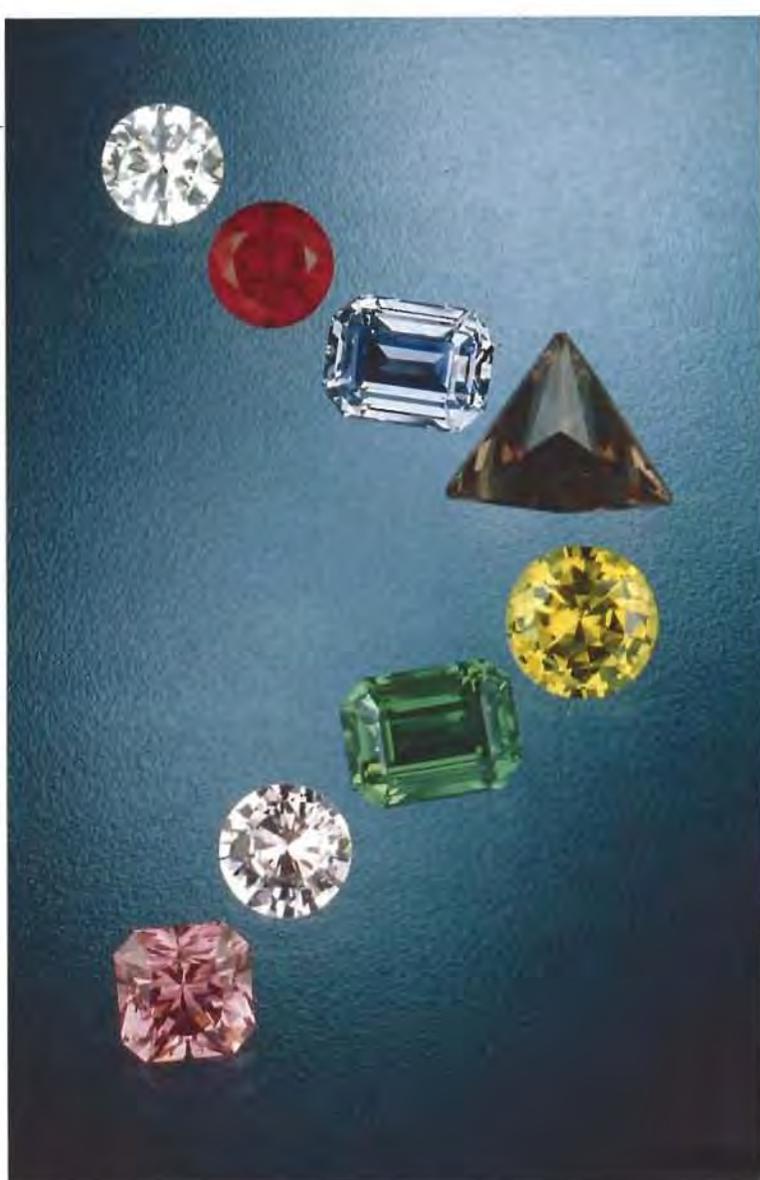


Figure 1. Union Carbide Corporation has produced many colors of synthetic sapphire by the Czochralski-pulling technique. Some examples include (from lower left): annealed pink (1.44 ct), as-grown pink (0.87 ct), green (2.28 ct), yellow (1.66 ct), brown (4.92 ct), violetish blue (2.20 ct), red (1.18 ct), near colorless (0.89 ct). Photo © GIA and Tino Hammid.

by oxidized  $Ti^{4+}$  (the common oxidation state of titanium in terrestrial minerals): the lower the  $Ti^{4+}$  concentration, the higher the laser efficiency. Because of this, synthetic Ti-sapphire is usually annealed under reducing conditions (see, e.g., Moulton, 1986), which converts residual  $Ti^{4+}$  impurity to  $Ti^{3+}$ .

## MATERIALS AND METHODS

We examined nine faceted samples and five samples of rough material in two general colors: slightly orangy pink and purplish pink. The more satu-

rated, slightly orangy pink samples (including material described by Union Carbide as having been annealed in a reducing atmosphere subsequent to crystal growth) are labeled "annealed" throughout this article. The paler, more purplish pink faceted sample resembles in all particulars the sample of as-grown rough material provided by Union Carbide, and these two samples are labeled "as grown" below.

Gemological examination of the faceted samples was performed as follows. Face-up colors were described by trained observers using both daylight-equivalent fluorescent and incandescent light sources; in no case (faceted or "rough") was any significant change in hue observed between the two light sources. These colors were described in terms of predominant and modifier hues (such as "purplish pink"). The refractive index (R.I.) of each was measured with a Duplex II refractometer and a filtered, near-monochromatic, Na-equivalent light source. Specific gravity was determined by the hydrostatic method. Fluorescence was observed by trained gemologists in a darkened room using a standard short-wave/long-wave ultraviolet lamp. Polarization behavior was noted

using a GIA GEM Illuminator polariscope, and absorption spectra were observed using a Beck handheld spectroscope on a GIA GEM Instruments base. To examine the internal features, we used a standard gemological microscope with various lighting techniques. For part of this examination, the samples were immersed in methylene iodide (diiodomethane). We tested for visible luminescence (often called transmission luminescence) in two ways: (1) with the loose stone on the spectroscope base; and (2) through the microscope, using a fiber-optic illuminator with a halogen light bulb as illumination source.

Trace-element chemistry was determined by energy-dispersive X-ray fluorescence (EDXRF) spectroscopy, using a Tracor Xray (now Spectrace Instruments) Spectrace 5000 with a rhodium-target X-ray tube. We performed quantitative analyses using the Fundamental Parameters method of Criss and Birks (see, e.g., Jenkins, 1980) with two sets of operating conditions: first, with an X-ray tube voltage of 15 kV, a 15-mA tube current, no filter, and a live time of 200 seconds, for determination of low-atomic-weight elements; and second, with an X-ray tube voltage of 25 kV, 25 mA

**TABLE 1.** Gemological properties of synthetic Ti-sapphires and other natural and synthetic pink sapphires.

Property	"Annealed" synthetic Ti-sapphire	"As-grown" synthetic Ti-sapphire	Natural pink sapphire	Cr-doped Czochralski synthetic pink sapphire
Color	Pink to orangy pink	Light pink	Pink to purple pink	Pink
Color distribution	Even to uneven	Even	(Variable)	Even
Clarity	Transparent	Transparent	Transparent to opaque	Transparent
Pleochroism ( $\epsilon$ )	Yellow to orangy pink	Near colorless	Orangy pink to orange-pink	Orangy pink
Pleochroism ( $\sigma$ )	Light pink to pinkish red	Light purplish pink	Purplish pink to purple-pink	Purplish pink
Optic character	Uniaxial negative	Uniaxial negative	Uniaxial negative	Uniaxial negative
Color filter reaction	Usually red (1 none, 1 orangy pink)	Greenish yellow	Moderate pink to dark red	Red
Transmission luminescence	None to moderate red	Slight scattering	Usually none, seldom red	None
R.I. ( $n_e$ )	1.759–1.760	1.760	1.757–1.771	1.760
R.I. ( $n_o$ )	1.767–1.769	1.768	1.765–1.779	1.768
Birefringence	0.008–0.009	0.008	0.008	0.008
Specific gravity	3.99 – 4.01	4.00	3.95 –4.10	3.99-4.01
Luminescence to long-wave UV	Inert to faint red	inert	Strong orange-red to strong red	Moderate-to-strong red or pinkish red, not chalky
Luminescence to short-wave UV	Weak to moderate blue, slightly to very chalky	Strong blue, slightly chalky	Faint to weak orange to red	Moderate red, not chalky; moderate pink, chalky
Spectroscopy spectrum (nm)	410 cutoff, weak 470, 500 band, 570 band, 670–690 cutoff	No sharp bands	468.5, 475, 476.5, 659.2, 668, 692.8, 694.2 lines	468.5, 475, 476.5, 659.2, 668, 692.8, 694.2 lines
Inclusions	Usually pinpoints; gas bubbles in one case	Pinpoints	(Variable)	None seen
Immersion	Color banding has gradual borders, if visible	(Too faint to see)	(Variable)	No features seen
Source of data	8 faceted samples, this study	1 faceted sample, this study	Webster (1994), GIA (1988)	6 faceted samples, new data <sup>a</sup>

<sup>a</sup> Testing performed by GIA Gem Trade Laboratory using same methods as for the Union Carbide synthetic Ti-sapphire. Samples loaned by Jerry Manning Opal Co., New York City.

tube current, aluminum filter, and live time of 200 seconds, for determination of intermediate-atomic-weight elements. Standards included tsavorite (for Al, Si), garnet (for Al, Si, Mn, Fe), and synthetic corundum (for Al); yields for Ca, Ti, V, Cr, and Ga were extrapolated from those for other elements. The standards were calibrated against microprobe compositions determined by Paul Carpenter at the California Institute of Technology. Ti is reported as weight percent titanium dioxide (TiO<sub>2</sub>; that is, as Ti<sup>4+</sup>), although it primarily occurs as Ti<sub>2</sub>O<sub>3</sub> (Ti<sup>3+</sup>) in synthetic Ti-sapphire.

Two polished samples of annealed and as-grown "rough" (288B and 297B) were also analyzed using a five-crystal JEOL Model 733 electron microprobe operating at a beam accelerating potential of 15 kV, a current of 35 nA, and a spot size between 10 and 25 μm. Standards include: Al<sub>2</sub>O<sub>3</sub> for Al, anorthite for Ca, TiO<sub>2</sub> for Ti, Cr<sub>2</sub>O<sub>3</sub> for Cr, and synthetic fayalite for Fe. Total iron was calculated as FeO, and total titanium as TiO<sub>2</sub>. Ga was not detected in these samples. The data were corrected using the program CITZAF (Armstrong, 1988). Each specimen was analyzed at three randomly selected locations.



Figure 2. These two annealed synthetic Ti-sapphires (2.97 ct and 1.44 ct) were cut from material similar to the 343.33-ct section of a boule on which they are seated. Courtesy of Union Carbide Corp.; photo by Robert Weldon.

We recorded UV-visible spectra on a Hitachi U-4001 spectrophotometer, using a resolution of 1 nm. To better understand the causes of color, we prepared crystallographically oriented pieces of some of our specimens so that we could obtain polarized absorption spectra. For this purpose, we selected three pieces of "rough" (two annealed, and one as-grown). From each specimen, we cut and polished a flat, parallel-windowed section containing the optic axis direction, as determined by the X-ray precession method. Polarized spectra were obtained using calcite polarizers.

## RESULTS

**Physical and Optical Properties.** For the nine faceted samples, table 1 summarizes the gemological properties and compares them to properties of natural pink sapphires, Czochralski-pulled synthetic pink sapphires colored by chromium, Chatham flux-grown synthetic pink sapphires, Kashan flux-grown synthetic sapphires, and commercially available flame-fusion synthetic pink sapphires.

A number of these properties distinguish synthetic Ti-sapphire from natural pink sapphires and from synthetic pink sapphires colored by chromium. These include its unusual lack of fluorescence to long-wave UV radiation, and especially its chalky blue fluorescence to short-wave

Chatham flux synthetic pink sapphire	Kashan flux synthetic pink sapphire	Flame-fusion synthetic pink sapphire
Purplish pink (Not reported) (Not reported)	Purplish pink Even Transparent	Pink to purplish pink Usually uneven Transparent
Orangy pink Purplish pink Uniaxial negative Strong red	Orangy pink Purplish pink Uniaxial negative Moderate red	Orangy pink to orange-pink Purplish pink to purple-pink Uniaxial negative Moderate pink to dark red
(Not reported)	(Not reported)	(Not reported)
1.759	1.760	1.762
1.768	1.769	1.770
0.009	0.009	0.008
3.99–4.00	4.00	About 4.00
Strong orangy red, weakly to moderately chalky	Moderate to strong red	Moderate to strong red
Strong orangy red, weakly to moderately chalky	Moderate red	Weak orangy red
468.5, 475, 476.5, 659.2, 668, 692.8, 694.2 lines	468.5, 475, 476.5, 659.2, 668, 692.8, 694.2 lines	468.5, 475, 476.5, 659.2, 668, 692.8, 694.2 lines
Flux, platinum metal, fingerprints (Not reported)	Wispy veils, rain, stringers (Not reported)	Gas bubbles, etc. Color banding (usually pronounced), etc.
Kammerling et al. (1994)	Henn and Schrader (1985), Kammerling et al. (1995a)	Webster (1994), GIA (1988)



Figure 3. Extremely small gas bubbles can be seen in this 2.97-ct Czochralski-pulled Ti-sapphire at 50× magnification. In the other samples we examined, these “pinpoints” were too small to be resolved as gas bubbles. Photomicrograph by John I. Koivula.

UV. The spectra of synthetic Ti sapphire as seen with a handheld spectroscope also appear unusually weak, with no chromium absorption or emission bands seen. These properties do not distinguish synthetic Ti-sapphires produced by Czochralski pulling from Ti-sapphires synthesized by other means; however, there are no known pink natural gem sapphires that owe their color to titanium alone.

**Magnification. Inclusions.** With the fiber-optic light, we observed small “pinpoint” inclusions (high-relief bubbles) in all of the faceted annealed samples examined. In one sample (figure 3), these “pinpoints” were large enough to be resolved as gas bubbles. The as-grown faceted sample also contained numerous pinpoint inclusions.

**Features Seen with Immersion.** We observed very subtle color banding in two annealed samples,

with the regions of different colors having diffuse boundaries (seen with immersion in methylene iodide) or color zoning visible only in polarized light. We did not discern any color zoning in the other annealed samples, or in the as-grown synthetic Ti-sapphire. Although Nassau as well as Crowningshield (1969) and Schmetzer (1986) mention finely striated curved color banding in Czochralski-pulled synthetic sapphires, no such bands were observed in these samples. We looked for twinning, but did not see any.

**Trace-Element Chemistry.** The quantitative measurements made by EDXRF analysis for calcium (Ca), Ti, vanadium (V), chromium (Cr), and iron (Fe) are reported in table 2. These elements are all commonly found in natural and synthetic corundums. We looked for gallium in all samples, but found no evidence of it. We also examined two of the samples (annealed 288B and as-grown 297B) with the electron microprobe, which yielded the same compositions as did EDXRF. Both analytical techniques are precise to ± 0.01 wt.%, based on counting statistics.

All of the annealed synthetic Ti-sapphires were found to contain titanium (ranging from 0.06 to 0.25 wt.% TiO<sub>2</sub>) and iron (in one case, as much as 0.04 wt.% FeO). The two as-grown synthetic Ti-sapphires revealed less titanium on average (0.04 to 0.08 wt.% titanium as TiO<sub>2</sub>) than the annealed samples, but they also have less saturated colors.

**UV-Visible Spectroscopy.** Pairs of polarized absorption spectra in the ELc (that is, incident light polarized perpendicular to the optic axis) and Ellc

TABLE 2. Partial chemical analyses of 11 synthetic Ti-sapphires.<sup>a</sup>

Trace elements <sup>b</sup>	Annealed (slightly orangy pink)						As-grown (purplish pink)				
	No. 0078 (1.44 ct)	No. 0079 (2.97 ct)	No. 288B <sup>c</sup> (11.41 ct)	No. 288C (8.40 ct)	No. 288D (11.34 ct)	No. 1530 (207.30 ct)	No. 1531 (522.57 ct)	No. 1532 (542.34 ct)	No. 1637 (1.07 ct)	No. 297B <sup>c</sup> (10.37 ct)	No. 1636 (0.87ct)
CaO	tr	tr	tr	tr	0.01	tr	tr	tr	0.02	tr	0.01
TiO <sub>2</sub>	0.18	0.16	0.10	0.12	0.11	0.13	0.06	0.16	0.25	0.08	0.04
V <sub>2</sub> O <sub>3</sub>	nd	tr	tr	nd	nd	nd	nd	nd	tr	nd	tr
Cr <sub>2</sub> O <sub>3</sub>	nd	nd	tr	nd	tr	nd	nd	nd	tr	nd	nd
FeO	tr	tr	tr	tr	tr	0.01	tr	nd	0.04	tr	tr

<sup>a</sup> Average of three spot analyses by EDXRF, in wt. % oxides.

<sup>b</sup> Abbreviations for analyses: nd = not detected in; tr = trace (detected at an amount lower than 0.01 wt. %).

<sup>c</sup> Electron microprobe analyses of three points on these samples gave the same average result as EDXRF analyses.

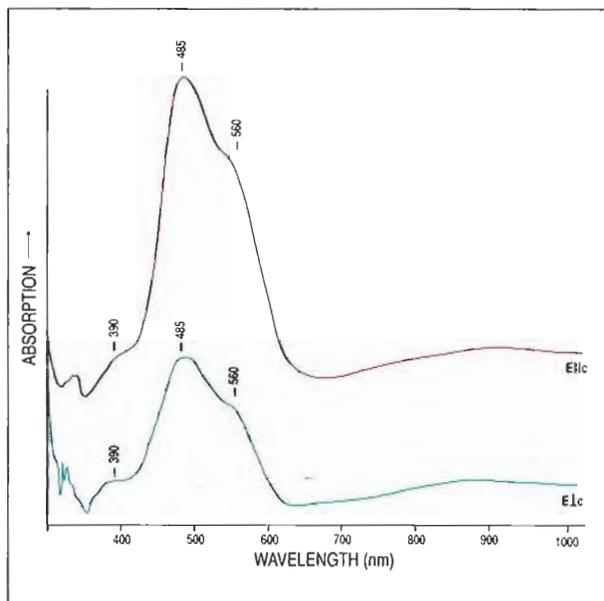


Figure 4. The polarized absorption spectra from the UV-visible spectrophotometer for annealed (slightly orangy pink) synthetic Ti-sapphire reveal important features at 485, 560, and 390 nm (sample 1532). The peaks at 485 and 560 nm provide evidence of the presence of  $Ti^{3+}$  and have not been found to date in natural sapphires.

(that is, incident light polarized parallel to the optic axis) directions are shown in figures 4 and 5 for annealed (slightly orangy) and as-grown (purplish) pink sapphire, respectively.

