

# GEMS & GEMOLOGY

VOLUME XXVIII

SPRING 1992



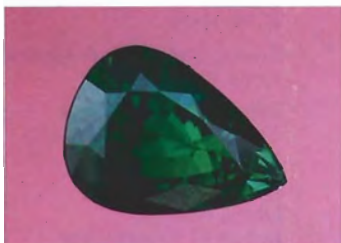
THE QUARTERLY JOURNAL OF THE GEMOLOGICAL INSTITUTE OF AMERICA

# GEMS & GEMOLOGY

SPRING 1992

VOLUME 28 NO. 1

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



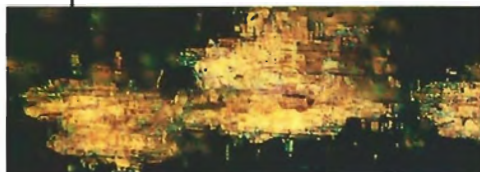
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*ABOUT THE COVER: The large deposit of distinctive orange to red "fire" opals at Querétaro, Mexico, is believed to be unique. To help solve the mystery of this unusual occurrence, modern techniques were used by authors R. J. Spencer, A. A. Levinson, and J. I. Koivula to determine the composition of the original liquid from which the gems formed. The stones shown here illustrate the variety of fine opals recovered from Querétaro. Fabricated in the early 20th century and signed by Theodore B. Starr, the Celtic buckle is composed of yellow gold, emeralds, sapphires, and diamonds, in addition to opal. The buckle is courtesy of R. Esmerian, Inc., New York. The 80.12-ct rough opal and the 16.27-ct cabochon are courtesy of Pala International, Fallbrook, 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 Winter 1991 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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# THE GEMS & GEMOLOGY MOST VALUABLE ARTICLE AWARD

By Alice S. Keller

**T**hank you, readers. Hundreds of you took the time to send us your votes for the "Most Valuable Article" published in 1991. The winning articles for 1991 represent a broader spectrum of topics than in most previous years. Again, though, you indicated that the identification of enhancements is your key concern, with the award of first place to the comprehensive "Fracture Filling of Emeralds: Opticon and Traditional Oils," by Robert C. Kammerling, John I. Koivula, Robert E. Kane, Patricia Maddison, James E. Shigley, and Emmanuel Fritsch. However, second place goes to an article that explained important new theories on diamond formation: "Age, Origin, and Emplacement of Diamonds: Scientific Advances in the Last Decade," by Melissa B. Kirkley, John J. Gurney, and Alfred A. Levinson. Winner of the third-place award is an article that represents the joint research efforts of a truly international team from the U.S., Switzerland, and Vietnam: "Rubies and Fancy Sapphires from Vietnam," by Robert E. Kane, Shane F. McClure, Robert C. Kammerling, Nguyen Dang Khoa, Carlo Mora, Saverio Repetto, Nguyen Duc Khai, and John I. Koivula.

The authors of these three articles will share cash prizes of \$1,000, \$500, and \$300, respectively. Photographs and brief biographies of the winning authors appear below. Congratulations also to Edward Schiller of Calgary, Alberta, Canada, whose ballot was randomly chosen to win the three-year subscription to *Gems & Gemology*.

We especially appreciated receiving comments—and suggestions—from so many of you on your ballots. In fact, in response to some of these comments, we are initiating a "Letters" section in this issue of *Gems & Gemology* (see pp. 72 and 73). Unlike the earlier "Editorial Forum" section, which appeared sporadically, we hope to make this a regular feature for your comments and suggestions on items published in *Gems & Gemology* and other important topics. This is *your* journal and we want it to work for *you*. Don't forget to write . . .

## F I R S T P L A C E

ROBERT C. KAMMERLING · JOHN I. KOIVULA ·  
ROBERT E. KANE · PATRICIA MADDISON ·  
JAMES E. SHIGLEY · EMMANUEL FRITSCH

**Robert C. Kammerling** is director of identification and research at the GIA Gem Trade Laboratory, Inc. in Santa Monica. He also coedits—with John I. Koivula and Emmanuel Fritsch—the Gem News section of *Gems & Gemology*, and he coauthored—with Dr. Cornelius S. Hurlbut—the book *Gemology*. Mr. Kammerling has a B.A. from the University of Illinois. **John I. Koivula**, GIA's chief gemologist, is world renowned for his expertise in inclusions and photomicrography. He is coauthor—with Dr. Edward J. Gübelin—of the *Photoatlas of Inclusions in Gemstones*. Mr. Koivula also holds bachelor's degrees in chemistry and mineralogy from Eastern Washington State University. **Robert E. Kane**, also a



James E. Shigley, Patricia Maddison, John I. Koivula, Robert C. Kammerling, Emmanuel Fritsch, Robert E. Kane

prolific author, is manager of identification at the GIA Gem Trade Laboratory, Santa Monica. With 14 years of laboratory experience, Mr. Kane's research specialties include colored diamonds, rare collector gems, and the separation of natural, synthetic, and treated gems. **Patricia Maddison** is a senior staff gemologist in the identification section of the GIA Gem Trade Laboratory, Santa Monica. Originally from Vancouver, Canada, Ms. Maddison has 14 years of experience in the jewelry industry (10 with GIA). **James E. Shigley**, who received his doctorate in geolo-

gy from Stanford University, is director of research at GIA. He has written several articles on natural, treated, and synthetic gem materials, and is currently directing research on gem identification. Manager of the GIA Research Department, **Emmanuel Fritsch** has written extensively on the application of spectroscopy to gemology, the origin of color in gem materials, and treated and synthetic gems. A native of France, he has an advanced degree in geological engineering from the Geology School in Nancy, France, and his Ph.D. from the Sorbonne in Paris.

## S E C O N D P L A C E

**MELISSA B. KIRKLEY · JOHN J. GURNEY · ALFRED A. LEVINSON**

A post-doctoral research officer in the Geochemistry Department of the University of Cape Town (UCT), South Africa, **Melissa B. Kirkley** is currently investigating stable-isotope and rare-earth-element geochemistry of mantle rocks and minerals. She has B.S. and M.S. degrees in geology from Colorado State University and a Ph.D. from UCT. **John J. Gurney** holds a personal chair in geochemistry at UCT, from which he also received his Ph.D. He has published widely in his main research fields of diamonds and upper-mantle petrology. **Alfred A. Levinson** is a pro-



*Melissa Kirkley*



*John Gurney*



*Alfred Levinson*

fessor in the Department of Geology and Geophysics at the University of Calgary, Alberta, Canada. A former editor of *Geochimica et Cosmochimica Acta*, Dr. Levinson has also written and edited a number of books in geochemistry. A native of New York, Dr. Levinson received his undergraduate and graduate degrees from the University of Michigan.

## T H I R D P L A C E

**ROBERT E. KANE · SHANE F. McCLURE · ROBERT C. KAMMERLING · NGUYEN DANG KHOA · CARLO MORA · SAVERIO REPETTO · NGUYEN DUC KHAI · JOHN I. KOIVULA**

*Photographs and biographies for Robert E. Kane, Robert C. Kammerling, and John I. Koivula appear under the first-place section.*

**Shane F. McClure** is a senior staff gemologist in the identification section of the GIA Gem Trade Laboratory, Santa Monica. Mr. McClure has 14 years of experience in the gem field. He is also an accomplished gem and jewelry photographer. The managing director of Vietnam's Intelviet Minerals and Realty, **Nguyen Dang Khoa** is a consulting geologist with 36 years of experience. He is a graduate of Hanoi Polytechnic Institute. **Carlo Mora**, a native of Turin, Italy, is a gemologist and gem cutter. Since 1981, he has been affiliated with the educational organization Fraul 2; from 1988 to 1991, he worked with FIMO



*Shane McClure*



*Carlo Mora*

Gem Stone S.A. of Chiasso, Switzerland, in their joint venture with the Vietnamese. **Saverio Repetto** is director of FIMO Gem Stone S.A. He has a degree in nuclear engineering from the Polytechnical University in Turin. **Nguyen Duc Khai**, born in Vinhphu Province, Vietnam, is senior geologist of the Council of Ministers, Hanoi. A member of the National Committee for Mineral Resources Approval, he holds a geological engineering degree from Hanoi University.

# GEM-QUALITY GREEN ZOISITE

By N. R. Barot and Edward W. Boehm

A new transparent, gem-quality green zoisite has been discovered in the Merelani Hills of mineral-rich Tanzania. The gemological properties are identical to those known for violetish blue tanzanite. The main differences are the pleochroic colors and the presence of chromium lines in the absorption spectrum of the green material. Chemical analyses demonstrated the presence of varying amounts of chromium and vanadium relative to the saturation of green.

## ABOUT THE AUTHORS

Dr. Barot, managing director of Ruby Centre, Nairobi, Kenya, is a gemologist who specializes in research on East African gemstones. Mr. Boehm, formerly with the Gübelin Gemmological Laboratory in Lucerne, Switzerland, is a geologist and gemologist with Pala International in Fallbrook, California.

*Acknowledgments:* The authors thank Dr. A. Parretti, of the Gübelin Gemmological Laboratory, and Prof. W. B. Stern, of the University of Basel, for preliminary research that led to the initiation of this article; Paul Carpenter, of the California Institute of Technology, for the microprobe analyses; William Larson, Josh Hall, and Gabriël Mattice, of Pala International, for helpful comments; Yianni Melas for research help; and Robert E. Kane and Robert C. Kammerling, of the GIA Gem Trade Laboratory, for their generous assistance. Special thanks to Dr. H. Krupp for his guidance in Tanzania.

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Tanzania has produced fine gems for most of the last century, but the past three decades have brought exceptional finds of both known and new gem materials. These discoveries include transparent green grossular garnet (tsavorite/tsavolite), violetish blue zoisite (tanzanite), "chrome" tourmaline, and ruby, as well as garnets and sapphires in a wide range of colors. The latest (first seen by the authors in February 1991) is a green gem-quality variety of zoisite (figure 1). This green stone exhibits the basic chemical, physical, and optical properties characteristic of zoisite; only the trichroic colors and chromogens are different from those of the well-known violetish blue to violet tanzanite.

Several names have been proposed for this new gem. Local miners first called it *Combat*, because it resembled the green of some military uniforms. *Güblinite* was proposed to the 1991 International Colored Gemstone Association (ICA) congress in honor of Dr. Edward Gübelin's contributions to the industry. Mineralogists prefer to call this material *green zoisite*, while many American dealers have adopted the term *chrome tanzanite*, in reference to the presence of chromium as the apparent coloring element (on the basis of preliminary research performed by the second author while at the Gübelin Gemmological Laboratory [Barot and Boehm, 1991]; further research has shown that the yellowish green to bluish green stones are colored by varying amounts of chromium and vanadium). For the purposes of this article, the authors will use the name *green tanzanite*, which is the one preferred by the Tanzanian Ministry of Water, Energy and Minerals (A. S. Zullu, pers. comm., 1992). Their proposal is based on the use of *tanzanite* for the gem variety of zoisite, in the same manner that *sapphire* is a gem variety of corundum. We hope, for the sake of this and other new gem materials, that an internationally recognized gemstone nomenclature committee will soon designate an official name.

Until 1991, zoisite occurred in Tanzania in only two varieties of interest to the gem trade. The most important has

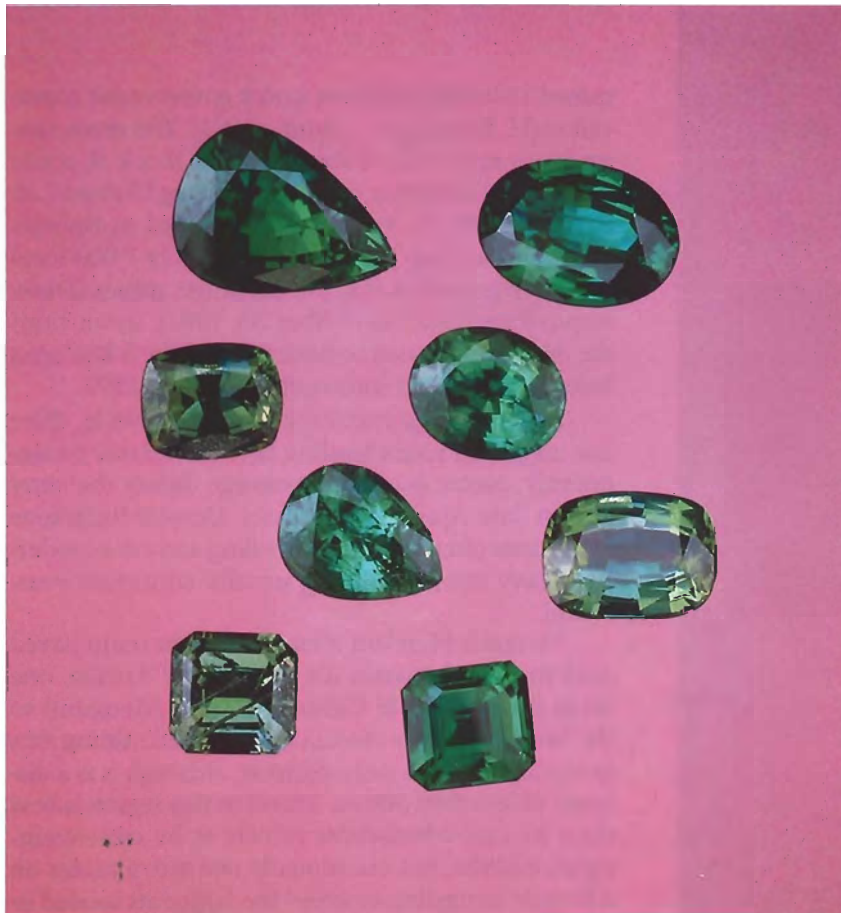


Figure 1. Newly arrived on the gem market are these transparent green tanzanites, first found in the Merelani Hills gem-mining region of Tanzania in early 1991. The stones range from 1.06 to 4.25 ct. Courtesy of Pala International; photo by Shane F. McClure.

been the gem-quality violetish blue tanzanite, which is colored by vanadium (Schmetzer, 1978). Most of these stones have a strong brown component that is removed by heat treatment. Some greenish blue stones have been found, but the color changes to blue after heat treatment (Schmetzer and Bank, 1978–79). The other gem zoisite from Tanzania is a massive opaque green variety, colored by chromium (Game, 1954; Schmetzer, 1982), that is found in association with amphibolite at the Longido mining area, several hundred kilometers northwest of Merelani. This aggregate of zoisite and hornblende is called anyolite in the trade (Gübelin, 1969), based on the word meaning *green* in native Masai. When associated with opaque ruby, it is known as ruby in zoisite (figure 2). Both anyolite and ruby in zoisite have been used extensively as carving materials. Although thulite—a massive, opaque, pink variety of zoisite colored by manganese—has been found in Norway, western Australia, Italy, Austria, the U.S.A. (Wyoming), and South Africa (Schumann, 1977), as well as Switzerland (Abrecht, 1981), only a few random pieces of transparent gem-quality pink zoisite have been found in Tanzania. A few pieces of transparent yellow tanzanite have also been

seen from Merelani (W. Larson, pers. comm., 1992). While a few pieces of transparent green tanzanite have appeared sporadically over the last 10 years, the recent find represents the first discovery of significant amounts of this material (H. Krupp, pers. comm., 1992).

This article reviews the occurrence and gemological properties of this new gem-quality green tanzanite, investigates the cause of color, and examines the effect of heat treatment on the different hues that have emerged to date. Although relatively small numbers of green tanzanite have been found thus far, this new discovery represents an important development in our understanding of zoisite and its potential as a gem species.

#### LOCATION AND ACCESS

The only location known to produce any notable quantity of transparent gem-quality zoisite (tanzanite) is in the Merelani Hills of Tanzania. Minor occurrences have been reported at Lelatema in Tanzania, and at Lualenyi and Lilani in Kenya (Naeser and Saul, 1974; Pohl and Niedermayr, 1978). Dr. John Saul has also reported minor occurrences of tanzanite in the Uluguru mountain range just south of Morogoro in



Figure 2. Before transparent green tanzanite was found in 1991, green zoisite was seen only in an opaque aggregate with hornblende known as anyolite, sometimes surrounding large hexagonal ruby crystals. Photo © Harold & Erica Van Pelt.

Tanzania (23rd International Gemological Conference, South Africa, 1991). To date, green tanzanite has been found only at Merelani.

Merelani (3°30'S—37°00'E; Keller, in press) is a hilly region situated south of the Kikuletwa River, 24 km from the Kilimanjaro International Airport near the town of Arusha (figure 3). The area received its name from the mererani tree, which is common to the region. The closest town is Mbuguni, also known by the locals as Zaire; it is presently closed to foreign visitors (H. Krupp, pers. comm., 1991).

The tanzanite deposit at Merelani was first discovered in 1967 (Bruce, 1968). Although the general mining area has grown, it is still relatively small, approximately 5 km long × 1 km wide. To promote more organized, sophisticated mining in the area, the Tanzanian government recently divided it into four sections (Blocks A–D; again, see figure 3) that are

mined independently but under government supervision (H. Krupp, pers. comm., 1991). The green tanzanite is reportedly being found in Block B, a site 845 m × 1,150 m that is held by Building Utilities Ltd. Rehabilitation (A. Suleman, as reported in Koivula and Kammerling, 1991). Approximately 7,000 local miners currently work the tanzanite mines (*Daily News-Tanzania*, November 30, 1991), down from the 35,000 estimated to have worked the 5 km<sup>2</sup> area before government intervention in early 1991.

As in most gem-mining areas worldwide, there are no paved roads leading into Merelani; consequently, access is often impossible during the rainy season (late April through June). Despite hazardous conditions often caused by flooding and cave-ins during heavy rainfall, mining usually continues year-round.

To reach Merelani after exiting the main paved road running between the airport and Arusha, one must drive south of Cairo and Zaire (Mbuguni) to the base of the hills. Access to the actual mining area in the hills is even more difficult, although it is a distance of less than 500 m. Travel in this region is best done by four-wheel-drive vehicle or by cross-country motorbike, but occasionally one sees a miner on a bicycle struggling to avoid the large ruts eroded in the dirt road.

Government permission must be obtained to gain admission to the mining area. For the most part, foreign visitors are not welcome by local miners. Mining rights are by government approval only.

## GEOLOGY AND OCCURRENCE

Zoisite, a species of the epidote group, is an orthorhombic polymorph of clinozoisite that forms under conditions of regional metamorphism (Hurlbut and Klein, 1977). The Merelani gem belt is located in the center of the Great Rift Valley region, which has undergone extensive regional metamorphism. Although some alluvial material has been found in low-lying areas and ancient streambeds, most violetish blue tanzanite occurs in fault zones (thrust planes) within outcrops of graphitic gneisses and schists. According to Malisa et al. (1986) and Malisa and Muhongo (1990), the primary deposits are located at the crest of the large Lelatema fold.

Mineralization of the zoisite is believed to have occurred some 600 million years ago, after the main phase of the Pan-African tectonothermal event and before the Rift Valley movements. During the



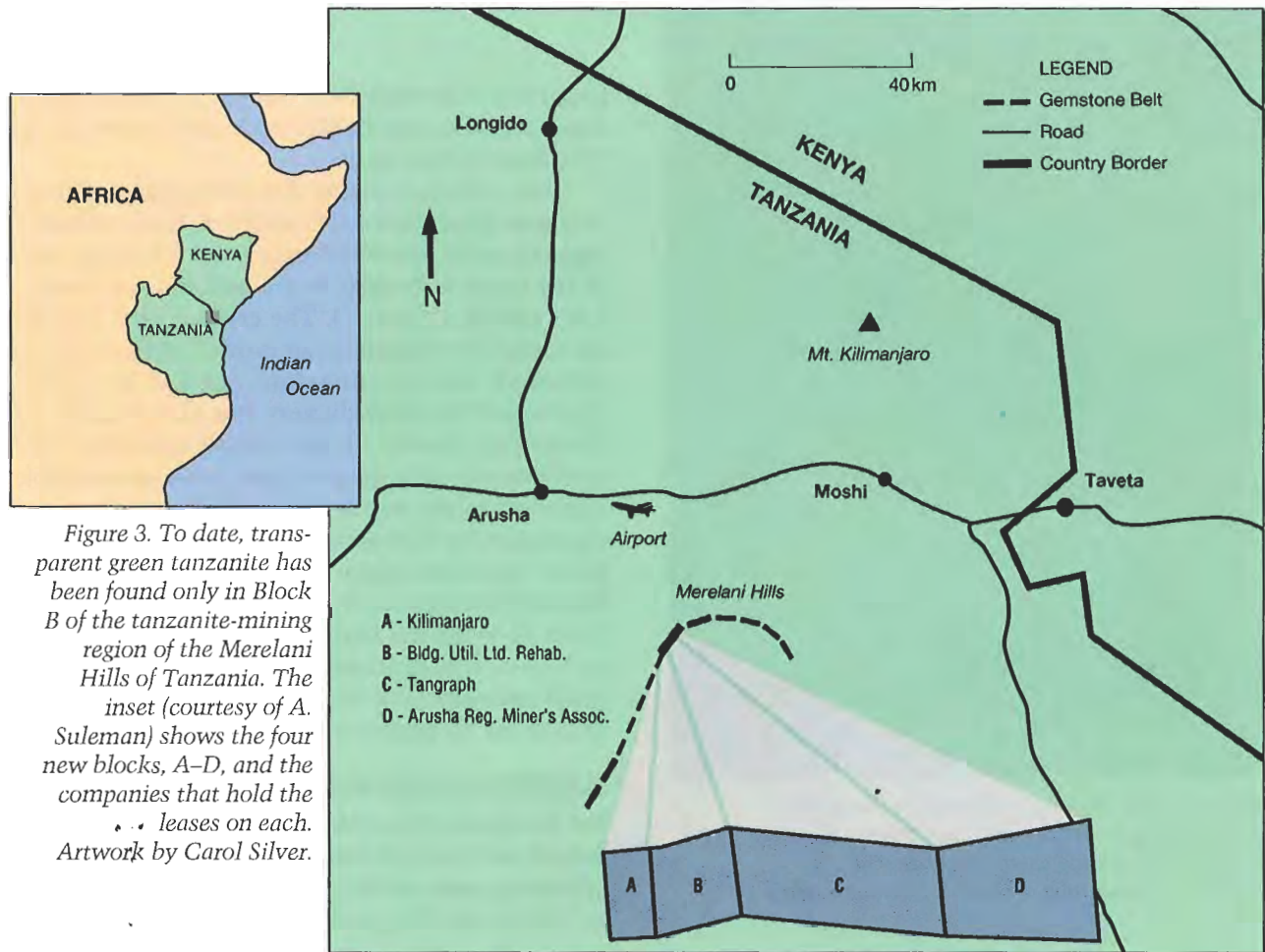


Figure 3. To date, transparent green tanzanite has been found only in Block B of the tanzanite-mining region of the Merelani Hills of Tanzania. The inset (courtesy of A. Suleman) shows the four new blocks, A–D, and the companies that hold the leases on each. Artwork by Carol Silver.

tectonothermal event, in which great variations in temperature occurred, zoisite, together with other silicates, carbonates, and clay minerals, crystallized from hot hydrothermal solutions that traveled through faults and fissures. The gneisses subsequently endured numerous stages of folding during regional tectonic activity (Malisa et al., 1986).

The authors speculate that the new, green tanzanite was formed under basically the same geologic conditions as the violetish blue variety, but within deeper, chromium-rich veins. This theory is partly substantiated by the fact that the green tanzanite is being found at greater depths as the miners continue to work downward (pers. comm. with miners, April 1991). Those stones that are yellowish green or bluish green in color—and, therefore, contain varying amounts of chromium—may have occurred in the zone between the shallower, vanadium-rich veins that host the violetish blue tanzanite and the deeper, chromium-rich veins that contain “pure” green tanzanite.

It is worth noting that green grossular garnet (tsavorite), which is chemically similar to zoisite (also a calcium aluminum silicate and colored by vanadium) but of a structurally different crystal system, is found throughout this region (P. Keller, pers. comm., 1992). Notable sizes of gem-quality tsavorite have been discovered in Block D, formerly known as the Karo pit (Kane et al., 1990).

#### MINING AND PRODUCTION

Violetish blue tanzanite was first mined by the open-pit method; now, more than 90% of mining is underground (Kane et al., 1990). The gem-quality green tanzanite was discovered in one of the deeper tunnels, at approximately 70 m below the surface. Although the government has assigned the new mining rights to encourage more organized, sophisticated mining, to date there is virtually no heavy equipment at the mines.

The miners rely on dynamite to penetrate the gneisses and schists in which the gem crystals are

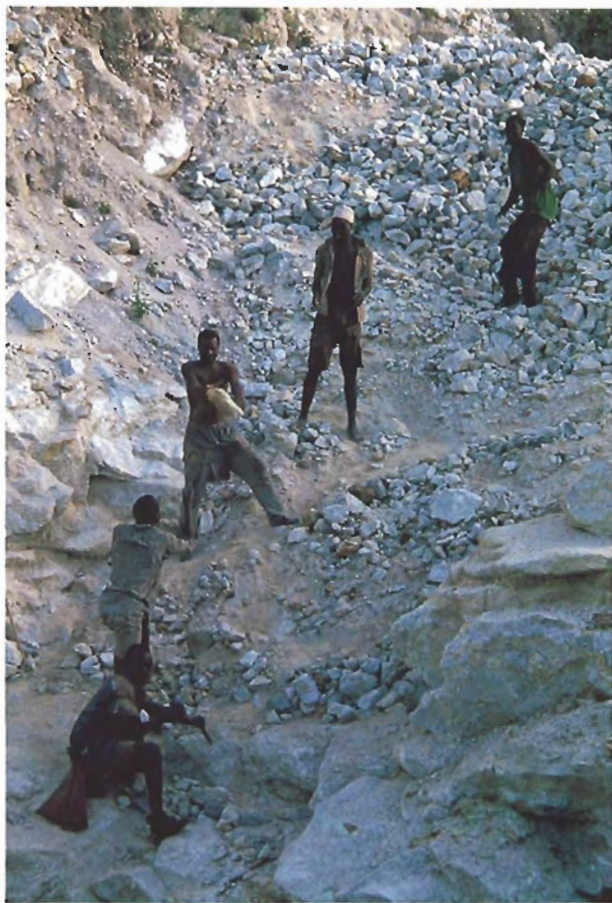


Figure 4. After they have blasted the hard rock, the miners remove the loose pieces from the often steep pits by tossing them "brigade style" from one miner to the next. Photo by Edward Boehm.

found. After blasting, they remove the loose rocks to the surface, tossing them from one miner to the next (figure 4). They then look for pockets of crystals in the newly exposed walls. The miners use picks and shovels to extract the gem crystals from the host rock (figure 5), depending on handmade kerosene lamps for illumination.

During a visit to the Merelani area in April and May 1991, one of the authors (EB) observed that few of the miners wore shoes and there was virtually no protective gear. Nor were there support structures to prevent cave-ins. Access to some of the tunnels was by rope, but only a few ropes served the complex maze. Many miners willingly risked their lives daily in pursuit of the valuable gems just to be able to buy necessities; most lived in thatched huts with mud walls and dirt floors. With the government's reorganization of the mining area, however, conditions should improve.

For the most part, the miners are "independent," but they report to the concerns that hold the leases on the various blocks. Virtually all of the gem material

found is sold in rough form through the leaseholders, who have been issued a Master Dealer's license by the Tanzanian government.

The authors estimate that 1,000 grams of green tanzanite have entered the market to date, producing approximately 500–800 faceted gems. Although most of the rough is broken, some well-formed crystals have emerged (figure 6). The crystals seen thus far are typical for tanzanite, an orthorhombic mineral, although the terminations tend to be acute. Production is currently very low (down to 10–20 stones per month). Of the stones available, only approximately 30% are pure green (with no noticeable modifier), while another 30% are bluish green and the remaining 40% are brownish green to yellowish green. The largest piece of rough known is a heavily included dark green crystal of 19 grams (again, see figure 6), while the largest cut stone seen thus far is a 15.61-ct triangular shape. One of the finest gem green tanzanites the authors have seen is the 11.23-ct cushion cut shown in figure 7.

#### MATERIALS AND METHODS

For this report, the authors examined more than 30 faceted dark green to medium brownish green to light yellowish green zoisites, ranging in weight from 1.06 to 5.86 ct; and 40 crystals, varying in color from dark

Figure 5. Most of the miners use only picks and shovels in their search for gem material. Photo by Edward Boehm.



green to light yellowish green and ranging in weight from 0.5 to 4.0 grams. All of the 70 research stones were submitted to a variety of gemological tests. Refractive indices were recorded with a GIA GEM Duplex II refractometer; specific gravity was measured on a Mettler hydrostatic electronic scale and by heavy liquids; long- and short-wave ultraviolet luminescence was determined using a USVL-15 Mineralight (handheld); and absorption spectra were recorded on a Beck prism spectroscope and a GIA-GEM handheld diffraction-grating spectroscope.

Ten of the sample stones (1.06–4.25 ct), one 4.65-ct medium blue tanzanite, and one 3.70-ct violetish blue tanzanite (figure 8) were also chemically analyzed by Paul Carpenter, of the California Institute of Technology, using a JEOL 733 electron microprobe with corrections based on Armstrong (1982, 1988).

The heat-treatment experiments were performed by the senior author in Nairobi, Kenya, using a Kasermann and Sperisen (Biel-Bienne, Switzerland) electric oven with a temperature/time system that provides a maximum temperature capacity of 1200°C from an electricity supply of 200 volts. A total of 40 gem-quality rough zoisites that showed green on at

*Figure 6. Some well-formed crystals of green tanzanite, like this 19-gram specimen, have been found at Merelani. Photo by Shane F. McClure.*



*Figure 7. This 11.23-ct green tanzanite displays the finest color seen by the authors to date. Photo © Harold & Erica Van Pelt.*

least one axis were selected and divided into five groups on the basis of their trichroic colors. The samples were sawed in half, with one half retained as a control while the other half was subjected to heat treatment. The halves to be treated were tightly packed in a plaster-of-paris powder and then placed in a crucible. The temperature of the oven was gradually raised to 650°C, over the course of approximately 30 minutes, and then was maintained at 650°C for an additional half hour. At this point, the oven was allowed to cool down naturally for about six hours. The samples were then removed from the crucible and compared to their untreated counterparts. Pleochroic colors were noted as observed down the three crystallographic axes with unpolarized light.

## GEMOLOGY

Most of the gemological properties of gem-quality green tanzanite overlap those already known for the violetish blue variety (table 1). However, there are some differences and similarities worth noting.

Specifically, the refractive indices, birefringence, and specific gravity of green tanzanite are essentially identical to those of the violetish blue variety, but the pleochroism and spectra are quite different (see Bank, 1969; Hurlbut, 1969; Strunz, 1969). Green tanzanite typically exhibits trichroism of a = greenish yellow to yellowish brown, b = yellowish green, and c = bluish green to brownish green (as compared to a =



*Figure 8. Microprobe analyses were performed on this group of gem-quality green and violetish blue tanzanites. The order in which they appear here, from left to right and top to bottom, is the same order in which they are presented in table 2. The stones in the bottom row were all heat treated. Courtesy of Pala International; photo by Shane F. McClure.*

violet blue, b = violet, and c = brownish red, respectively, for typical violetish blue tanzanite). The stones we tested showed weak to moderate chromium absorption bands at 660 and 680 nm, which are not found in other colors of transparent tanzanite. Note that these spectral features might not be visible with a hand spectroscope in smaller and/or paler stones.

Faceted violetish blue tanzanites tend to be flawless, because most inclusions that could fracture the stones (due to varying thermal expansion) during heat treatment are removed in the cutting process. However, the following have been identified petrographically as inclusions in zoisite: rutile, sphene, xenotime, diopside, quartz, and tremolite (Malisa et al., 1986). In 1975, using X-ray diffraction analysis, Dunn identified black mineral inclusions that had first been observed in tanzanite by Eppler (1969) as graphite. In 1976, Gübelin and Weibel also verified the

presence of tremolite-actinolite as inclusions in tanzanite. Past microscopic and X-ray diffraction analyses have also identified calcite and gypsum in gem zoisite (Malisa et al., 1986).

Because most of the green tanzanites are not subjected to heat treatment, virtually all of the samples studied—both rough and cut—contained some type of inclusion. Secondary, fingerprint-like fluid inclusions could be seen in most of the rough (figure 9) and in some of the cut stones. The authors also observed two-phase (liquid and solid) and three-phase (liquid, one or two solids, and gas) inclusions. We believe that the opaque solid observed in some of the fluid-filled cavities in green tanzanite (figure 10) may be graphite, on the basis of crystal morphology and its known occurrence in violetish blue tanzanite. The authors have also observed what resembles a zircon crystal surrounded by small feathers, possibly the

result of thermal expansion or natural radiation in a bluish green tanzanite (figure 11). However, because zircon has never before been reported in zoisite, further testing is needed before a firm identification can be made.

Growth tubes—a common feature in zoisites—and unidentified acicular inclusions were observed in the gem-quality green tanzanites as well (figures 12 and 13), usually throughout the entire stone. These features are believed to be responsible for the chatoyancy obtained in some of the cabochons (figure 14).

**TABLE 1.** Gemological properties of transparent green zoisite found in the Merelani Hills, Tanzania<sup>a</sup>.

Color	
Hue	Bluish green to yellowish green
Tone	Light to dark
Saturation	Light-medium to strong
Refractive Indices	1.688–1.696 to 1.691–1.700
Birefringence	0.008 to 0.010
Polariscope reaction	Doubly refractive
Optical absorption spectrum (hand spectroscope)	Broad absorption of the violet and most of the blue portion of the spectrum and weak-to-distinct absorption bands at 660 and 680 nm
Transmission luminescence	Inert
Chelsea color filter	Inert
Fluorescence to U.V. radiation	
Long-wave	Inert
Short-wave	Inert
Phosphorescence to U.V. radiation	None
Specific gravity	3.35 to 3.37
Pleochroic colors	
a-axis	Greenish yellow to yellowish brown
b-axis	Yellowish green
c-axis	Bluish green to brownish green
Microscopy	Multiphase inclusions; possibly graphite, zircon(?); unidentified "needles"; growth tubes

<sup>a</sup> Properties listed, except pleochroic colors, were obtained from 17 faceted stones ranging in weight from 0.70 to 4.25 ct. Pleochroic colors were determined from 40 rough samples ranging in weight from 0.5 to 4.0 g. See text for instrumentation used.

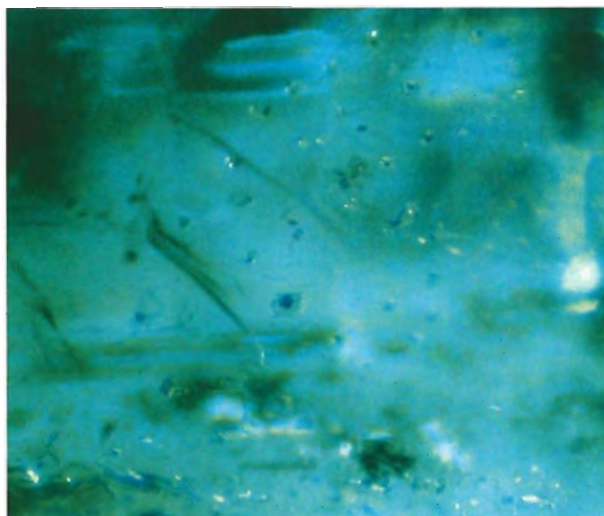


Figure 9. Fingerprint-like fluid inclusions, which probably formed after the crystal, were common in the green tanzanites examined. Photomicrograph by N. R. Barot; magnified 70 ×.

#### CHEMICAL COMPOSITION

Zoisite (tanzanite) is a calcium aluminum silicate,  $\text{Ca}_2\text{Al}_3(\text{SiO}_4)_3(\text{OH})$ , which may contain varying trace elements substituting for aluminum (Ghose and Tsang, 1971). Gem-quality violetish blue zoisite (tanzanite) owes its color primarily to vanadium ( $\text{V}^{3+}$ ) substituting for aluminum ( $\text{Al}^{3+}$ ; Hurlbut, 1969), while

Figure 10. The black hexagonal crystals in these two-phase, fluid and solid, inclusions in a bluish green tanzanite are probably graphite. Photomicrograph by N. R. Barot; magnified 70 ×.



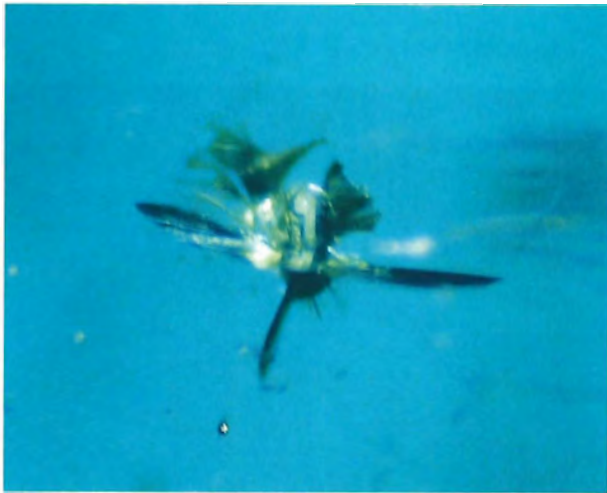


Figure 11. This crystal is believed to be zircon because it is surrounded by "feathers" (tension cracks?), which are usually caused by exposure to natural radiation. Photomicrograph by N. R. Barot; magnified 70 ×.

opaque green zoisite (anyolite) and the new translucent to transparent green tanzanite receive their color primarily from chromium ( $\text{Cr}^{3+}$ ), also substituting for aluminum (Game, 1954; Schmetzer, 1982; table 2). However, all the stones we tested contained at least minor amounts of both vanadium and chromium (for more information, see Beckwith et al., 1972; figure 15). Chemically, the structure of zoisite is amenable to substitution of aluminum by chromium and/or vanadium because the atoms of all three elements are of similar size.

Again, it is interesting to note the presence of another calcium aluminum silicate, tsavorite, in this area. In fact, tsavorite sometimes occurs in nodules

Figure 12. Growth tubes were common in the green tanzanites examined. They appear to intersect in this 1.11-ct gem-quality stone. Photomicrograph by E. Boehm; magnified 28 ×.

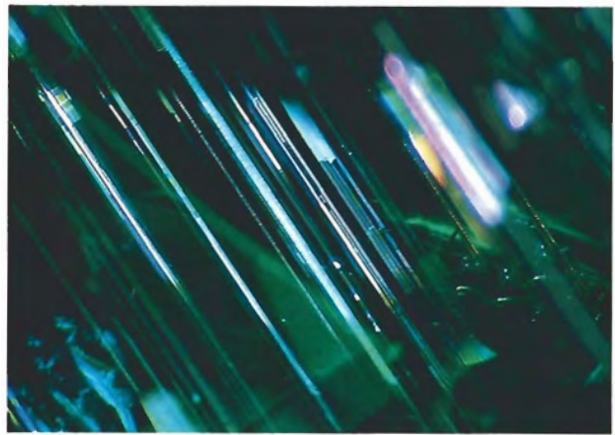
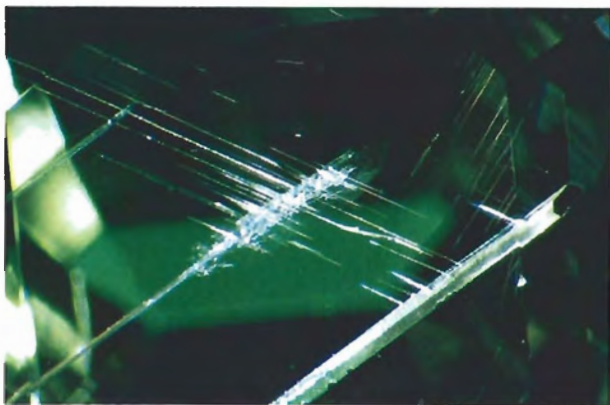


Figure 13. The growth tubes observed in the green tanzanites sometimes displayed interference colors. Photomicrograph by E. Boehm; magnified 30 ×.

surrounded by kelyphitic shells of tanzanite (Kane et al., 1990). Although tsavorite receives its color primarily from  $\text{V}^{3+}$  substituting for  $\text{Al}^{3+}$ , traces of chromium are also present (Manson and Stockton, 1982). Chrome-bearing tourmaline also occurs just south of Merelani in Lössogonoi. The presence of chromium in the bedrock and in other gem minerals in this region could explain why gem-quality green zoisite is also emerging with an influencing amount of chromium (Bank and Henn, 1988).

Figure 14. Densely packed acicular growth tubes produced chatoyancy in this 0.95-ct green tanzanite. Photo by Shane F. McClure.



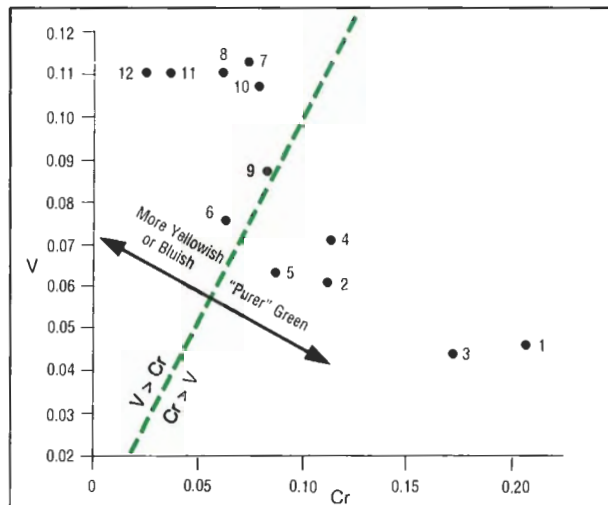


Figure 15. A comparison of the weight percentages of vanadium to chromium in the 12 faceted tanzanites analyzed (see table 2) shows the relationship of color to these chromogens. As chromium increasingly dominates vanadium, the color becomes a "purer" green; on the other hand, as vanadium increases, the color becomes more bluish or yellowish.

## EFFECTS OF HEAT TREATMENT

The violetish blue color commonly associated with tanzanite is usually the result of heat treatment, at approximately 500°C, of zoisites with strong brown to yellow modifiers (that is, the conversion of  $V^{3+}$  to  $V^{4+}$ ; Schmetzer and Bank, 1978–79). The authors subjected the five groups of rough gem-quality green tanzanites described above and in table 3 to temperatures up to 650°C. The seven stones that were dark green to medium slightly bluish green down the c-axis showed no change in color (figure 16, left). This lack of response is most likely because the color in these stones is due to appreciable amounts of  $Cr^{3+}$  (again, see figure 15), which does not respond to heat the way  $V^{3+}$  does. However, the remaining 33 stones did change on heating (figure 16, right).

Specifically, tanzanites that showed bluish green (figure 17, left) to brownish green responded to heat treatment by turning greenish blue (figure 17, right). This corresponds to the response reported by Schmetzer and Bank (1978–79) for bluish green zoisites with nearly equal amounts of chromium and vanadium.

TABLE 2. Results of electron microprobe analyses<sup>a</sup> of gem-quality green and blue zoisites.

Sample no.	Green—yellowish green (not heated)								Blue (heated)			
	1	2	3	4	5	6	7	8	9	10	11	12
Weight (ct)	1.06	4.25	2.38	1.49	1.48	1.81	1.33	1.11	4.14	1.49	4.65	3.70
Color <sup>b</sup>	med G	dk G	dk bG	med bG	med bG	med yG	med yG	lt yG	med sl g B	med sl gr B	med B	med v B
Oxide (wt.%)												
MgO	0.09	0.03	0.06	0.05	0.02	0.05	0.04	0.04	0.05	0.04	0.05	0.05
Al <sub>2</sub> O <sub>3</sub>	32.89	33.41	33.23	33.11	33.01	33.25	33.24	33.34	33.25	33.24	33.20	33.42
SiO <sub>2</sub>	39.82	39.61	39.80	39.76	39.49	38.91	39.10	39.59	39.58	38.30	39.89	39.02
CaO	23.91	24.01	23.93	24.15	24.02	23.91	24.00	24.25	24.16	23.98	23.88	24.12
TiO <sub>2</sub>	0.04	0.03	0.06	0.03	0.01	0.04	0.03	0.01	0.05	0.02	0.03	0.04
<b>V<sub>2</sub>O<sub>3</sub></b>	<b>0.07</b>	<b>0.09</b>	<b>0.06</b>	<b>0.10</b>	<b>0.09</b>	<b>0.11</b>	<b>0.17</b>	<b>0.16</b>	<b>0.13</b>	<b>0.16</b>	<b>0.16</b>	<b>0.16</b>
<b>Cr<sub>2</sub>O<sub>3</sub></b>	<b>0.30</b>	<b>0.16</b>	<b>0.26</b>	<b>0.17</b>	<b>0.13</b>	<b>0.09</b>	<b>0.11</b>	<b>0.09</b>	<b>0.12</b>	<b>0.11</b>	<b>0.05</b>	<b>0.04</b>
MnO	0.02	n.d.	0.01	0.01	0.01	0.01	n.d.	n.d.	0.01	0.01	n.d.	0.02
Fe <sub>2</sub> O <sub>3</sub>	0.01	0.01	0.01	n.d.	n.d.	0.01	n.d.	0.01	0.01	0.01	0.02	0.01
ZnO	0.02	0.01	0.02	0.01	n.d.	n.d.	0.01	0.01	n.d.	0.02	0.01	0.01
SrO	0.27	0.26	0.27	0.27	0.35	0.23	0.06	0.14	0.21	0.13	0.54	0.09
Ga <sub>2</sub> O <sub>3</sub>	0.03	0.01	0.03	0.03	0.02	0.04	0.01	0.02	0.03	0.01	0.03	0.03
	97.47	97.63	97.74	97.69	97.15	96.65	96.77	97.66	97.60	96.03	97.86	97.01

<sup>a</sup>Analyses were performed by Paul Carpenter of the California Institute of Technology on a JEOL 733 electron microprobe operating at 15 keV, a current of 35 nA, and a spot size between 10 and 25 μm. Each specimen was analyzed at three randomly selected locations; an average analysis is shown for each sample; n.d. = not detected.

<sup>b</sup>Color key: sl = slightly, lt = light, med = medium, dk = dark, y = yellowish, g = greenish, b = bluish, gr = grayish, v = violetish, G = green, B = blue.

**TABLE 3.** Results of heat treatment of 40 gem-quality green zoisite crystals.<sup>a</sup>

Group	No. of samples	Before heat treatment			After heat treatment		
		a-axis	b-axis	c-axis	a-axis	b-axis	c-axis
I	3	Greenish yellow	Yellowish green	Dark green	—————	No change	—————
II	4	Greenish yellow	Yellowish green	Medium slightly bluish green	—————	No change	—————
III	8	Greenish brown	Yellowish green	Dark bluish green	Light bluish green	Yellowish green	Dark greenish blue
IV	10	Yellowish brown	Purple	Dark brownish green	Light blue	Light purple	Medium greenish blue
V	15	Yellowish brown	Purple	Medium brownish green	Light blue	Light purple	Light greenish blue

<sup>a</sup> See text for full description of experimental materials and methods.

Even though our research showed that dark bluish green to medium brownish green tanzanites will respond to heat treatment, our experience is that such enhancement has not been routinely practiced on such stones thus far because of the rarity of the green color and the risk of damaging stones that have inclusions. From this research, we also know that not all green tanzanites will respond to heat treatment, and it appears that a “pure” green color can only occur in nature.

## CONCLUSION

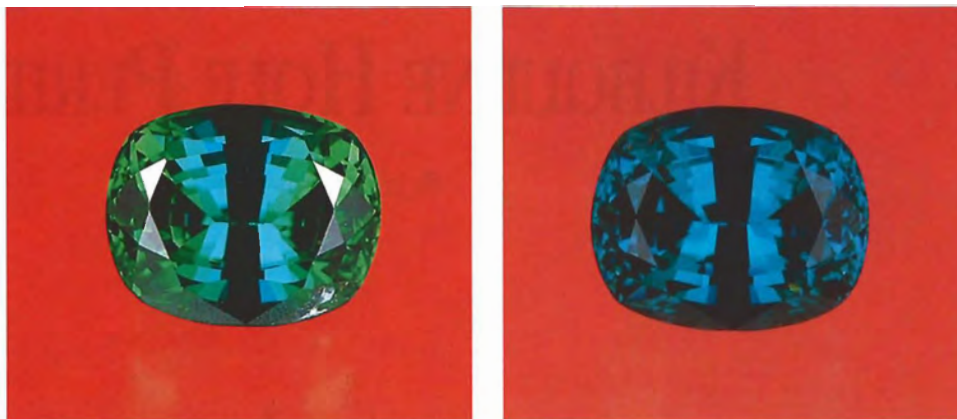
To date, limited quantities of green tanzanite have been found in one small area deep in Block B of the Merelani Hills, the primary source of fine violetish blue tanzanite. Approximately 30% of the 1,000 grams of green tanzanite that have reached the market thus far are a “pure” green, colored primarily by chromium, that does not respond to heat treatment; the remaining yellowish green to brownish green stones, which we found to be colored by varying amounts of



Figure 16. For the heat-treatment experiments, crystals were cut in half, with one half used as the control specimen and the other heated to 650°C. Here the halves of two specimens show, on the left (total weight, 3.64 ct), that there was no change in the “pure” green material and, on the right (total weight, 5.94 ct), the change produced in material that was originally brownish green. Photo by Shane F. McClure.



Figure 17. When the 4.14-ct bluish green tanzanite on the left was heated to 650°C, a deep, slightly greenish blue (right) was created. Photos by Shane F. McClure.



vanadium and chromium, will be affected by heat enhancement.

Because the supply of these stones has been irregular since their discovery in early 1991, it is uncertain how much green tanzanite actually exists. However, active mining and exploration continue in this area.

Prospective buyers should beware, however, as recent parcels presented as green tanzanite have included tsavorite, chrome tourmaline, apatite, glass, and YAG, all of which may be separated from green tanzanite by the simple use of a dichroscope to verify the latter's trichroic colors.

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# KILBOURNE HOLE PERIDOT

By John R. Fuhrbach

*This little-known source of gem-quality peridot, located in southwestern New Mexico, produces small but brilliant gems. Kilbourne Hole peridot is found in the explosion debris of a 180,000-year-old volcano, usually in elliptical "xenolith bombs." Kilbourne Hole peridot has a greater color range than the San Carlos, Arizona, material and an additional characteristic inclusion. Although the deposit is not being mined commercially, thousands of carats of gem-quality peridot have been found there.*

## ABOUT THE AUTHOR

Mr. Fuhrbach is a gemologist and retail jeweler in Amarillo, Texas, who specializes in unique gemstones and jewelry.

Acknowledgments: John I. Koivula and Emmanuel Fritsch of GIA helped with inclusions and spectrophotometry, respectively. George B. Asquith of Texas Tech University and Marc L. Wilson of the New Mexico Bureau of Mines confirmed the identity of associated minerals. At the GIA Gem Trade Laboratory, C. W. Fryer did the X-ray diffraction analysis of inclusions. Meredith Mercer and Mike Moon of GIA performed the infrared and U.V.-visible spectroscopy. Kurt Nassau facilitated the  $Co^{60}$  irradiation experiment. Special thanks to Patricia Robertson-Fuhrbach for her companionship, tireless collecting of specimens, and proofreading and to Edward J. Gübelin for reading the final draft.

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The use of peridot as a gem dates to 1500 B.C., when it was mined by Egyptian slaves on the island of Zabargad, off the Egyptian coast. The Egyptians knew the prized material by its Greek name *topazion* (allegedly from the Greek verb "to seek," because the island source was often enveloped in mist; Gübelin, 1975). In 1790, mineralogist A.G. Werner named the typically green mineral *olivine*, after the Latin for "olive."

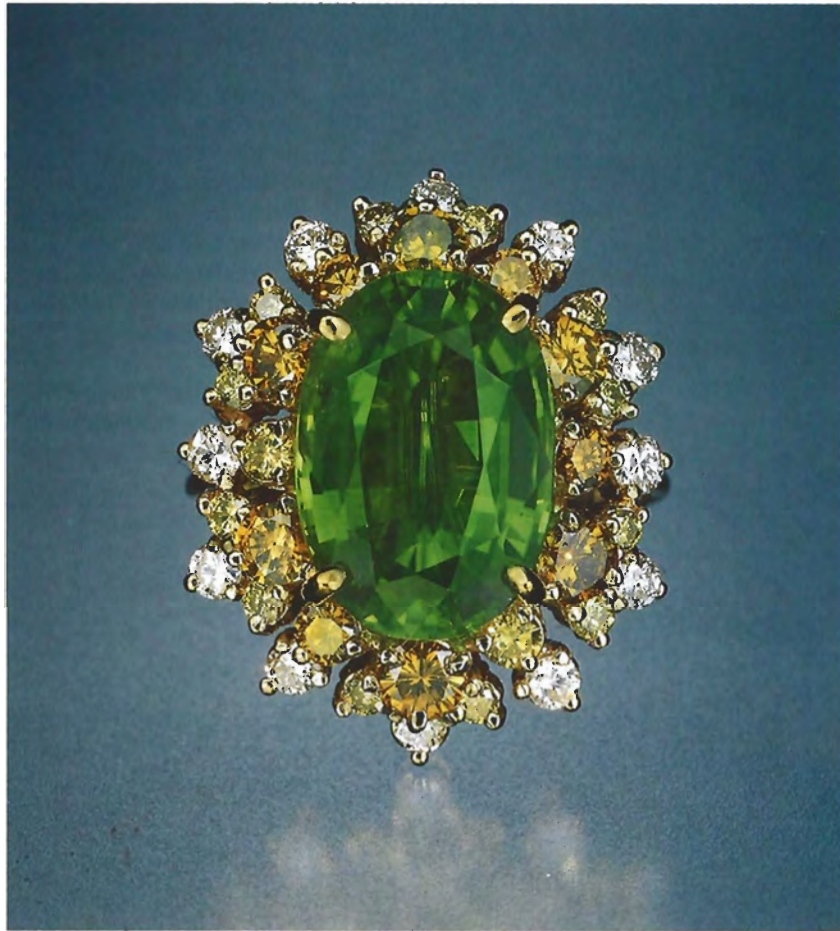
Today, the mineral is still referred to by geologists and mineralogists as olivine, but by gemologists as peridot—a French name adapted from the Arabic *faradat*, meaning "gemstone" (Gübelin, 1981). Composition varies along a solid-solution series between forsterite and fayalite, but most single-crystal material falls within the range of 70%–90% forsterite.