Four pieces of slightly orangy pink sapphire "rough" and four faceted annealed synthetic Ti-sapphires showed very similar (unpolarized) UV-visible spectra, with a prominent peak centered at approximately 485 nm, a strong shoulder at roughly 560 nm, and a smaller peak centered at about 390 nm.

The spectrum of the as-grown piece of synthetic pink sapphire, which looks purplish rather than orangy, superimposes the 485/560 pair on a weak but very broad band with its maximum at about 840 nm (figure 5). This feature causes the 560 shoulder to appear to be almost equal in size to the 485 peak in the E1c direction.

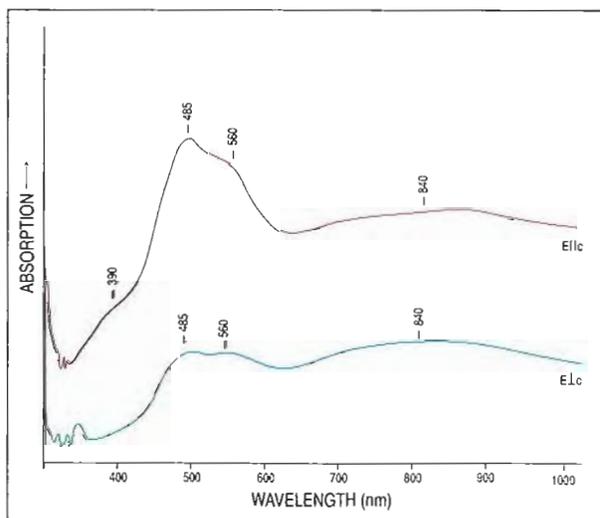
## DISCUSSION

**Separation from Natural Sapphire.** In general, Czochralski-pulled corundum may be separated from very fine, inclusion-free natural examples with great difficulty, or only by advanced testing

methods. In many stones, inclusions are not visible, or they are so small as to be ambiguous in interpretation—and one cannot conclude that a stone is synthetic simply because it is "too good." In the case of synthetic Ti-sapphire, however, some of the gemological properties are different from those of natural pink sapphires because synthetic Ti-sapphire contains  $Ti^{3+}$ , which has not been found to date in pink natural sapphires, and has little or no  $Cr^{3+}$ . These distinctive properties include: no luminescence to long-wave UV radiation; chalky blue luminescence to short-wave UV radiation (due to octahedral  $Ti^{4+}O_6$  impurities: see below); and a faint but different spectrum as seen with a spectroscope (especially with regard to the lack of chromium emission lines in the red). Also, the samples in our study contained "pinpoint" inclusions, which were sometimes resolvable as gas bubbles. In the final analysis, when there are not enough gemological clues to identify an unknown stone unambiguously, a synthetic Ti-sapphire can be reliably separated from a pink sapphire colored by chromium by means of its chemistry or UV-visible absorption spectrum.

**Causes of the Colors.** Natural pink sapphires, like rubies, owe their color to chromium (Nassau, 1980; Fritsch and Rossman, 1988). Broad chromium

Figure 5. The polarized absorption spectra for as-grown (purplish pink) synthetic Ti-sapphire (a separate slice of sample 297B) superimpose the 485/560 pair on a weak but broad band with a maximum at about 840 nm. This latter peak is consistent with Fe-Ti charge transfer.



peaks in natural pink sapphires and rubies occur at roughly 410 nm and 550 nm, whereas the peaks in synthetic Ti-sapphires are seen at approximately 390, 485, and 560 nm. The natural orangy pink sapphires that we have seen, and that have been reported in the literature (Schmetzer et al., 1983; Fritsch and Rossman, 1988), contain chromium and iron (sometimes determined to be  $\text{Fe}^{3+}$ ) or chromium and magnesium ( $\text{Mg}^{2+}$ ). Therefore, they show chromium spectra in addition to other features.

*Annealed Pink.* The coloration of the slightly orangy pink (annealed) synthetic sapphires we examined is due to trivalent titanium: The peaks seen in the UV-visible spectra at 485 and 560 nm are typical in position and polarization for  $\text{Ti}^{3+}$  in corundum (McClure, 1962; Townsend, 1968; Eigenmann et al., 1972; Moskvina et al., 1980; Moulton, 1986; again, see figures 4 and 5.) The small peak at 390 nm is not seen in most materials colored by  $\text{Ti}^{3+}$ , and has been attributed to defects (Bessonova et al., 1976) or included  $\text{Al}_2\text{TiO}_5$  (Winkler et al., 1966).

*As-Grown Pink.* An additional broad feature is found in the spectrum of as-grown synthetic Ti-sapphire at about 840 nm (figure 5); this peak is broader at lower wavelengths in the  $E \perp c$  direction. The position and polarization behavior of this peak is consistent with Fe-Ti charge transfer, as seen in Verneuil synthetic sapphires doped with both Fe and Ti (see, for instance, Eigenmann et al., 1972). (However, Moulton [1986] has described this peak as due to charge transfer between  $\text{Ti}^{3+}$  and  $\text{Ti}^{4+}$ .) Only trace amounts of iron—such as those present in our samples, according to the EDXRF results in table 2—would be necessary to account for this broad feature, which would disappear with reduction-annealing (as in the Eigenmann et al. study, and as seen in our samples).

*Luminescence Behavior.* The blue fluorescence to short-wave UV radiation observed in our samples is virtually identical to that described by Blasse and Verweij (1990) for Ti-doped synthetic sapphires. These authors showed that this emission is due to charge-transfer transitions in a titanate group, that is,  $\text{Ti}^{4+}$  in octahedral coordination in a site in the corundum structure that is normally empty. (This group is usually designat-

ed  $\text{Ti}^{4+}\text{O}_6$ .) We therefore believe that the fluorescence behavior of our samples, both annealed and as-grown, is due to these titanate groups, which are present as impurities because of the titanium doping. The fluorescence is more pronounced in the as-grown samples, which have greater amounts of Ti in oxidized species.

The red transmission luminescence (i.e., luminescence excited by transmitted visible light) observed in our annealed samples is due to  $\text{Ti}^{3+}$ . Although some rubies and pink sapphires colored by  $\text{Cr}^{3+}$  also luminesce, and can be used for laser materials ("ruby" lasers), details of the emission spectra for the two chromophores are quite different.

## SUMMARY AND CONCLUSION

Czochralski-pulled synthetic corundum is not as common in the marketplace as flame-fusion synthetic corundum, but it can be far more difficult to separate from clean natural material. Identification is easiest for a Czochralski-pulled material for which the cause of color is different from that in the corresponding natural stone. In the case of (possibly orangy) pink synthetic sapphires colored by  $\text{Ti}^{3+}$ , the faint absorption spectrum lacking "chrome lines" and the unusual fluorescence behavior are highly suspicious.  $\text{Ti}^{3+}$  is responsible for the absorption spectrum (and red transmission luminescence), and an oxidized interstitial titanium impurity causes the short-wave UV fluorescence. When an unknown stone is suspected of being synthetic Ti-sapphire, a cautious gemologist may wish to confirm this by using high magnification to search for included gas bubbles; failing that, advanced testing may be in order.

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## LAB NOTES

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## ALEXANDRITE

**Fracture Filled, with High R.I. Values**

Recently, the West Coast GIA Gem Trade Laboratory was asked to identify a 0.45-ct semitransparent pear-shaped modified brilliant that exhibited a color change from dark bluish green in daylight-equivalent fluorescent lighting to dark reddish purple in incandescent light. Although standard gemological testing identified the stone as natural alexandrite, it had atypically high refractive-index values: 1.753–1.761. Energy-dispersive X-ray fluorescence (EDXRF) chemical analysis, performed by GIA Research, revealed unusually high concentrations of chromium, titanium, and iron—to one or more of which we tentatively attribute the high R.I. values.

This stone was also noteworthy because of several surface-reaching fractures that contained a transparent, colorless substance. This filler flowed within the fractures when the heated tip of a thermal reaction tester was brought near the surface. Therefore, the stone was identified as natural alexandrite, with a note accompanying the conclusion of the identification report that evidence of clarity enhancement was present.

*RCK and SFM*

## SYNTHETIC ALEXANDRITE

**Flux Grown, without Diagnostic Inclusions**

In almost all cases where classic gem-testing methods are sufficient to separate natural gems from their syn-

thetic counterparts, characteristic inclusions provide the key information. In our experience, this is typically true for flux-grown synthetic alexandrite, which usually contains inclusions of residual flux. By contrast, although we can sometimes identify Czochralski-pulled synthetic alexandrite by its inclusions—curved growth features or gas bubbles—we typically must rely on infrared spectroscopy to separate this material from natural alexandrite.

In April 1995, the West Coast lab received for identification a 1.08-ct transparent oval brilliant that appeared green under daylight-equivalent fluorescent lighting and pinkish purple under incandescent light. This color change—combined with refractive indices of 1.746–1.751, a biaxial optical interference figure, and the diagnostic absorption spectrum—identified it as the alexandrite variety of chrysoberyl, but not whether it was natural or synthetic. The weak red fluorescence to both long- and short-wave ultraviolet radiation was similarly ambiguous, as reactions of these strengths are consistent with both natural alexandrite and the flux-grown synthetic.

Magnification revealed straight and angular growth that we felt was indicative, but not proof, of a flux synthetic. What did prove the specimen to be synthetic was infrared spectroscopy, especially the absence of the water-related absorptions around 3000  $\text{cm}^{-1}$  that are typical of natural alexandrite (see, e.g., C. M. Stockton and R. E. Kane, "The Distinction of Natural from Synthetic

Alexandrite by Infrared Spectroscopy," *Gems & Gemology*, Spring 1988, pp. 44–46). *RCK*

## CORUNDUM

**Diffusion Treated**

Three transparent purplish red oval mixed-cut stones (1–1½ ct) were received in the East Coast lab for an identification report. They were similar in color to those rubies that are commonly mined in Thailand (figure 1). The gemological properties, primarily the optical ones, identified them as corundum. Although the spectra of the two larger stones lacked distinct absorption features, the spectrum of the smallest one had a weak absorption band at 450 nm. No other absorption feature typical of either ruby or sapphire was seen in the spectra of any of the stones.

With 10× magnification, we noted in the smallest stone an opaque, light grayish blue silky zone with a hexagonal outline that appeared to be the core of the stone—and thus provided proof of natural origin. This feature probably accounted for the weak 450-nm absorption band in that stone. There was also a small "fingerprint" inclusion and a crystal that had altered to look like a "cotton ball." The other two stones had inclusions of fine fingerprints and some

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

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Figure 1. These diffusion-treated red stones (1–1½ ct) resemble those rubies that are typically seen from Thailand.

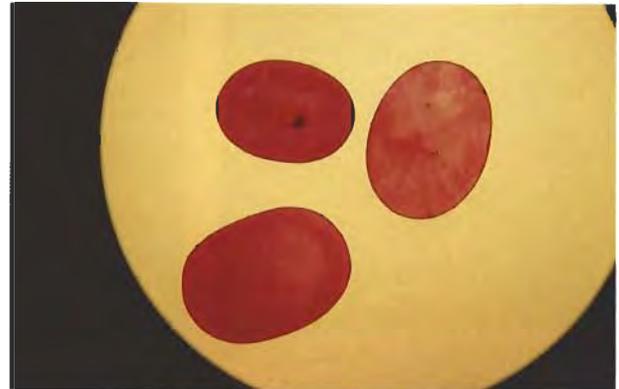


Figure 2. With immersion, the stones in figure 1 show concentrations of color at the facet junctions—typical of diffusion-treated stones.

transparent crystals. However, the facets on all three stones lacked the smooth, flat look of a well-cut gem. Instead, the surfaces were uneven, with some areas that were slightly rippled and had many minute cracks, giving the impression of a surface coating.

When we examined the middle-sized stone in diffused light, through the crown, we noted that all of the pavilion facet junctions seemed to be more strongly colored. When the stones were immersed in methylene iodide (figure 2), this concentration of color along the facet junctions was easily seen, proving diffusion treatment. On the basis of these observations, we identified the stones simply as diffusion-treated corundum. *KH*

## DIAMOND

### Inclusions Affect Body Color

Sometimes inclusions are the main cause of color in a diamond. In the most common example of this phenomenon, dark inclusions in a near-colorless diamond contribute to an appearance considerably darker than the intrinsic body color and may lead to a lower color grade for the stone. More rarely, a bright colored inclusion contributes to the color of a colored diamond, which was the case with a 3.36-ct very light green mar-

quise seen in the East Coast laboratory last fall. The diamond contained a row of included crystals, most of which appeared to be diamond (figure

Figure 3. This crystal in a row of included crystals is green. It imparts a green component to the face-up appearance of this otherwise near-colorless 3.36-ct marquise diamond. Magnified 126×.



3). However, at least one of the crystals was prismatic and yellow-green, an appearance that suggested either pale diopside or enstatite.

Testing indicates this inclusion is the sole source of green color in the diamond. A visible spectrum showed no absorption at 741 nm, the primary line of the GR1 center, which proved that the stone had not been exposed to ionizing radiation. Small dark spots around some of the diamond-like included crystals looked at first like radiation stains, but at higher magnification we determined that they were graphite.

In other cases, colored inclusions do not contribute to the color of a diamond. In figure 4, for example, an eye-visible brownish orange inclusion breaks the table surface of a 5.10-ct Fancy yellow cut-cornered rectangular modified brilliant-cut diamond. Color and morphology suggest that the inclusion is garnet. EDXRF analysis of the inclusion showed the presence of iron and manganese, which supports this identification and suggests almandine-spessartine. Although this eclogitic garnet was centered in the table and substantially lowered the diamond's clarity grade, it made a striking contrast against the yellow body color of the host diamond but did not seem to contribute to the overall color of the stone. *TM and IR*

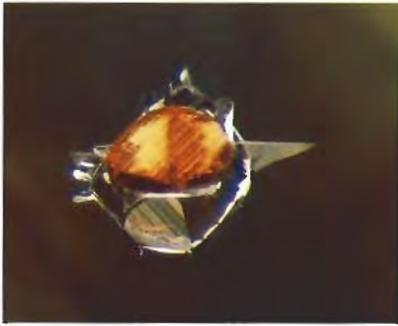


Figure 4. The garnet inclusion in the center of this 5.10-ct Fancy yellow diamond has no apparent effect on the stone's overall color. Magnified 40x.

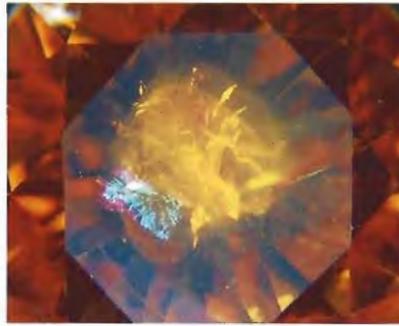


Figure 5. Ordinary iridescence is seen when looking down on the unfilled portion of the fracture in this 1.19-ct yellow round brilliant. Magnified 15x.

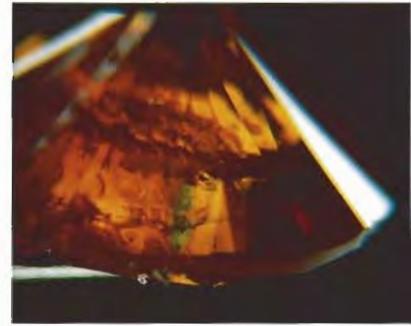


Figure 6. Another part of the complex fracture in figure 5 is filled; it shows green (bright-field) and red (in reflected darkfield) flash colors. Magnified 20x.

#### With Iridescence in an Incompletely Filled Fracture

Identification of fracture filling continues to be a great concern in the diamond trade, and the laboratory sees both straightforward and challenging examples of this treatment. A 1.19-ct yellow round brilliant (figure 5), submitted for a report on origin of color, proved to be one of the more complicated cases seen in the East Coast lab. Because the color of the gem may distort or hide flash-effect colors, a filled fracture can be more difficult to find in a fancy-color diamond than in a colorless to light-yellow stone. Recognizing the presence of a filling in this stone was especially challenging because part of this complex fracture also showed natural iridescence.

In this situation, identification was accomplished by careful attention to the details revealed during microscopic examination. Of prime concern was separating iridescence from the flash effect. First, we found that iridescence was seen when we looked perpendicular to the fracture plane (again, see figure 5), but the flash effect was visible only when we looked nearly parallel to the plane of the fracture. Second, several colors were seen simultaneously in the iridescent area (green, greenish blue, and purple), whereas the flash-effect

colors were only seen one at a time, depending on the lighting (bright or dark background; figure 6): green in brightfield and, at the right in figure 6, red where a reflection of the fracture is seen in darkfield. At high magnification, the filled portion of the fracture also showed small bub-

bles and flow lines, whereas the iridescent, unfilled part of the fracture appeared white and feathery, with moderate relief. (Note that all of these features are described on the "Identification of Filled Diamonds" chart published with the Summer 1995 issue of *Gems & Gemology*.)

Figure 7. This imitation emerald necklace consists of 5.10–16.0 mm natural beryl beads that have been coated with a green plastic.

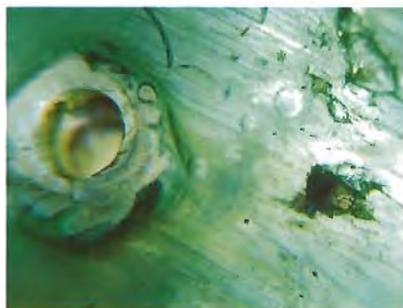


In keeping with GIA GTL policy, we did not determine either color origin or a color grade for this stone. Instead, we issued an identification report only, with a comment in the conclusion that disclosed that the diamond had a foreign material in surface-reaching fractures. *IR*

### Imitation EMERALD Plastic-Coated Beryl

When staff members in the East Coast lab saw the broken necklace of variegated translucent-to-transparent green beads shown in figure 7, our first impression was that we were looking at an emerald necklace with unusually symmetrical beads. The results of our first test—exposing the necklace to long-wave UV radiation—did not immediately arouse suspicion, as the chalky yellow reaction would be expected of heavily oiled emeralds. The dull reddish appearance through the Chelsea color filter also was not out of the ordinary. However, thorough examination of the beads with magnification gave cause for alarm: Around each of the drill holes, we noted a dark green ring that contained flattened gas bubbles. Figure 8 shows these features in a bead that our client kindly allowed us to remove from the strand for further testing. Examination of the loose bead readily revealed a transparent

Figure 8. With 10× magnification, a green coating with flattened gas bubbles can be seen on one bead that was removed from the strand shown in figure 7.



green coating. When some of the coating was removed and tested separately, it appeared red under the color filter and fluoresced chalky yellow when exposed to long-wave UV radiation. Its elastic nature and reaction to the "hot point" identified the coating as a plastic. With the coating completely removed, the bead appeared light green in color, and the optical and physical properties matched those of natural beryl. Therefore, the necklace was identified as green plastic-coated natural beryl. *GRC*

### JADEITE JADE

#### Assemblages

From time to time, the laboratory receives for identification items that are later identified as assemblages. Among the less-common assembled stones we have reported on in this section are a spinel-synthetic ruby doublet (Winter, 1984, p. 231), a star sapphire-sapphire doublet (Fall 1985, p. 171), a ruby doublet (Spring 1987, pp. 47-48), and assembled cultured blister pearls (Summer 1991, p. 111).