Peridot occurs virtually worldwide and perhaps throughout the universe. The most notable gem deposits are found in Myanmar (formerly Burma, which furnishes the largest cut gems) and Arizona, but other noteworthy localities are in Antarctica, Australia, Brazil, China, Finland, Germany, Hawaii, Italy, Kenya, Mexico, New Caledonia, Norway, and Russia (see, e.g., Arem, 1987). In addition, peridot was found on the moon by the crews of Apollo 11 and Apollo 12, and has repeatedly been encountered in meteorites (pallasites).

One of the lesser-known deposits is Kilbourne Hole, New Mexico, which was briefly described by Lindberg (1975) and mentioned by Shaub and Shaub (1975) but has not otherwise been investigated in the literature. Although well-formed single crystals have not been found at Kilbourne, several fragments as large as 33 ct and several nodules with areas of cuttable peridot as large as 128 ct have been examined and cut by the author (figure 1).

## LOCATION AND ACCESS

Kilbourne Hole is a late Pleistocene (approximately 180,000 years old; Seager et al., 1984) volcanic crater (figure 2) located



*Figure 1. Kilbourne Hole, New Mexico, is one of the least studied and yet most interesting of the known localities for gem-quality peridot. This 9.58-ct Kilbourne Hole peridot, surrounded by diamonds, is set in an 18k gold ring designed by the author. Photo © Harold & Erica Van Pelt.*

about 32 km (20 mi.) southwest of Las Cruces, New Mexico, and only about 20 km (12.5 mi.) north of the U.S. border with Mexico (figure 3). Access to the deposit can be determined by following U.S. Geological Survey maps from the towns of Afton, New Mexico, or El Paso, Texas. The roads may be hazardous, often with high clearances and deep sand, so a four-wheel-drive all-terrain vehicle should be used.

The altitude varies from 1,284 m (4,212 ft.) on the southern rim of the maar to 1,330 m (4,362 ft.) at the top of the eastern sand dunes and ridges, and drops some 134 m (438 ft.) from the eastern rim of the caldera to the bottom of the caldera dry lake. For several kilometers around, the area consists of desert sparsely vegetated with yucca and bush mesquite (again, see figure 2). Typical daytime temperatures in early July are approximately 47°C (117°F) at the rim and 53°C (127°F) on the dry-lake bottom, with humidity of only 1%. What little rainfall there is occurs during the last weeks of August. Thus, water is nonexistent and visitors must bring their own.

Because of the intense heat most of the year, prospecting and/or camping is recommended only

from late November through February. Even then, five varieties of poisonous desert rattlesnakes inhabit the region; familiarity with desert survival is essential for camping in the area. Most of the land is under government supervision, and access is unrestricted; the approximately one-third of the northeast section that is on private land is fenced off.

#### **GEOLOGY AND OCCURRENCE**

The elliptical Kilbourne Hole is approximately 3.2 km long × 2.2 km wide. It is classified as a maar (a crater formed by violent explosion without igneous extrusion) and resembles other maars found in Germany, India, Mexico, and elsewhere in New Mexico (Seager, 1987). Except to the south, it is surrounded by a prominent rim of ejecta (material thrown out of an active volcano), that is as much as 46 m above the La Mesa plains and up to 107 m above the crater floor. The outer walls of the rim have gentle slopes; the inner walls are steep to vertical.

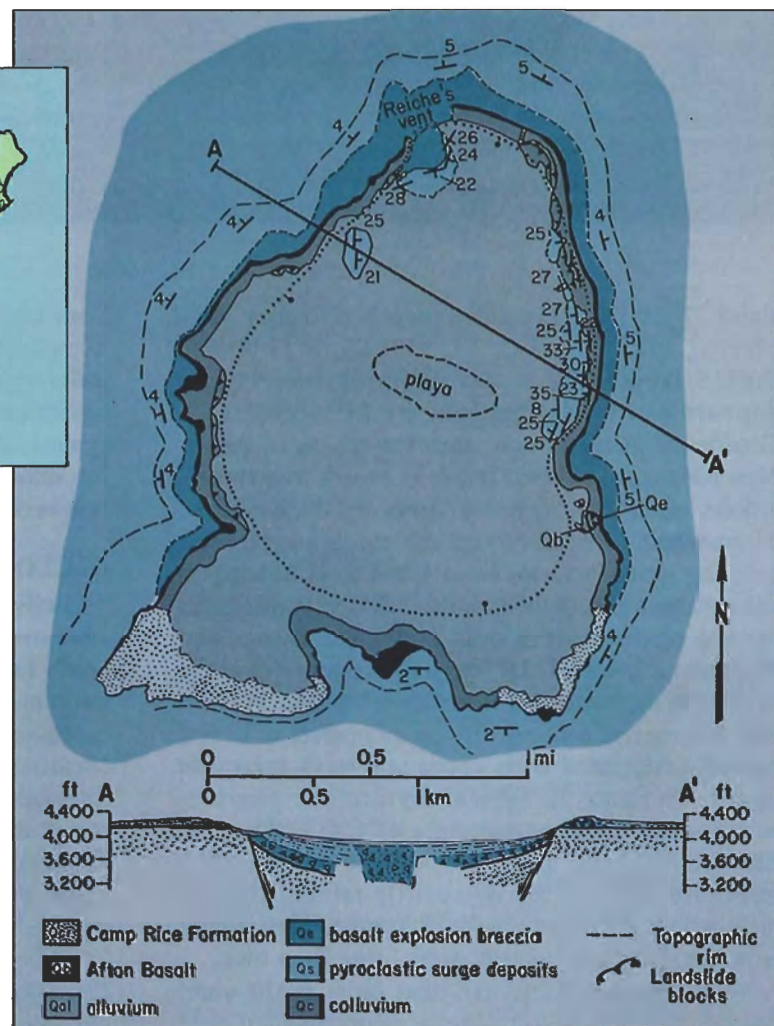
The precrater rocks belong to the early to middle Pleistocene Camp Rice formation (Gile et al., 1981) overlain by the Afton basalt (again, see figure 3). Over



Figure 2. Kilbourne Hole is an extinct volcano, approximately 7 km<sup>2</sup> in area. Gem-quality peridot is found scattered throughout the area, having weathered out of the tuff-ring ejecta that form the walls of the crater. The terrain in this extremely dry area is barren, occupied primarily by bush mesquite, yucca, and rattlesnakes.



Figure 3. Kilbourne Hole lies in Doña Ana County, New Mexico, close to the border with Mexico. The geologic map not only delineates the rim of the crater but also the various units that comprise the crater and the rim. The peridot-containing "xenolith bombs" have been found in situ primarily in Qe, the basalt explosion breccia; only a few have been found in the pyroclastic surge deposits, the upper unit of the tuff-ring ejecta. Geologic map by W. R. Seager, New Mexico State University.



these rocks lie the tuff-ring ejecta deposits, from the explosion phase of the crater's formation, which form the rim, back slopes, and upper half of the crater wall (again, see figure 2). The lower portion of the tuff-ring ejecta is absent in some areas and up to 50 m thick in others. It is a breccia that consists of angular blocks of Afton basalt in a matrix of unstratified pyroclastic fall deposits, including mantle and lower-to-upper crustal "xenolith bombs" (Reiche, 1940). The upper part of the tuff-ring ejecta consists of much finer grained stratified pyroclastic-surge and pyroclastic-fall deposits up to 35 m (about 115 ft.) thick on the east rim (Shoemaker, 1957; Hoffer, 1976; Brenner, 1979; Stuart and Brenner, 1979; Stuart, 1981).

The peridot is an early crystallization, formed during the solidification of igneous rocks from the liquid magmatic phase (Northrop, 1959; Gübelin, 1975). Essentially, when the volcano erupted, it threw liquid magma into the atmosphere. As portions of the magma spun through the air, their outer surfaces cooled first, retaining an elliptical shape due to the spinning action. This outer crust acted as insulation, allowing the molten interior enough time to cool that crystals could form. Thus, peridot is found with augite and diopside (and occasionally enstatite and bronzite) inside these basalt-coated "xenolith bombs" (figure 4), which may be as large as 25 cm (about 10 in.) in diameter (Lindberg, 1974), and as fragments (figure 5) lying on the ground. The "bombs" appear *in situ* only in the tuff-ring ejecta, most commonly in the

Figure 4. Basalt-coated "xenolith bombs," like the one shown here, often contain gem-quality peridot. They can be picked up off the surface, where they have weathered out of the surrounding tuff ring. A sharp tap with a hammer will break open the "bomb" and reveal any gem material inside.



Figure 5. Fragmentary pieces of peridot, much of it facet grade, are also found lying on the ground at Kilbourne Hole. The large "fragment" in the center here weighs 33 ct; most of the pieces that surround it are small (less than 2 ct) but of good color and clarity.

lower portion. Eons of weathering have exposed these potato-shaped masses and left thousands lying on the ground above the caldera rim. The author and his wife recovered more than 1,433 ct of facetable material in only five days, entirely by handpicking "bombs" and fragments from the surface; several visits have yielded a total "production" of some 4,000 ct of cuttable peridot. However, there is no evidence in the literature or at the locality that Kilbourne Hole has ever been formally mined.

#### MATERIALS AND METHODS

A study collection of 1,026 rough samples (total weight approximately 610 ct) and 21 faceted stones (total weight 54.24 ct) was divided initially into four color groups, designated KH1, KH2, KH3, and KH4; KH2 and KH3 were subsequently combined. Gemological properties were taken on a subset of 146 representative samples.

Refractive indices were determined with a Rayner refractometer and high-intensity sodium-vapor lamp. Pleochroism was determined with a GIA-GEM polariscope, Rayner and GIA calcite dichroscopes, and a Bausch & Lomb petrographic microscope. Specific gravities were taken hydrostatically using stabilized 1,2-dibromomethane and a Christian Becker analytical balance. Ultraviolet testing was done with high-intensity (100W), filtered, mercury-vapor lamps at



Figure 6. Evidence of peridot can be seen along the broken portions of these basalt-coated xenolith "bombs." These nodules range from  $7 \times 5.5 \times 4$  cm (0.25 kg) to  $23 \times 23 \times 19$  cm (15.9 kg). The largest "bombs" generally do not produce the largest facetable material.

typical short (253.7 nm) and long (366.0 nm) wavelengths.

Optical spectra were observed under darkroom conditions with two desk-top spectroscopy units, one with a Beck prism spectroscopy and the other with a GIA-GEM digital-readout, scanning, diffraction-grating spectroscopy. Optical and infrared spectroscopy were also performed for eight samples—one tablet and one faceted gem from each of the original four color groups—on a Pye-Unicam 8800 U.V.-visible spectrophotometer and a Nicolet 60SX FTIR spectrometer.

Chemical analyses were obtained—from 83 samples ground to 200 mesh and screened from the three final color groups KH1, KH2/3, and KH4—by proton-induced X-ray emission (PIXE) analysis. This non-

destructive method, which is similar in principle to energy-dispersive X-ray fluorescence (EDXRF), employs an accelerator to drive a high-speed stream of protons toward the target sample. Each element in the sample responds by producing characteristic X-rays, which are detected and counted; within minutes of exposure, a computer produces quantitative data over the entire chemical spectrum.

#### DESCRIPTION OF THE MATERIAL

Chemically, peridot is a magnesium-iron orthosilicate with the general formula  $(\text{Mg,Fe})_2\text{SiO}_4$ . It is a member of the olivine group and, compositionally, belongs to an isomorphous series in which it lies closer to the end member forsterite ( $\text{Mg}_2\text{SiO}_4$ , at the low end of the R.I./S.G. scale) than to the other end member, fayalite ( $\text{Fe}_2\text{SiO}_4$ , with high R.I. and S.G.; Gübelin, 1975). Olivine is orthorhombic, with imperfect (010) and (100) cleavage and a Mohs hardness of 6.5 to 7. Optically, it is biaxial, with moderate to high birefringence.

Most of the "bombs" recovered at Kilbourne Hole were 10–25 cm (4–10 in.) long and showed evidence of weathering and limonite surface coloring, presumably from the decomposition of iron compounds leached to the nodule surface. One nonweathered "bomb" (approximately  $25 \times 15 \times 7$  cm) shown freshly broken in figure 4, weighed 4.5 kg. It does not appear that there are typical shapes for "bombs" that contain cuttable peridot (figure 6); any of the pieces is just as likely to reveal a mixture of fractured peridot, augite, diopside, and possibly enstatite and bronzite.

Figure 7. This collection of approximately 941 ct of typical facet-grade Kilbourne Hole peridot represents about five days of collecting and illustrates—with the exception of yellowish brown to dark brown—the range of colors found.



The collection illustrated in figure 7 represents the range of peridot colors, except pale yellowish brown and the darker browns, found at Kilbourne Hole in the course of five days of collecting. The surfaces of facetable pieces larger than 1 ct exhibit numerous conchoidal fractures and a "sandblasted" appearance typical of material found near the top of the eastern basalt rim and desert-sand slopes.

Although one notable specimen contained two large—128 ct and 26 ct—gem-quality pieces of rough (figure 8), most of the gem-quality material recovered by the author was small and produced jewelry-quality stones under 0.5 ct.

Only about 10% yielded gems over 0.5 ct and up to 10 ct. The cut stones tend to be very bright, with particularly fine clarity (figures 9 and 10). The author estimates that only 15%–20% of the material found is suitable for faceting because of the numerous fractures inherent in the rough.

None of the Kilbourne Hole material recovered to date exhibits asterism or chatoyancy, although both have been reported in the literature for peridot from other localities.

Figure 8. The best "bomb" found to date yielded two pieces of facetable rough weighing 128 and 26 ct.

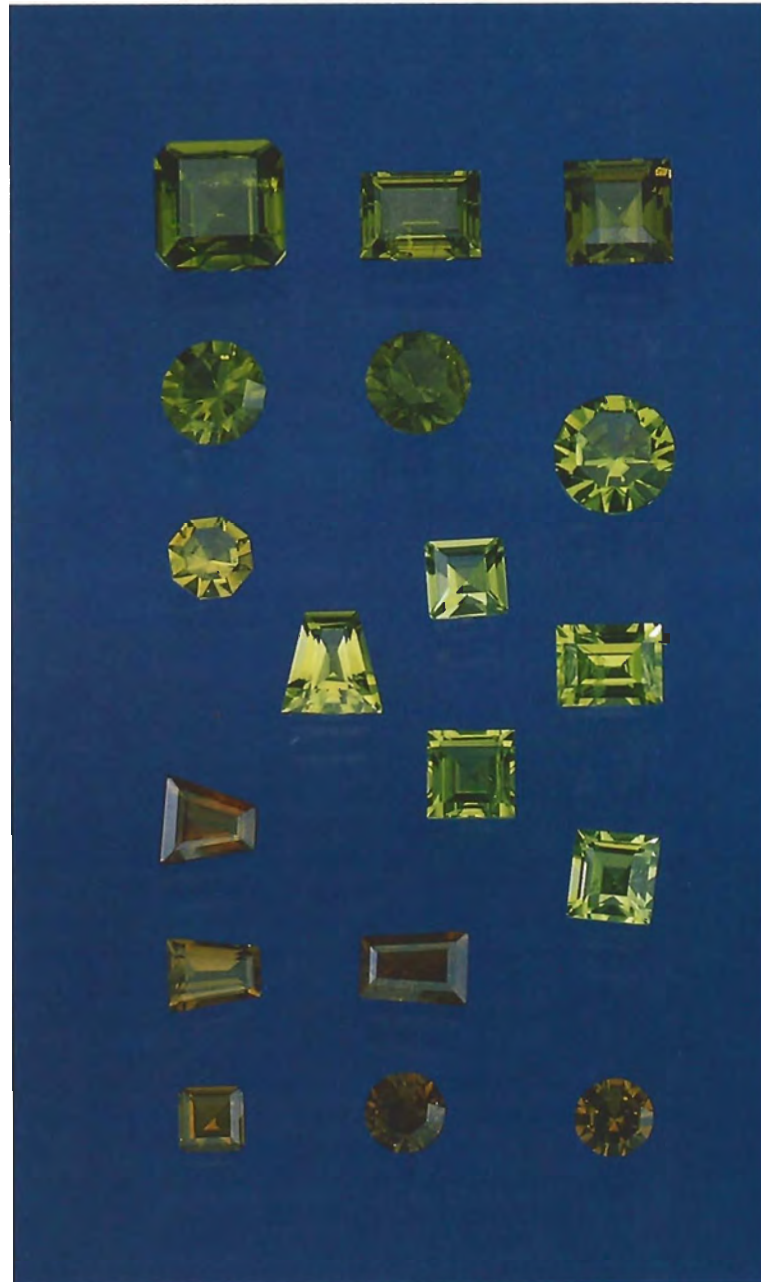


Figure 9. These three clusters (0.12 to 2.00 ct) are representative of the three main color groups—KH1 (center), KH2/3 (top), and KH4 (bottom)—in which the Kilbourne Hole peridot occurs. Note the fine clarity. Photo by Shane McClure.

#### GEMOLOGICAL PROPERTIES

Color descriptions of representative specimens from the three color groups include: for KH1, light greenish yellow to yellowish green; for KH2/3, medium



Figure 10. This 1.43-ct Kilbourne Hole peridot is of optimum color and virtually flawless. Courtesy of Edward J. Gübelin; photo by Robert Weldon.

dark, slightly brownish, yellowish green; and for KH4, medium to dark yellowish brown.

Refractive indices vary in direct proportion to color variations from yellow through green to brown (see table 1). The observed ranges were:  $n_{\alpha} = 1.654\text{--}1.673$ ,  $n_{\beta} = 1.673\text{--}1.691$ , and  $n_{\gamma} = 1.691\text{--}1.709$ , with a birefringence of 0.034–0.038. Pleochroism is distinct, with color combinations for the three color categories of: (KH1) light yellow and light yellowish green, (KH2/3) medium yellow to orangy yellow and medium yellowish green, and (KH4) medium to dark brownish yellow and medium to dark yellowish brown. Specific gravities of 3.415 to 3.499 were obtained. All specimens remained inert to both long- and short-wave ultraviolet radiation.

## SPECTROSCOPY

Absorption bands were observed in all specimens at 452, 473, and 640 nm, the last being relatively weak. A moderately strong band centered at about 492 nm was also observed with the prism spectroscope, but the diffraction-grating unit resolved it into two bands at about 497 and 489 nm. Spectrophotometry of eight samples (two from each original color group) revealed these and additional weak bands as follows: 402, 410, 453, 472, 487, 495, 530, and 634 nm (figure 11). As one might expect, all features were less apparent in the paler stones. These spectral features have all been

observed previously in peridot from other localities, particularly those from Arizona (Farrell and Newnham, 1965; Burns, 1974; Koivula, 1981).

## CHEMICAL COMPOSITION AND ORIGIN OF COLOR

The data obtained by PIXE chemical analyses of three samples of Kilbourne Hole peridot revealed compositions typical for peridot from around the world (table 1). Closer examination of the data, however, reveals information about the causes of color in the Kilbourne material. Mg:Fe ratios for the KH1 (greenish yellow to yellowish green) samples were on the order of 4.65:1, as compared to around 3.64:1 for the KH2/3 (yellowish green with olive green) and 2.52:1 for the KH4 (medium to dark brown with little or no green) samples. Table 1 also shows that, as Mg content decreases, both Cr and Ni also decrease, while Fe content and depth of color increase. Thus, it appears that neither Cr nor Ni contributes to an increase in green coloration.

TABLE 1. Gemological properties and chemical composition of three representative samples of Kilbourne Hole peridot.

Properties and elements	KH1	KH2/3	KH4
Color <sup>a</sup>	lt. gY	med. yG	med. yB
R.I. $n_{\alpha}$	1.659	1.663	1.669
$n_{\beta}$	1.674	1.679	1.684
$n_{\gamma}$	1.693	1.698	1.705
S.G.	3.415	3.426	3.499
Chemistry <sup>b</sup> (wt.%)			
Mg	28.223	26.674	25.898
Si	16.576	15.821	16.081
K	0.013	0.017	0.016
Ca	0.078	0.058	0.098
Cr	0.027	0.013	0.010
Mn	0.096	0.116	0.152
Fe	6.067	7.324	10.280
Ni	0.234	0.192	0.174
Zn	0.004	0.003	0.006
O	48.679	49.776	47.275
Total	99.997	99.994	99.990

<sup>a</sup>Color descriptions are as follows: lt. = light, med. = medium, g = greenish, y = yellowish, Y = yellow, G = green, B = brown.

<sup>b</sup>Analyses performed on the PIXE system of a General Ionex Corp. Tandatron accelerator with an intense proton beam of up to 3 MeV; a Tracor lithium-drifted silicon X-ray detector; and a multichannel analyzer system.



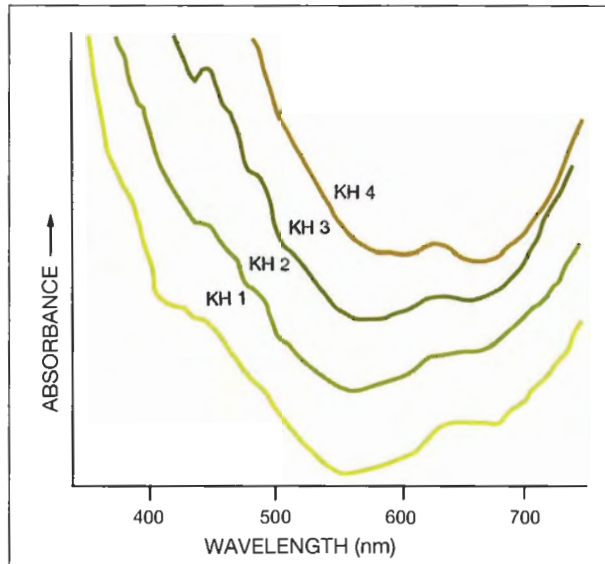


Figure 11. These U.V.-visible spectra were taken on representative samples of peridot from the major color groups found at Kilbourne Hole. The spectra were measured on parallel-window samples of similar thickness (approximately 1.5 mm) and recorded using a Pye-Unicam 8800 spectrophotometer.

Yellowish green peridot is a classic example of coloration by a transition metal ion, in this case  $\text{Fe}^{2+}$  (Farrell and Newnham, 1965). Traces of chromium have been reported as contributing to the green color (Arem, 1987), but no support for this was found here.

Spectrophotometry revealed essentially three components that, together, leave a transmission window centered around 550 nm, which corresponds to yellowish green (again, see figure 11). The first of these is an absorption tail that absorbs much of the red and orange. This feature has been observed in peridots from other localities and is related to near-infrared absorptions that are attributed to  $\text{Fe}^{2+}$  (Burns, 1974).

The second component is the series of bands in the visible range, most of which have also been attributed to  $\text{Fe}^{2+}$  (Farrell and Newnham, 1965). The suggestion that some are related to  $\text{Mn}^{2+}$  (Gunawardene, 1985) was not substantiated.

The third spectral component is a general increase in absorption from about 550 nm toward the ultraviolet, which contributes brown. Studies on synthetic forsterite (Weeks et al., 1974) and on other gem silicates and oxides (Fritsch and Rossman, 1987) indicate that this feature may arise from charge-transfer

phenomena between oxygen and transition metal ions such as  $\text{Fe}^{3+}$  or  $\text{Ti}^{4+}$ . However, the iron-rich olivine end member fayalite is often amber colored in thin section regardless of Ti content (Deer et al., 1982), which suggests that Fe alone may be responsible.

## MICROSCOPIC FEATURES

Several thousand carats of rough material collected by the author at Kilbourne Hole over a number of years were examined with the microscope. From these, a study collection of 2,213 samples was assembled that represents the complete range of inclusions observed. Although limited in variety by geologic mode of formation, the inclusions in Kilbourne Hole material, like those in peridots from other localities (Gübelin, 1974; Gübelin and Koivula, 1986), are gemologically diagnostic for peridot, if not for the locality. However, the "black" inclusions in Kilbourne peridots are notably smaller and fewer in number than those found in material from Arizona.

Four mineral inclusions were identified in Kilbourne Hole peridots: hercynite, forsterite, diopside, and biotite. Hercynite has not previously been described in peridots from other localities. Both primary and secondary fluid inclusions were also observed, as were the "lily pad" inclusions characteristic of peridot.

**Hercynite.** The most common type of mineral inclusion in Kilbourne Hole peridot, which seemed to be present in virtually all of the stones examined, is hercynite, a member of the spinel group. The inclusions are primarily opaque black octahedra and distorted octahedra, some flattened to an almost tabular habit. Tension fractures usually surround these inclusions, as a result of the expansion of the hercynite against the host peridot during formation (figure 12).

In appearance, the hercynite inclusions in Kilbourne Hole peridot resemble both chromite (Koivula, 1981; Koivula and Fryer, 1986) and chromian spinel (Dunn, 1974) as found in peridot from Arizona. Nevertheless, X-ray diffraction analysis of two separate crystals removed from a random selection of Kilbourne peridot fragments revealed their identity as hercynite ( $\text{Fe}^{+2}\text{Al}_2\text{O}_4$ ). Thorough search of the gemological and mineralogic literature failed to disclose any mention of hercynite in peridot. All previous references to "black single-crystal" inclusions in peridot refer to them as "black euhedral chromite octahedra" or "dark reddish brown octahedra of chromian spinel and black chromite crystallites" or "a metallic protogenetic chromite crystal" (see, e.g.,

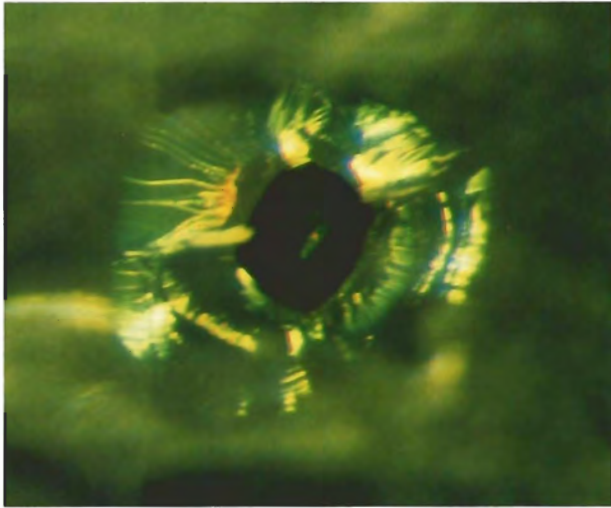
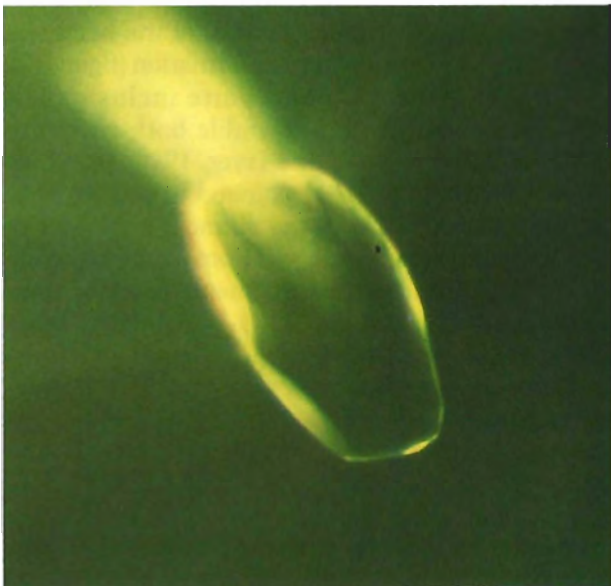


Figure 12. The most common mineral inclusion found in Kilbourne Hole peridot is hercynite, which is typically surrounded by a tension fracture, as shown here. Hercynite has not previously been observed in peridots from other localities. Photomicrograph by Edward J. Gübelin; magnified 40 $\times$ .

Gübelin and Koivula, 1986). It is still possible, however, that some of the opaque black mineral inclusions in Kilbourne peridot are chromian spinel or chromite.

**Forsterite.** Peridot and forsterite are essentially the same mineral, so inclusions of the latter show

Figure 13. A slight interface makes this forsterite crystal visible within the host Kilbourne Hole peridot. Photomicrograph by John I. Koivula; magnified 45 $\times$ .

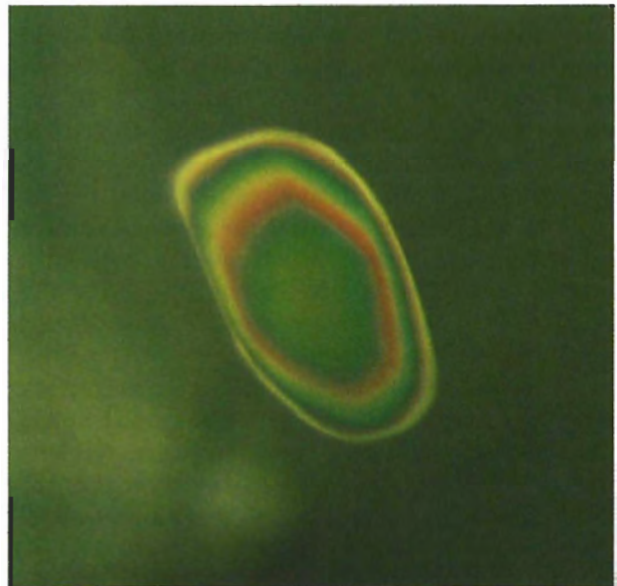


virtually no relief from the surrounding peridot and are usually very difficult to detect. In Kilbourne Hole peridots, however, some forsterite inclusions exhibit enough interface to make them visible in standard darkfield illumination (figure 13). Some also have a different optic orientation, so they stand out with polarized light (figure 14). One small, essentially colorless rounded grain was partially freed from its peridot host for X-ray diffraction analysis; it was confirmed to be forsterite.

**Diopside.** Bright "emerald" green diopside crystals were also identified by X-ray diffraction analysis. These inclusions appear as transparent to translucent rounded protogenetic blebs of low relief with a "chrome" green color (figure 15) that is darker than that of the surrounding peridot. When the diopside crystals are very small, however, their color tends to blend into that of the peridot host. Diopside has also been reported in peridot from Arizona (Koivula et al., 1980; Koivula, 1981) and China (Koivula and Fryer, 1986).

**Biotite.** Biotite is perhaps the rarest mineral inclusion found in Kilbourne Hole peridot; only a single example was observed during this study, and identification was made visually. The inclusion consisted of translucent brown euhedral flakes of pseudo-hexagonal biotite mica (figure 16). Similar inclusions

Figure 14. The same forsterite crystal shown in figure 13 also stands out in polarized light because of the difference in optic orientation from the host peridot. Photomicrograph by John I. Koivula; magnified 45 $\times$ .



have been observed and identified as biotite in peridot from other localities, including Myanmar (Gübelin, 1974; Gübelin and Koivula, 1986), Arizona (Koivula, 1981), and China (Koivula and Fryer, 1986).

**“Lily Pads.”** The “lily-pad” inclusion is common to peridots from virtually every locality. Kilbourne Hole peridots are no exception (figure 17), although the disks are smaller and significantly fewer in number than those observed in material from San Carlos, Arizona. These circular to ovoid disks, known as

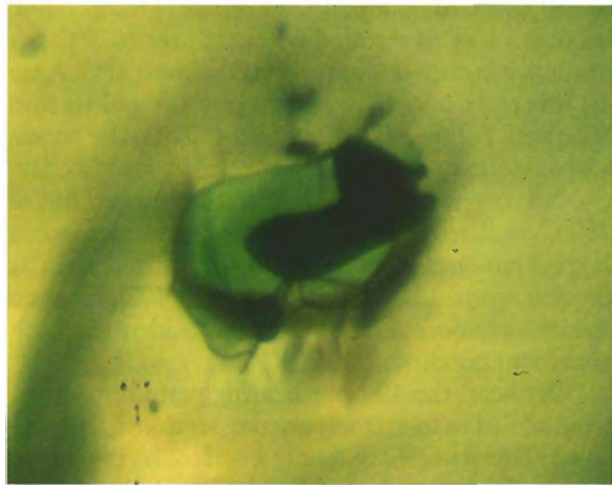


Figure 15. This “chrome” diopside inclusion, associated with black hercynite, exhibits the low relief and bright green color typical of this mineral. Photomicrograph by John I. Koivula; magnified 50 ×.

Figure 16. These pseudo-hexagonal, translucent brown biotite crystals were the only example of this mineral seen in the study collection of Kilbourne Hole peridot. Photomicrograph by Edward J. Gübelin; magnified 26 ×.

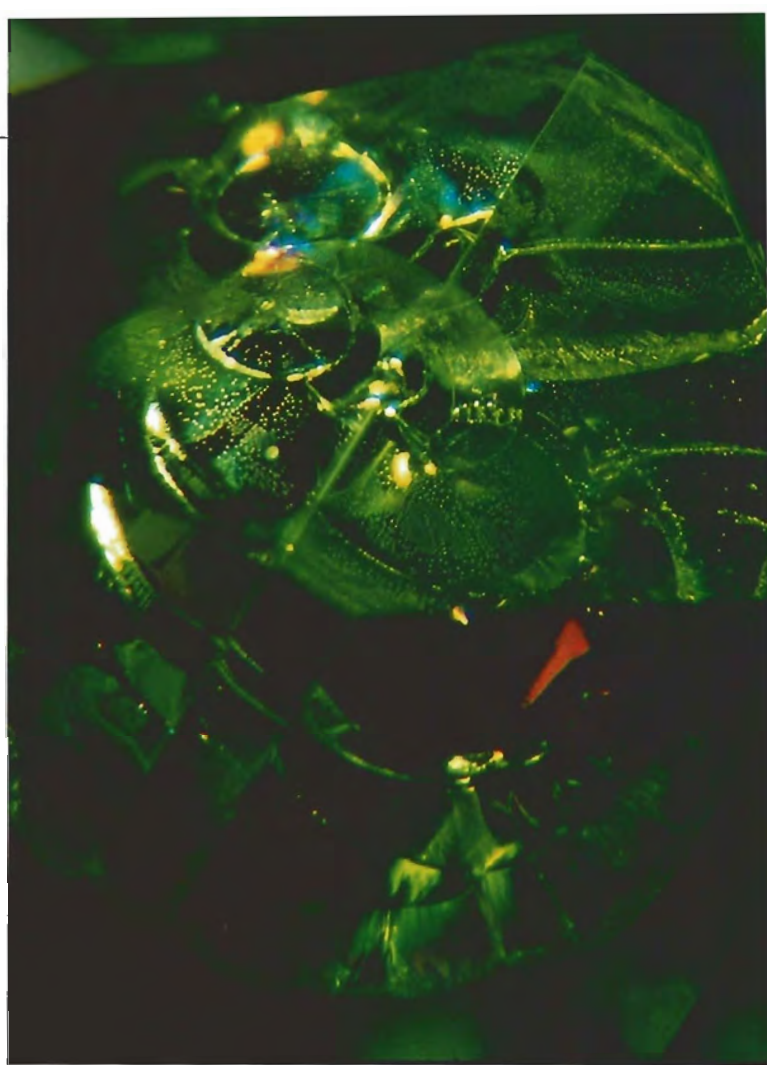
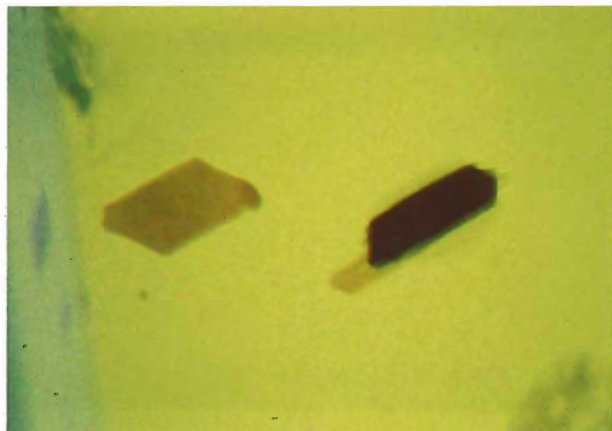


Figure 17. Decrepitation halos surrounding negative crystals, inclusion features descriptively known as “lily pads,” are also found in Kilbourne peridots. Photomicrograph by Edward J. Gübelin; magnified 21 ×.

decrepitation halos, are cleavages that result from the rupturing of tiny fluid-filled (usually carbon dioxide and natural glass) negative crystals.

**Glass Blebs.** Natural glass occurs in Kilbourne Hole peridot as blebs of various shapes, most commonly semicircular to somewhat oval, but often extremely elongated (figure 18). In all cases, examination with polarized light revealed behavior consistent with an amorphous compound such as glass.

Identification was confirmed by heating experiments. All of these inclusions contained shrinkage-related spherical bubbles. None of the bubbles was observed to move or change size during the slight heating that occurs on prolonged exposure to a microscope lamp. This, and the presence of more than one bubble per inclusion, proves that the fluid that fills the negative crystals has the high viscosity associated

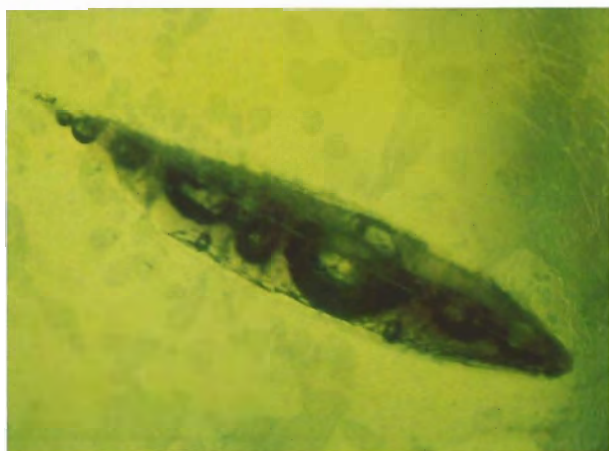
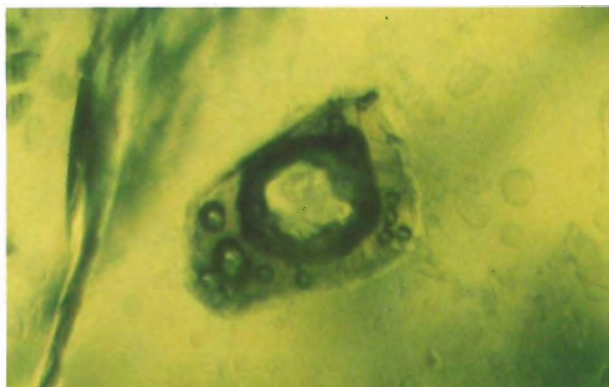


Figure 18. Natural glass inclusions, in a variety of shapes, were seen in several specimens of Kilbourne Hole peridot. All contained gas bubbles. Photomicrographs by John I. Koivula; magnified 50 ×.

with glass. Additional heating experiments performed by John Koivula of GIA revealed that these blebs soften at just below 1000°C, consistent with glass.

**Smoke-like Veils.** Previously noted in peridots from Arizona and China (Koivula, 1981; Gübelin and Koivula, 1986; Koivula and Fryer, 1986), smoke-like veiling is relatively common in Kilbourne Hole peridots (figure 19). It results from incomplete solid solution that occurs as the peridot is brought to the earth's surface and cools in the basalt, producing visible strain caused by dislocations (Kohlstedt et al., 1976). These veils always look like ghostly white streamers when viewed with darkfield illumination.

**"Fingerprints."** Partially healed secondary fractures in the form of fingerprint-like patterns (figure 20) were observed in a few of the Kilbourne Hole peridots. They resemble those found in peridot from Myanmar,

Egypt, and China (Gübelin and Koivula, 1986; Koivula and Fryer, 1986).

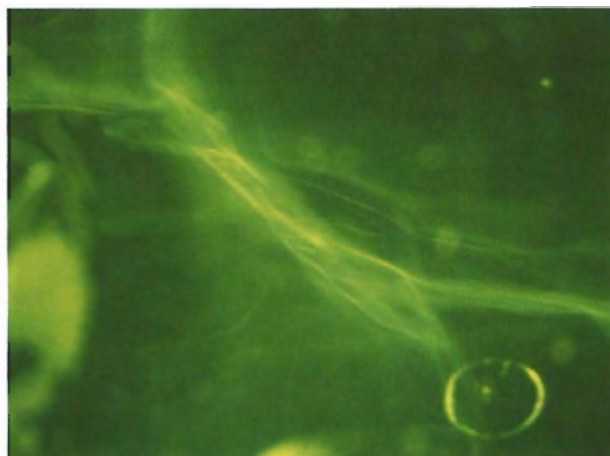
#### HEAT TREATMENT AND IRRADIATION

Co<sup>60</sup> irradiation of both faceted and rough specimens of Kilbourne peridot, including the samples described previously under "Chemical Composition," produced no observable change in color.

Twenty samples each from KH1 through KH4 were heat treated in air at 50° increments, from 100° to 750°C, for 10-hour periods. The rate of temperature increase was controlled by computer to 2°C per minute. No change was observed below 650°C. After 10 hours at 650°C, a brown surface coloration appeared. Following the period at 700°C, the brown surface coloration was accompanied by an oxide layer with a metallic luster. A final 10-hour heating, at 750°C, resulted in a "peacock-blue" oxidation over a layer of brown color. Similar iridescence was noted by Stockton and Manson (1983) on the surface of an Arizona peridot subjected to virtually identical heat-treatment conditions.

Between the 10-hour heating periods, samples were cooled to room temperature, sectioned, and polished. This revealed that only a surface layer—which was easily removed—had been affected. Where fractures existed in the original specimen, the oxidation invaded the fractures and appeared as orangy brown "stains."

Figure 19. Another relatively common internal feature of Kilbourne Hole peridot is smoke-like veiling. Photomicrograph by John I. Koivula; magnified 35 ×.



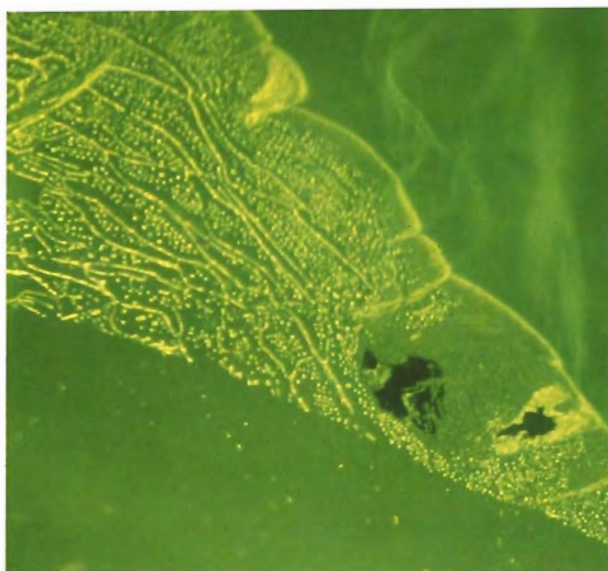


Figure 20. Also found in Kilbourne Hole peridots were partially healed secondary fractures that form "fingerprint" inclusions. Photomicrograph by John I. Koivula; magnified 40 ×.

## CONCLUSION

Kilbourne Hole produces exceptionally bright and lively faceted peridots with clarity and color comparable to fine yellow-green peridot from other gem localities. The gemological properties and chemical composition are consistent with those recorded for peridot. However, the Kilbourne Hole stones contain one inclusion, hercynite, that has not been reported in peridot from other sources. Moreover, Kilbourne Hole peridot virtually lacks the large black inclusions found in commercially available Arizona material. The body color does not respond to heat or radiation treatment.

While the Kilbourne Hole material appears to be plentiful, most cut gems are smaller than 1 ct. Currently, the deposit is not being actively worked.

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# OPAL FROM QUERÉTARO, MEXICO: FLUID INCLUSION STUDY

By Ronald J. Spencer, Alfred A. Levinson, and John I. Koivula

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*The distinctive orange-to-red "fire" opals from Querétaro have not been found in significant quantities at any other locality. Through modern analytical methods, it has been determined that these opals formed at about 160°C, from hydrous silica gels contained in fluids with small (up to 10%), variable amounts of NaCl and CO<sub>2</sub>. These data, combined with geologic data, help explain the rare occurrence of this type of rhyolitic opal deposit.*

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The Querétaro area, about 200 km northwest of Mexico City, has produced distinctive gem-quality opals for at least a hundred years. These opals occur in cavities and fractures within rhyolitic lava flows and are mined in open pits. They are unique among opals because of their unusual orange to red color and translucent to transparent diaphaneity (figure 1), unusually low refractive index (1.42–1.43, to as low as 1.37), and distinctive inclusions (see Koivula et al., 1983). They also represent the only significant amounts of gem-quality opal known to occur in a rhyolite. To date, however, little research has been conducted into the nature of the geologic environment that produced these unique stones.

Important clues to the geologic conditions that created a particular gem material can be found in its inclusions. Koivula et al. (1983) and Gübelin (1985,

1986) provide the only detailed investigations of inclusions in the opals from Querétaro. They report three-phase (rare), two-phase, and single-phase inclusions. Mineral inclusions identified by X-ray diffraction are hornblende (some altered to limonite), goethite, hematite, fluorite, quartz, cristobalite, and chalcedony. Kaolinite was tentatively identified by X-ray diffraction, and pyrite was identified visually. Several inclusions in opals from this area are also illustrated in Gübelin and Koivula (1986).

However, there has been no attempt to study the chemical compositions of the fluids and gases in the inclusions. Further, other than generalized statements to the effect that Mexican opals must have formed at high temperatures because they are in volcanic (lava) rocks (see, e.g., Gübelin, 1986), there has been no attempt to quantify their temperature of formation. We do know that Australian opals form at low temperatures from circulating groundwaters and are found in sedimentary environments (see, e.g., Keller, 1990).

The modern methods of *microthermometry* and *mass spectrometry* are ideally suited to obtain data that can be used to determine the composition of fluid and gas inclusions, and the temperature of formation of the host minerals. (Please see the "Glossary" for definitions of these and other technical terms indicated by italics in this article.) The authors have applied these methods to analyze fluid inclusions in these Mexican opals and thus gain a better understanding of their mode of formation.

#### ABOUT THE AUTHORS

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Figure 1. One of the most distinctive gem opals is the orange to red "fire" opal found in the area of Querétaro, Mexico. Here, cabochons of this material have been set—with rutilated quartz, agate, and sapphire—into an unusual pendant-and-earrings combination designed by Paula Kreviche. Courtesy of Paula Kreviche; photo © Harold & Erica Van Pelt.

## BACKGROUND

Fluid inclusions contain droplets of the mineral's nurturing environment that were caught in defects or other "traps" on the crystal surface during growth (Roedder, 1984). These features are frequently called "voids" in the gemological literature, but liquids usually fill these "voids" completely as long as the mineral remains at the elevated temperatures present during formation. Then, as the liquid cools and contracts, a tiny gas bubble may form in the space made available by the smaller volume of the cool liquid; this is frequently seen in quartz, Sri Lankan sapphires, and Colombian emeralds, among others. By gently heating a mineral until the gas is reabsorbed into the expanding liquid, we can establish the temperature at which the mineral grew, that is, the *homogenization temperature*. Further, if the fluid is solidified by freezing, we can estimate the chemical composition of

the fluid by determining: (a) the temperature at which the fluid freezes, and (b) the *melting point of the fluid*. The composition of gases trapped in fluid inclusions can be ascertained by opening the fluid inclusions under vacuum (by breaking the specimen) and then introducing the released gases into a *mass spectrometer*.

## EXPERIMENTAL METHODS

Several thousand tumble-polished opals were inspected with the microscope, but only a few were found suitable for the studies contemplated. These studies included:

- A. The slow, carefully controlled heating of four samples containing liquid-gas inclusions. A Fluid Inc. heating/freezing stage (figure 2) was used to determine the homogenization tem-

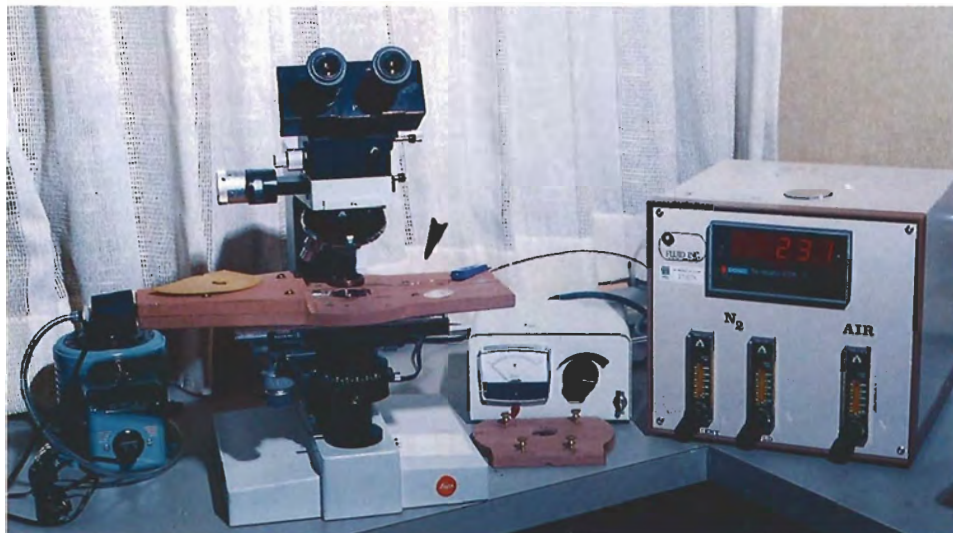


Figure 2. Microthermometric experiments were conducted using this heating-freezing stage (thin, brown in color; see arrow), which was set up on a petrographic microscope. This instrument allows the researcher to observe changes in the fluid inclusion as it is exposed to different temperatures—which are displayed on the right (23.1°C in this case)—at any moment during an experiment.

## GLOSSARY

**Clathrate** A solid containing water and a gas, which in this case is H<sub>2</sub>O plus CO<sub>2</sub>. These are stable only at low temperatures (the maximum temperature at which any solid CO<sub>2</sub> clathrate is stable is about +10°C).

**Decrepitation** When a mineral, such as opal, “breaks up” (fractures) on heating.

**Eutectic temperature** The lowest possible melting point in a multi-component (e.g., H<sub>2</sub>O-NaCl) system.

**Homogenization temperature** The temperature at which primary liquid-and-gas inclusions become a single phase, which is assumed to be equivalent to the host’s temperature of formation.

**Mass spectrometer** An instrument designed to measure the *molecular mass* of a gas (on the basis of which its composition can be determined).

**Melting point of fluids** The point at which a liquid that has been solidified by freezing (such as ice), melts when it is heated.

**Microthermometry** Observation under the microscope of changes caused by temperature variations.

**Molecular mass** The weight of one mole of a molecule. For water, H<sub>2</sub>O mass = 18.

**Phase separation** The process by which two phases form from one; e.g., a CO<sub>2</sub>-rich gas plus an aqueous liquid form from a single fluid state that contains both.

**Reversible (equilibrium)** A chemical/physical reaction that can be caused to change direction by a small change in temperature.

**Saline** Containing any dissolved salt, such as sodium chloride [NaCl].

**Supercooled liquid** A liquid that remains liquid below its normal solidification temperature, e.g., water that remains liquid below 0°C.

perature (assumed to be equivalent to the temperature of formation of the opal host).

B. Melting-point studies of the fluids from three of the above samples, and of certain crystals that form at freezing temperatures, to estimate the chemical compositions of the fluids.

C. Mass spectrometry of released gases from 30 samples to determine the compositions of the gases (figure 3).

Mass spectra were obtained at room temperature. The opals were placed under vacuum, and several background scans were made. The mass spectrometer was then set to scan when a pressure burst from the release of a gas was detected. To release the gases trapped in the fluid inclusions, we lifted ball bearings with a magnet and then dropped them on the samples. A *molecular mass* range of 1 to 125 was scanned at 3 milliseconds per mass unit.