On rare occasions, we encounter assembled stones that have been fabricated from jadeite (see, e.g., the jadeite doublets described in the Spring 1958 and Fall 1986 Lab Notes sections, pp. 134 and 172, respectively). We have also seen, in an unassembled state, examples of a jadeite assemblage that consisted of three pieces of translucent, near-colorless jadeite: (1) a cabochon that was inserted into (2) a hollow dome and cemented to (3) a flat base. The thin space between the hollow dome and the cabochon is filled with a green, jelly-like substance that gives the assembled stone the color of fine green jadeite. Such stones are difficult to identify if they are mounted in such a way that the contact zone between the hollow cabochon and the flat back cannot be examined directly.

In spring 1995, the West Coast lab received for identification a translucent mottled-green carving



Figure 9. A small chip on the jadeite portion of this assemblage reveals how very thin the jadeite shell is. Magnified 25×.

that measured about 33.33 mm long × 22.03 mm wide. The depth could not be determined—and the back could not be examined—because the carving was mounted in a closed-back yellow-metal pendant. A spot R.I. reading gave a value of 1.66, and examination with a desk-model prism spectroscope revealed a series of "chrome lines" in the red end of the spectrum. These properties are consistent with natural-color jadeite. However, magnification revealed that the carving was actually composed of a thin, hollow shell of jadeite that had been filled with a transparent, colorless substance. The filler contained some small gas bubbles, a few of which could be seen through the top of the carving. We also noted remnants of the filler on the surface of the carving, at various points around the circumference, and it was exposed at one place—where the thin shell had a small chip (figure 9). When probed with a sharp metal pin, the filler was easily indented. FTIR spectroscopy of the filler revealed strong absorptions similar to those of some polymers known to have been used in the impregnation of jadeite. Using a millimeter gauge, we estimated the thickness of the jadeite shell at the edge of the carving to be only 0.05 to 0.10 mm. On the basis of this examination, we identified the item as an assemblage consisting of a thin, hollow, natural-color jadeite jade carving filled with colorless plastic.



Figure 10. This 25.05 × 18.72 mm mounted carving proved to be an assemblage of jadeite jade and plastic.

Soon after identifying this assemblage, the West Coast lab received a similar-appearing mounted carving (25.05 × 18.72 mm, see figure 10) from another client. Gemological testing proved that this was also an assemblage that consisted of a natural-color jadeite jade shell filled with colorless plastic (figure 11). This jadeite shell was estimated to be even thinner, with many gas bubbles in the filler. Several of these were seen at the contact of the jadeite and filler when the piece was examined from above using intense fiber-optic illumination (figure 12). Small openings in the back of the mounting enabled us to see through the plastic filler to the back of the hollowed-out carving. We were surprised to see that the back of the carving conformed exactly to the contours of the top. We do not know how these assemblages were manufactured. Considering the extremely thin shell (so thin that it actually fractured at one prong), it would seem to be a very exacting and difficult process.



Figure 11. The thin edge of the hollowed-out carving shown in figure 10 was visible between the mounting and the bottom of the stone. The plastic filler (which is actually colorless, but appears green in this photo because of the jadeite shell) can be seen under the edge of the jadeite, following the contours of the carving. Magnified 13×.

These were the first such items we had encountered in the GIA Gem Trade Laboratory (an apparently similar item—a carving of Guan Im—was recently examined by the AIGS laboratory in Bangkok, as reported in *JewelSiam*, Vol. 6, No. 4, 1995, p. 110). However, we have previously



Figure 12. When examined from above using magnification and bright fiber-optic illumination, gas bubbles can be seen in the filler where it contacts the jadeite shell. Magnified 16×.

examined thin, dark-colored jadeite mounted in a closed-back setting that was highly polished on the inside to act like a mirror. This improved the apparent transparency and lightened the color to a pleasing tone. It is likely that the assemblages described in the preceding two paragraphs were carved from similar—perhaps even darker green—pieces of jadeite. The thin shell was then filled with plastic for added strength. Such dark green jadeite is often called Yunan jade. It

Figure 13. At first glance, this 62.26-ct glass imitation (50.10 × 26.30 × 10.30 mm) appears to be carved jadeite.



may be cut into thin pieces and used, for example, in drop earrings, where it displays an attractive color in transmitted light. *RCK and SFM*

### Finely Detailed Glass Imitation

Over the years, both East and West Coast labs have examined a number of glass imitations of jade. These have included hololith bracelets and "carved" stones set in jewelry (see, e.g., Gem Trade Lab Notes, Fall 1982, pp. 171–172; Fall 1983, pp. 173–174). In addition to these items, we have seen many other glass imitations of carved and engraved jadeite at trade shows.

In spring 1995, the West Coast lab received for identification what at first appeared to be a 62.26-ct piece of carved jadeite (figure 13). Gemological testing, however, revealed properties inconsistent with jadeite, including a 1.56 spot R.I.; a weak, mottled greenish blue fluorescence to short-wave UV radiation; and a spectrum showing general absorption from 400 to 480 nm and from 650 to 700 nm. Magnification revealed a number of key features, including gas bubbles, flow lines, mold marks, fine surface cracks resembling crazing, and minute conchoidal fractures with a vitreous luster. On the basis of this examination, we identified the item as glass, a manufactured product.

All the glass imitations of carved jadeite that we had encountered in

*Figure 14. At 45× magnification, the unusually fine detail of the item in figure 13 is evident—as is the fact that it was molded, not carved.*



*Figure 15. These dyed feldspar scarabs, measuring 14.0 × 10.0 × 5.3 mm each, were misrepresented in the trade as lapis lazuli.*

the past were characterized by fairly coarse details in rather low relief. This item, however, exhibited very fine detail in high relief (figure 14). The intricacy of the apparent carving contributed greatly to the effectiveness of this imitation. *RCK*

### Imitation LAPIS LAZULI

The pair of blue scarabs shown in figure 15 were submitted to the East Coast lab in October 1994. They had been offered in the trade as lapis lazuli, a gem material that they superficially resembled. With 10× magnification (figure 16), the material looked more like sodalite, except that the color distribution was "wrong," with concentrations of blue color in the fractures that proved that the color was produced by dye. More testing, including X-ray diffraction analysis, proved that the material was dyed feldspar. It remains to be seen whether this represents an attempt to develop a commercial product, or it was simply a "one-shot" experiment. *GRC*

### OPAL

#### Glass Imitation "Mexican"

So-called "precious" opal—opal displaying play-of-color—has been imitated by a number of manufactured



*Figure 16. Magnification of one of the scarabs in figure 15 reveals dye concentrations in the fractures, which are responsible for the lapis-like color. Magnified 10×.*

gem materials. Among the better known and more convincing of these are the plastic imitation that shows a true play-of-color and the glass imitation known as "Slocum stone."

However, phenomenal opal is not the only opal used as a gem material. Other types include a translucent-to-opaque blue material from Peru that can closely resemble chalcidony colored by chrysocolla (see, for example, the Summer 1991 Gem News section, pp. 120–121) and various transparent to semi-transparent types. The latter include colorless "water" opal and the yellow, red, or

*Figure 17. The 3.55-ct oval orange modified brilliant (about 12.01 × 9.79 × 6.39 mm) on the left is actually glass. The 2.35-ct triangular step cut is a natural opal from Mexico.*



orange-to-brown material that is known in the trade as "fire," "cherry," or "Mexican" opal.

In the summer of 1995, the West Coast laboratory was asked to examine two faceted stones, a 3.55-ct transparent orange oval modified brilliant (figure 17) and a 2.21-ct transparent red emerald cut. These reportedly came from a parcel of stones that our client had purchased as opal in Mexico. However, subsequent gemological testing of samples by the client revealed properties that were outside the reported ranges for opal. GIA GTL determined the following properties on the two samples we tested (those for the red sample are given first): R.I.—1.522, 1.480; S.G. (determined hydrostatically)—2.64, 2.39; polariscope reaction—singly refractive, anomalously doubly refractive with snake-like bands noted; UV fluorescence—both were inert to long-wave UV radiation and fluoresced a faint, chalky yellow to short-wave UV. Magnification revealed small gas bubbles in both stones.

While the R.I. and S.G. values of the red specimen were well above the

general values reported in the gemological literature for opal, those of the orange stone—which had the more convincing appearance, with minute inclusions that could easily have been overlooked without careful microscopic examination—were only slightly higher than those reported for the upper ranges of opal. However, the type of opal from Mexico that these two stones resembled typically has below-average values, that is, an R.I. of 1.44 or lower and an S.G. of about 2.00–2.10 (see R. T. Liddicoat, *Handbook of Gem Identification*, 12th ed., 1987, p. 280). On the basis of the information gathered, we identified both stones as glass, a manufactured product.

For research purposes, we examined these specimens further using Fourier-Transform infrared (FTIR) spectroscopy and EDXRF analysis. For comparison, we also tested a reference sample of opal from Mexico that had a very similar appearance (again, see figure 17). The natural opal revealed many features in its FTIR spectrum, including: a sharp peak at 5253  $\text{cm}^{-1}$ ; a broader peak centered at 5100  $\text{cm}^{-1}$ ; a less intense

pair of peaks at 4515  $\text{cm}^{-1}$  (sharp) and 4415  $\text{cm}^{-1}$  (broad), which are not found in all opals; a shoulder at about 3950  $\text{cm}^{-1}$ ; and strong absorption from 3735  $\text{cm}^{-1}$  to 600  $\text{cm}^{-1}$ . In contrast, the spectra of the two glass samples were very similar to each other, but very different from the natural stone: They showed a very small, broad absorption peak at 4490  $\text{cm}^{-1}$ , a broad plateau with an absorption edge at 3558  $\text{cm}^{-1}$  and an absorption peak at 2775  $\text{cm}^{-1}$ , and very strong absorption from about 2250  $\text{cm}^{-1}$  to 600  $\text{cm}^{-1}$ . (Synthetic opals have FTIR spectra different from either of these.)

The EDXRF data were also quite interesting. The reference natural Mexican opal contained Si, K, Ca, Mn, and Fe. (It is believed that the color of these opals is due to disseminated iron oxide/hydroxide particles; see, e.g., E. Fritsch and G. R. Rossman, "An Update on Color in Gems. Part 3," *Gems & Gemology*, Summer 1988, pp. 81–102). In the redder of the two glass samples, we found additional elements, notably Se. Subsequent examination with high-energy X-rays of additional orange and red glass samples with similar gemological properties showed that Cd is present in such glasses as well. Many red and orange glasses owe their color to the presence of cadmium selenide or cadmium sulfo-selenide; these glasses are commonly referred to as "selenium glass" (see, for instance, C. A. Hampel, Ed., *Encyclopedia of the Chemical Elements*, Reinhold, New York, 1968, p. 632). These glasses can mimic the colors and diaphaneity of "cherry" and "fire" opals with remarkable success.

MLJ, RCK, and SFM

Figure 18. These approximately 9.4-mm beads make convincing replicas of black pearls.



### Black PEARL Imitations

In January 1995, what seemed to be a strand of dark, silvery, gray-to-black pearls (averaging about 9.4 mm in diameter; figure 18) arrived at the

West Coast lab for identification. On closer examination, however, it became clear that the surfaces of these beads, unlike natural or cultured pearls, had a hazy appearance and a rubbery texture.

Examination of the individual beads at 10× magnification showed that these were actually pearl imitations: Three distinct components were seen around most of the drill holes. As these superficially convincing imitations differed from those that we usually encounter, we decided to identify the various components. As illustrated in figure 19, the inner core consisted of a colorless translucent bead covered by several thin, silvery, gray-to-black layers; another coating, thicker still and transparent, formed the outermost layer.

The bead core had a conchoidal fracture, vitreous luster, and an amorphous structure, as determined by X-ray diffraction. EDXRF analysis revealed the presence of lead. On the basis of these properties, we concluded that the core bead was probably fashioned from leaded glass, which explains the heft of the strand.

Determining the composition of the thin, silvery layers surrounding the core beads was a more interesting

*Figure 19. Three distinct components—including a leaded glass bead, thin layers of bismuth oxide chloride, and a thicker rubber-like coating—are visible around the drill hole of this imitation black pearl. Magnified 10×.*



challenge. Magnification revealed that they were an iridescent platy substance. When touched with a probe, the silvery layers exhibited elastic properties. The X-ray diffraction pattern for this substance matched that for bismoclite, a bismuth oxide chloride. This material has been documented as a coating material for imitation pearls [J. P. Poirot, "Imitation Pearls and Their Coatings," in *Transactions of the XXI International Gemmological Conference*, Brazil, 1987]. Its use separates these imitations from Majorica imitation pearls, which are coated with a guanine-based substance [J. Hanano et al., "Majorica Imitation Pearls," *Gems & Gemology*, Fall 1990, pp. 178–188], or those coated with a lead carbonate.

Testing by FTIR spectroscopy produced a pattern very similar to that of Majorica imitation pearls. Although we could not determine the precise reason for the similar patterns, they may reflect the use of similar polymers or binding agents in the coating materials.

Last, although we do not know the exact composition of the outer coating, we did determine that it was a slightly hazy—but otherwise essentially transparent—thick, rubber-like substance that contained gas bubbles in some areas and was peeling around several drill holes. It was probably added to protect the silvery bismoclite layers from wear.

CYW

### Large SYNTHETIC RUBY

This past summer, a manufacturer of synthetic corundum shared the Czochralski-pulled synthetic ruby shown in figure 20 with staff members of the East Coast lab. The modified triangular mixed cut weighed 115.56 ct and was completely transparent, with a strong red color that had no purple or brown components. Although natural ruby may be found in large sizes, it usually contains so



*Figure 20. This 115.56-ct synthetic ruby has an unmodified red color and high transparency.*

many inclusions that the diaphaneity is translucent rather than transparent.

One area of the pavilion of this large synthetic showed fine curved striae, but otherwise it was free of inclusions or variations in color. Because of the large size and transparency, a slight doubling of the pavilion facet junctions—a rare sight in corundum, which has low birefringence—was visible through the table. The manufacturer of this synthetic ruby reports that he is using a new process in which growth is controlled on a scale of several inches, with the goal of producing material that is entirely free of inclusions or disruptions of the crystal structure (such as twinning or graining) up to sizes as large as 500+ ct.

IR

### PHOTO CREDITS

Nicholas DelRe supplied the pictures used in figures 1, 2, 5–8, 15, and 16. The photomicrograph in figure 3 was taken by V. J. Cracco. The photomicrograph in figure 4 was taken by John I. Koivula. Shane McClure provided figures 9–12 and 19. Figures 13, 14, 17, and 18 were taken by Maha DeMaggio. Figure 20 is courtesy of R. Guillen.

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## DIAMONDS

**Diamond with mobile diamond inclusion.** Some of the most interesting gemstone inclusions are those that contain one or more mobile components. Among these natural kinetic works of art are inclusions that change appearance when heat is applied. An example is a two-phase, carbon dioxide fluid inclusion in quartz that homogenizes to a single phase when a thermal reaction tester is brought near. Sometimes, just the heat from a microscope's incandescent light is enough to cause this change. Other inclusions change their appearance when a stone is merely repositioned in the tweezers or stoneholder, as with three-phase inclusions in emeralds.

Inclusions with visibly mobile phases are rare in diamond. So two of the editors (RCK and JIK) were delighted at the opportunity to briefly examine a flat, twinned diamond crystal (with one polished octahedral face) that contained a movable diamond inclusion (figure 1). We learned from the owner that the diamond was previously examined in detail by one of the contributing editors (HAH); the results of his investigation follow.

The slightly brownish gray diamond weighed 1.09 ct and measured 7.23 mm long × 3.03 mm deep. It was transparent, except in the area of the cavity containing the movable inclusion, where it was semi-transparent.

The diamond crystal was twinned after the spinel law (i.e., it was a macle), and the large cavity roughly duplicated the external contours of the host. The mobile crystal inclusion within that cavity was triangular (almost equilateral) and indented along its horizontal plane of symmetry (the twin plane); trigons were observed on its surface, and it was less transparent than the host but of a similar color. UV-visible absorption spectrometry revealed that the crystal inclusion is a diamond with the same type-Ia characteristics as its host (although the inclusion's absorption was about 2.5 times stronger).

On the basis of this examination, we feel that the mobile diamond inclusion resulted from a growth stage earlier than that of the hollow host. Although we could not identify the material that originally filled the cavity, it probably was a gas that escaped through a fissure during cutting of the octahedral face. The height of the cavity, about 1.7 mm, did not permit the diamond inclusion to tumble freely, although it did move easily in two dimensions.

**Update on Russian diamond mining.** While in Russia to attend the Sixth International Kimberlite Conference, in Novosibirsk, GIA Directors James E. Shigley and D. Vincent Manson visited kimberlite pipes in the Siberian



*Figure 1. Note the movement of this triangular diamond inclusion in a large cavity when its host 1.09-ct macle is turned 180°. Photos by John I. Koivula.*

Sakha (Yakutia) Republic, the source of 95% of Russia's diamond wealth. They provided the following report on the current status of diamond mining in this region.

There was almost no activity at two of the sites. Flooding had forced the closure of the International pit. The quarry-like Zarnitza prospect (site of the first Siberian diamond find in 1954) was also inactive.

The other pipes visited—the Mir, Udachnaya, Aikhal, and Jubilee—were active to some degree. All were open-pit operations.

The Mir pit, also plagued by flooding, showed limited evidence of recent mining. However, ore was being trucked from nearby stockpiles, presumably headed for processing.

Udachnaya seemed to be the most productive of the sites. The large, six-story processing plant there appeared to be in full operation (figure 2). It serviced not only that giant pit, but also some ore trucked in from the Aikhal and Jubilee sites, about 80 km (50 miles) away.

No information was provided on production figures at any of the sites, nor were visitors given any but the vaguest details on day-to-day operations. However, Udachnaya officials did show visitors about 20 colorless, gem-quality diamonds, which ranged from approximately one-half to 20 carats.

During the GIA team's visit to this remote region near the Arctic Circle, daylight lasted from 3 a.m. until midnight; the daytime high temperature was a balmy 80°F (26°C), a far cry from the endless nights and harsh weather that miners must endure during winter months. It was interesting to learn that winter mining at Udachnaya ceases when temperatures drop below about -50°F (-45°C), not because miners cannot cope with the cold, but because an inversion layer forms at that temperature, trapping potentially deadly methane gas in the deep pit.

**Spy ship looks for diamonds.** Namco, the Namibian Minerals Corporation, has chartered a 2,200-ton vessel—formerly a Soviet spy ship—for use in its offshore diamond operations, according to the July 3, 1995, issue of *Diamond Intelligence Briefs*. The ship will be used for evaluations and bulk samplings in Hottentots Bay and in the mouth of the Olifants River.

## COLORED STONES

**Cat's-eye apatites from Madagascar.** A Spring 1995 Gem News entry (p. 60) described large faceted blue-green apatites from Madagascar, which are sometimes called "neon" or "Paraíba" apatites. This year, we also saw a few large cat's-eye apatites from this same locality. One such stone was an 11.45-ct cabochon (figure 3), loaned to GIA by Thomas M. Schneider, of San Diego, California. Magnification revealed the cause of the chatoyancy—a multitude of tiny, white-appearing, reflecting, short acicu-



Figure 2. Visitors are dwarfed by machinery inside the Udachnaya diamond-processing plant, in the Siberian Sakha (Yakutia) Republic of the Russian Federation. Photo by James E. Shigley.



Figure 3. Note the pronounced eye and unusual color of this 11.45-ct blue-green apatite cabochon, reportedly from Madagascar. Short, barely visible white needles cause the chatoyancy (inset). Photo by Shane F. McClure; photomicrograph by John I. Koivula, magnified 50×.



Figure 4. Often sold as Eilat stone from Israel (left, 5.40 ct) is this similar-appearing material from Peru (right, 5.41 ct). Photo by Maha DeMaggio.

lar “fibers” (figure 3 [inset]). Many longer, needle-like black inclusions (oriented in the same direction) were also present, but they seemed too sparse to significantly contribute to the chatoyancy. Although cat’s-eye apatite is not uncommon, stones of this color are very unusual.

**“Eilat stone” from Israel and Peru.** The trade name *Eilat stone* is given to a blue-to-green ornamental rock with a mottled appearance that contains variable amounts of copper minerals. According to Webster’s *Gems* (5th ed., Butterworth-Heinemann, 1994), typical constituents are chrysocolla, turquoise, and pseudomalachite (a copper phosphate mineral). The material is named for its original source, reportedly King Solomon’s copper mines, not far from the Israeli Red Sea port of Eilat.

This gem material has been seen in the trade for many years, and was readily available at the February Tucson shows for at least the past several years. However, one knowledgeable dealer said that much of the material being sold as Eilat stone is not from Israel. Instead, similar-appearing material, recovered as a by-product of copper mining in Peru, is being misrepresented as Eilat stone, that is, as coming from the Israeli source. An Israeli gem dealer confirmed this, adding that material was being exported from South America to Israel and then re-exported as Eilat stone. Two representative pieces—one from Israel and one from Peru—are shown in figure 4.

Because it is often necessary to characterize the minerals in ornamental gem materials such as these—which are essentially inhomogeneous rocks—we frequently need advanced testing for their identification. It would be difficult, if not impossible, for most gemologists to separate the two materials using standard gem-testing methods.

**Six-rayed star emerald.** Recently, a 10.03-ct round, cabochon-cut emerald was submitted by M. P. Steinbach, of Gindorf, Germany, to one of the contributing editors (KS) for examination. The emerald had a fairly well-defined

star (figure 5) and was said to originate from a Brazilian emerald mine.

The stone had strong pleochroism, with an intense blue-green color parallel, and a light yellowish green color perpendicular, to the c-axis. This pleochroism was due to a distinct “aquamarine” (that is, iron-bearing) component, which was found in the absorption spectrum of the gemstone in addition to the well-known chromium absorption bands of emerald.

Microscopic examination showed channel-like inclusions that were oriented parallel to the c-axis. However, the star was actually caused by three series of as-yet-unidentified small, elongated particles with an orientation perpendicular to the c-axis.

Although cat’s-eye emeralds from different localities are occasionally found in the trade, star emeralds are exceptionally rare. The Spring 1995 Gem News section contains an entry on cat’s-eye and star emeralds (pp. 60–61), including a 5.93-ct stone reportedly from Brazil’s Santa Terezinha de Goiás mining area. Because the aquamarine component in the absorption spectrum of the 10.03-ct stone is typical of emeralds from Santa Terezinha, this stone may also come from that locality.

**Faceted genthelvite: A gemological first.** The editors were recently provided for examination—by C. D. (Dee) Parsons, of Santa Paula, California—a small faceted gem-

Figure 5. This unusual 10.03-ct star emerald revealed features consistent with emeralds from Santa Terezinha, Brazil. Photo © GIA and Tino Hammid.



stone that proved to be most unusual. The transparent purplish red-brown stone (figure 6) weighed just 0.33 ct and measured  $4.38 \times 3.57 \times 2.19$  mm. The only internal features in this modified rectangular step-cut were a series of mirror-like fractures, most of which were concentrated along one edge. It had been sold to Mr. Parsons as "danalite" by a Brazilian dealer.

We first subjected the stone to the standard battery of gemological tests, with the following results: R.I. of 1.742; singly refractive; S.G. (by the hydrostatic method) of 3.68–3.70; inert to both long- and short-wave UV radiation. A most unusual feature was that it showed a typical almandine-rhodolite visible-light absorption spectrum (see, e.g., R. T. Liddicoat, *Handbook of Gem Identification*, 12th ed., 1987).

A search of the gemological literature uncovered nothing on the mineral danalite, and the properties attributed to danalite in mineralogical texts did not match those that had been obtained from the faceted stone. Since danalite,  $\text{Fe}_4\text{Be}_3(\text{SiO}_4)_3\text{S}$ , forms a solid solution with helvite,  $\text{Mn}_4\text{Be}_3(\text{SiO}_4)_3\text{S}$ , and genthelvite,  $\text{Zn}_4\text{Be}_3(\text{SiO}_4)_3\text{S}$ , we decided to compare the properties of this stone with those reported for other end-members of the helvite mineral group. A virtually perfect match was obtained for genthelvite.

To confirm the identity, we tested the stone with both X-ray powder diffraction analysis and energy dispersive X-ray fluorescence (EDXRF) spectrometry. X-ray diffraction analysis showed that the stone was in the helvite group, while EDXRF revealed a significant amount of zinc present, in addition to the expected silicon and sulfur. Lesser amounts of manganese and iron were also detected. The greater amount of zinc, coupled with the R.I. and S.G. values, identified this stone as gen-

Figure 6. This 0.33-ct genthelvite is the first faceted example of this mineral that the editors have encountered. Photo by Maha DeMaggio.

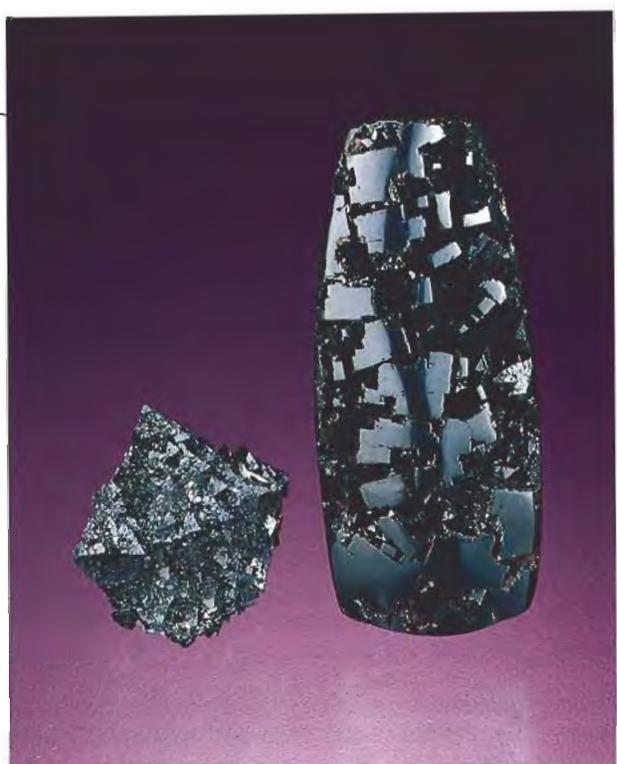


Figure 7. The 71.02-ct ( $39.33 \times 16.88 \times 8.04$  mm) hausmannite cabochon (right) was cut from material similar to the accompanying 37.87-ct tetragonal hausmannite crystal. Photo © GIA and Tino Hammid.

thelvite. (Beryllium [Be] and oxygen [O] cannot be detected by EDXRF.)

Because all the gemological properties shown by this stone fell within the range reported for pyrope-almandine mixtures, it would be impossible for a gemologist, armed with only the traditional series of gem-testing instruments, to identify this stone as genthelvite. X-ray diffraction and chemical analyses would also be needed.

**"Drusy" hausmannite.** In recent years, we have noted the trade's increased interest in gems whose surfaces are not polished smooth, but are left naturally crystalline. When the size of these crystals is measured in hundredths to tenths of millimeters, the surface sparkles. This effect is seen in the so-called drusy gem materials, including uvarovite matrix, cobaltian calcite and dolomite, and quartz druses over chrysocolla and psilomelane (see, for instance, the Spring 1991 and 1994 Gem News sections, pp. 49 and 53, respectively).

Gary Abbott, of Abbott Gems, Roswell, Georgia, has been cutting "drusy" cabochons of larger-grained materials, including the black opaque manganese oxides hausmannite (figure 7) and manganite. His hausmannite cabochons can take on an imposing, architectural appearance. One editor (MLJ) acquired a 71.02-ct drusy cabochon from Mr. Abbott for examination. Because of the nature of the material, we were able to obtain only a few gemological properties, as follows: R.I.—over the limits of a standard refractometer (greater than 1.81); no absorption features noted with a desk-model spectroscope; no magnetism.

Specific gravity was not determined due to the roughness of the surface (too many air bubbles remained trapped between crystals to permit a meaningful determination). We saw no pleochroism with polarized reflected light, although in reflected light the edges of polished crystal faces looked brownish black whereas the rectangular cores looked darker and "purer" black. An X-ray powder diffraction pattern showed only lines for hausmannite.

Hausmannite from the Kalahari manganese field in South Africa occurs as crusts of tetragonal (pseudo-octahedral) crystals growing from the matrix in near-parallel orientation. Cut one way (as in figure 7), the crystals show square cross-sections; cut another way, they form parallel triangles. As was the case with our sample, Mr. Abbott usually backs the pieces with a lighter material to provide rigidity.

**Costa Rican jade museum.** On a trip to Costa Rica late last year, one of the editors (RCK) visited the Marco Fidel Tristán Castro Jade Museum in the capital, San José. Located on the top floor of the Instituto Nacional de Seguros (National Insurance Institute), this small, but very well-organized, facility displays hundreds of pre-Columbian jadeite carvings. A few are back-lit to show their translucency and richness of color.

In pre-Columbian times, the area encompassed by what is now the Republic of Costa Rica was home to a major lapidary industry, according to displays within the museum and the museum guidebook (C. Balsler, Ed., *Jade Precolombiano de Costa Rica*, 3rd ed., Instituto Nacional de Seguros, San José, Costa Rica, 1993). Jade first became a regional commodity around 800 B.C., when groups of Olmecs arrived from the north in search of the prized "blue jade," described in the museum catalog as a blue-green diopside jadeite. (However, no source of jadeite has been found in Costa Rica; most is believed to have come from nearby Guatemala.) Many Olmec lapidary techniques and motifs—especially anthropomorphic axe-gods (typically about 10–12 cm high)—are seen in the carvings discovered in Costa Rica. Regional lapidary activity peaked in the period from around 100 B.C. to 500 A.D.

Other jade-like materials were also worked by the native lapidaries. Some (including green-gray talc, steatite, serpentine, and green jasper) are also displayed in the museum.

**Green opal from Serbia.** In addition to the well-known play-of-color and relatively transparent "jelly" opals, we occasionally see nonphenomenal opals of lower diaphaneity that are valued for their unusual body colors. Such materials include green opal from East Africa (see, e.g., the article by J. I. Koivula and C. W. Fryer in *Gems & Gemology*, Winter 1984, pp. 226–227) and pink opal from Peru (Winter 1991 *Gem News*, pp. 259–260).

At a major gem show earlier this year, the editors came across some rough material labeled "crysopal." According to the vendor, it came from southern Serbia, near the



Figure 8. This 21.08-ct cabochon and the 64-gram piece of rough opal from which it was cut are reportedly from Serbia. Photo by Maha DeMaggio.

Macedonian border, and first entered the market by way of Sweden in 1992. By early 1995, however, it was no longer coming out of Serbia because of the armed conflicts in that area.

Anders Karlsson, of Rox Arcana, Carmel, California, subsequently donated a rough sample to GIA, from which was cut a 21.08-ct pear-shaped cabochon (figure 8). The translucent cabochon was a pale, slightly bluish green (Munsell 7.5G 8/5), with a lightly mottled color distribution, an aggregate optic character, and a negative color-filter reaction (that is, it appeared green through the Chelsea filter). The spot R.I. was 1.46; S.G., measured hydrostatically, was 2.10, but measurement was complicated by the fact that the stone was porous, soaking up water as weights were taken. The cabochon was inert to short-wave UV radiation, and fluoresced an even, faint chalky green to long-wave UV. The spectrum seen through a handheld spectroscope showed cut-off edges at 450 and 620 nm. Magnification revealed some healed fractures and veining. Qualitative EDXRF spectrometry showed major Si and minor Ni (nickel, probably the cause of color), K, Ca, V, and Zn.

The gemological properties recorded for this Serbian material are comparable to those of Tanzanian green opal, described in the previously mentioned article by Koivula and Fryer. Green nickel-bearing opal has also been found in Poland, Australia, and Peru.

**"Deep" quartz from Africa.** Just when we thought that we had heard every name for quartz, one of the editors saw a new one—"deep" quartz. Specimens of some otherwise ordinary looking rock crystal quartz were being offered as "deep" quartz by one enterprising dealer at the February Tucson shows. His explanation for the name: The speci-



Figure 9. The Eastern Desert of Egypt was given as the source of this 27.94-ct green quartz scarab. Photo by Maha DeMaggio.

mens came from “deep” in the Earth—one to one-and-a-half miles below its surface, to be exact, in the Vaal Reefs mine at Orkney, South Africa.

**Egyptian green quartz.** During a visit to Egypt, one of the editors (RCK) purchased in the town of Luxor a number of gem materials from Egyptian localities. Although the vendor, a local jeweler and avid gem and mineral collector, could identify most of the materials in question and their geographic origins, he had little information about some of them.

One such ornamental gem was an opaque, medium-dark green material that the vendor had purchased from Bedouin tribespeople. They reportedly collected it some-

Figure 10. This 18.07-ct tablet (18.25 × 16.35 × 6.25 mm) is quartz with inclusions of hematite or a similar material. Photo by Maha DeMaggio.



where in the Eastern Desert. The vendor indicated that, while it superficially resembled some feldspars and serpentines from the same general area, this green stone was harder to fashion, requiring more time to cut. A 27.94-ct mottled green scarab fashioned from this material was purchased for examination (figure 9).

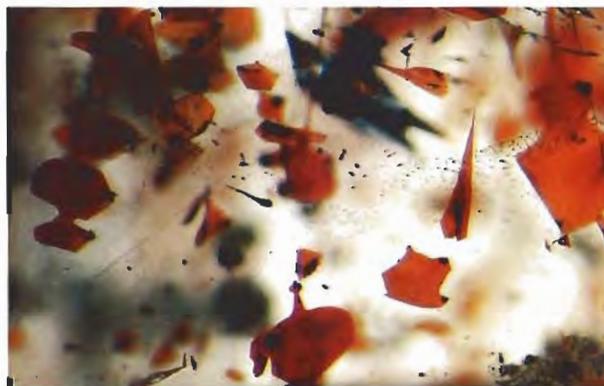
Standard gemological testing produced: a 1.54 spot R.I.; a faint yellowish green luminescence to long-wave UV radiation, and no reaction to short-wave UV; a vague absorption band at 670 nm, as noted through a desk-model prism spectroscope; and a 2.64 S.G., determined hydrostatically. Magnification revealed a pseudo-fibrous structure. X-ray powder diffraction analysis produced a match with a standard reference pattern for quartz.

EDXRF analysis revealed, in addition to the expected silicon, a number of other elements. Among these was a fairly large concentration of chromium, which was the most likely cause of the green color. Chromium, however, is virtually unknown as a trace-element chromophore in quartz. This fact, combined with the abundance of other elements, indicated that finely disseminated, chromium-colored mineral inclusions produced the overall green color of this gem.

**Quartz with “hematite” inclusions.** In the Spring 1995 Gem News section, we reported on “strawberry” quartz colored by inclusions of goethite and lepidocrocite (pp. 63–64). In July 1995, Michael Randall, of Gem Reflections, San Anselmo, California provided two samples of a similar material for our examination. This “spangled” quartz (see, e.g., figure 10), reportedly from Madagascar, was colored by bright orangy red flakes of an iron-bearing material, probably thin plates of hematite (figure 11).