## RESULTS

**Observations with the Microscope.** Most of the fluid inclusions in the Mexican opals studied here contained a single fluid or a fluid plus a solid (see, e.g., figure 4). To determine the nature of these inclusions, we attempted to induce the formation of a gas phase by “stretching”—that is, we heated the samples to build pressure within the fluid inclusions in order to “stretch” the enclosing solid (samples were heated to the point where they began to fracture and break apart, about 160°C). However, no gas phase formed on cooling of the inclusions to room temperature. If these fluid inclusions had been composed of water, this heating would have produced a stretching of the

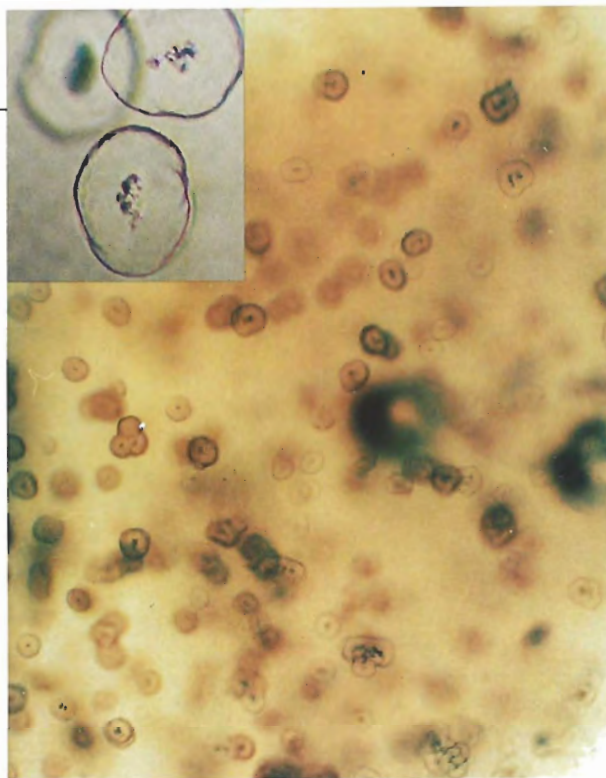
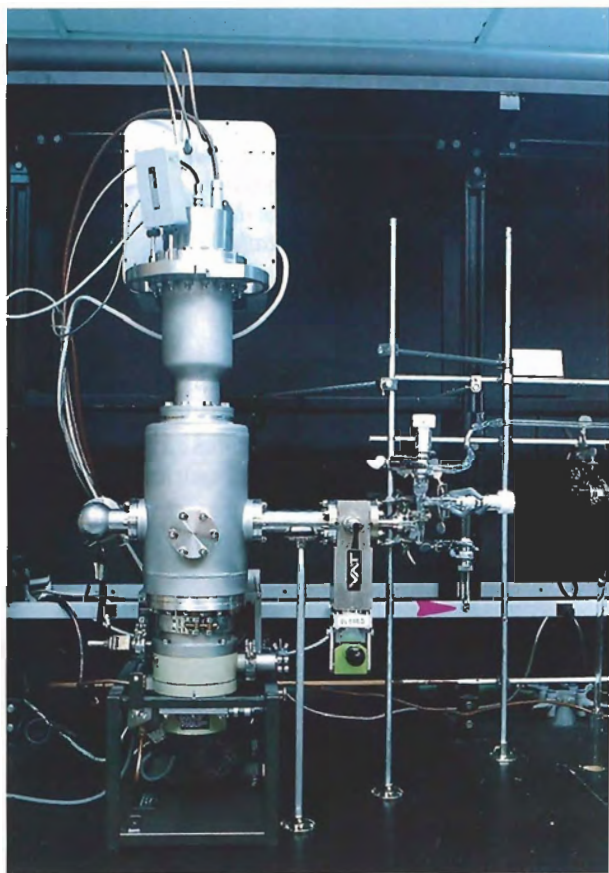


host opal as the water expanded, as occurs in aqueous inclusions in other minerals such as quartz and calcite. From the failure of the heating procedure to stretch the opal, we concluded that most of the fluid inclusions in Mexican opals (again, see figure 4) are composed of a gel rather than a liquid. To confirm our findings, we also cooled the samples to  $-120^{\circ}\text{C}$ . Similarly, we observed no changes.

Because these types of inclusions do not provide the information needed to analyze the temperature and composition of the original mineral-forming solutions, we subsequently limited our investigation to those fluid inclusions in which a gas was evident.

Of the four samples in which we had identified aqueous liquid-gas inclusions, one particularly useful specimen contained numerous liquid-gas (vapor) inclusions as well as liquid-solid and liquid-solid-gas inclusions. An overall view of this Mexican opal,

*Figure 3. This mass spectrometer (a quadrupole type) was used to determine the composition of the gases released from the opals. The arrow points to the chamber in which the sample is placed. Gases released from the sample pass through the glass tubing into the mass spectrometer for analysis.*



*Figure 4. These fluid and fluid-solid inclusions are typical of those observed in the thousands of Mexican opals examined. The major portion of the photograph was taken at  $50\times$ ; the inset, at  $580\times$ .*

which is about 1 cm in longest dimension, is shown in figure 5 (bottom center). The locations of selected fluid inclusions (labeled A through E) are shown on the overall view. The individual fluid inclusions are shown at higher magnification in the surrounding photographs. These inclusions have a variety of liquid-gas ratios, and two (A and B) also contain solids (crystals). From this sample, we obtained data that we believe, on the basis of our experience with similar materials, are representative of the opal-forming fluids from the Querétaro area.

**Microthermometry—Heating.** Homogenization temperatures were obtained from two-phase, aqueous liquid-gas, inclusions in one of the four samples mentioned above (not shown). The inclusions homogenized to a single liquid at about  $160^{\circ}\text{C}$ , just as the sample cracked and broke apart (*decrepitated*). Two of the other samples with two-phase, liquid-gas, inclusions decrepitated prior to homogenization.

The fluid inclusions in the fourth sample (figure 5) did not homogenize when heated to  $150^{\circ}\text{C}$  (the maximum temperature to which we heated them in order to avoid fracturing at  $160^{\circ}\text{C}$ ), which indicates that they formed at a temperature higher than  $150^{\circ}\text{C}$ , in qualitative agreement with the  $160^{\circ}\text{C}$  homogenization temperature found in the specimen mentioned above. Subsequently, valuable chemical information was also obtained from these fluid inclusions.

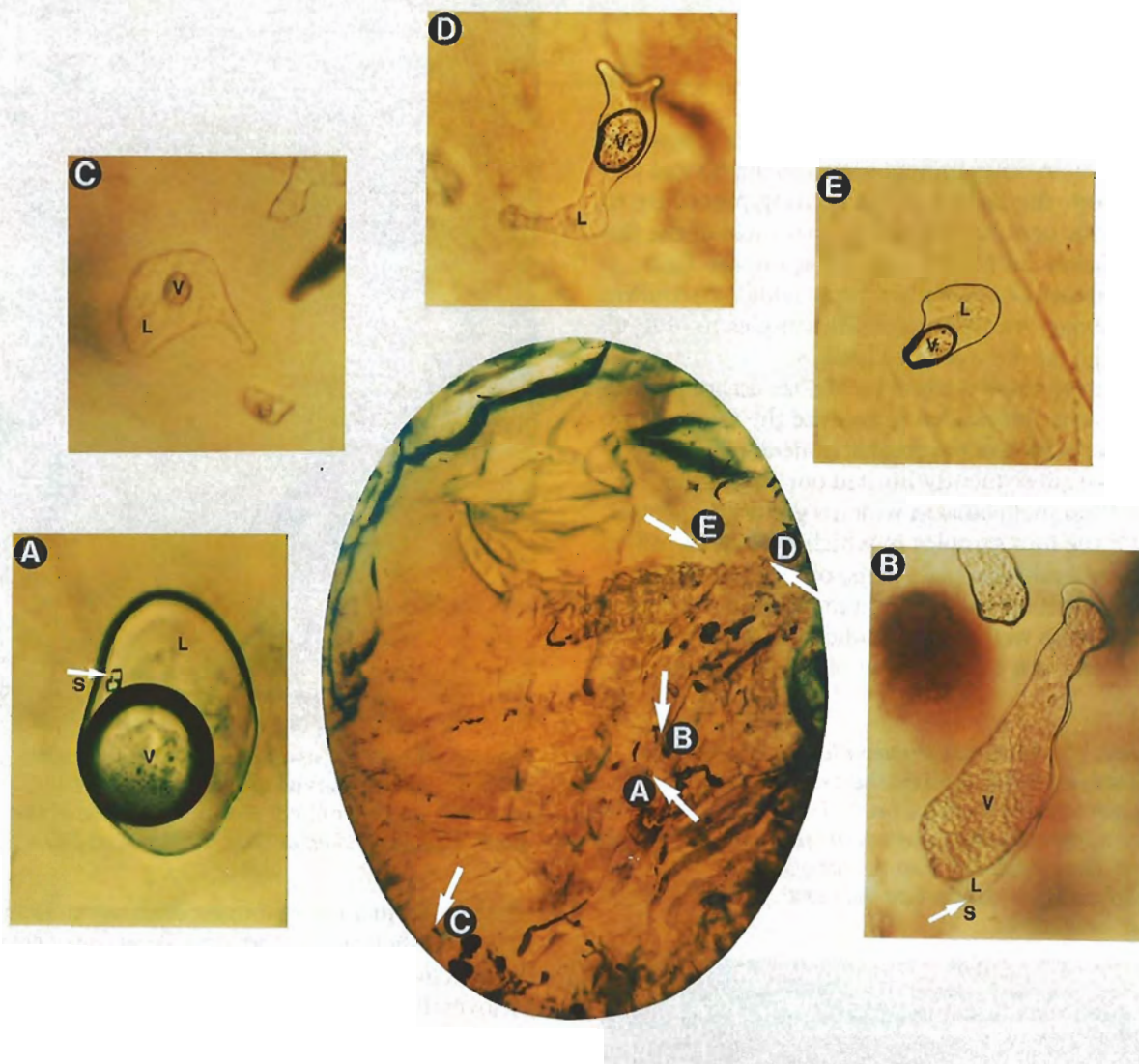


Figure 5. This specimen provided some of the most important data for this study. The large photograph is an overall view of the oval-shaped Querétaro opal, which is approximately 1 cm in longest dimension. Several individual fluid inclusions in the stone are labeled, A through E. Enlarged views of these fluid inclusions show liquid (L), solid (S), and gas (vapor-V) phases, as appropriate. See text for further details. Magnification of the individual inclusions is 235 ×.

**Microthermometry—Freezing.** Fluid inclusions in the sample shown in figure 5 were frozen (solidified) by circulating nitrogen gas through liquid nitrogen and blowing the resultant cold gas (temperature about  $-195^{\circ}\text{C}$ ) across the sample. All measurements were made during warming because the inclusion fluids are metastable on cooling; that is, *supercooled liquid* persists to a very low temperature ( $-100^{\circ}\text{C}$ ) before solids form. The solidified fluids (ice is an example of a solidified fluid) melt with a *reversible or equilibrium* behavior (ice may not form on cooling until  $-100^{\circ}\text{C}$ , but if pure it will always melt at  $0^{\circ}\text{C}$ ).

Fluid inclusions A and B (figure 5) began to melt when the frozen inclusions were warmed to about  $-22^{\circ}\text{C}$ . This is the  $\text{H}_2\text{O-NaCl}$  eutectic temperature; that is, it is characteristic of fluids that are domi-

nantly  $\text{H}_2\text{O-NaCl}$ . The final melting temperatures for these two frozen fluid inclusions were  $-2.1^{\circ}\text{C}$  and  $-7.7^{\circ}\text{C}$ , respectively, which indicates *salinities* (NaCl content) from near seawater composition (3.5 wt. %; seawater ice melts at  $-1.9^{\circ}\text{C}$ ) where the melting point is  $-2.1^{\circ}\text{C}$ , to salinities about three times seawater where the melting point is  $-7.7^{\circ}\text{C}$ .

Frozen fluid inclusions C, D, and E behaved quite differently on warming. They began to melt at about  $-8^{\circ}\text{C}$ , that is, at significantly higher temperatures than did frozen fluid inclusions A and B. Frozen fluid inclusion C had a final melting temperature of  $+0.6^{\circ}\text{C}$ , whereas frozen fluid inclusions D and E both had a final melting temperature of  $+1.7^{\circ}\text{C}$ . Other frozen fluid inclusions from this sample (not shown) had final melting temperatures as high as  $+1.8^{\circ}\text{C}$ .

These high final melt temperatures indicate the melting of a *clathrate*, rather than ice. Mass spectrometry was used to identify the composition of this clathrate as well as that of the saline inclusions A and B.

**Mass Spectrometry.** When fluid inclusion B was cracked, the released gas produced a spectrum in the mass spectrometer that showed only H<sub>2</sub>O (figure 6, left; the NaCl present is not detected by the mass spectrometer because it is not gaseous). However, the vapor released when fluid inclusion C was cracked produced a spectrum (figure 6, right) that shows significant carbon dioxide (CO<sub>2</sub> major peak at mass 44) in addition to H<sub>2</sub>O. Because other fluid inclusions may have opened at the time the sample was broken, it is difficult to quantify the composition of any individual inclusion.

Mass spectra were also obtained from 29 samples containing one- and two-phase (fluid-solid) inclusions (again, see figure 4). These mass spectra showed only H<sub>2</sub>O peaks. We did not observe other gases (such as nitrogen or oxygen) in any of the fluid inclusions analyzed. We believe, because only H<sub>2</sub>O was released and because of the heating and freezing behavior of these fluid inclusions, that they contain hydrous silica gel. Although no gaseous phase was produced in the stretching experiments discussed above, the very high vacuum conditions of the mass spectrometer enabled the extraction of H<sub>2</sub>O from the hydrous gel.

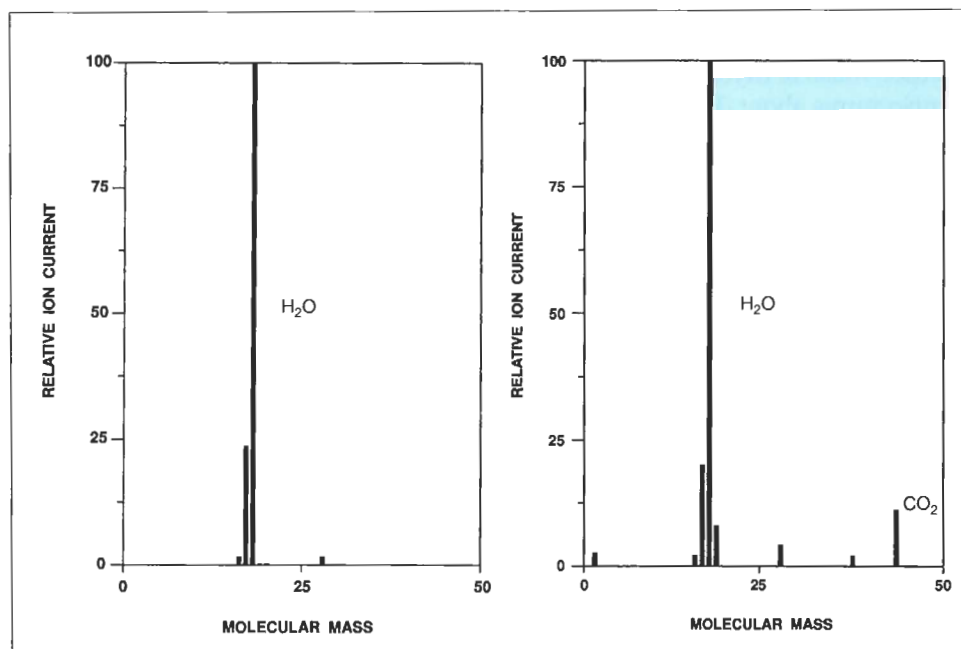
## DISCUSSION

Like numerous other researchers (see, e.g., Roedder, 1984), we believe that large, isolated, fluid inclusions similar to those found here are primary and were trapped as the opals formed.

The most common type of fluid inclusions observed in the Mexican opals we examined were one- and two-phase, fluid and fluid-solid. We did not attempt to identify the solid phases, which have been studied in detail by Koivula et al. (1983) and Gübelin (1985). Because these fluid/fluid-solid inclusions (see figure 4) exhibited no change on heating or cooling and produced spectra that showed only water in the mass spectrometer, we interpret these inclusions to be dominantly hydrous silica gel, and we believe that the opals formed from these gels. The solids in the fluid inclusions are likely "trapped" rather than "daughter" crystals, in agreement with the conclusions of earlier workers (Koivula et al., 1983; Gübelin and Koivula, 1986). The "trapped" crystals, labeled "S" in figures 5A and 5B, are rhombohedral and have high birefringence, so they are assumed to be a carbonate mineral (e.g., calcite).

Homogenization temperatures were obtained from fluid inclusions in one sample that contained an aqueous liquid and gas at room temperature. The fluid inclusions homogenized to a liquid at about 160°C, just as the opal decrepitated. The temperatures obtained from these fluid inclusions and the failure of any of the two-phase, liquid-gas, inclusions from oth-

Figure 6. These mass spectra reveal that fluid inclusion B (left) of figure 5 contains only water, and fluid inclusion C (right) of figure 5 contains both water and carbon dioxide (CO<sub>2</sub>). Relative ion current is a measure of the abundance of the gases.



er samples to homogenize up to 150°C indicate that these opals trapped fluids during their formation at temperatures near or slightly above 160°C.

NaCl is believed present in inclusions A and B of the stone shown in figure 5 on the basis of their melting temperatures. Carbon dioxide was identified in inclusions C, D, and E of this same specimen on the basis of melting point and mass spectrometry, and we believe that the low-temperature solids observed to melt above 0°C in these fluid inclusions are CO<sub>2</sub>-H<sub>2</sub>O clathrates.

The wide range of liquid-gas ratios in the fluid inclusions from the sample shown in figure 5 also suggests that both phases are primary. Because these inclusions do not contain atmospheric gases (nitrogen or oxygen), we conclude that the different liquid-gas ratios are not a result of the leakage of fluids and their replacement by a gas. Rather, these inclusions were trapped in a system in which both liquid and gas were present (i.e., a boiling system) in varying proportions and represent the composition of the opal-forming solutions.

#### SIGNIFICANCE FOR EXPLORATION

The data obtained in this study permit us to speculate both on why gem-quality opals of the Mexican type appear to be unique to this area and on the geologic setting in which additional deposits might be found. It is important to recognize that these gem materials occur in rhyolitic lava flows as secondary fillings in gas cavities or other available sites (Koivula et al., 1983). Rhyolite in general, and rhyolitic flows in particular, are much less common than basalt and andesite, the most abundant types of volcanic rocks. Further, rocks of rhyolitic composition crystallize at temperatures about 300°C lower than those of the more abundant volcanics (rhyolite, 800°C; basalt, 1100°C). The silica (SiO<sub>2</sub>) content of rhyolite (70%) is also considerably higher than that of basalt (50%), and the contents of other major elements (Fe, Mg, Ca, Al) are much lower.

The interaction of waters of moderate salinity (whose origins could be either meteoric or hydrothermal, or mixtures of both) with surrounding rhyolitic rocks will result in waters with a high proportion of silica in solution, but low contents of other elements. Such waters probably obtained their high dissolved silica content, the precursor to the hydrous silica gel, through interaction with rhyolites while they were still hot. Subsequently, the opal precipitated from the hydrous silica gel in cavities and other appropriate sites as the water cooled to 160°C. For these opals to have been preserved, it is essential that the host rocks were never reheated above this temperature.

The several required factors—the rhyolitic composition of the rock (particularly the high SiO<sub>2</sub>), the low abundance of other elements (e.g., Fe, Mg, Ca, Al) that might have resulted in the precipitation of other minerals (e.g., zeolites, clays), the proper water temperatures for both leaching and precipitation, and the absence of overheating—in combination resulted in the rare occurrence of this gem material. Further exploration must take these factors into account.

#### CONCLUSIONS

The "fire" opals mined in Querétaro, Mexico, are interpreted to have formed at temperatures near or slightly above 160°C, in a hydrothermal system isolated from the atmosphere, from a hydrous silica gel that is present in many of the fluid inclusions. The aqueous fluids contain mixtures of H<sub>2</sub>O, NaCl, and CO<sub>2</sub> that were trapped in some fluid inclusions. It appears that some of the fluids underwent *phase separation* (boiling) during formation of the opals. Because carbon dioxide—along with different proportions of H<sub>2</sub>O—is preferentially lost from fluids during phase separation, this resulted in the trapping of different proportions of aqueous liquid, water vapor, carbon dioxide, and sodium chloride.

Exploration for Mexican-type opals elsewhere in the world must consider the unusual combination of geologic factors required to form this type of deposit.

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# NATURAL-COLOR NONCONDUCTIVE GRAY-TO-BLUE DIAMONDS

By Emmanuel Fritsch and Kenneth Scarratt

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*Two new categories of gray-to-blue diamonds are described. First, two type IIb blue crystals with what appears to be a type IIa outer skin were not electrically conductive in the rough, but conducted electricity once faceted. Second, some non-electrically conductive gray-to-grayish blue diamonds from the Argyle mine, Australia, were determined to be type Ia and to contain unusually high amounts of hydrogen. This latter type of coloration, not previously reported for diamonds, may be due to hydrogen-related defects in the crystal structure.*

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To date, all natural-color blue diamonds described in the literature have been electrically conductive. In fact, the measurement of electrical conductivity has been a major deciding factor in gemological testing for artificial coloration in blue diamonds: All natural-color stones were believed to be type IIb and electrical conductors, whereas all laboratory-irradiated stones were insulators (Custers, 1954; Liddicoat, 1987). However, the authors have examined several diamonds in the gray-to-blue range—known to be natural color because of other tests or the fact that they were obtained directly from the mine—that did *not* conduct

electricity. Moreover, the ultraviolet luminescence of these stones was significantly different from that of the majority of natural blue and bluish gray diamonds.

This report presents the gemological properties of what appear to be two new categories of blue diamonds. First, we studied two crystals that did not test positive for electrical conductivity in the rough, but were electrically conductive after they had been cut. Second, we examined four faceted stones, all from the Argyle mine in northwestern Australia, that are type Ia, insulating, gray-to-grayish blue diamonds, in contrast to the type IIb character expected for diamonds of similar color (see Box A for a detailed discussion of diamond types).

#### ABOUT THE AUTHORS

Dr. Fritsch is manager of the Research Department at the Gemological Institute of America, Santa Monica, California. Mr. Scarratt is chief executive officer of the Gem Testing Laboratory of Great Britain, London.

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#### MATERIALS AND METHODS

Table 1 gives a basic description of the six diamonds studied for this article. Stones A and B (rough and cut) and C (cut) were examined and color graded at the Gem Testing Laboratory of Great Britain (GTL-GB); faceted stones A and B, as well as stones D, E, and F, were examined at GIA Research and color graded at the GIA Gem Trade Laboratory. The color descriptions provided by each lab are noted in the table. We do not know the locality of origin of stones A and B, but stones C to F came from the Argyle mine in northwestern Australia.

Using a standard voltmeter for the stones tested in the GTL-GB and a GIA-GEM conductometer for those tested in GIA Research, we measured electrical conductivity as the difference in potential between two separate points on the surface of the diamond. We recorded ultraviolet-visible absorption spectra at liquid-nitrogen temperature using a Pye-Unicam 8800 spectrophotometer. Infrared spectra were recorded in a transmission mode on a Nicolet 510 (GTL-GB) or a 60SX (GIA Research) FTIR spectrometer at room temperature, with a resolution of 4 cm<sup>-1</sup>.

### NONCONDUCTIVE BLUE DIAMOND CRYSTALS

Stones A and B were first examined in the rough and found to be electrical insulators, although they displayed the grayish blue-to-blue colors typical of natural blue diamonds. One should note that it may sometimes be difficult to detect electrical conductivity on rough type IIb stones, because their irregular shape and etched surface may not allow a good electrical contact. Our measurements, however, were

conducted with sharp probes to ensure the best contact. These stones appeared to be a true anomaly, as the infrared absorption spectra of both were in fact typical of type IIb, electrically conductive diamonds.

Stone A was retested for electrical conductivity both during the cutting operation and after its completion. Stone B was retested only after faceting was completed. Faceting of stone A produced a 4.15-ct fancy bluish gray pear shape; faceting of stone B resulted in a remarkable 3.06-ct fancy dark blue square cushion cut (figure 1). Stone A was found to conduct electricity after it had been blocked; both A and B did so after faceting. The infrared spectra of both stones after cutting were the same as those taken on the rough. Because stone B is significantly bluer than stone A, the former showed stronger absorption in the region above 3000 cm<sup>-1</sup>. Truly blue diamonds (those without a secondary color modifier) generally exhibit stronger type IIb absorptions in the infrared than grayish blue-to-bluish gray stones. A small hump at about 1295 cm<sup>-1</sup>, although situated in a region where absorptions due to nitrogen typically occur, is

**TABLE 1.** Description of the six natural-color diamonds.

Sample	Weight (ct)	Color	Shape	Comments	Type <sup>a</sup>	Electrical conductivity	Ultraviolet luminescence <sup>b</sup>	
							Long-wave	Short-wave
<b>A</b>								
Before faceting	12.83	Gray blue <sup>c</sup>	Roughly triangular		IIb	No	————	————
After faceting	4.15	Fancy bluish black <sup>c</sup> Fancy bluish gray <sup>d</sup>	Pear shape		IIb	Yes	V. wk. orange	Wk. to mod. orange V. long reddish orange phosphorescence
<b>B</b>								
Before faceting	5.38	"Royal blue" <sup>c</sup>	Roughly triangular	Radiation stains	IIb	No	————	————
After faceting	3.06	Fancy blue <sup>c</sup> Fancy dark blue <sup>d</sup>	Square cushion	Internally flawless	IIb	Yes	Inert	Mod. orange Reddish orange phosphorescence
<b>C</b>	0.30	Grayish blue <sup>c</sup>	Emerald cut	From Argyle mine	Ia	No	Strong yellow Wk. to mod. phosphorescence	Wk. orangy yellow Wk. to mod. phosphorescence
<b>D</b>	0.34	Fancy gray <sup>d</sup>	Round brilliant	From Argyle mine	Ia	No	Strong yellow Wk. to mod. phosphorescence	Wk. orangy yellow Wk. to mod. phosphorescence
<b>E</b>	0.75	Fancy gray <sup>d</sup>	Marquise	From Argyle mine	Ia	No	Not tested	Not tested
<b>F</b>	0.68	Fancy gray <sup>d</sup>	Pear	From Argyle mine	Ia	No	Mod. yellow Wk. to mod. phosphorescence	Wk. yellow Wk. to mod. phosphorescence

<sup>a</sup> As determined by infrared spectroscopy.

<sup>b</sup> Abbreviations: v. = very, wk. = weak, mod. = moderate.

<sup>c</sup> Color terminology of the Gem Testing Laboratory of Great Britain.

<sup>d</sup> Color terminology of the GIA Gem Trade Laboratory.

a feature observed in the spectra of all natural type IIb diamonds (see, e.g., Smith and Taylor, 1962).