The most obvious features seen with magnification were curving transparent orangy red platy inclusions. Randomly oriented throughout the cabochon, they were

Figure 11. The hematite-like features in the quartz tablet shown in figure 10 appear as thin, curving orangy red plates when viewed with 10× magnification. Photomicrograph by John I. Koivula.



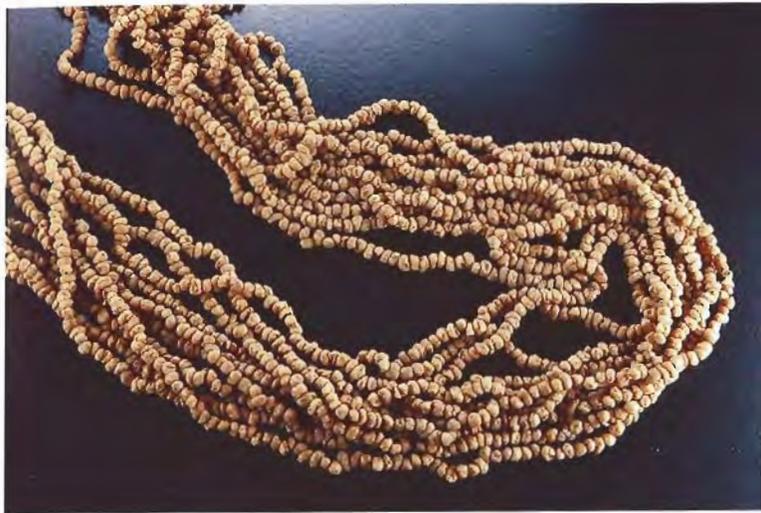


Figure 12. This 10-strand necklace (about 100 grams total weight) is made up of approximately 3,800 beads of resin that are said to come from western Africa. Although commonly sold as "myrrh," it probably is not the resin of the relatively rare *Commiphora myrrha*. Photo by Maha DeMaggio.

concentrated in one layer parallel to a rhombohedral face in a rough sample that we also examined. The morphology of these plates was unusual. Each grew outward from one corner in an elongated fashion (as the host quartz crystal grew), sometimes pinching and re-swelling to form an "hourglass" or "cello" shape (one such plate is visible in figure 11). Also seen were radial crystal aggregates that appeared white to pale green.

**Aromatic resin necklace: A form of myrrh?** Some natural plant materials are recognized as gems. The most notable example of plant-produced gem materials is the fossil resin amber. Modern resins such as copal are also used for jewelry purposes. Another resin sometimes used as an ornamental material is the yellow-brown material sold as "myrrh."

One of the editors (RCK) recently acquired a multi-strand necklace of this material (figure 12) in order to characterize its gemological properties. The 100-gram necklace was composed of ten 36-inch (90 cm) strands with about 380 button-shaped beads, 2.5 to 5 mm in diameter, per strand. Gemological testing of a few beads separated from one strand revealed the following properties: color—yellowish brown to brown; diaphaneity—translucent; color distribution—even; aggregate reaction in the polariscope ; R.I.—1.41 (spot); S.G.—1.27 (measured hydrostatically); fluorescence—even chalky moderate yellow to long-wave UV, even chalky weak yellow to short-wave UV; phosphorescence—none; absorption spectrum—430-nm cutoff (that is, a typical "brown" spec-

trum). With magnification, individual beads showed a mottled appearance, with brown speckles. This material melts easily when approached with a thermal reaction tester ("hot point"), scratches with a fingernail (Mohs hardness below 2.5), and has a granular fracture and a characteristic sweet, spicy odor. The hardness is so low that "myrrh" beads can be polished by rubbing them against a sheet of paper.

Fourier-Transform infrared (FTIR) spectroscopy of one bead revealed broad absorption peaks at 5180, 4778, and 4000  $\text{cm}^{-1}$ , and two sharp peaks at 4339 and 4264  $\text{cm}^{-1}$ ; this is distinct from the spectrum of the harder resin amber (see, e.g., "Amber Simulant: Natural Resin in Plastic," in the Summer 1995 Gem News, pp. 134–136).

Myrrh has a long and illustrious history. The actual substance called myrrh is a gum resin produced by *Commiphora* (*Balsamodendron*) species, especially *Commiphora myrrha*. In 1770, Dr. John Cook wrote *The Natural History of Lac, Amber, and Myrrh (etc.)*, which detailed the medicinal properties of this substance (quoted by H. Fraquet, *Amber*, Butterworths, London, 1987). L. S. Dubin, in *The History of Beads, from 30,000 B.C. to the Present* (Abrams, New York, 1987, pp. 90–91), mentions the late medieval practice of wearing myrrh-filled pomanders as rosary beads, in the hopes of warding off the plague. Possibly the most famous use of myrrh was, with gold and frankincense, as a gift from the three Wisemen to the newborn Jesus (Matthew 2:11). As an aside, the "murrhina" or "murrhine" that Pliny mentioned in his *Natural History* was not myrrh, but probably banded fluorite or chalcedony (see, e.g., J. Sinkankas, *Gemology: An Annotated Bibliography*, Scarecrow Press, Matuchen, NJ, 1993, entries 952, 1461, 5004, 5615, 5747, 6834).

Other "organic" materials made into scented beads include: sandalwood, cloves, "California Flower Beads" of the 1910's to 1920's (probably dyed and scented plaster), and beads made from a paste of aloe wood, cloves, musk, ambergris, flower petals, and aromatic leaves (P. Francis, *Beads of the World*, Schiffer Publishing, Atglen, PA, 1994, p. 37). Francis (*op. cit.*) notes that the material commonly called myrrh—in our opinion, probably including this necklace—is the resin of a tree or shrub different from the somewhat rare *C. myrrha*. He adds that it is "shaped into beads, colored and given various forms in Western Africa."

**Update on Mong Hsu ruby.** Smaller rubies—under 1 ct—from Mong Hsu, Myanmar (Burma), were plentiful at this year's Tucson shows, but there seemed to be fewer stones above 1 ct than the previous year. Echoing this observation was a dealer with Gemstone International, Seattle, Washington. He had difficulty, he said, in locating good Mong Hsu stones in the 2-ct range on a trip to Bangkok in late 1994, although such stones were fairly easy to find the year before.

However, one feature of heat-treated Mong Hsu rubies is threatening their distribution altogether. The



Figure 13. These three rubies (0.83–1.18 ct) are from the Cowee Valley, North Carolina. Photo by Maha DeMaggio.



Figure 14. Inclusions of brownish red rutile are evident in this ruby from the Cowee Valley, North Carolina. Photomicrograph by John I. Koivula; magnified 25 $\times$ .

rubies are typically packed in a flux, such as boron, for heat treatment; some of this flux evidently reacts during the high-temperature treatment to form a colorless glassy solid that fills some surface-reaching fractures in the rubies. (Peretti et al. speculated that this material might be an aluminum borate; see "Rubies from Mong Hsu," *Gems & Gemology*, Spring 1995, pp. 2–26.) Stones with such fillings are not acceptable to some ruby customers: Buyers in Japan and Europe have returned them to their suppliers. Thailand's gem traders and exporters recently agreed to halt sales of treated gems from Chanthaburi, which is where the Mong Hsu rubies are heated (see "Thailand Halts the Export of All Treated Gemstones," *Diamond Intelligence Briefs*, March 19, 1995, p. 1227).

**Rubies and sapphires from North Carolina.** GIA researchers recently examined a suite of rough and faceted rubies and sapphires from the Cowee Valley, Macon County, North Carolina (figure 13). These samples were loaned to GIA by Robin Dinnes, of Cowee Valley Lapidary, Franklin, North Carolina. One of the better-known occurrences of gem corundum in the United States (for a description, see *Gemstones of North America*, by J. Sinkankas, Van Nostrand Reinhold, 1975, pp. 50–53), this locality has been mined on a small scale for gem material and mineral specimens for the past 65 years. The gem corundum occurs as crystals embedded in either blue or red clays, along with other alluvial minerals such as rhodolite and pyrope garnet, rutile, and sillimanite.

The suite that we examined consisted of 10 faceted stones, 11 cabochons, and some rough material. Two thirds were sapphires, and the remainder were rubies. The largest faceted sapphire was 2.65 ct, and the largest faceted ruby was 1.35 ct.

Most of the faceted rubies were semi-transparent (even cloudy) because of numerous fractures. Most of these fractures were partially healed, and appeared as veils

or "fingerprints." Rubies found in the red clays were usually stained yellow-brown (presumably by iron oxides) on their surfaces and along fractures. In addition, the samples contained prominent grains of brownish red rutile inclusions (figure 14), as well as tiny, intersecting needles. All of the rubies were color zoned, with irregular-shaped areas that appeared either more purplish red or more orangy red (possibly due to the previously mentioned staining). The gemological properties of this material were consistent with those of rubies in general. EDXRF analysis of three samples revealed the presence of Cr, Fe, Ti, Ca, and Ga—all elements often found in natural rubies.

The faceted sapphires were similar to the rubies in their rutile and needle-like inclusions, and in their semi-transparent or translucent appearance. In some cases, cabochon-cut sapphires exhibited weak asterism.

This was one of the first opportunities we have had to examine material known to be from this locality.

**Purple scapolite from Tajikistan.** The importance of Russia and other republics of the former Soviet Union as sources of gemstones, both natural and synthetic, continues to be reinforced at major gem shows. In addition to those materials mentioned in the Spring and Summer Gem News columns, we have recently seen faceted purple scapolite, which is being marketed by the Russian Colored Stone Company, of Golden, Colorado. The scapolite is reportedly a new find in Tajikistan's Pamir Mountains, at about 5,000 m elevation—so high that miners must wear oxygen masks while they work, according to company representative Alexey Eremin.

Mr. Eremin loaned us a 1.79-ct (7.40–7.50  $\times$  6.83 mm) round modified brilliant (figure 15) for examination. Gemological properties determined were: color—purple; diaphaneity—transparent; pleochroism—strong, purple and near colorless; optic character—uniaxial; R.I.—1.539 and 1.550; birefringence—0.011; specific gravity (deter-



Figure 15. Tajikistan's Pamir Mountains are the source of this 1.79-ct scapolite. Photo by Maha DeMaggio.

mined hydrostatically)—2.61; fluorescence—inert to long-wave UV and a very weak pinkish orange reaction to short-wave UV; absorption spectrum—very faint absorption line at 600 nm. With magnification, a few needle-like crystals (one broken into a stringer) were visible in the stone.

Gem scapolite is a mineral series between the two end-members marialite,  $\text{Na}_4(\text{Al}_3\text{Si}_9\text{O}_{24})\text{Cl}$ , and meionite,  $\text{Ca}_4(\text{Al}_6\text{Si}_6\text{O}_{24})\text{CO}_3$ . Using refractive indices of the speci-

men stone, and comparison data in Deer, Howie and Zussman's *Introduction to Rock Forming Minerals* (Longman Group, London, 1974, p. 387), we determined its composition—assuming that it contained only these two end-members—to be about 81% marialite and 19% meionite.

**Large spinel from Tajikistan.** Spinel is another gem material being recovered from this former Soviet republic in Central Asia. We know of one particularly exceptional stone, a 532-ct piece of rough spinel, that was fashioned into a number of gems. The largest of these gems weighed 146.43 ct and was named the "Katherina" by the purchaser of the rough, the Netherlands-based AGT International (see "Spectacular Spinel," by P. Bancroft, *Lapidary Journal*, February 1990, p. 25).

The Katherina was subsequently recut to 123.14 ct (E. Caplan, pers. comm., 1995) and the refashioned stone loaned to GIA for examination. Although recut, it retained its basic step-cut cushion shape (figure 16). The stone exhibited properties consistent with natural spinel from other localities. Described as "virtually flawless" in the *Lapidary Journal* article, the stone revealed a small plane of what appeared to be octahedral negative crystals near the culet when examined with magnification. These substantiate the stone's natural origin. EDXRF chemical analysis by GIA Research showed only a tiny amount of zinc (Zn), which is consistent with Zn concentrations that have been documented in other spinels from this locality.

**Color-change zircons.** Many color-change gemstones have been described in the gemological literature, but not until Scottish gemologist Alan Hodgkinson informed us of a



Figure 16. This 123.14-ct spinel was cut from a 532-ct piece of rough that came from Tajikistan's Pamir Mountains. Courtesy of Evan Caplan, Los Angeles; photo by Shane F. McClure.



Figure 17. *Opticon, or a similar synthetic resin, was used to impregnate this 17.19-ct fibrous-appearing malachite. Photo by Maha DeMaggio.*

2.25-ct stone that turned blue in day (or fluorescent) light and green in incandescent light had we ever heard of a color-change zircon. Mr. Hodgkinson forwarded the following report of his examination of this stone, which was loaned to him by Keith Mitchell.

The refractive indices were 1.923 and 1.985, with a birefringence of 0.062. The specific gravity was 4.68. When the stone was examined in incandescent light, the color of the ordinary ray was "olive" green and that of the extraordinary ray, greenish blue. Through the Chelsea filter, a grayish pink color was evident. There was no reaction to long- or short-wave UV. A Geiger counter detected slight radioactivity (with 1.3 counts per second above background), which is typical for green zircons. In the handheld spectroscope, the stone displayed a strong uranium spectrum. EDXRF analysis showed zirconium and silicon to be the two major components. Also present was hafnium—which commonly substitutes for zirconium in nature—and uranium. The uranium concentration was estimated to be 1.55 wt. %  $UO_2$ .

## ENHANCEMENTS

**Impregnated malachite.** Although polymer-impregnated jadeite has received the most attention in the trade and technical press lately, other gem materials are also similarly treated. These include porous turquoise and a chalky-appearing opal from Piauí, Brazil.

At a major gem show this year, the editors found some unusual-appearing malachite. The vendor maintained that it came from Morenci, Arizona, an area known as a source of turquoise and other copper-mineral gems. What first caught our attention was the material's orientation: It had been cut to show its fibrous texture along the length of the cabochons (figure 17). The material also exhibited both unusually high luster and depth of color.

A sample cabochon was purchased for gemological investigation. R.I. testing on the flat base revealed a 1.58 reading with no birefringence blink. Spot R.I. testing on different areas of the top produced either vague readings in the high 1.50s or a very weak birefringence blink in the range expected for malachite (about 1.66 to over-the-limits). Specific gravity, determined by hydrostatic weighing, gave a value of 3.76; although low for compact malachite, it was within the range reported in the gemological literature for this gem species. The stone was inert to short-wave UV. Long-wave UV caused the top of the stone to fluoresce a very weak, mottled chalky blue; a similar but stronger reaction was seen from the base of the stone. With magnification, we noted a transparent, colorless substance that formed a layer on the base and partially filled a large cavity. This substance was most apparent in the areas that reacted to long-wave UV. Infrared spectroscopy revealed absorption features similar to those that we have documented for the epoxy resin Opticon.

Another vendor selling similar-appearing material—Joe Jehlks, of Horizon Mineral Company, Houston, Texas—said that he used Opticon resin to treat Morenci malachite and described how he did it. The rough material was first heated in a toaster oven to roughly 150°–250°F for a few hours. It was then removed from the oven, coated with Opticon, and returned to the oven for more heating (typically overnight). The material was then slabbed and the process repeated on the individual slabs: heating, coating with Opticon, then heating again. This sequence was repeated after preforming and through the pre-polishing stage. By the time the material was ready for its final polish, it was thoroughly impregnated, so that further Opticon treatment was not necessary. Mr. Jehlks maintained that the chemical catalyst—that is, the polymerizing agent—provided with Opticon was not necessary in this treatment process. The multiple low-temperature heatings alone were sufficient to harden the synthetic resin.

## SYNTHETICS AND SIMULANTS

**Unusual color-zoned synthetic amethyst.** While visiting the firm of Pinky Trading in Bangkok, one of the editors (RCK) saw a synthetic amethyst crystal from Russia with exceptionally uneven—"speckled" or "leopard spot"—color distribution. Although a distinct, patchy color distribution is typical for natural amethyst, zoning in synthetic amethyst is usually very subtle (see, for example, figure 12 in "A Simple Procedure to Separate Natural from Synthetic Amethyst on the Basis of Twinning," by R. Crowningshield et al., *Gems & Gemology*, Fall 1986, pp. 130–139).

The Russian crystal (figure 18) was obtained for examination. The typical crystal morphology of quartz explains its unusual appearance. Quartz is a mineral that



Figure 18. Color zoning is very apparent in this 167-gram piece of synthetic amethyst manufactured in Russia. Photo by Maha DeMaggio.

appears to have hexagonal [six-sided] symmetry, but it really is trigonal, or symmetric to three-fold rotations. Crystals typically have six pyramidal faces coming to a common apex. These are called *rhombohedral* faces, which appear alike at first glance, but actually occur in two alternating sets: *positive* (*r*) and *negative* (*z*) faces. In natural and synthetic quartz, color-causing impurities concentrate selectively in different sectors, or regions where certain faces grow; in particular, the darker purple color in natural amethyst—and the purple zones in ametrine—usually develop in sectors under the positive *r* faces [see, e.g., F. Hassan, "Amethyst," *Mineralogical Record*, Vol. 3, No. 5, 1972, pp. 221–225; P. M. Vasconcelos et al., "The Anahí Ametrine Mine, Bolivia," *Gems & Gemology*, Spring 1994, pp. 4–23].

Because the Russian specimen grew on a seed plane cut perpendicular to the *c*-axis, it looks very different from natural crystals in shape. Instead of one set each of *r* and *z* faces, the Russian synthetic has multiple parallel sets of these faces, in three orientations each. Microscopic observation of the color zoning in the Russian specimen demonstrated that the darker-color regions (*r* faces) grew as expanding rhombic pyramids from points inside the crystal (figure 19).

The editors are not aware of any similar "speckled" or "leopard spot" color zoning in natural amethyst from any documented locality. Therefore, the presence of such zoning should be considered indicative of synthetic origin.

**More on Czochraski "pulled" synthetic sapphires.** The Spring 1993 and Summer 1994 Gem News sections con-

tain entries on Czochraski-pulled synthetic sapphires seen at the 1993 and 1994 Tucson shows. All the colors mentioned in those entries—including blue—were again seen at the 1995 shows. According to one vendor of this material, Gerry Manning of Manning International, New York, the pulled synthetic blue sapphire crystals are unevenly colored. The first-grown portions of the rod-shaped crystals are lightest in color; the rods become increasingly darker toward the opposite end (the last part to crystallize). The color zoning described by Mr. Manning differs from that seen in split boules of flame-fusion synthetic blue sapphire. There, the color is typically lightest in the center and progressively darker toward the periphery.

Mr. Manning provided two faceted blue specimens (figure 20) for gemological characterization. Properties determined were: R.I.— $n_e = 1.760$ ;  $n_o = 1.768$ ; birefringence—0.008; S.G. (determined hydrostatically)—4.00 to 4.01. Both specimens were inert to long-wave UV and fluoresced a weak, chalky bluish green to short-wave UV. All these properties are similar to those of flame-fusion synthetic blue sapphires. We also noted weak red fluorescence to intense transmitted light from a fiber-optic light source, and the samples appeared faintly pink through the Chelsea color filter. These latter two reactions have been noted in some violetish blue flame-fusion synthetic sapphires that contain traces of chromium, as well as in some natural blue-to-violet sapphires from Sri Lanka that also contain traces of chromium.

Magnification revealed minute gas bubbles in both samples. Unlike flame-fusion synthetic sapphires, however, although the color of our samples did not appear totally uniform we could not resolve curved color banding using

Figure 19. Magnification reveals that the color of the synthetic amethyst in figure 18 formed as expanding rhombohedral wedges in the crystal. This color zoning is unlike anything we have seen in natural amethyst. Photomicrograph by John I. Koivula; magnified 4x.





Figure 20. The Czochralski method was used to produce these two synthetic sapphires (1.64 and 1.76 ct). Photo by Maha DeMaggio.

diffused transmitted light and magnification. Only when this lighting technique was combined with immersion of the samples in methylene iodide could we see wide, slightly curved blue banding, which is proof of synthesis.

**Tanzanite-colored synthetic sapphire.** As tanzanite continues to be one of the more commercially important colored stones, materials that resemble tanzanite are increasingly in demand. In the Spring 1995 Gem News section (p. 62), we reported on iolite (the mineral cordierite), which has been promoted as a less-expensive alternative to tanzanite. Another recently promoted alternative is violet-blue synthetic sapphire, marketed under such trademarked names as "Cortanite" and "Coranite." International Colored Gemstone Association (ICA) Lab Alert No. 83, by Mrs. Shyamala Fernandes, stated that this material has been sold in India as tanzanite.

Recently, we examined five samples of this synthetic sapphire, ranging from 0.97 to 4.07 ct (see, e.g., figure 21).

Figure 21. These two synthetic sapphires (2.00 ct and 4.07 ct) are typical of material being sold as a tanzanite simulant. Photo by Maha DeMaggio.



Four were obtained from Gemstones International, of Sayreville, New Jersey; the fifth was marketed by Lannyte Corp., of Houston, Texas.

Gemological properties were determined as follows: color—violetish blue to violet; diaphaneity—transparent; pleochroism—moderate, violet (ordinary ray) to light blue, light grayish blue, or light greenish blue (extraordinary ray); optic character—uniaxial negative; Chelsea filter reaction—none to weak red; R.I.— $n_e = 1.760$  to  $1.761$  and  $n_o = 1.769$ ; birefringence— $0.008$  to  $0.009$ ; S.G.— $4.00$  to  $4.02$ ; fluorescence—inert to long-wave UV, even, chalky weak-to-moderate bluish green to blue-green to short-wave UV; very faint to weak red transmission; absorption spectrum—none (four samples), diffuse 560–620 band and faint 690 line (darkest sample). All five samples had obvious curved color banding (figure 22) and pinpoint inclusions that are most likely gas bubbles (typi-



Figure 22. Curved color banding is obvious in this synthetic sapphire being marketed as a tanzanite substitute. The material is also strongly color zoned, with darker crowns and lighter pavilions. Photomicrograph by John I. Koivula; immersion, magnified 3 $\times$ .

cal of Verneuil synthetic sapphires); the curved banding was also obvious when viewed with magnification and short-wave UV as a radiation source.

EDXRF spectroscopy revealed, in addition to major aluminum, trace amounts of iron, titanium, and—in the darkest-colored stone (from Lannyte)— $0.003$  wt.% Cr as  $Cr_2O_3$ .

There were at least two possible explanations for the atypically violet hues of these synthetics: the orientation of the faceted samples with regard to the optic axis of the material, and their chromium content. All five samples were strongly color zoned, with darker crowns and near-colorless culets (again, see figure 22). The optic axes of the five were oriented at  $45^\circ$ ,  $50$ – $60^\circ$ ,  $55$ – $60^\circ$ ,  $80$ – $85^\circ$ , and  $90^\circ$ , respectively, to the table (that is, the optic axis ori-

ented at 90° went through the girdle of the stone); the smaller the optic-axis angle was, the more violet the stone appeared. Because all of the samples preferentially emitted red light (i.e., they were "red transmitters"), we believe that chromium content (which was below the detection limits of our standard EDXRF conditions in four of the five samples) was also implicated as a cause of the violet color.

**Natural and synthetic quartz "constructs."** The Winter 1992 Gem News section described an attractive "gem construct" (pp. 277–278) composed of rhodolite garnet, colorless topaz, and iolite. We used the term *construct* because the item was *intentionally* produced to show the individual components. This differs from most assembled



Figure 23. This 33.83-ct gem construct contains both natural and synthetic quartz components. Fashioned by Bashir Beekzad; photo by Maha DeMaggio.

stones, which are produced to imitate other gems or to permit the use of thin sections of material, such as opal, that would otherwise lack sufficient durability for jewelry use.

At a gem show this year, the editors saw another interesting gem construct, this one with both natural and synthetic quartz (figure 23). Synthetic quartz was used in the construct when the desired color of natural quartz (blue and dark green, for example) was unavailable, according to Gul Beekzad, of Freedom Valley Gems, Fremont, California. Rutilated quartz—which has no synthetic counterpart—was used for one end of the construct.

## ANNOUNCEMENTS

**Dates set for February 1996 Tucson shows.** The American Gem Trade Association (AGTA) GemFair will run from Wednesday, January 31, to Monday, February 5, 1996, at the Tucson Convention Center. After that show leaves, the Tucson Gem & Mineral Society will take over the Convention Center for its show from February 8 to 11. At the Holiday Inn City Center (Broadway) from February 2–9 will be the Gem & Lapidary Dealers Association (GLDA) show. Other show venues include the: Best Western Executive Inn, Boatner's Service Station, Day's Inn Convention Center, Desert Inn, Discovery Inn, Holiday Inn Holidome, Howard Johnson Midtown, Pueblo Inn, Rodeway Inn, Scottish Rite Temple, Southwest Center for Music, Tucson East Hilton & Towers, Tucson Exposition Center, and Windmill Inn. Times and dates of shows vary at each location. Consult the show guide, which will be available at the different Tucson venues, for further information.

**Education at the Tucson AGTA GemFair.** The AGTA GemFair (January 31–February 5 at the Tucson Convention Center) will feature a comprehensive gem-education program. For information, contact AGTA at (800) 972-1162 or (214) 742-4367.

GIA will also hold classes and seminars from Saturday, January 27, through Tuesday, February 6. Gemology extension classes include Diamond Grading, Gem Identification, Day with Colored Stones, Identifying Challenging Synthetics, and Detecting Treated Emerald, Ruby, and Sapphire. New for 1996 are individual seminars on Alternatives for Red, Green and Blue Gems. Also available will be Jewelry Manufacturing Arts seminars and workshops on topics such as mold making, channel setting, wax carving, jewelry repair, forging, finishing, and soldering. For further information on GIA classes in Tucson, call (800) 421-7250, extension 269.

**Visit *Gems & Gemology* in Tucson.** *Gems & Gemology* Editor Alice S. Keller and Assistant Editor Irv Dierdorff will be staffing the *Gems & Gemology* booth in the Galleria section (middle floor) of the Tucson Convention Center for the duration of the AGTA show, January 31–February 5. Drop by to ask questions, share information, or just say hello. Many back issues will be available.

**More GIA Tucson show news.** Also in the Galleria section of the Tucson convention center during the AGTA show with booths of their own will be the GIA: Bookstore, Alumni, Education, Advanced Retail Managements Systems, and GEM Instruments. The bookstore, GIA Education, and GIA GEM Instruments also will have booths in the lobby (numbers 6 and 7) at the GLDA show.

## STANDARD CATALOG OF GEM VALUES, 2nd Edition

By Anna M. Miller and John Sinkankas, 271 pp., illus., publ. by Geoscience Press, Tucson, AZ, 1994. US\$24.00\*

This update of Dr. Sinkankas' 1968 *Van Nostrand's Standard Catalog of Gems* carries through most of the same basic information in simple terms that made the original a classic. It is an excellent introduction to the characteristics of value in gem rough, cut stones, engraved gems, gem carvings, and pearls. One of the first price guides ever published, it still covers areas that none of its current competitors have reached, especially in gem rough and uncommon stones.

Unfortunately, the editing and reproduction of the second edition are not of the same quality as the first. The frequent typographical errors, misspellings, partial sentences, and misdirected references—not seen in the first edition—detract from the book's readability. The same 15 black-and-white photos were sharper 25 years ago. In addition, the 1994 volume continues factual errors found in the original edition (e.g., De Beers rough diamond sales are still called "sightings") as well as some out-of-date information and locality names (e.g., Rhodesia, Peking). The updated section on faceted diamonds is especially weak, both in facts and prices.

Prices quoted are identified as "1993 U.S. average retail prices," but the authors do not explain what constitutes retail markets for gem rough, loose stones, and the like. As with any price list, the usefulness of this one is limited by how broadly the material being valued is categorized. Vague descriptions with wide price ranges are almost never wrong, but they are of limited benefit to buyers, sellers, and appraisers. On the positive side, the price listings do give indications of the extremes of the markets for each variety, as described.

In this second edition, the strong content outweighs the disappointing publication quality. I look forward to a more polished third edition.

CHARLES I. CARMONA  
Guild Laboratories Inc.  
Los Angeles, California

## Reviews

SUSAN B. JOHNSON AND  
JANA E. MIYAHIRA, EDITORS

### OTHER BOOKS RECEIVED

**Diamond Exploration into the 21st Century**, edited by W. L. Griffin, 367 pp., illus., publ. as Vol. 53 of the *Journal of Geochemical Exploration, Elsevier Science, Amsterdam, 1995, US\$250*. Diamond exploration is being feverishly conducted on all continents except Antarctica; currently about US\$400 million is spent annually. This collection of 18 invited papers by authors from eight countries gives an overview of modern diamond exploration research, techniques, and results. Four papers from Russia are particularly interesting, given the Russians' success in diamond exploration and the fact that their approaches developed differently because of their long isolation.

The volume is divided into four parts: (1) *Background* (5 papers) covers the formation of diamonds and the nature, abundance, location, and selected economic aspects of primary (pipe) deposits; (2) *Area Selection* (3 papers) discusses geologic controls and prediction of favorable areas for primary deposits; (3) *Finding the Target* (6 papers) considers proper methods for collecting indicator mineral samples, laboratory processing, and geophysical exploration methods, as well as the basic principles of alluvial diamond exploration; and (4) *Prioritisation and Evaluation* (4 papers) includes interpretation of the chemical compositions of indicator minerals, petrographic studies, and statistical evaluation of several parameters (e.g., microdiamond counts) used to determine those pipes that are likely to be economic—recognizing that fewer than 1% of all pipes discovered will be economic.

This book contains much newly released information on diamond exploration. Knowledgeable gemologists will find the *Background* part particularly valuable.

A. A. LEVINSON  
University of Calgary  
Calgary, Alberta, Canada

**The New Alchemists: Breaking Through the Barriers of High Pressure**, by Robert M. Hazen, xvi, 287 pp., illus., publ. by Smithsonian Press, Washington, DC, 1993. US\$23.00.\* Although the title may sound more like a chemical treatise than anything to do with gems, the "high pressure" is actually that needed to convert carbon into diamond. In fact, this book is a valuable history of the long search for successful diamond synthesis.

The author provides an interesting, readable text, mostly written in the style of *National Geographic* magazine. It is based on his long experience in high-pressure research in the laboratory of the Carnegie Institute, Washington, DC. In the course of his work, he learned much about early experiments in high-pressure research—as by Percy W. Bridgman (1882–1961), Loring Coes Jr. (1915–1978), and others—which ultimately led to the success of General Electric and ASEA, the Swedish equivalent of GE (ASEA actually produced synthetic diamond before GE, but, for some still unexplained reason, according to Hazen, kept this fact secret). Hazen relates the official and personal struggles of these investigators in a very entertaining fashion, with the result that much anecdote leavens what otherwise might have been a dull text.

This treatise is the best background source for the modern history of diamond synthesis. It is wholeheartedly recommended to all students of diamond history.

JOHN SINKANKAS  
Perilithon Books  
San Diego, California

*\*This book is available for purchase through the GIA Bookstore, 1660 Stewart Street, Santa Monica, CA 90404. Telephone (800) 421-7250, ext. 282; outside the U.S. (310) 829-2991, ext. 282. Fax: (310) 449-1161.*

# GEMOLOGICAL ABSTRACTS

C. W. FRYER, EDITOR

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## COLORED STONES AND ORGANIC MATERIALS

**Lapis.** Vol. 19, No. 11, 1994, 72 pp.

This jubilee (200th) issue—entirely in German—will satisfy all who crave to learn about the lore and adventure surrounding gems. W. Nesenzew describes the discovery of the Siberian diamond deposits in "Die russischen Diamanten," from his book *Im Reich der Steine* (*In the Realm of Stones*, Thun/Frankfurt am Main, 1986). An extract from F. Klein's book *Smaragde unter dem Urwald* (*Emeralds Under the Jungle*, Berlin, 1941) explores the risks of the Colombian emerald industry early in this century, the rediscovery of the Chivor mine, and the discovery of the 630-ct Patricia emerald (now in the collection of the American Museum of Natural History, New York). P. Voillot takes the reader on a "wild trip" to find the aquamarines of Hunza Valley ("Der wilde Weg zu den Aquamarinen"), just in time to see the opening of a rich pegmatite pocket. A. Weerth's "never-ending story" ("Lapis-Lazuli, die unendliche Geschichte") covers the entire history of lapis lazuli, surveys deposits worldwide, and describes the condition of Afghanistan's mines today. Also included are a comprehensive, up-to-date report on diamond mineralogy ("Steckbrief Diamant") and a description of an expedition that retraced part of Alexander von Humboldt's 1829 travels to Siberia. Many photos, both historical and contemporary, illustrate the issue. RT

**Microsurfaces, a photo essay dedicated to Bill Hicks.** J. I. Koivula, *Australian Gemmologist*, Vol. 18, No. 10, May 1994, pp. 323–325.

A world-renowned photographer of inclusions, John I. Koivula offers 12 color photomicrographs as tribute to the late Bill Hicks, former editor in chief of *Australian Gemmologist*. These photomicrographs show spectacular gemstone surface growth and etch features that often reflect internal-growth conditions. Mr. Koivula challenges the view of those who believe that only mirror-flat surfaces on crystal faces represent perfection. Masterful lighting emphasizes the geometric three-dimensional beauty of these surface features. The photos and accompanying article are a fitting tribute to a dedicated editor. JEC

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*This section is designed to provide as complete a record as practical of the recent literature on gems and gemology. Articles are selected for abstracting solely at the discretion of the section editor and his 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.*

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**Mineral industry surveys: Gemstones.** U.S. Department of the Interior, Bureau of Mines, *Annual Review 1994*, 16 pp.

Updated annually, this survey summarizes world gem production and consumption statistics. A two-page summary describes the nature of the study, with most of the information contained in the tables. These include: a four-page guide to the gemological properties and other information on selected gem materials, synthetic gemstone production methods, value of domestic gemstone production (by gemstone), diamond prices, colored stone prices, diamond exports and re-exports (i.e., of imported diamonds faceted in the United States) to various countries, U.S. imports for consumption of diamonds (by kind, weight, and country), U.S. imports for consumption of colored stones (by kind and country), U.S. imports of synthetic and imitation gemstones, summary table of U.S. imports (by variety), and world production statistics for diamonds (1990–1994). New this year is the inclusion of shell (as nuclei for cultured pearls) in the “Value of U.S. gemstone production” statistics.

Interesting facts gleaned from these tables include: 1994 U.S. (natural) gemstone production rose to \$22.2 million (M) from \$19.5M in 1993 (excluding \$33M in shell bead nuclei—about the same as 1993). The most important gems in 1994 were corundum (\$2.81M in 1994, up from \$0.313M in 1993), gem feldspar (\$2.62M in 1994, up from \$0.701M in 1993), turquoise (\$1.71M in 1994, down from \$3.04M in 1993), opal (\$1.12M in 1994, up from \$0.639M in 1993), and garnet (\$0.78M in 1994, up from \$0.233M in 1993). Production of some materials declined, notably tourmaline (\$9.53M in 1993, \$14,000 in 1994), peridot (\$1.52M in 1993, \$0.635M in 1994), and agate (\$1.41M in 1993, \$0.234M in 1994).

In 1994, the U.S. imported more rough diamonds from the United Kingdom (482,000 ct, for \$224.8M) than from any other country; more carats of unset faceted diamonds  $\leq 0.5$  ct each from India than from any other country (6.15 Mct, for \$1125.7M), and more carats of unset faceted diamonds over 0.5 ct each from Israel (1.35 Mct, for \$1570.3M). The U.S. imported the most carats of emeralds (2.31M) from India, but the greatest value of emeralds (\$89.1M) from Colombia. The U.S. imported the most corundum gems—rubies and sapphires—from Thailand. The U.S. imported about \$10M of synthetic stones each from Germany and Thailand, and \$48.1M of imitation gemstones from Austria (home of Swarovsky). Total imports in 1994 were \$5.73 billion in unset (rough and cut) diamonds, \$227M in emeralds, \$197M in corundum gems, nearly \$29M in pearls, \$4.63M in coral, \$143.7M in other natural gemstones, \$42.66M in synthetics, and \$60.9M in imitation gems.