From our observations, one can only assume that the outer skin of both crystals consisted of a different diamond type, one that is not electrically conductive. This layer was not detected by infrared spectroscopy, either because it was probably of type IIa diamond, and therefore did not modify the shape of the infrared spectrum, or because it was of type Ia but too thin to induce a measurable absorption. The nonconductive layer was undoubtedly removed during faceting, so that the two stones conducted electricity afterward. This is a good example of the presence of two different diamond types within the same crystal, a concept that is not always made clear in the gemological description of diamonds (again, see Box A).

Interestingly, faceted stones A and B were also found to exhibit unusual luminescence behavior after faceting. Most natural blue diamonds are inert to ultraviolet radiation, both long- and short-wave, or show only an extremely weak yellow phosphorescence to short wavelengths. When exposed to long-wave U.V. radiation, stone B was inert but stone A emitted a very weak orange luminescence. When exposed to short-wave U.V., however, both stones produced a reddish orange luminescence of weak-to-moderate intensity. This light emission was followed by a persistent reddish orange phosphorescence after the ultraviolet lamp was turned off. The phosphorescence lasted unusually long in stone A: It was visible for more than four minutes in a completely darkened room. These two stones are therefore similar in their fluorescence characteristics to the Hope diamond (Crowningshield, 1989). Sometimes, blue



Figure 1. The crystals from which this 4.15-ct fancy bluish gray pear shape (stone A) and 3.06-ct fancy dark blue cushion modified brilliant (stone B) were fashioned were not electrically conductive, although the faceted stones are. Diamonds courtesy of Mr. R. Vainer and Mr. Th. Horovitz; photo by Robert Weldon.

diamonds are represented as having been cut from the same rough as the Hope because of their orangy red luminescence. Stone B provides a well-documented counter-example to this naive belief.

Of additional interest was the presence in stone B of brown radiation stains on the surface of the rough (figure 2). Such stains are known to result from irradiation by alpha particles, possibly coming from uranium radioisotopes (Meyer et al., 1965). Although they are fairly common on type Ia diamonds, radiation stains have been reported only once before on type IIb diamonds (Hargett, 1991).

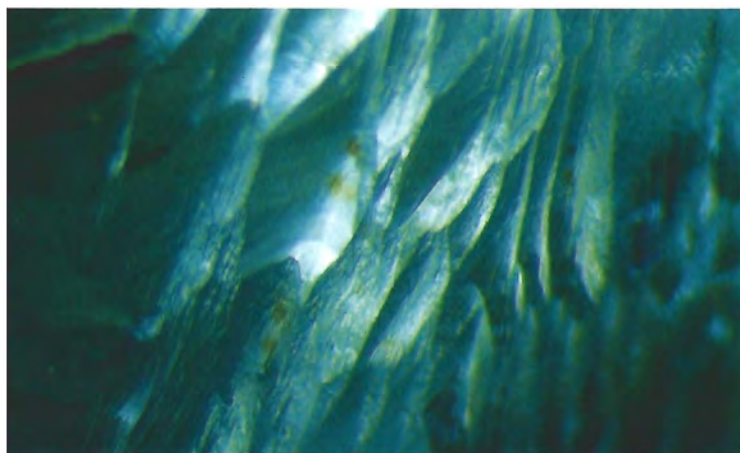


Figure 2. Brown radiation stains were observed on the surface of stone B before it was faceted. Photomicrograph by Kenneth Scarratt; magnified 10 $\times$ .

## BOX A: A NOTE ON DIAMOND TYPES

An ideal diamond crystal is colorless and its structure is made exclusively of carbon atoms, regularly arranged in a perfect lattice. Most natural gem diamonds, however, contain a number of defects and/or impurities, which may significantly affect some of the physical properties, such as color or electrical conductivity, of the stone. Some impurities such as nitrogen or boron may substitute for carbon atoms, which means that one carbon atom is replaced by one nitrogen or boron atom in the diamond structure. When a carbon atom is missing, the empty volume it leaves in the structure is called a vacancy.

To account for the differences in physical properties observed, in 1934 Robertson et al. conveniently grouped diamonds into two main "types"—type I and type II. Historically, these types have been distinguished on the basis of their ultraviolet transparency and absorption in the infrared—specifically in the 1000–1400  $\text{cm}^{-1}$  section (also called "the nitrogen region") of the mid-infrared range (Clark et al., 1979).

The characteristic absorption features in the infrared spectra of type I diamonds (see figure A-1) have been attributed to the presence of nitrogen in a number of different forms. Type I diamonds can be further subdivided into types Ia and Ib depending on the form that the nitrogen takes within the crystal structure of the individual stone. The nitrogen in type Ia diamond is present in various aggregated forms. The A aggregate is a pair of singly substituting nitrogen atoms, and the B aggregate is formed from an even number of nitrogen atoms, not exceeding eight (Bursill and Glaisher [1985] propose four nitrogen atoms surrounding a vacancy). The presence of one of these two aggregates allows type Ia diamonds to be further categorized into two subdivisions, types IaA and IaB, according to which aggregate is involved. However, most Ia diamonds contain both the A and the B forms in various proportions (and are sometimes noted for this reason as type IaAB; the spectrum of the type Ia diamond in figure A-1 is that of a type IaAB diamond). Another aggregate center, the N3 center, composed of three nitrogen atoms surrounding a vacancy, is believed to be formed by a minor side reaction during the main aggregation process of A to B (Woods, 1986). This aggregate is responsible for the N2 and N3 systems, which are best known to gemologists as "Cape lines" or "Cape series" in the visible-range absorption spectrum. Note that the A and B aggregates have characteristic absorption features in the infrared (and none in the visible), whereas the N3 center has typical absorption features in the visible (but none in the infrared).

Type Ia diamonds usually contain large amounts of nitrogen impurity (1000 ppm is common, but they may

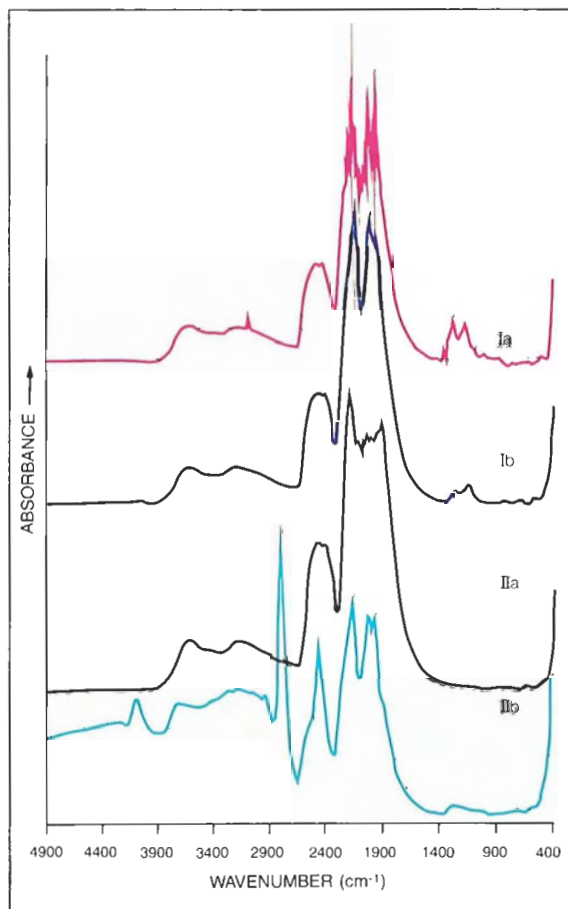


Figure A-1. These infrared spectra illustrate the four basic types of diamond. Each type can be characterized by its transmission in the 1000–1400  $\text{cm}^{-1}$  range. In addition, absorption in that range identifies some of the kinds of aggregates present in type Ia diamonds.

have up to 3000 ppm; see Field, 1983). Depending on the strength of the "Cape series," type Ia diamonds may vary in hue from near-colorless (possibly a weak band at 415 nm, with none of the other bands in the series being present) to a deep "Cape" yellow (in which all of the bands in the series are present in some strength, particularly the 478-nm band). Other factors may sometimes affect the color, and type Ia diamonds are effectively opaque to wavelengths shorter than 300 nm. The vast majority of gem diamonds are type Ia.



Type Ib diamonds are distinguished by the fact that the nitrogen atoms they contain are dispersed in isolated substitutional sites (i.e., one nitrogen atom replaces one carbon atom in a number of carbon atom sites). These nitrogen atoms produce a characteristic infrared absorption feature with a peak at  $1131\text{ cm}^{-1}$  (again, see figure A-1). Type Ib diamonds contain only small amounts of nitrogen (usually about 25 to 50 ppm, but 500 ppm has been reported for synthetic type Ib diamonds; Clark et al., 1979; Field, 1983). The dispersed nitrogen atoms are responsible for the continuous and gradual absorption of wavelengths shorter than 560 nm (Clark et al., 1979). Therefore, type Ib diamonds generally do not show sharp absorption lines in the hand-held spectroscope, in contrast to type Ia stones. Their absorption in the visible region tends to produce a deep yellow (in rare instances, brown) body color. Because of the deep yellow color, such diamonds are sometimes referred to in the trade as "true canaries." Type Ib diamonds are said to be rare, at least among gem-quality crystals.

The total amount of nitrogen present in type I diamonds is the sum of nitrogen contained as singly substituting nitrogen, A and B aggregates, N3 centers, and other nitrogen-containing defects that do not absorb in the visible or infrared range.

Type II diamonds do not show any of the nitrogen-related absorption features in the infrared that are present in type I stones (again, see figure A-1), and therefore they are believed to contain no significant amount of nitrogen (Field, 1979). It is interesting to note that the definition of type II diamonds actually rests on an instrumentation limit, that is, the detection limit of the infrared spectrometer used. With the advances that have been made in infrared spectroscopy, especially the development of the more sensitive Fourier-Transform infrared (FTIR) spectrophotometer, a diamond formerly identified as a pure type II might today be called, for example, a type Ia diamond with a very low nitrogen content.

Type II diamonds that do not conduct electricity are designated type IIa. They may contain up to 20 ppm of nitrogen (not detected by infrared spectroscopy; Badzian et al., 1986). These diamonds are very transparent in the short-wave ultraviolet range, down to approximately 230 nm. By testing stones for their short-wave ultraviolet transparency, gemologists have generally been able to successfully separate type IIa diamonds from other diamonds in the absence of sophisticated equipment (Fryer, 1981). Unless type IIa diamonds contain structural defects, they do not absorb visible light; therefore, they are usually colorless. While famous colorless diamonds such as the Cullinan and Koh-i-Noor gems are type IIa, other type IIa diamonds may have a yellow to brown or pink body color, due to unknown color centers (Collins, 1982). Type IIa gem diamonds are believed to be rare.

Type II diamonds that conduct electricity have been called type IIb. Natural-color blue diamonds reported prior to this article have all been type IIb. Type IIb stones show a distinct spectrum extending over the whole mid-infrared range that is quite different in appearance from that of the other types (again, see figure A-1). Such stones contain boron as an impurity, in concentrations of a few parts per million or less (Lightowers and Collins, 1976; Badzian et al., 1986). They transmit light down to about 230 nm (as do type IIa). The boron atoms create an absorption in the near infrared that extends into the visible range, absorbing some of the red and orange; therefore, type IIb diamonds are commonly blue. However, their color often shows a gray component, and sometimes they are pure gray. Occasionally, when very pale, they appear to be near-colorless.

The differences in these diamond types relate to differences in trace-element chemistry. For example, the average nitrogen concentration decreases from types Ia to Ib to II. Boron has so far been reported only in type IIb stones (Field, 1979). Hydrogen has been found exclusively in type I stones (Fritsch and Scarratt, 1989). Diamond types are, therefore, more than just a convenient way to classify diamonds on the basis of their infrared spectra; they also have potentially important geochemical significance. For example, different types of diamond may represent different geologic origins.

The relative rarity of the various diamond types reported here reflects the figures provided in the preponderance of the literature (e.g., Field, 1983). Although it provides a "common wisdom" on the subject, one should keep in mind that the proportions cited (presumably) for all diamonds mined may not necessarily apply to diamonds of gem quality, or to colored diamonds or any other subgroup. For example, Tolansky and Rawle-Cope (1969) demonstrated that there is an unusually high proportion of type IIa diamonds among high-clarity microdiamonds, whereas type IIa diamonds are reported (by Field, 1983) as being uncommon in gem quality.

In many articles describing diamonds, it is generally implied that one diamond crystal contains only one diamond type. Actually, most diamond crystals are a more or less homogeneous mixture of different types. For example, most natural type Ib diamonds have a type IaA component, too, which can be recognized in their infrared spectra. Also, Milledge et al. (1989; see also Boyd et al., 1987) demonstrated that type Ia diamond shows very thin growth banding of various "nuances" of diamond types, such as a strong variation in the relative proportion of A and B aggregates. Gemologists should remember, for gem identification procedures, that many gem diamond crystals may not be composed of one single diamond type.



Figure 3. Stone E in this study is a natural-color gray non-electrically conductive type Ia diamond from the Argyle mine, in northwestern Australia. Stone courtesy of Argyle Diamonds; photo by Robert Weldon.

### NONCONDUCTIVE GRAY-TO-GRAYISH BLUE DIAMONDS FROM ARGYLE

Stones C to F were all tested as faceted stones. Although the gray-to-grayish blue colors they display resemble those normally seen in natural type IIb, electrically conductive, diamonds (figure 3), they do not conduct electricity. Moreover, their ultraviolet-visible absorption spectra differ significantly from that which is perceived as normal for gray-to-blue diamonds (Collins, 1982), as do their infrared spectra.

These stones fluoresced a moderate to strong yellow to orangy yellow to long-wave ultraviolet radiation, and a weak to moderate yellow to orangy yellow to short-wave U.V. They also displayed a weak to moderate yellow phosphorescence to both wavelengths. Although we could find no prior reference to such luminescence behavior in natural gray-to-blue diamonds, it is not uncommon for type Ia faceted diamonds.

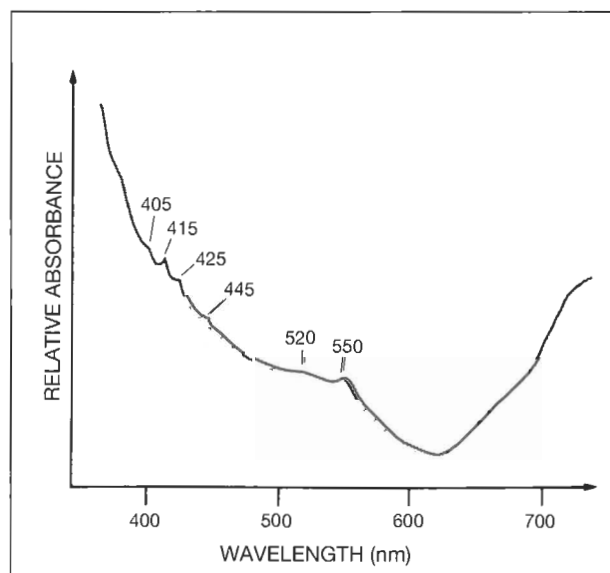
The U.V.-visible absorption spectra of stones C to F (figure 4) show two bands, at 405 and 415 nm, that are superimposed on the increasing absorption toward the ultraviolet (the "U.V. cutoff"). They represent the N3 center, which is responsible for the "Cape lines" commonly found in the visible spectra of type Ia diamonds but has not been reported to occur in natural blue diamonds. Two weak absorptions at about 425 and 445 nm are accompanied by a broad, complex absorption system that has an apparent maximum at about 550 nm and a distinct shoulder near 520 nm. Absorption increases from approximately

600 nm toward the infrared. With the exception of the N3 system, these features have not been described previously in the literature on the spectra of diamonds (although some features at approximately the same wavelengths but with different shapes or widths have been reported).

At present, we cannot explain the variation in hue among these stones. Answering this question would require a detailed study of transmission spectra and thus the availability of parallel-window samples of known thickness, which are virtually impossible to obtain on gem-quality—especially faceted—diamonds of such great value.

Since the spectra of stones C to F reveal that they are type Ia rather than IIb, their lack of electrical conductivity cannot be explained by a zonation of diamond type within the stone, as in the situation described for the two pieces of rough. Most remarkably, the infrared spectra of all four stones show very sharp bands at about 1498, 2786, and 4499  $\text{cm}^{-1}$ , with two very intense ones at 3107 and 3237  $\text{cm}^{-1}$  (figure 5). There are also a number of related absorptions in the near-infrared (around 5555, 5880, 6070, 7500, 7850, 8255, and 8615  $\text{cm}^{-1}$ ), some relatively new to the scientific literature (Fritsch et al., 1991). In fact, the spectrum in figure 5 is similar to that reported by Fritsch and Scarratt (1989) as typical for a group of

Figure 4. The U.V.-visible absorption spectrum of the gray diamond (stone E) in figure 3 proves that it is a type Ia diamond.



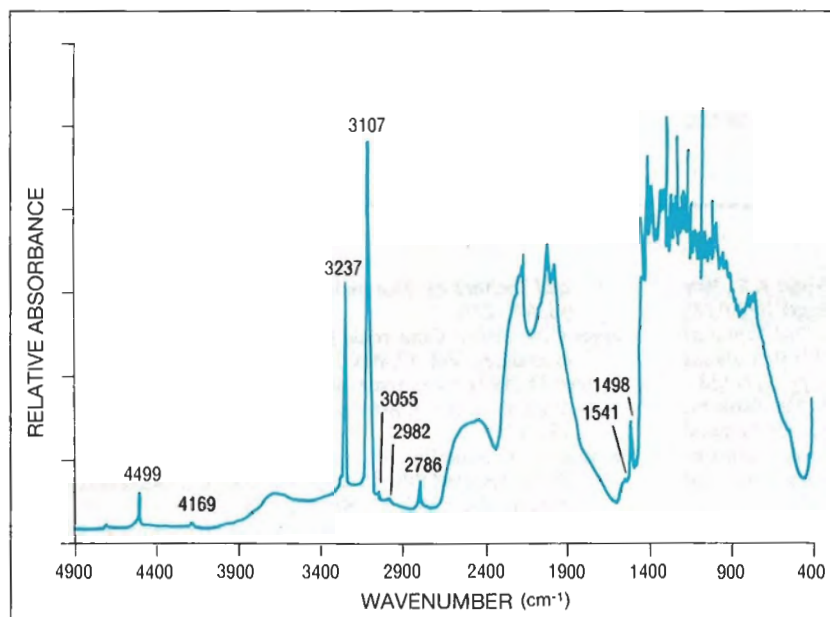


Figure 5. The room-temperature mid-infrared absorption spectrum of stone E, while unusually intense for diamonds, is typical of those recorded to date for gray-to-blue diamonds from the Argyle mine, Australia. The sharp bands at 2786, 3107, 3237 and 4499  $\text{cm}^{-1}$  are due to hydrogen. The “noise” between 1400 and 600  $\text{cm}^{-1}$  is due to complete absorption of these energies by the diamond.

diamonds with a gray component to their color. The sharp bands at 3107 and 3237  $\text{cm}^{-1}$  in figure 5 have been attributed to hydrogen complexes (Woods and Collins, 1983; Davies et al., 1984). They are, however, unusually intense in these Argyle diamonds.

In fact, these unusually intense absorption features related to hydrogen have been observed in over 100 colored diamonds from various sources that we have studied. We have found distinctive absorption features or behavior (a list is provided in Fritsch et al., 1991) in all of these “hydrogen-rich” diamonds, which can be brown to yellow to gray, gray to blue or violet, white (opalescent), or exhibit a “chameleon” behavior. The broad absorption complex around 550 nm reported for the stones examined for this article is one of these unusual absorptions, and is responsible for a gray-to-blue coloration. This absorption complex has been observed in more than a dozen stones, always in association with very strong hydrogen bands in the infrared. This suggests that the presence of the 550-nm absorption complex and the other unusual absorption features associated with it correlates to the presence of hydrogen-related defects. Quantitative research is ongoing to confirm this hypothesis.

## DISCUSSION AND CONCLUSIONS

The samples described here demonstrate the existence of natural-color gray-to-blue diamonds that do not test positive for electrical conductivity, some in

the rough and others in faceted form. We conclude that there are natural-color non-electrically conductive gray-to-blue diamonds, and that the absence of electrical conductivity should not be used as the sole criterion in identifying a diamond in this color range as treated. Of course, electrically conductive gray-to-blue natural diamonds are invariably of natural color (with the exception of the currently very rare, noncommercially available near-colorless diamonds that have been treated with blue synthetic diamond thin films; as reported by Fritsch in Koivula and Kammerling, 1991). Therefore, gray-to-blue diamonds can no longer be separated from their treated counterparts on the basis of electrical conductivity alone.

We have also described here a number of previously unreported absorption features in the visible spectrum that appear to be responsible for a newly observed kind of blue-to-gray coloration in gem diamonds. We believe that these features may be related to the presence of unusually high concentrations of hydrogen. Previously, nitrogen—mostly in combination with structural defects—and boron were the only trace elements thought to play a role in the coloration of diamonds. To the best of our knowledge, this is the first time that hydrogen has been suggested as a cause of color in diamonds.

So, when a gray-to-grayish blue diamond does not test as electrically conductive, luminescence must be taken into greater consideration. If the stone exhibits a yellow to yellow-green luminescence that

is stronger to long- than short-wave ultraviolet radiation, and produces a moderate yellow phosphorescence after exposure to both wavelengths, it is probably a natural-color diamond that belongs to the

new category of blue-to-gray diamonds described here. We recommend, however, that U.V.-visible and infrared absorption spectroscopy be used to confirm this diagnosis.

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# PERIDOT AS AN INTERPLANETARY GEMSTONE

By John Sinkankas, John I. Koivula, and Gerhard Becker

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*The stony-iron meteorites known as pallasites are famed for the areas of yellowish green olivines they contain. Since the earliest description by Peter Simon Pallas in the 18th century, reference has been made to the gem-like nature of these meteorite "inclusions." Not until the early 20th century, however, was there any record of a faceted pallasitic olivine, and only recently have a handful of stones been available for gemological examination. Study of nine peridots faceted from pallasites revealed properties within the range known for peridots plus a common inclusion feature never before observed in their terrestrial counterparts.*

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**P**eridot, the gem variety of olivine, is relatively soft and fragile when compared to diamond, corundum, spinel, and a number of other gemstones. It also is known to shatter on exposure to high temperatures, such as those encountered in jewelry manufacturing. Nevertheless, some peridots are able to survive the journey from outer space and a fiery passage through the Earth's atmosphere as a major component of the stony-iron meteorites known as pallasites.

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*Dr. Sinkankas is a retired naval captain residing in La Jolla, California; he has authored numerous books and articles on lapidary work, mineralogy, and gem and mineral collecting. Mr. Koivula is chief gemologist at the Gemological Institute of America, Santa Monica, California. Mr. Becker, a prominent gem designer and lapidary, is head of Friedrich August Becker, Idar-Oberstein, Germany.*

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The ability of some peridot to withstand high temperatures is demonstrated by the occurrence of transparent, facetable masses and crystals in volcanic and metamorphic environments. Notable occurrences include the basalts of Peridot Mesa, Arizona (Sinkankas, 1959; Koivula, 1981) and the marbles of the Mogok region, Myanmar (Burma). The latter yields faceted gems in excess of 100 ct. A lower-temperature hydrothermal environment characterizes the beautiful, sharply terminated crystals that have been found since antiquity in veins on Zabargad (St. John's Island) in the Red Sea (Moon, 1923; Wilson, 1976; Gübelin, 1981; Bancroft, 1984). Other occurrences of olivine, including peridot, are recorded by Hintze (1897) and Doelter (1914). Summaries of properties are also given by Deer et al. (1966), Wilson (1976), Koivula (1981), and Stockton and Manson (1983).

Although much has been written about pallasites since they were first described in 1776, including comprehensive reports on the olivines contained therein, the historic literature carries only a few references to the gem potential of these olivines. Recently, however, one of the authors (GB) supervised the faceting of several olivines removed from a large pallasite that was found in Esquel, Argentina. Eight of these were studied for this report (seven are illustrated in figure 1). The authors also obtained from the American Museum of Natural History a peridot faceted several decades ago from the Eagle Station, Kentucky, pallasite (figure 2). This article

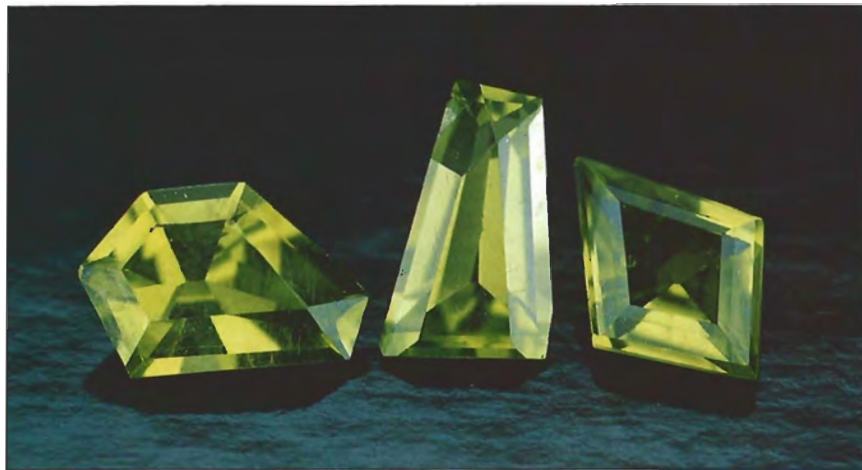


Figure 1. All of these peridots were faceted by Andreas Becker from olivines extracted from the Esquel, Argentina, pallasite. The stones on the right range from 0.25 to 1.39 ct and are courtesy of Robert A. Haag; the stones on the left range from 0.39 to 0.51 ct and are courtesy of Dale Dubin. Photos © Tino Hammid.



reviews historic references to these unusual olivines and presents the results of a gemological examination of nine faceted pallasitic peridots.

#### OLIVINE IN METEORITES

Extraterrestrial olivine is abundant in relatively large grains only in pallasites. These stony-iron meteorites were named for the famous German naturalist, geologist, and traveler Peter Simon Pallas (1741–1811), who first described the type specimen—a 680-kg (McCall, 1973) mass found near the town of Krasnoyarsk, Siberia, in 1749 (Pallas, 1776). This specimen was originally called the “Pallas iron” but, as is now customary, has been renamed Krasnoyarsk after the locality. In Pallas’s time, the true origin of meteorites was the subject of much wonder and speculation. Many scientists regarded them as peculiar products of the Earth’s crust; only the more daring suggested an extraterrestrial origin. The strongest arguments for the latter were advanced by Ernst Florens Friedrich Chladni (1756–1827), a German scientist best known for his studies of sound and its propagation, in his monograph on the Pallas iron (Wasson, 1974, introduction to facsimile of Chladni, 1794).