A few warnings: The gemstone guide contains some terms that the GIA Gem Trade Laboratory (for instance) does not use, including *bixbite* for red beryl, *chrysolite* for yellow or green or brown chrysoberyl (sometimes peridot is also called chrysolite), *cairngorm* for smoky quartz, and *hiddenite* for yellow to green spodumene. Also, “Gemological Institute of America (GIA) color grades”

are NOT “rare white” for E color, or “traces of color” for G, H, or I (as was stated in the footnote to table 4 of this monograph). MLJ

**Notes from the Gem and Pearl Testing Laboratory Bahrain—4.** A. Bubshait and N. B. Sturman, *Journal of Gemmology*, Vol. 24, No. 6, 1995, pp. 401–404.

The concentric structure of natural pearls (testing pearls is 95% of the lab's work) seen with X-radiography varies considerably, from pronounced to barely visible. The latter occurs in pearls that probably formed over long periods of time with stable environmental conditions, while pearls that grew in less stable conditions variously produced more calcium carbonate or more conchiolin (the dark rings in X-radiographs).

The lab recently encountered an unusual green synthetic corundum that looked like an emerald and was initially purported to be glass; its identification was straightforward. A filled crackled Verneuil synthetic ruby exhibited white lines on an X-radiograph. The filling material contained numerous flattened bubbles and a surface luster distinctly different from that of the host synthetic ruby. The source of these treated synthetic rubies is still unknown. Five “emeralds” offered at a suspiciously low price proved to be synthetic on the basis of their low R.I.'s, low S.G.'s, and characteristic inclusions. On the basis of these properties, four appeared to be Biron or Russian hydrothermal synthetics and one a Seiko synthetic emerald. CMS

**Photogenic inclusions in moldavite.** A. de Goutière, *Journal of Gemmology*, Vol. 24, No. 6, 1995, pp. 415–419.

Tektites, including moldavite, are natural glasses that formed when meteorites struck the Earth. The samples illustrated here are from Czechoslovakia and Thailand, but tektites have been found in many localities around the world. Three types of inclusions in moldavite—lechatelierite (pure silica glass), gas bubbles, and “Schlieren” (elongated, “treacly” inclusions)—are superbly illustrated in these photomicrographs. When all three are found together, they are indicative (although not conclusive) of southern Bohemia or southern Moravia as the locality of origin. CMS

**Trace elements as colouring agents in jadeites.** H. Harder, *Journal of Gemmology*, Vol. 24, No. 7, 1995, pp. 508–511.

The broad range of colors in which jadeite occurs—including white, lilac, brown, orange, blue, black, and green—is caused by trace elements, the effects of which are summarized in this review article. Most common is iron. Its oxidation states are responsible for the range white-green-black. Chromium is responsible for the finest green colors, while nickel also may contribute to variations in green. Lilac, mauve, and lavender are due to varying proportions of manganese, cobalt, chromium, and iron. CMS

**1995 production keeps pace.** *National Jeweler*, August 1, 1995, p. 24.

Despite expected decreases because of the long 1994 winter, this year's production of freshwater cultured pearls from the Tennessee River was as strong as the year before, according to the American Pearl Company. A production increase is expected for 1996 because pearl-farming operations started early, in February 1995 (instead of late March), because of a mild winter.

The American Pearl Company has been culturing fancy-shaped pearls on the Kentucky Lake of the Tennessee River for about 20 years, during which demand for fancy shapes has steadily increased. Production of semi-round-to-round cultured freshwater pearls is limited but is expected to increase in the next three to four years. Natural pearl production, however, is down. Zebra mussels, brought from Europe on the hulls of ships, are suffocating those Tennessee River mussels that produce pearls and are used for nuclei production. Although the American Pearl Company no longer produces shell nuclei, "Not even the Japanese have been able to develop an alternative," according to American Pearl Company president Gina Latendresse. The company is working with government agencies to reproduce endangered species on the Tennessee River. *MD*

## DIAMONDS

**Argyle diamond output flat.** *Diamond Industry Week*, July 31, 1995, p. 6.

The Argyle (AK1) open-pit diamond mine produced 0.5% fewer diamonds in the first half of 1995 than in the first half of 1994, despite processing more ore. (The figures are 19.044 million carats [Mct] from 6.676 million metric tons of ore for the first six months of 1995, versus 19.144 Mct from 6.017 million metric tons of ore for the same period in 1994.) Diamonds are recovered from two types of ore, hard rock and alluvium, with 1995 yields of 4.15 ct per metric ton of hard ore recovered (down from 4.77 ct per metric ton in 1994), and 0.575 ct per metric ton of alluvial ore recovered (about the same as 1994).

The figures are "in line," according to the article, with expectations that AK1 surface-mine reserves will be exhausted by 2004. Mining may continue underground, however, and Argyle venture partners, CRA Ltd. and Ashton Mining Ltd., are expected to announce their plans in this regard by late 1995. *MLJ*

**Diamonds.** W. D. Hausel, *International California Mining Journal*, Vol. 64, No. 12, August 1995, pp. 28-31.

This article reviews a few properties of natural diamonds, especially those from diamond pipes on the Colorado-Wyoming border. Natural diamond crystals are typically octahedral, dodecahedral, or hexoctahedral in habit. Some inclusions in diamond can be used to date the diamond; "host rocks" are substantially younger than the diamonds themselves. Mineral inclusions in diamonds are of two petrologic types—peridotitic (P-type) or

eclogitic (E-type). P-types contain inclusions of olivine, orthopyroxene, clinopyroxene, pyrope garnet, chromite, diamond, graphite, and/or sulfides; E-type diamonds may contain sodium-rich clinopyroxene, almandite-pyrope garnet, rutile, kyanite, corundum, coesite, graphite, and/or diamond.

Over 100 kimberlite pipes have been found along the Colorado-Wyoming border by searching for eclogitic and peridotitic garnets. Eclogitic pyropes that occur with diamonds are classified as "Group I" garnets. They typically contain high percentages of sodium and calcium but are low in chromium. The Sloan 1 kimberlite in Colorado is an eclogitic kimberlite pipe. *MLJ*

**Diamond fever dwindling in Australia.** J. Rice, *Mazal U'Bracha*, Vol. 12, No. 67, May 1995, pp. 82-83.

Australian diamond exploration efforts are suffering economic setbacks as once-optimistic investors pull out of start-up mining and exploration companies. The firms were darlings of the international stock market a few years ago, when inexperienced investors poured in cash, hoping for lucrative discoveries. In 1995, even as the first promising exploration reports came out, fears of oversupply and unrestricted Russian production fueled the exodus from Australian diamond-mining stocks. The market also realized that small companies are too undercapitalized to engage in serious diamond exploration.

Analyst David Russell, of Saw James Capel Ltd. (no city or country given), believes that investor fears of overproduction are largely groundless and that problems of oversupply are temporary. *AC*

**Diamond interest in Argentina.** *Mining Journal, London*, July 21, 1995, p. 44.

One of the earliest recognized pieces of evidence in support of plate tectonics (known as "continental drift" in early years of the theory's formation) was how the Atlantic Ocean coastlines of South America and Africa seemed to fit together like gigantic puzzle pieces. Part of those once interlocked pieces, now separated by the Atlantic, are South Africa and Argentina/Uruguay. Perhaps using this reasoning, an Australian company (Challenger Mining International Ltd.) and two Canadian companies (La Plata Gold and Rome Resources Corp.) have separately requested permission to explore for gold and diamonds in 50,000-hectare regions of Argentina's Buenos Aires Province. This province is thought to be geologically similar to mining regions of South Africa, according to provincial officials. *MLJ*

**Diamond sales for DFR.** *Mining Journal, London*, July 21, 1995, p. 46.

Diamond Fields Resources (DFR) has sold at tender in Antwerp 6,636 carats of diamonds for C\$1.1 million. These diamonds come from DFR's holdings in South Africa and Namibia. In South Africa, the Loxton Dal mine has recently been upgraded, with a new separation plant to improve diamond recovery. In Namibia, DFR

marine geologists have confirmed a resource of over one million carats (with an average price of US\$165 per carat), in certain parts of the concession at water depths between 30 and 80 m. *MLJ*

**Exploration: BHP-DiaMet Update.** *Mining Journal*, London, February 24, 1995, p. 144.

One of the still-promising Canadian diamond areas is the Northwest Territories Lac de Gras region. Diamond valuations have been completed for three pipes controlled by BHP-DiaMet. The Fox pipe was given a value of US\$126 per carat (based on 2,060 carats at an ore grade of 0.27 carats per ton); the Panda pipe was valued at \$132 per carat (based on 2,778 carats at a grade of 0.93 carats per ton); and the Misery pipe had a value of \$44 per carat (based on 438 carats at a grade of 3.3 carats per ton). Draft environmental impact statement guidelines have been published, and BHP-DiaMet is preparing a response. *MLJ*

**Exploration in permafrost.** J. Chadwick, *Mining Magazine*, Vol. 325, No. 8336, February 1995, pp. 103, 105.

Although this article is about a lead-zinc mine (the Polaris mine, on Little Cornwallis Island, Northwest Territories) in the Canadian Arctic, one suspects that proposed diamond-mining ventures in the region face similar problems. Miners must cope with wind-chill factors pushing temperatures to  $-100^{\circ}\text{C}$  and very little precipitation (about the same as the Sahara Desert). Temperatures in the mine must be kept below freezing because the mine is completely contained in permafrost: Walls would "melt" if allowed to warm. Other problems include polar bears; the corrosive and costly drilling fluid (CaCl-bearing salt water); access to supplies (Europe is closer than southern Canada); and surveying problems, in a place where magnetic instrumentation does not work. In deeper permafrost, gas emergencies are also possible. *MLJ*

**In search of Russia's motherlode.** S. Miller, *Mazal U'Bracha*, Vol. 9, No. 64, January 1995, pp. 68-69.

Archangel Diamond Corporation (ADC) has accomplished what other mining companies only dream of: It obtained a license to explore the virtually untapped former Soviet Union's emerging Archangel diamond region, believed to be the second richest in the world, in a joint venture with the Russian Archangel State Geological Enterprise. ADC's 25-year license permits the exploration of major properties in northwest Russia near the border with Finland. Five kimberlite pipes at one site (Lomonosova) are expected to yield 250 million carats, with a projected worth of about US\$37 billion. Another site (Verkhotina) has eight pipes, and as many as 10 more may be in the area. All diamonds recovered so far have been of "good quality." Geologists have drilled 24 holes in a third property (Windy Ridge) and recovered diamonds from all.

ADC Chief Executive Officer Andrew Malim downplayed reports that diamond mining in the area is prohibitively costly and difficult, citing comparatively easy site access by road, air, and—eventually—a railroad that is

now under construction. Because slurry mining is used, kimberlite ore can be processed for as little as \$7 a ton, compared to \$15 a ton worldwide. *AC*

**Limpopo diamond search.** *Mining Journal*, London, August 11, 1995, p. 96.

South Africa has granted a prospecting permit to Duo Corp., allowing them to search for alluvial diamonds in Limpopo River gravels, in the South Africa/Zimbabwe border region. However, this 9,000-hectare area near Kruger National Park contains one of the last pristine forests of baobab trees, as well as sycamore figs, fever trees, and a rich archeological site. Consequently, environmental groups oppose strip mining. *MLJ*

**Majhgawan diamondiferous pipe, Madhya Pradesh, India—A review.** A. K. Chatterjee and K. S. Rao, *Journal Geological Society of India*, Vol. 45, No. 2, 1995, pp. 175-189.

The Majhgawan pipe, which is 15 km from the city of Panna in central India, was discovered in 1827, about 40 years before the South African pipes. Thus, it is the first diamond-bearing pipe (primary deposit) ever discovered. However, like other diamond deposits in India, it was considered alluvial (secondary) until 1930, when its primary nature was recognized and it was reclassified as a kimberlite.

Studies since 1988 have reclassified the pipe as a lamproite. This paper reviews the history of the Majhgawan pipe, primarily from a geologic perspective, with the objective of determining parameters useful in finding other diamond-bearing pipes in the region.

After detailed evaluation of the mineralogy, petrology, and chemistry of the rocks that comprise the pipe, the authors conclude that it has characteristics intermediate between those of kimberlite and lamproite. In addition to geophysical surveys, heavy-mineral indicators could be used to find this type of pipe, including high-chromium garnet (G-9 type), high-magnesia chromite and spinel, and the absence of ilmenite.

This pipe has been India's main diamond producer in recent years. Current annual production averages about 18,000 carats; at this rate, reserves are sufficient to the middle of the next century. The ore grade is about 0.1 carat per metric ton, and diamonds average 0.45 ct in size. Gem diamonds (42% of production) are typically of high quality and presently worth about US\$200 per carat. *AAL*

**The origin, formation and emplacement of diamonds.** M. Strather, *Australian Gemmologist*, Vol. 18, No. 11, 1994, pp. 342-345.

Intended for a nontechnical audience, this short review article addresses where diamonds come from, how they form, and how they arrive at the surface of the Earth. For the most part, it is a good summary of current knowledge on these subjects; however, some statements are not quite correct.

There is a pressure-temperature regime—called the “Diamond Stability Zone”—in the Earth’s upper mantle in which diamonds nucleate and form. The carbon in diamonds comes from two sources: homogenized “primordial” carbon that has been present since Earth’s formation, and “recycled” carbon (from limestones, etc.) that has been subducted back into the Earth. As indicated by inclusions, there are two diamond types: (1) those formed in ultramafic rocks (peridotites, i.e., igneous rocks of extremely silica-depleted composition, related to oceanic basalts); and (2) those formed in high-pressure metamorphic rocks (eclogites). Peridotitic (ultramafic) diamonds contain primordial carbon; eclogitic diamonds contain recycled carbon.

Diamonds are brought to the Earth’s surface by columns (“plumes”) of magma rising from depths of about 130–180 km. There are two types of diamond-bearing igneous bodies: (1) kimberlites—carbon-dioxide-rich magmas related to carbonatites, which form “champagne flute”-shaped bodies and may contain both peridotitic and eclogitic diamonds (as in, e.g., South Africa); and (2) lamproites—alkali-rich magmas, which form “margarita glass”-shaped bodies and contain primarily eclogitic diamonds (as in, e.g., Australia). Diamonds are generally older than their transporting magmas. Kimberlites rise suddenly: The most dramatic estimates of their emplacement ascent times have them climbing 135 km in four to 15 hours!

As for “less-than-correct” statements: The Earth is most probably about 4.5 billion years old (F. Press and R. Siever, *Earth*, 2nd ed., W. H. Freeman and Co., San Francisco, CA, 1978) not 4.70 billion, and the oldest “basement” rocks known are 3.9-billion-year-old metamorphic rocks in Greenland. It is somewhat misleading to say that “all the present continents (except Europe) have more than one craton.” Cratons under both North America and Europe are composites, according to the 1992 Levinson et al. *Gems & Gemology* article listed as one of Ms. Strather’s references. If a craton must be 1.5 billion years old before a kimberlite forms, this does not mean that most kimberlites are older than 2.5 billion years. In addition, magma pipes, as plumes, probably punch their way up through weaker regions in the crust and do not require pre-existing fractures extending down through the crust. The most serious oversight however, is the failure to reference statements as they occur in the text.

The field of high-pressure petrology is large, lively, and constantly evolving. New chapters in the life-stories of diamonds are likely to surface at any geologic conference. Despite the few inaccuracies, Ms. Strather is to be lauded for attempting to distill a large amount of raw data into such a compact article. MLJ

**Russian sales bring down De Beers earnings.** *International California Mining Journal*, Vol. 64, No. 10, June 1995, p. 63.

De Beers’s 1994 earnings were 7% lower than 1993 (\$555 million versus \$595 million). De Beers Chairman Julian Ogilvie Thompson said that Russian sales of polished and rough diamonds reduced sales by the Central Selling

Organisation (CSO) by 3%. De Beers and the CSO were trying to persuade Russian authorities to adhere to quotas.

MLJ

**Russian update.** *Diamond Industry Week*, June 12, 1995, pp. 5–6.

Russia produced 19.72 million carats of diamonds in 1994, and sold 26.36 million carats of rough and cut stones, worth US\$2.28 billion. (The discrepancy in these numbers is not as serious as it first appears; Russia exports diamonds to Israel and Belgium for processing, which are then imported back into Russia.) The Ydachnyi [Udachnaya] mine in Yakutia, operated by Almazy Rossii-Sakha (ARS), accounted for 18 million carats of 1994 Russian production; ARS was responsible for 98% of all diamonds produced in Russia.

As for sales, Russia wants its current quota of 26% of all CSO sales upped to 33%. However, De Beers claims that Russia already exported diamonds worth US\$700–800 million outside of the CSO agreement. Russia seeks to improve its market position by increasing domestic diamond polishing, but this also requires negotiations with the CSO on pricing policies. MLJ

**Sibeka anniversary.** *Mining Journal*, London, June 16, 1995, p. 450.

For 50 years, the world’s top diamond producer (by volume) was Brussels-based Sibeka, which operated the mines of Mbujimaya and Lulua in Zaire. This short report profiles Sibeka, which celebrated its 75th anniversary in 1994. Currently, the company is active in four diamond-industry sectors: mining in Zaire (partial ownership of the Zaire mining company Miba); diamond research in the United States (Exmin) and China (partial ownership of Hunan Sibeka); synthetic diamond production (partial ownership of Megapode Holdings); and the manufacture of super-abrasive tools (Diamant Boart).

Miba’s diamond production (in Zaire) rose from 4.53 million carats (Mct) in 1993 to 4.88 Mct in 1994. Ten years ago, however, diamond exports from Zaire were around 20 Mct annually. Ore grades for alluvial deposits are falling, to 3.16 ct/m<sup>3</sup>; however, kimberlite ore grades have risen to 2.49 ct/m<sup>3</sup>. Supply restrictions and “clandestine operators” continue to cause problems.

The consumption of industrial diamonds has increased 13% per year for the last 20 years, and the world supply is around 700 Mct per year. Of this, only 60 Mct annually comes from “industrial grade” natural diamonds, so more than 90% of industrial diamonds are synthetic. Consequently, Megapode reached record sales volumes last year, but prices for industrial diamonds have dropped due to excess supply. MLJ

**‘Stealth’ bucket excavates diamonds.** *Mining Magazine*, Vol. 173, No. 1, July 1995, p. 6.

Diamond mining is rough on machinery. Extensive research into “aggressive” wear conditions at the Orapa and Letlhakane open-pit diamond mines in Botswana was used to lengthen the lifespan of wheel-loader buckets

fivefold. Computer-assisted strain gauges and design led to modifications that include single-piece casting and relocated welds. *MLJ*

**Striker finds kimberlite evidence.** *Mining Journal*, London, July 14, 1995, p. 26.

Striker Resources NL has found evidence of more kimberlites at its Beta Creek project in the far north of Western Australia. Also, Striker is purchasing the adjacent Forrest River tenements, which contain five diamond-bearing kimberlites. *MLJ*

**United Reef diamond recovery proceeding on schedule.** *Diamond Industry Week*, August 7, 1995, pp. 5–6.

On June 9, 1995, United Reef Ltd. opened a new diamond recovery plant on its Bamingui River diamond property in the Central African Republic. In June and July, 1,202 diamonds (518.31 carats) were recovered from the river gravels, including three "gem quality" stones of 6.24, 7.32, and 9.70 ct. The first sale of diamonds from the property is scheduled for September. *MLJ*

## GEM LOCALITIES

**Angola's minerals. Miner attraction.** *The Economist*, July 1, 1995, pp. 56, 58.

After nearly three decades of civil war, Angola now appears to have a fragile peace. This presents great opportunities for mineral exploration in general, and for diamond production in particular. At present, artisanal mining (in this case, illegal digging and smuggling) of good-quality alluvial diamonds is again prevalent; about US\$20 million worth are now "exported" each week (an annual rate of approximately \$1 billion).

New laws favorable to foreign investment (the state's monopoly on mineral rights has been abolished) are attracting the attention of diamond companies from several countries. These companies are more interested in the potential of the 600-odd known kimberlite pipes, as production from these is easier to protect and control than that from the more spread-out alluvial deposits.

A Brazilian-Russian-Angolan consortium is particularly interested in the Catoca pipe in Lunda Norte Province. When mining begins there (possibly by the end of the century), it is expected to produce 940,000 carats annually for the first nine years and up to 5 million carats per year for the next 30 years after that. Angola is also rich in gold, copper, platinum, phosphates, quartz, manganese, oil, marble, and industrial minerals. *AAL*

**Chinese ruby and sapphire—a brief history.** O. Balibert and R. W. Hughes, *Journal of Gemmology*, Vol. 24, No. 7, 1995, pp. 467–473.

Information on the history of gem mining in China is virtually nonexistent, and the few known sources remain untranslated from the original Chinese. As a result, this article focuses primarily on the development of corundum mining since the late 1970s. The most important localities are Penglai (Hainan Island), and deposits in

Fujian, Shandong, and Yunnan Provinces. Other, less well-documented localities are also cited. Material from Shandong Province is routinely heat treated, but experiments on Penglai corundum have met with mixed success. Only Yunnan, to date, is producing significant quantities of ruby. *CMS*

**Emerald mine to become nature preserve.** *International California Mining Journal*, Vol. 64, No. 11, July 1995, p. 30.

Most of the Rist and Ellis Emerald Mines property in Hiddenite, North Carolina, has been purchased by a former Hiddenite resident, who plans to turn the 190 acres into a state park, with a museum and a nature preserve. Eileen Sharpe, 87, bought 19 parcels at public auction for \$648,850. Ms. Sharpe spent her childhood days hunting for treasure. And she found it—quartz, emeralds, and aquamarine. She wanted to make sure that future generations of children had the same chance. North Carolina would have lost one of its most unique natural wonders if the land had been broken up, she said. Gemstones were first discovered in Hiddenite in 1875, and for many years the Rist family operated the property as a public mining site. *MLJ*

**Ontario—Amethyst County. Die Amethystminen an der Thunder Bay, Ontario, Kanada (The Amethyst Mines of Thunder Bay, Ontario, Canada).** J. Zenz, *Lapis*, Vol. 20, No. 2, 1995, pp. 35–40, 58.

This article (in German) gives comprehensive information on amethyst deposits in the Thunder Bay, Ontario, region: Their genesis and occurrence in veins of different magmatic and sedimentary formations and basaltic lavas; their discovery and exploitation; and a description of five major amethyst mines. Some of the amethyst is used in jewelry, but the mines are mainly of interest to tourists and, of course, mineral collectors. Numerous photos show the mines, the range of amethyst found there, and other quartz varieties also recovered. *RT*

**The Roraima.** E. B. Heylman, *International California Mining Journal*, Vol. 64, No. 5, January 1995, pp. 31–33.

The Roraima Group of Precambrian rocks is at least 1.8 billion years old and forms highlands throughout Venezuela, Guyana, Surinam, and northern Brazil. Rock types include conglomerates, sandstones (conglomeritic and cross-bedded), quartzite, chert, jasper, and red shales; the most important alluvial minerals found in stream beds from the Roraima are gold and diamonds. Roraima rocks form some of the world's highest cliffs (up to 2,600 feet—800 m—tall) and distinctive flat-topped mountains called "tepuys," which have their own isolated ecosystems. Similar rocks in Sierra Leone and Liberia, in western Africa, are probably the same rock formations, but they split from the Roraima when the Atlantic Ocean opened up.

Diamonds are found in paleochannels far downstream from the Roraima rocks. Most are colorless or yellow, but some are brown or black. The author labels as

"probably a gross exaggeration" tales that prospectors climbing isolated outcrops of the Roraima Group have scooped up diamonds by the handful from some ledges. Even so, diamonds appear to be found throughout the group, including atop 9,219-foot (2,810-m) Mt. Roraima.

The Roraima Group is probably the source for alluvial diamonds in the Rio Caroni and other rivers in Venezuela. The Amazonas basin in southern Venezuela, and adjoining regions in Brazil and Colombia, are good prospects for further diamond exploration. The jungle environment makes the three-to-four-month dry season the best time to explore. *MLJ*

**Trove of Maya jade recovered in Belize shaft.** *National Geographic*, Vol. 18, No. 19, May 1995, p. 19.

In the summer of 1994, archaeologist Pamela Weiss discovered 900 jade artifacts in a shaft in the ruins of a Maya city near the village of Blue Creek in Belize. It is believed that the jade pieces—beads, earspools, and pendants, some of which bear the likenesses of gods associated with Maya kingship—are related to a royal funeral that took place about 1,500 years ago. Many of the pieces were ritually "killed" before burial. This trove is second in size only to the 1984 discovery of Maya jade at Calakmul, Mexico. *MLJ*

## INSTRUMENTS AND TECHNIQUES

**The inclinometer for refractometers: The latest developments.** A. Molin  i Sala, *Journal of Gemmology*, Vol. 24, No. 6, 1995, pp. 405–409.

The improved version of this aid to refractometry is described in detail and its use discussed. (A inclinometer enables a gemologist to better manipulate a gemstone on the refractometer's hemicylinder, so that more accurate data can be obtained.) For complete information on the use and application of this instrument, interested readers should also look up the 1985 *Journal of Gemmology* article by the same author. *CMS*

**The infrared microscope and rapid identification of gemstones.** G. Yan, L. Jingszhi, and Z. Beili, *Journal of Gemmology*, Vol. 24, No. 6, 1995, pp. 411–414.

The difficulties that are sometimes encountered in obtaining good infrared spectra from faceted gemstones usually can be overcome by the use of an infrared microscope like the one described in this article. First use the microscope's visible-light optics to focus on the sample, and then use its infrared system to collect the data. Samples of cat's-eye diopside, kornerupine, and sillimanite illustrate the method's effectiveness. Infrared spectra (illustrated) in the range of 500 to 1500  $\text{cm}^{-1}$  clearly separate these gem materials, which can be difficult to distinguish by traditional gemological methods. *CMS*

**More on the classical chemical testing of minerals.** D. M. Morong, *Mineral News*, Vol. 11, No. 3, March 1995, pp. 8–9.

Many field collectors and "hands-on" gemologists would like to identify unknown mineral samples by themselves.

Before the sophisticated modern era of analytical chemistry, with its microprobes and mass spectrometers, chemists had successfully identified mineral species with little more than a workbench, some glassware, a few chemicals, and a contact goniometer. Modern mineralogical do-it-yourselfers can duplicate many of these early determinative tests, but they probably prefer to do so under less hazardous conditions than their 19th-century predecessors. This article describes some equipment required to build a home analytical chemistry laboratory, and recommends some simple precautions to safely work there. One main concern of the author is that tests should yield useful results; to that end, it is suggested that known samples be tested at the same time as unknown ones, and that the work environment be kept scrupulously clean.

Chemistry is, in some ways, an innately hazardous activity, and many necessary chemicals—acids, ammonia, even minerals containing arsenic, sulfur, or mercury—cannot be made harmless. Nevertheless, home chemistry experimentation builds self-reliance, and the detective work involved can be very enjoyable. This article is a follow-up to a previous article in *Mineral News* by the same author. *MLJ*

**The pulse cathodoluminescence of corundums** (in Russian with English abstract). V. I. Solomonov, S. G. Mikhailov, V. V. Osipov, V. N. Avdonin, M. F. Vasilevskaya, and V. I. Yakshin, *Proceedings of the Russian Mineralogical Society*, Vol. 123, No. 6, 1994, pp. 39–51.

This proposed pulse cathodoluminescence (PCL) method uses nanosecond high-current, pulse-repeated electron beams as an alternative to the usual continuous low-current electron streams. Measurements are taken in the 340–800 nm range, and do not involve destruction or preheating of the sample. Spectra of natural and synthetic corundums (except Vietnamese sapphires) have a strong red band with dominant chromium lines at 694.3 and 692.9 nm; the maximum intensity was shown by synthetic rubies and the minimum intensity, by gray-blue natural corundum. There are two new broad bands seen in the PCL spectrum of corundums: in the blue (482 nm) and green (555 nm). They dominate the PCL spectra of Vietnamese sapphires. Some PCL spectra of spinels are also presented. *RAH*

## JEWELRY HISTORY

**Around the mall and beyond.** M. Kernan, *Smithsonian*, Vol. 25, No. 11, February 1995, pp. 16–19.

Over the years, historians with the Smithsonian Archives have interviewed several long-time curators of the museum's various departments. This article summarizes part of one such interview, a fascinating oral history given by the late Edward P. Henderson, a former curator in the National Museum of Natural History's Department of Mineral Sciences. In the interview, Mr. Henderson reminisced about the circuitous journey of the Hope Diamond after the 1947 death of owner Evalyn Walsh McLean until

it was donated to the Smithsonian by famed New York jeweler Harry Winston (who *mailed* it there) several years later. Mr. Henderson also relates his work with meteorites (having one cut in half at a local Navy yard); the task of cleaning and appraising gems recovered from the rubble of post-war Japan; and some of the quirky personalities he dealt with during his museum tenure, which started in 1929 and extended until 1988 (the last 23 years as an honorary research associate, following his formal retirement in 1965). AC

**The Cheapside Hoard confusion.** J. G. Gosling, *Journal of Gemmology*, Vol. 24, No. 6, 1995, pp. 395–400.

In 1912, a “treasure” of 16th-century jewelry was unearthed near the corner of Friday Street and Cheapside in London. Perhaps more fascinating than the jewelry itself are the many stories about how the treasure was found. Common to all versions is that workmen unearthed the jewelry, and a London “antiquary”—George Lawrence—purchased it from them. Items from the Cheapside Hoard are displayed in various British museums (mostly at the Museum of London), but the author makes a plea for the entire collection to be reunited and a new catalog published. Four items are pictured and described, including a watch set in a Colombian emerald crystal and pendants of amethyst and emerald fashioned to look like bunches of grapes. CMS

**Materials used in manufacturing cylinder seals.** D. Liberty, *Celator*, Vol. 9, No. 4, April 1995, p. 22.

Ancient Mesopotamia, like modern China, used seals to stamp signatures. However, Mesopotamian seals were cylinder-shaped, and were rolled across unfired clay “documents” to sign them. Ideally, hard, decorative stones—such as lapis lazuli—were used for these cylinder seals. However, since *all* stones were rare in the Tigris-Euphrates Valley, less valuable materials (and imitations) were also used. Materials included: limestone and rock crystal (4th millennium B.C.); lapis, fire-hardened steatite (soapstone), bitumen covered with gold foil, and glass and “glassy paste” imitations of lapis (3rd millennium B.C.); lower-quality lapis, serpentine, and chlorite (Akkadian period, late 3rd millennium B.C.); hematite and magnetite rock (2nd millennium B.C.); and varieties of quartz and chalcedony as well as faience (2nd millennium B.C. and more recently). Cylinder-seal production in the Middle East continued until the end of the Achaemenid period (330 B.C.).

This short review ends by recommending D. Collon’s book, *First Impressions* (University of Chicago Press, 1988), for more information about cylinder seals. MLJ

## JEWELRY RETAILING

**Rare Gems Fetch Record Highs in Geneva.** *National Jeweler*, July 16, 1995, p. 26.

The Antiquoriums’ May gem and jewelry auction in Geneva, Switzerland, took in over US\$1 million. Buyers focused on colored stones and period pieces, including an

Art Deco tutti-frutti necklace set with rubies, sapphires, pearls, and a carved 150-ct emerald. It sold for \$54,000. Rare and Exotic Gemstones, a new auction section, debuted with four of six lots selling. A yellow-gold, platinum, and pearl chain—from which was suspended a 12.50-ct conch pearl—went for more than \$27,000. The “world’s largest red emerald” [red beryl], which weighed 8.03 ct and had been estimated at \$150,000 to \$160,000, did not sell. MD

**Sales down at Myanma emporium.** *National Jeweler*, Vol. 39, No. 10, May 16, 1995, p. 32.

According to auction organizer Myanma Gems Enterprise, more than US\$7 million was brought in from the sale of 380 lots at the 32nd Myanma Gems, Jade & Pearl Emporium held in Yangon, Myanmar, in March. Sales were down 15% from last year’s \$8.5 million. Most lots contained jadeite; a few contained low-quality South Sea pearls. Jadeite sales at the auction totaled almost \$5.4 million, up 10.5% over the \$4.9 million sold in 1994. However, the number of lots sold decreased by 17%, from 280 in 1994 to 232 this year. A total of 277 companies from 15 countries attended the sale. MD

## PRECIOUS METALS

**‘Fingerprinting’ gold samples aids theft detection.** *Mining Magazine*, Vol. 172, No. 2, February 1995, pp. 122–123.

A new technique has been developed for identifying gold—and other precious metals—in bullion, artifacts, or jewelry samples. Called LA-ICP-MS, for Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry, the technique measures the element and isotope composition and the relative ratio of trace elements in material ablated (i.e., removed or vaporized) by laser from a sample. Each source (mining district, mine, or historic period) may potentially have a unique “fingerprint,” and a library of standard sample “fingerprints” from various sources is being produced. Unfortunately, this short report does not say how much sample is ablated to produce the “fingerprint”—that is, whether the testing could be considered destructive. MLJ

## SYNTHETICS AND SIMULANTS

**Russian hydrothermal synthetic emeralds: Characterization of the inclusions.** F. Sosso and B. Piacenza, *Journal of Gemmology*, Vol. 24, No. 7, 1995, pp. 501–507.

The seven faceted synthetic emeralds and one “rough” sample examined for this article came from a single 39-gram specimen, which originally had a colorless beryl seed plate in its center, as well as a portion of the metal wire on which the seed had been suspended during growth. SEM-EDS qualitative chemical analyses were obtained on the inclusions. The synthetic emerald was found to have traces of the same elements—Fe, Cr, and Ni—as composed this wire. Inclusions with a metallic

luster consisted of Fe, Cr, and Ti oxides; this is the first documented occurrence of Ti in inclusions in hydrothermal synthetic emerald. Various other microscopic features are also described and illustrated in this informative article, which sheds further light on the complex area of emerald identification. CMS

## TREATMENTS

**Identification of bleached wax- and polymer-impregnated jadeite by X-ray photoelectron spectroscopy.** T. L. Tan, T. S. Tay, F. C. Loh, K. L. Tan, and S. M. Tang, *Journal of Gemmology*, Vol. 24, No. 7, 1995, pp. 475-483.

X-ray photoelectron spectroscopy (XPS) has been found effective in nondestructively identifying this problematic jadeite treatment. The results of XPS tests on 16 samples of treated and untreated jadeite agreed with testing by traditional gemological and infrared spectroscopic methods. The authors describe the technical details of this technique (new to gemology) in great depth. Sample XPS spectra clearly illustrate the differences among natural, wax-polished, bleached wax-impregnated, and bleached polymer-impregnated jadeite. The authors warn that this technique may not detect other impregnation materials, so a negative test does not necessarily mean that a particular sample is untreated. CMS

## MISCELLANEOUS

**Artisanal mining comes of age.** *Mining Journal*, London, June 16, 1995, pp. 446-447.

Artisanal mining is mining without mechanical assistance. These small-scale operations, which "have a history as long as mankind," have undergone a resurgence over the past 25 years. For instance, in sub-Saharan Africa, it is estimated that 1.5 million workers are involved in artisanal mining of gold alone, annually producing over 40 tons.

Artisanal mining is problematic because it is generally "manifestly illegal, environmentally unsound, and socially disruptive." As a result, beginning in the 1970s, several conferences have attempted to define and regulate "small-scale mining." A breakthrough occurred at a 1993 conference in Harare, sponsored by the United Nations. A round-table discussion in May 1995, hosted by the World Bank, followed up on the Harare precepts.

Some attendees at these meetings have recommended shifting regulatory focus from enforcing prohibition of artisanal mining to transforming it into formal, regulated mining: They advocate making artisanal mining mainstream rather than marginal. In fact, it was suggested that anyone who makes a mineral find should be able to register it in his or her own name as a property right (without the need for capitalization or working of the claim). MLJ

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