In speaking of extraterrestrial, Earth-like bodies that could have provided meteorites, Wasson states elsewhere that “pallasites were probably formed by violent events that mixed mantle and core materials” (1985, p. 93), thus accounting for the spongy structure of the nickel-iron alloy that encloses the olivine nodules. The metallic portions of pallasites consist of kamacite and plessite, two nickel-iron alloys believed to have been the principal constituents of the core, while the olivine itself was derived from the mantle. Much of the olivine is sufficiently low in iron to be classed as peridot, which approaches forsterite ( $Mg_2SiO_4$ ), the magnesium-silicate end member of the olivine group. As iron substitutes for the magnesium, the color changes toward brown to fully black in the opposite, iron-silicate end member, fayalite ( $Fe_2SiO_4$ ). For descriptions and remarks on pallasites in general, see Dodd (1986), Farrington (1915b), Hintze (1897), Krinov (1960), McCann (1973), and Wasson (1985). Farrington, among others, called the transparent olivine in pallasites “chrysolite,” a term once commonly used to designate peridots that were more yellowish green (Bristow, 1861). The term is now in disfavor; for an excellent discussion of peridot nomenclature, see Gübelin (1981).



Figure 2. This 0.52-ct peridot was faceted from olivine found in the Eagle Station, Kentucky, pallasite. It is currently part of the collection at the American Museum of Natural History, New York (catalogue no. 42748). Photo © Tino Hammid.

### PALLASITIC OLIVINE AS A POTENTIAL GEM MATERIAL

Pallas himself hinted at the gem-like appearance of the Krasnoyarsk pallasite olivines, which he described as "rounded and elongated drops of a very brittle but hard, amber-yellow, transparent glass" (Farrington, 1915b, p. 182). Farrington also noted that "Count Bournon in 1802 showed that this was similar to terrestrial chrysolite and Howard in the same year [see Brown, 1953, p. 1802] gave an analysis [that] indicated the mineral to be chrysolite."

The earliest published illustrations of meteorites, one of which includes a specimen of the Pallas iron, are engravings in Schreiber (1820). From the reproduction of the Krasnoyarsk pallasite shown in figure 3, it is evident that the olivine nodules are prominent and largely transparent. However, so far as is known, no gem has been cut from this olivine.

Noted American gemologist George Frederick Kunz (1856–1932) also suggested the suitability of meteoritic olivine for gems. He first remarked on the transparent olivine in the Glorieta Mountain, New Mexico, pallasite in 1886. Later (1890, p. 101), he reported that he had obtained from this meteorite "some peridots of 1 carat weight that were transpar-

ent and yellowish-green in color." Unfortunately, he did not state whether any were cut into gems.

### FACETED PALLASITIC PERIDOTS IN HISTORY

It is likely, however, that George F. Kunz had a hand in the extraction and perhaps even faceting of another pallasitic peridot, the stone shown here as figure 2. The catalogue, *A Collection of Gems, American and Foreign, Cut and in Their Natural State . . .*, published by Tiffany and Co. for the 1900 Paris Exposition, reports the presence of an olivine from the Eagle Station, Kentucky, meteorite. This Tiffany catalogue was no doubt prepared by Kunz, who had first described the Eagle Station meteorite in 1887. According to George Harlow of the American Museum (pers. comm., 1992), the original accession card, in the handwriting of then-curator Louis Pope Gratacap, refers to a "cut stone and chips" as being the same listed in the Tiffany catalogue as no. 347. Unfortunately, the Tiffany catalogue does not state whether this stone was faceted, and there is no date on the Gratacap accession card, although we know the peridot must have been cut before Gratacap's death in 1918. In light of Kunz's propensity for faceting any

Figure 3. The transparent character of the olivines in the Krasnoyarsk pallasite are evident in this watercolor reproduction, by John Sinkankas, of the color engraving of a fragment of the original pallasite shown in Plate VIII of Schreibers (1820).



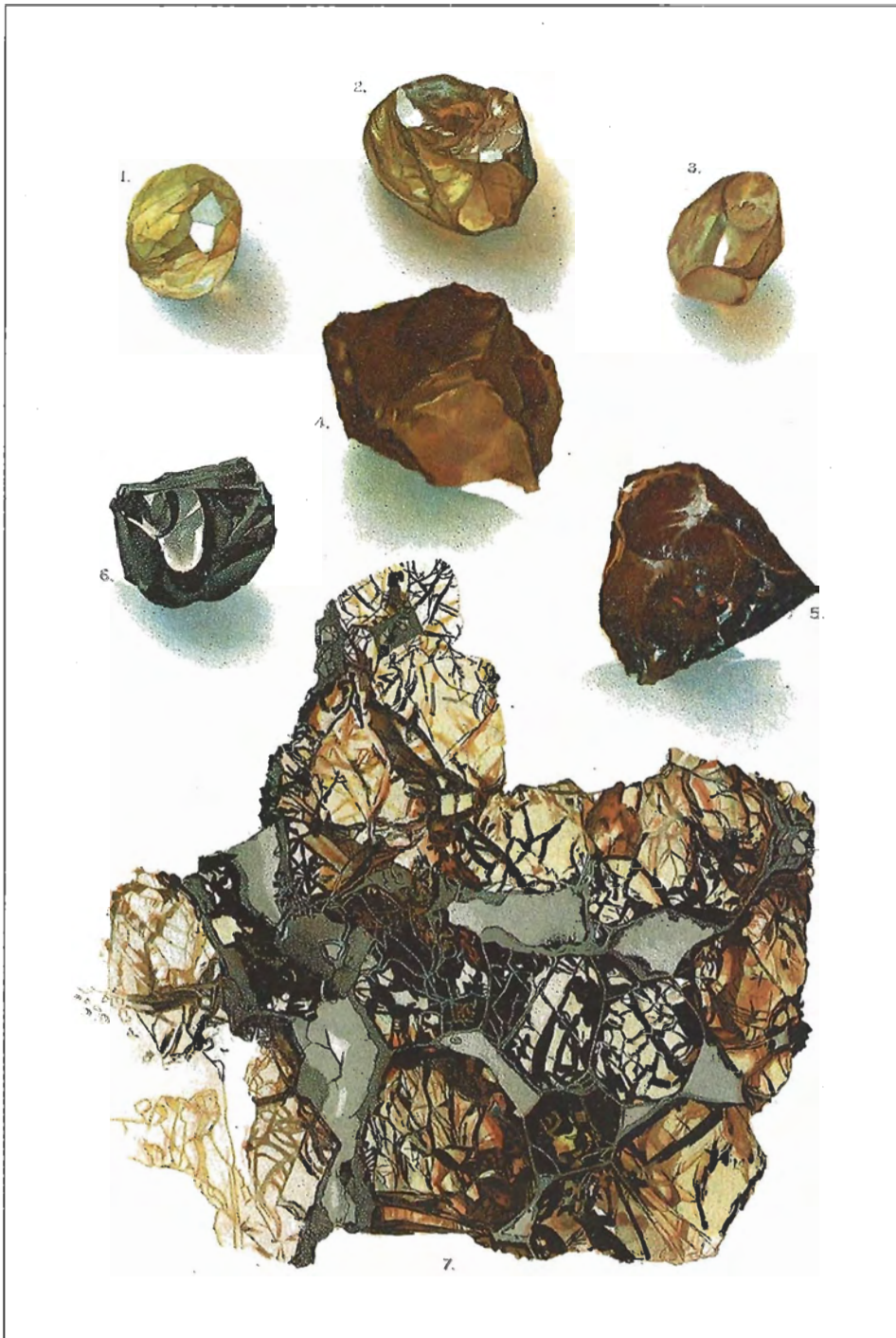


Figure 4. Plate XXVII from Mingaye (1916) shows a slice of the Molong, New South Wales, pallasite together with various pieces removed from the meteorite and, in the upper left-hand corner, the faceted gem cut from one of the Molong olivines.

American material that could be cut, it may have been faceted when it was displayed at the Paris Exposition. This stone may actually be the first faceted pallasitic peridot of record.

The earliest confirmation of a faceted extraterrestrial peridot is given in the description by Mingaye (1916) of the pallasite found in 1912 near Molong,

New South Wales, Australia. Mingaye described the circumstances of the discovery, the precise location, the weights of the two masses comprising this meteorite (approximately 204 lbs. [93 kg] and 28 lbs. [13 kg]), and the chemical compositions of the metallic portion and the olivine. Light yellow olivine chosen for analysis gave principal components of  $\text{SiO}_2$  (40.40 wt.%),



FeO (9.59 wt.%), and MgO (47.70 wt.%), which falls mid-range for typical forsterite compositions (Arem, 1987). Mingaye also found a specific gravity of 3.357 and noted that "the olivine ranges from dark-black, shades of red, to pale lemon yellow in colour, the crystals being largely fractured in the cooling of the meteorite in falling through space to reach earth. These were found cemented in the solid nickeliferous iron particles . . . and *one small piece free from flaws has been cut by the Department Lapidary as a gem stone.*"

The gem is shown in the upper left-hand corner of Mingaye's Plate XXVII, here reproduced as figure 4. The same plate also shows a slice of the Molong pallasite, which indicates the volume occupied by olivine as compared to the metallic constituents. The text identifies Mr. W. H. Gilding of the New South Wales Department of Mines as the lapidary but, unfortunately, provides no further information. According to Dr. G. S. Gibbons of the Geological Survey of New South Wales (pers. comm., 1990), neither the slice nor the objects associated with it can now be found, due to relocation of the department's collections.

Tcherwinski (1916) provided additional data from his study of a 109.4-gram fragment of the Molong pallasite. He noted that the iron is "much decomposed," but the "olivine seems here and there quite fresh . . . light yellow colour, inclining to green." Tcherwinski also commented that he "could not, under the microscope, discover the primary inclusions" in the olivine.

A much more recent attempt to obtain a gem from meteoritic peridot is recounted by Nininger (1972), who collected most of the pieces of the Brenham, Kansas, pallasite, which fell in the late 19th century, and extracted various fragments for study and dispersal. He noted (pp. 83–84) that "in one instance my cut revealed a perfectly beautiful crystal, transparent but of greenish golden hue, which I determined to remove and have mounted in a ring for my wife . . . I thought. How romantic, to present a ring with a gem cut *out of this world!*" The peridot was taken to a jeweler, who was cautioned that it must be treated carefully. Finally, after a long delay, the jeweler admitted that he had broken the gem while mounting it. Nininger closed his anecdote with the remark that "I have never found another perfect crystal."

#### FACETING PALLASITIC PERIDOT

In 1990, one of the authors (GB) noted relatively large transparent to translucent areas in slices taken from the Esquel, Argentina, pallasite, which had recently

been acquired by meteorite dealer Robert Haag. The author identified several olivines that promised to yield small faceted gems and took them back to Idar-Oberstein, Germany, where they were subsequently faceted by Andreas Becker (figure 5).

The olivine "raisins" extracted from the pallasite slices were sawed with extremely thin diamond-charged saw blades, then preformed on diamond-charged laps, and finally faceted using the traditional, fully handheld "jamb-peg." The flexibility of the jamb-peg enabled Becker to obtain maximum recovery from the rough. Polishing was performed on an alloy lap of 60% lead and 40% tin, charged with "diamantine" powder (aluminum oxide). Further details of this cutting process have been reported by Frazier and Frazier (1992).

Compared to the San Carlos basalt peridots, the Esquel olivines appeared to be more brittle, perhaps because of the greater stresses imposed on them during growth and, later, celestial flight and impact. Also because of these stresses, most of the olivines in the Esquel pallasite are heavily fractured. Even with a relatively transparent piece, the yield is only 15% to 20%. To date, Mr. Becker has faceted fewer than 30 peridots extracted from the Esquel pallasite. Although additional gem material is undoubtedly present in this meteorite, we do not know how much and speculate that the sizes will continue to be small.

Figure 5. Andreas Becker faceted the pallasitic peridots on the right from transparent pieces of olivine (like those at center) removed from slices of the Esquel, Argentina, pallasite similar to that shown on the left.



## GEMOLOGICAL PROPERTIES OF PALLASITIC PERIDOTS

Over the last year, one of the authors (JK) and a colleague, Chris Smith, studied the gemological properties of a total of nine faceted meteoritic peridot (again, see figures 1 and 2), eight from the Esquel fall mentioned above and one from the Eagle Station pallasite loaned by the American Museum of Natural History (new catalogue no. 42748). The properties obtained are reported in table 1 and discussed below.

**Visual Appearance.** The samples range in size from a 0.25-ct round mixed cut ( $3.97-4.06 \times 2.18$  mm) to a 1.39-ct triangular step cut ( $7.14 \times 7.00 \times 4.82$  mm). They range in color from greenish yellow to yellowish green in light to medium-dark tones. Diaphaneity varies from transparent to translucent, depending on the abundance of inclusions. Compared to peridot of terrestrial origin, we found the colors to be less vivid and to be somewhat muddy in several specimens.

**Refractive Index.** All of the gems were well polished, permitting good optical contact with the refractometer hemicylinder. We obtained refractive indices and birefringence for each of the nine gems using a near monochromatic, sodium-equivalent light source and a Duplex II refractometer. The values obtained (see table 1) were consistent with those known for terrestrial peridot from various localities, although the R.I. of the Eagle Station stone was unusually high. According to Dr. Brian Mason (pers. comm., 1992), who has studied olivines from both pallasites, the higher R.I. for this stone is to be expected in light of the significantly higher Fe content of the olivines from the Eagle Station material as compared to those from Esquel and most other pallasites.

With the refractometer, the optic character was found to be biaxial (confirmed with a polariscope), with the optic sign varying between  $-$ ,  $+$ , and  $+/-$ .

**Specific Gravity.** All of the stones sank relatively slowly in methylene iodide (S.G. = 3.32), with only very slight differences in the sink rate. From this, the specific gravity of the nine gems was estimated to be 3.4.

Next, the samples were weighed hydrostatically on an appropriately modified Mettler CM1200 carat-weight electronic balance. Values averaged from three separate determinations done on each stone at room temperature ranged from  $3.37 \pm 0.05$  on the 0.34-ct Esquel stone to  $3.47 \pm 0.05$  for the Eagle Station stone (again, see table 1). These values, too, are within the accepted range for peridot.

**Ultraviolet Fluorescence.** Under darkroom conditions, all nine gems were exposed to both long-wave and short-wave ultraviolet radiation. As expected for peridot, the stones proved to be inert and without phosphorescence.

**Spectroscopy.** To observe the visible-light absorption characteristics of the nine pallasitic peridot, we used three different tabletop-model spectrosopes—a Beck prism spectroscope, a GIA GEM Instruments Discan diffraction grating spectroscope, and a new prototype prism spectroscope also from GIA GEM Instruments—on all nine stones. Absorption bands were noted at approximately 456 nm, 474 nm, and 495 nm. The larger and/or darker the stone was, the stronger the absorption features were. The spectra observed in these pallasitic peridot are virtually identical to those shown by their terrestrial counterparts (Liddicoat, 1989).

**TABLE 1.** Gemological properties of nine pallasitic peridot<sup>a</sup>.

Locality	Weight (ct)	Refractive index			Optic character Biaxial	Specific gravity
		$\alpha$	$\beta$	$\gamma$		
Argentina	0.25	1.655	1.675	1.690	$-$	3.42 $\pm$ 0.05
Argentina	0.34	1.652	1.670	1.688	$+/-$	3.37 $\pm$ 0.05
Argentina	0.39	1.656	1.670	1.691	$+$	3.44 $\pm$ 0.05
Argentina	0.40	1.656	1.670	1.691	$+$	3.42 $\pm$ 0.05
Argentina	0.51	1.656	1.670	1.691	$+$	3.43 $\pm$ 0.05
Kentucky	0.52	1.669	1.688	1.705	$-$	3.47 $\pm$ 0.05
Argentina	0.53	1.655	1.673	1.691	$+/-$	3.38 $\pm$ 0.05
Argentina	1.25	1.656	1.670	1.691	$+$	3.42 $\pm$ 0.03
Argentina	1.39	1.650	1.671	1.690	$+$	3.38 $\pm$ 0.02

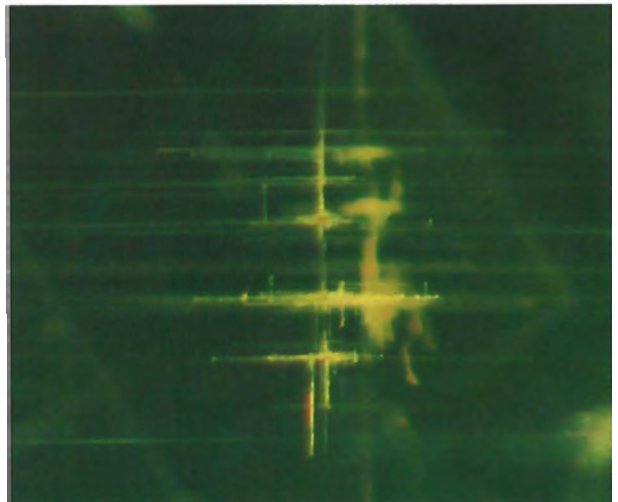
<sup>a</sup>See text for details of testing methods used.

**Internal Characteristics.** In several of the stones, inclusions were visible with little or no magnification. When examined using a gemological microscope, all of the stones revealed two sets of light yellow-brown acicular inclusions that appeared to be oriented at 90° to each other (figure 6). These inclusions possibly formed as a result of stress- and heat-induced alteration of and/or exsolution from the host olivine. A study of the available literature on inclusions shows that this type of acicular inclusion has never been reported in terrestrial peridot. It is therefore suggested that these inclusions can be considered as highly diagnostic for pallasiitic peridot.

**Pleochroism.** With a calcite dichroscope and a white light source, weak to very weak pleochroism was noted, in various shades of green and yellow with slight brown overtones.

**Chelsea Filter Reaction.** When examined through the Chelsea color filter with a fiber-optic light source, all of the samples appeared to have essentially the same color as the filter itself (yellowish green). The strength of the observed color varied with the depth of color of the stone being examined.

Figure 6. All nine of the pallasiitic peridots studied contained acicular inclusions of an unknown material oriented in a plane at what appears to be 90° to one another. These are possibly formed by stress- and heat-caused alteration of—and/or exsolution from—the host olivine. Such inclusions have not been reported in peridot from any terrestrial locality. Photomicrograph by John I. Koivula, magnified 25×.



While several stones contained what appeared to be tiny black particles, these were generally too small to resolve clearly. The 1.39-ct triangular step cut, however, contained an obviously rounded particle with a dark metallic luster that measured 0.6 mm in diameter (figure 10). Because of the dark color, metallic luster, immediate presence of iron oxide-colored staining, and known association with nickel-iron meteorites, this and similar dark particles in pallasiitic peridot may be elemental nickel-iron. To prove this, however, some material would have to be sacrificed for chemical analysis.

Fractures or cleavages that reached the surface of these stones almost always contained red-brown iron oxide staining similar to that shown in the oval sample, reddish brown iron-stained patches oriented in cleavage planes were observed (figure 8). These might be the result of the oxidation of tiny nickel-iron particles derived from the parent meteorite. These patches also showed colorful reflective iridescence when viewed in incident white light (figure 9). Since all of the patches reflected light at the same angle of illumination, all were oriented in the same plane.

In the two largest stones, the acicular inclusions were so abundant that the stones appeared translucent (figure 7). If such stones were properly oriented and cut *en cabochon*, they might yield gems that display asterism.

Figure 7. Sometimes the acicular inclusions are so dense that the host is rendered translucent. It is possible that such pallasiitic peridots would form cabochons. Photomicrograph by John I. Koivula, magnified 25×.



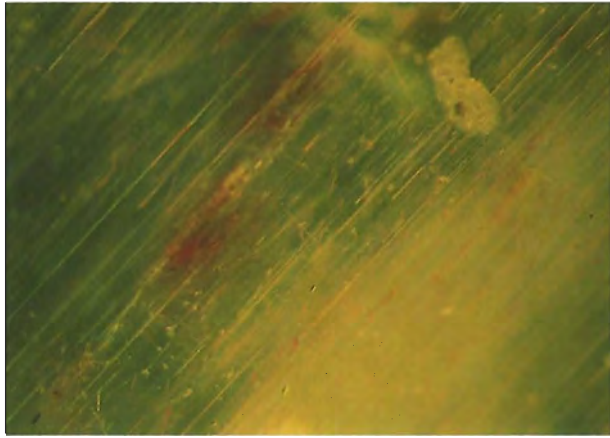


Figure 8. The 1.25-ct stone contained reddish brown, iron-stained patches oriented in cleavage planes. These may be the result of the oxidation of tiny nickle-iron particles derived from the parent meteorite. Photomicrograph by John I. Koivula; magnified 30 ×.

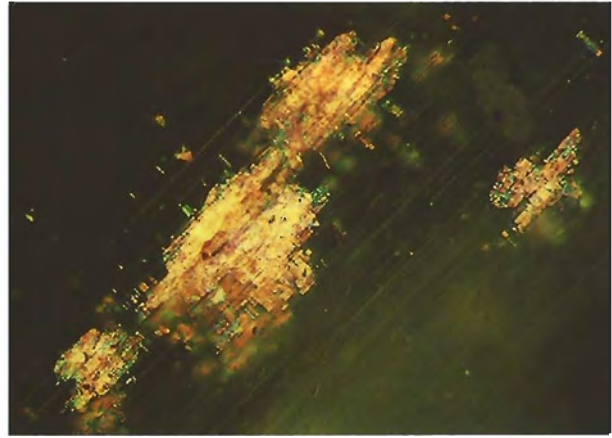


Figure 9. The reddish brown, iron-stained patches shown in figure 8 were reflectively iridescent when viewed in incident light, and all proved to be oriented in the same plane. Photomicrograph by John I. Koivula; magnified 30 ×.

## CONCLUSION

The olivine-rich meteorites known as pallasites sometimes contain areas of olivine that are large and transparent enough to yield small faceted gems of the peridot variety. To date, however, few such stones have been cut and they must, therefore, be counted as among the rarest of all gems.

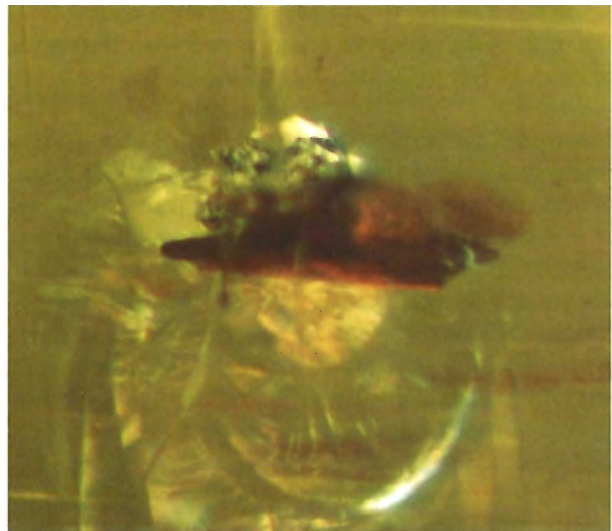
The earliest faceted specimen may well be the Eagle Station, Kentucky, stone in the collection of the American Museum of Natural History in New York. We know that an olivine displayed by Tiffany & Co. in 1900 was described as "cut" in an American Museum accession card that must have been written before 1918. A more certain date is ascribed to the gem cut from the Molong, New South Wales material; this fall was discovered in 1912 and, by the time Mingaye furnished his description and color plate in 1916, the gem had already been cut. Another attempt at gem use of pallasitic peridot—this time from the Brenham, Kansas, pallasite—was made by H. H. Nininger some time in the late 1920s. The fortunate appearance of the olivine-rich Esquel meteorite and the extraction and cutting of faceted stones therefrom by Andreas Becker greatly enlarges our resources of this extreme rarity among gems.

The pallasitic peridots examined for this study proved to be remarkably similar to terrestrial peridots. The most notable difference is the presence of acicular inclusions in the Esquel and Eagle Station material that have never been recorded in terrestrial peridots. While substantial differences in properties were noted between the material from the two mete-

orites, these appear to be related to the special character of the Eagle Station olivines (B. Mason, pers. comm., 1992).

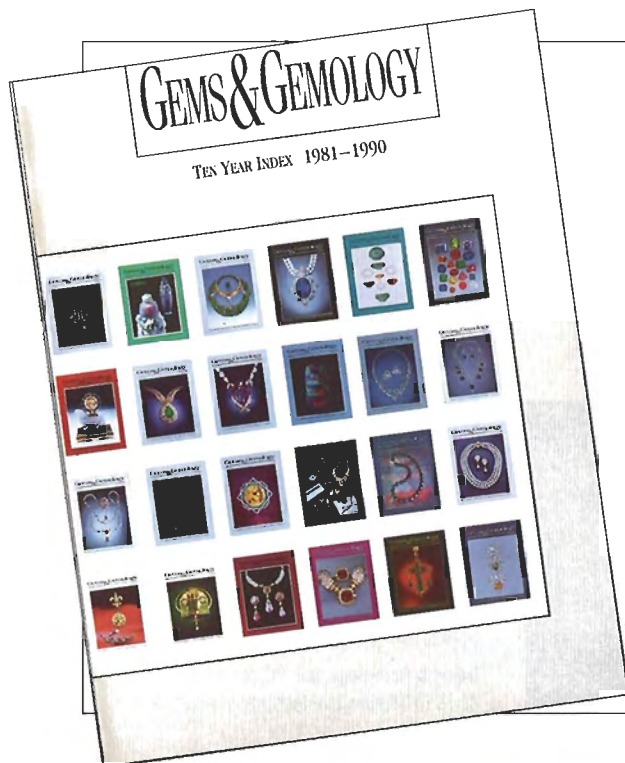
Numerous museum collections around the world contain specimens of pallasites with olivines suitable for faceting into gems, although most finished stones would weigh less than one carat. Experience with the cutting of the Esquel stones suggests that no special problems should be anticipated in preforming, faceting, and polishing pallasitic peridots, aside from their tendency toward brittleness.

Figure 10. The 1.39-ct peridot contained a 0.6-mm-diameter rounded particle with a dark metallic luster. Such particles may be composed of elemental nickle-iron. Photomicrograph by John I. Koivula.



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### CALCAREOUS CONCRETION From the Bailer Shell?

East and West Coast labs examined yet another unusual nonnacreous calcareous concretion. The opaque light brownish yellow sphere measured approximately 27 mm in diameter and showed a sheen-like effect over its entire surface (figure 1). When the sphere was examined with low-power magnification, the flame-like structure commonly seen in conch or various clam concretions became visible. Because of the much larger size and unusual coloration of this concretion, we reasoned that it must have been produced by a different mollusk. The visual characteristics are similar to those of concretions found in the Bailer shell (*Melo amphora*), which lives in

*Figure 1. This 27-mm-diameter calcareous concretion is similar to those found in the Bailer shell, Melo amphora. Note the sheen and flame-like structure.*



the Indo-Pacific region, as noted in the November 1990 issue of *Australian Gemmologist*. KH

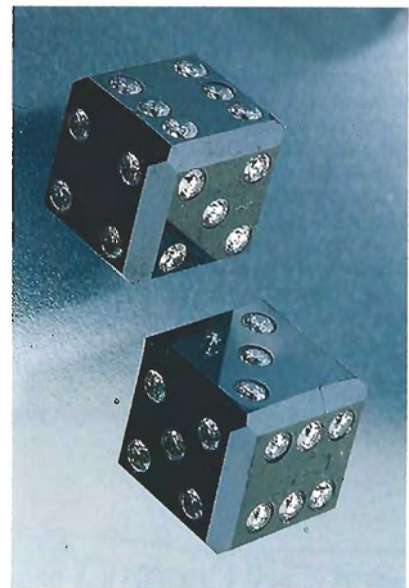
### DIAMOND With Aggregate Crystallization

A major New York diamond dealer recently found a remarkable aggregate of two gem-quality diamond crystals in his CSO sight. It was examined by GIA Research and both East and West Coast laboratories.

Each of the two diamonds in the aggregate are rounded dodecahedra with etched faces (figure 2). Unlike a twin crystal, they grew together with no particular common crystallographic orientation. The most likely hypothesis is that the two diamonds were very close to each other during growth and ended up growing into each other at random, forming the aggregate.

Although such aggregates are com-

*Figure 2. Two gem-quality diamond crystals have grown together to form this unusual aggregate, which weighs 3.34 ct.*



*Figure 3. These dice (15.94 and 18.04 ct, respectively) were fashioned from natural-color black diamonds. The smaller measured approximately 10 mm on a side; the larger, approximately 10.5 mm.*

mon for fast-growing, industrial-quality diamonds, the probability of this type of aggregate growth occurring in slow-growing, gem-quality diamonds is very low. We at GIA know of only one other such aggregate.

*Emmanuel Fritsch*

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

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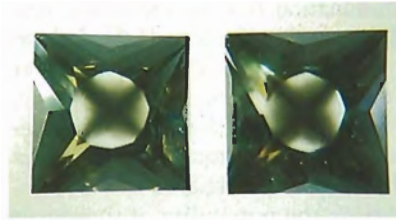


Figure 4. A brown cross-like cloud is a focal point in each of these 1.28- and 1.38-ct natural-color gray diamonds.

#### Black Dice and Gray with "Crosses"

The handsome pair of faceted black diamond dice shown in figure 3 were recently submitted to the East Coast lab for origin-of-color determination. We do not know the crystal form of the rough from which they were cut. However, we determined them to be natural color. Near-colorless round-brilliant diamonds were used to form the spots on the dice.

We were also asked to determine origin of color for a pair of dark gray square modified brilliants, which weighed 1.28 and 1.38 ct. Each stone contained a brown octahedral cloud that had been cleverly oriented by the cutter to appear as a central cross (figure 4). These stones were also natural color. GRC

Figure 5. Prominent etch marks can be seen on the surface of this 1-ct diamond that was damaged in a fire. Magnified 18 $\times$ .



#### Fire Damaged

Figure 5 shows the remains of an approximately 1.00-ct round-brilliant-cut diamond that was salvaged from the ashes of a home destroyed in last fall's Oakland, California, fire. The damaged stone was shown to East Coast lab staff by a New York client, who was recutting the stone.

To the unaided eye, the fragment had a gray, frosted surface. When the surface was examined with magnification, etch marks could be seen all over it, similar to those seen on rough diamond crystals. For example, the table had prominent square pits—resembling those that sometimes occur on natural cube faces of gem-quality diamonds. Several pavilion facets (which must have approximately paralleled the octahedral faces) had triangular etch pits, like the trigons sometimes seen on the octahedral surfaces of rough diamonds.

It would be interesting to know what conditions produced the etching. Was the diamond in an area of the fire that had an ample air supply or one deprived of air, that is, an oxidizing or reducing atmosphere? Were chemicals involved?

Whatever the conditions, damage was confined to the surface. After recutting, a "new," 0.51-ct stone (figure 6) emerged from the badly damaged original. GRC

Figure 6. The fire-damaged stone shown in figure 5 was recut to produce this 0.51-ct diamond.



#### Green, with Natural Surface Color

In our ongoing study and documentation of green diamonds at both labs, we welcome every opportunity to follow rough diamonds through the manufacturing process (see *Gems & Gemology*, Summer 1991, p. 109). These repeated observations allow the labs to examine how properties—such as U.V. luminescence, U.V.-visible and infrared spectra, and color distribution—may change with cutting. We have noted that some absorption features are altered or created, most likely because of heat generated during cutting and polishing.

The 7.56-ct octahedral crystal shown in figure 7, examined in the East



Figure 7. This 7.56-ct (12.33  $\times$  12.17  $\times$  12.13 mm) octahedral diamond is an example of rough with green surface color.

Coast lab, is a surface-color green diamond. Note the abundant starburst-like green radiation stains (estimated depth of penetration, 0.20 mm), which resulted from exposure to alpha particles emitted by radioactive nuclides. The crystal (reportedly from Brazil) also had a few brown radiation stains in one area (figure 8). Because of their close proximity to a green stain, also seen in figure 8, they could not have resulted from a general heating.

Surface-colored green rough rarely yields a finished stone with any green color. However, this stone was cut care-

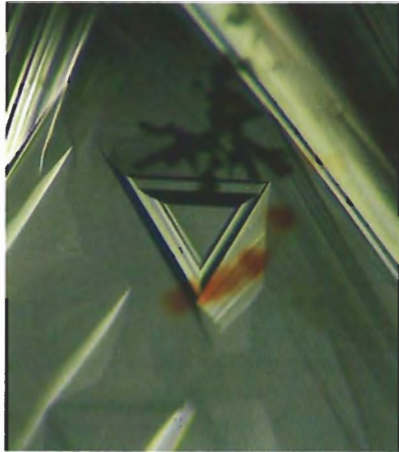


Figure 8. Brown stains were observed next to a green one at a trigon on the rough diamond shown in figure 7. Magnified 126 ×.

fully to enhance the very shallow layer of color through internal reflections. The crystal was sawed off-center, producing a 6.02-ct square modified brilliant (figure 9) and an 0.88-ct cut cornered rectangular mixed cut. The cutter obtained an almost unbelievable weight recovery of over 91%!

No special precautions were taken to cool the stone during manufacture, yet the radiation stains remained green. Total sawing time was approximately 26 hours. The longest continuous sawing time was 12 hours, and the longest continuous cutting or polishing operation took four hours.

As part of his effort to retain some of the shallow green color in the finished stones, the cutter left extremely large naturals on the upper pavilions of both. Naturals comprise about 30% of the surface area of the 6.02-ct stone, including the girdle (figure 10). When we examined the two stones table down, with a view through the polished parts of the pavilion, we determined the body color of both to be a slightly greenish yellow, approximately equal to "M" on the GIA color-grading scale. However, the size, position, and surface color of the naturals allowed both stones to retain enough color to qualify, faceup, as fancy or fan-

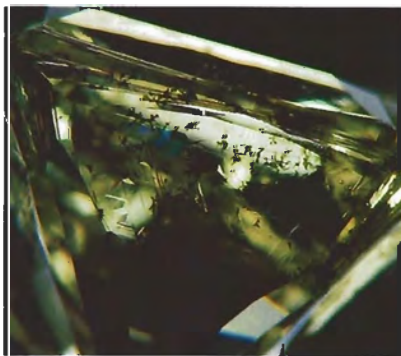


Figure 9. This 6.02-ct stone was cut from the 7.56-ct rough diamond in figure 7, together with a smaller, 0.88-ct, stone.

cy light grades. The 6.02 was graded Fancy Grayish Yellowish Green and the 0.88, Fancy Light Yellowish Green.

Both the rough and finished stones fluoresced weak orange to long-wave U.V. radiation, but were inert to short-wave U.V. No graining was visible in the original crystal, but cutting revealed weak planar graining along octahedral planes. There was no detectable transmission luminescence with microscope

Figure 10. To retain as much of the original green as possible, the cutter left large naturals on the pavilion surfaces and girdle of both the 6.02-ct diamond shown in figure 9 and its smaller counterpart. This cutting technique also undoubtedly contributed to the exceptional weight retention. Magnified 15 ×.



illumination, or when the stones were illuminated by the lamp in the desktop spectroscope. A Victoreen Geiger counter (see *Gems & Gemology*, Winter 1988, p. 196) registered no radiation above background levels in either the rough or the finished stones, eliminating the possibility of treatment with a radioactive compound such as radium bromide.

The spectral features, as observed with a spectrophotometer, were consistent with those of known natural surface-color rough and polished diamonds. The rough crystal showed a spectrum with strong Cape lines, a 3H center at 504 nm, and a moderate-strength GR1 center from radiation. The zero-phonon line of this center at 741 nm was well defined, but broad—as observed in other natural-color stones with abundant green surface stains. The larger finished stone yielded an identical optical spectrum. The smaller stone showed no 3H absorption and only a very weak GR1, which may have resulted from the passage of a large flux of heat through a small stone during cutting and polishing. It is also possible that the spectral differences reflect an uneven distribution of impurities in this diamond crystal. Most diamond crystals are chemically inhomogeneous, which can lead to both spectral and color differences in stones cut from a single piece of rough.

TM and Ilene Reinitz

## EMERALD

Identifying inclusions in an emerald is one of the most important ways of determining synthetic or natural origin. The East Coast lab received two green stones, reportedly emeralds, with very similar-looking inclusions. Microscopic examination of one stone (1.19 ct) revealed spicule-like inclusions (figure 11) that, along with other gemological tests, identified it as a hydrothermally grown synthetic emerald. Spicule-like inclusions in synthetics are two-phase growth features capped by transparent-to-translucent irregularly shaped crystals that, in syn-



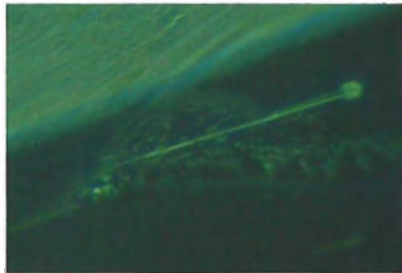
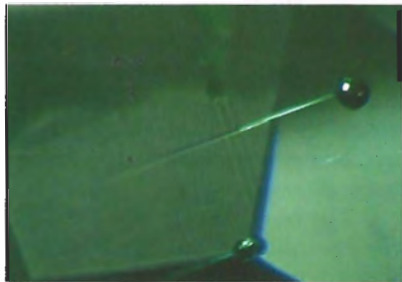


Figure 11. This spicule-like inclusion in a synthetic emerald has a transparent crystal cap typical of hydrothermally grown material. Magnified 126 ×.

Figure 12. This inclusion in a natural emerald appears similar to the spicule shown in figure 11. However, it is probably a tapered growth blockage; note that the crystal cap is opaque and yellow. Magnified 60 ×.



thetic emerald, are usually phenakite.

Initial examination of the other specimen (a 2+ct stone mounted in a ring) revealed inclusions similar in shape to the ones seen above (figure 12), which might suggest that this stone was also a synthetic. However, the high refractive index, presence of hexagonal crystals (probably calcite), and observation of type 1 and type 2 H<sub>2</sub>O bands in the infrared spectrum, in combination with other gemological tests, led us to conclude that it was a natural emerald. Closer inspection with the microscope revealed that the spicule-like inclusions—probably tapered growth blockages—were different from those seen in synthetic stones; in particular, the euhedral crystal caps were opaque and yellow. This is another example of the hazards of

making an identification based on only one characteristic or test.

Nicholas DelRe

### Imitation LAPIS LAZULI

Figure 13 illustrates one of the most unusual lapis lazuli imitations ever seen in the West Coast laboratory. To the unaided eye, the opaque, slightly violetish blue 4-ct rectangular bar-cut cabochon appeared to be fine lapis lazuli. However, the stone lacked the smooth texture and high polish that contributes to the attractiveness of lapis. With oblique illumination, a distinct granular structure—similar to fine-grained marble—was visible. With magnification, the structural characteristics became more obvious. The material consisted primarily of transparent near-colorless tabular grains, interspersed with irregularly shaped opaque blue areas that produced the prominent blue color (figure 14).

Gemological properties were determined as follows: R.I.—1.55 (spot method), S.G.—2.85 (estimated by heavy liquids). The stone fluoresced a strong chalky greenish yellow to short-wave U.V. radiation, but weak red to long-wave U.V. There was no reaction to the hot needle of the thermal reaction tester and no evidence of dye when

Figure 13. This 4-ct imitation superficially resembles fine-quality lapis lazuli.



Figure 14. At 30 × magnification, transparent, near-colorless granules and areas of blue coloration are readily apparent in the stone shown in figure 13.

a white cotton swab soaked with acetone was gently rubbed over the surface. Chemical analysis by EDXRF showed Si, Al, Mg, K, Ca, and trace amounts of Ti, V, and Fe. X-ray diffraction testing on both near-colorless and colored areas revealed patterns that matched phlogopite mica. These properties indicated that the stone was a manufactured product, possibly a ceramic. The coloring agent has yet to be identified. KH

### OPAL, with Natural Cellular Structure

The West Coast laboratory examined a spectacular natural opal with an unusual mosaic pattern to the play-of-color (figure 15). The extraordinary play-of-color layer comprised about one-quarter of the thickness of the stone, while the remaining three-quarters were primarily natural gray potch, with only some minor play-of-color visible. The vivid geometric play-of-color patches ranged through all the spectral colors when the stone was moved under a stationary light source. The patches were separated from each other by fine serrated seams of black potch.

Several play-of-color patches had a

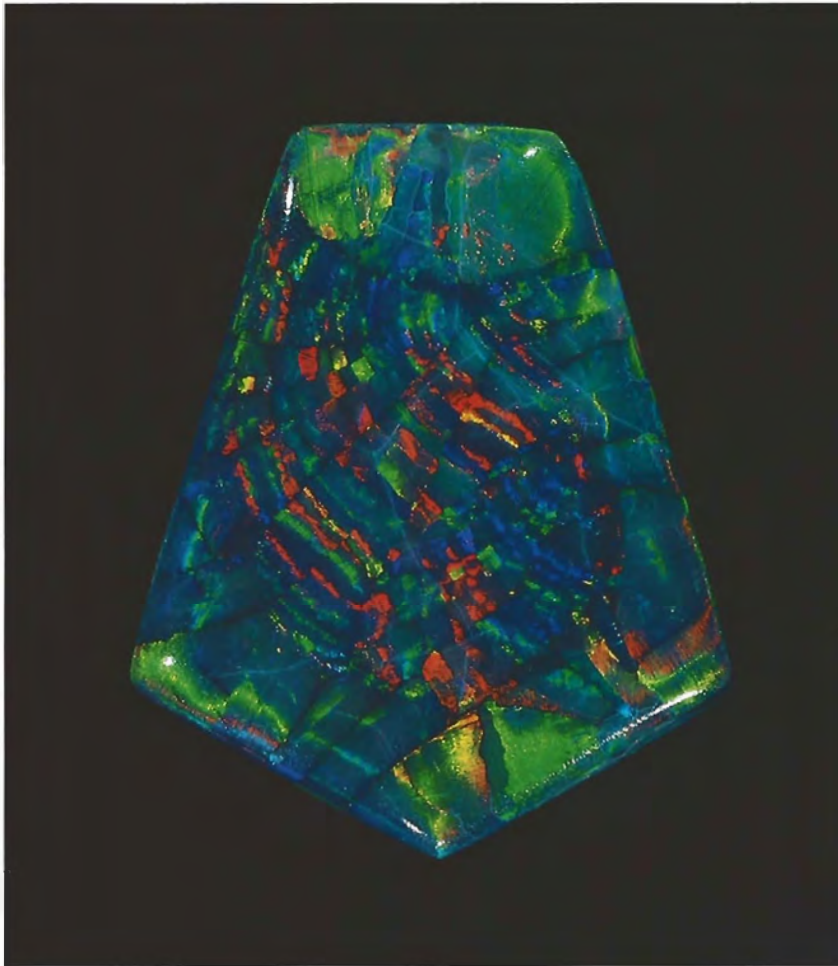
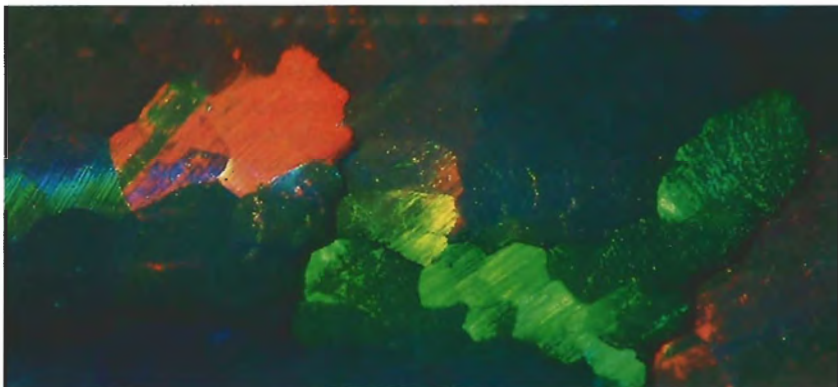


Figure 15. An excellent example of mosaic pattern to the play-of color is seen in this 7.86-ct (20.28 × 16.66 × 4.66 mm) natural opal.

Figure 16. The natural "honeycomb" structure in the opal shown in figure 15 is readily apparent with oblique fiber-optic illumination. Magnified 30 ×.



fine "honeycomb" cellular pattern (figure 16) that, at first glance, closely resembled the snakeskin effect seen in synthetic black opal. In synthetic black opal, however, each individual patch

of color can be followed deep into the stone. Natural patches tend to be much shallower and less uniform in their penetration. Also, the natural patches vary more in size and shape.

Gemological properties of this opal are consistent with those of Australian black opal, with a 1.44 spot R.I. reading on the Duplex II refractometer. The stone fluoresced a strong chalky blue to long-wave U.V. radiation, and phosphoresced a moderate greenish white. Gilson and Inamori synthetic opals fluoresce a dull yellowish green with no phosphorescence. The stone showed some crazing, a subtle reminder that such perfection in nature rarely comes without a price.

Patricia Maddison

### Unusual POLYNESIAN CULTURED PEARLS

Natural-color black South Seas cultured pearls are usually nucleated with approximately 9-mm-diameter shell beads made from any one of several varieties of American freshwater mussels. As with other bead-nucleated cultured pearls, the shell bead usually comprises most of the weight and volume of the pearl. The South Seas product, however, generally has a thicker nacre deposit.

The East Coast lab recently tested the beautiful natural-color black cultured pearl necklace shown in figure 17. The cultured pearls ranged in size from approximately 12 to 16 mm. When the necklace was X-rayed, we were surprised to see that two of the pearls (marked in figure 17) lacked bead centers. However, the X-radiograph (figure 18) does show some evidence of mantle-tissue nucleation in both.

We hypothesize that these two cultured pearls lost contact with the mantle tissue at an early stage after growth was initiated. Such pearls are usually not very large, but these grew to approximately 14 mm. *DH*

### PINITE

From time to time we encounter carved gem materials or beads that are euphemistically called jade, as the green bead shown in figure 19 was represented to our client.



Figure 17. The natural-color black cultured pearls in this necklace range from 12 to 16 mm. The two marked pearls, which we believe are also cultured, did not show bead nuclei in the X-radiograph (figure 18).

However, routine gemological testing by the East Coast lab proved that this material was not jadeite, nephrite, or even serpentine—a common jade substitute. The refractive

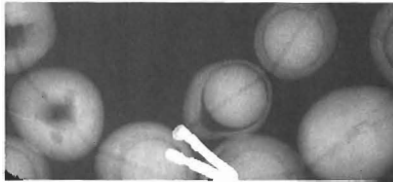


Figure 18. The X-radiograph of the necklace in figure 17 revealed that two pearls do not have bead nuclei.

index was 1.57; the specific gravity (obtained by the hydrostatic method) was approximately 2.80; the hardness test (performed inside the drill hole) was about 3 1/2 on the Mohs scale. There was no reaction to hydrochloric acid or the color filter.

Because of the many massive minerals that could have similar properties, we turned to X-ray diffraction analysis. X-ray diffraction proved this material to be pinite, a form of muscovite mica. A pinite carving that we previously identified is described and illustrated in *Gems & Gemology*, Fall 1983, p. 176.

The bead also showed chromium absorption lines in the hand spectroscope. Care must be taken when evaluating these lines because strong chromium lines may sometimes

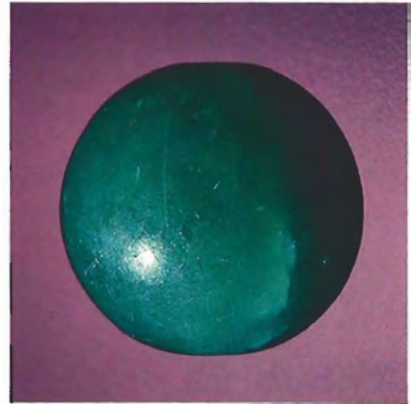


Figure 19. This 9.80-mm-diameter pinite bead was sold as jade.

resemble aniline dye bands. X-ray fluorescence analysis confirmed the presence of chromium. *DH*

#### PHOTO CREDITS

Figures 1, 13, and 19 are by Tino Hammid. Figure 2 is by Robert Weldon. Figures 3–12 and 17 were taken by Nicholas DelRe. John I. Koivula is responsible for the photomicrograph used in figure 14. The photo in figure 15 is © Harold and Erica Van Pelt. Figure 16 photomicrograph is by Patricia Maddison. The X-radiograph in figure 18 was supplied by Robert Crowningshield.

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GF52



# GEM NEWS

JOHN I. KOIVULA, ROBERT C. KAMMERLING AND EMMANUEL FRITSCH, EDITORS

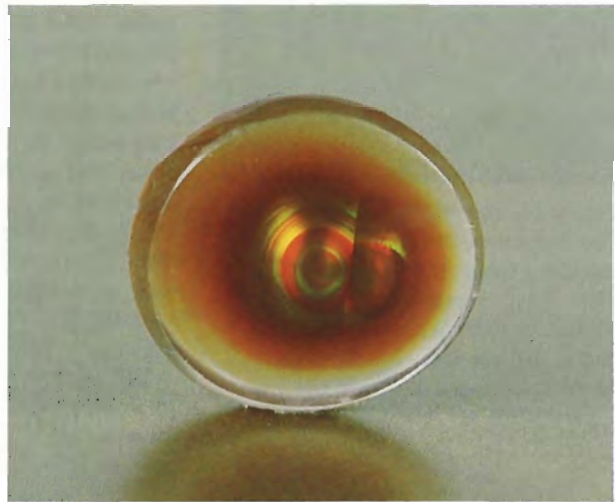
## TUCSON '92

As in years past, the Gem News editors traveled to Tucson, Arizona, in February to attend the many concurrent gem shows. These range from sophisticated presentations like the AGTA Gem Fair in the Tucson Convention Center to "tailgate" shows set up at gas stations and in open lots. Following are some of the highlights of this year's events, based on the editors' observations and those provided by other GIA staff members.

### DIAMONDS

**Colored diamonds.** Colored diamonds were abundant in small sizes. Brownish yellow to grayish yellow to brown were most common, although one booth was filled with natural pink diamonds. Most unusual was a series of white "opalescent" diamonds from the Panna mine in India, displayed by Mahlotra Inc. of New York. Colored diamonds with a well-documented geographic origin are rare. GIA Research tested three of these "opalescent" stones. The properties of all were typical of this kind of diamond: All were pure type IaB, with unusually intense hydrogen-related absorptions in the infrared region of the electromagnetic spectrum, and all had pervasive whitish graining.

*Figure 2. These fine-quality amazonite cabochons, 4.03 ct (left) and 3.07 ct (right), are from the Marambaia region of Minas Gerais, Brazil. Photo by Maha Smith.*



*Figure 1. This 6.04-ct fire agate has a natural frame of near-colorless, almost transparent chalcedony. Photo by Maha Smith.*

### COLORED STONES

**Unusual fire agate.** Although some exceptionally fine fire agates were displayed in the main shows this year, the most interesting specimen seen by the editors was found at a small roadside stand. The iridescent botryoidal center of this 6.04-ct (15.66 × 14.31 × 3.87 mm) agate is surrounded by almost transparent, near-colorless chalcedony instead of the typical brown translucent to opaque material (figure 1).

**Fine amazonite from Brazil.** Fine-quality amazonite from the Marambaia region of Minas Gerais, Brazil, was available in cut form. This particular greenish blue material showed little of the white, grid-like mottling we usually associate with this feldspar variety (figure 2), although close examination revealed a somewhat uneven texture and the sub-surface sheen typical of amazonite. Standard gemological testing yielded properties consistent with those reported in the literature for amazonite.

**Baltic amber more plentiful.** With the opening of Eastern Europe, Baltic amber has become more plentiful. We saw

a number of dealers from Poland, primarily selling polished pieces and jewelry such as pendants. Although most of what we saw was promoted as—and appeared to be—natural amber, some dealers also offered reconstructed material. Visual examination of some of the latter specimens revealed the grain boundaries typical of this sintered material.

**Faceted apatites from Madagascar.** Greenish blue apatite from Madagascar first appeared at Tucson last year, mostly in the rough. This year, large quantities of faceted material from this occurrence were available, with clean stones over 3 ct fairly common. It is surprising to see apatite being faceted for jewelry use because it is too soft (5 on the Mohs scale) for use in items such as rings.

**African aquamarine.** We noted aquamarines from several African sources. The firm of Gebrüder Bank displayed a few dozen beautifully faceted medium-dark-blue stones ranging up to 16.41 ct. Peter Kiecksee reported that these were from a new find in Mozambique, a country that is a known source of stones of this exceptional color. It was not clear whether this material was from a new locality or from a recent find in a previously worked mine.

The firm of Gebrüder Henn of Idar-Oberstein had several dozen extraordinary specimen-quality crystals that reportedly were from a new source in Nigeria. The dark greenish blue crystals were transparent and heavily etched. Some measured almost 10 cm (4 in.) long.

Aquamarines from Zambia were again available. These stones were typically slightly grayish blue in some of the darker tones in which this beryl variety is found.

**Axinite from Russia.** We saw a small number of exceptionally fine crystals of the rare gem mineral axinite, with edges so sharp that one of the editors actually cut a finger on a crystal. William W. Pinch, of Pittsford, New York, provided a large, fine example for examination. This 36.6-mm-long crystal (figure 3) showed gemological properties consistent with axinite. Mr. Pinch reported the locality as the Poly Ural Mountains, Komi Region, northern Russia. Because of their rarity and exceptional form, it is unlikely that these crystals will ever be used as faceting material.

**Beryl from Russia.** The need for hard currency in Russia was apparent from the abundance of yellow to blue beryl from this region seen at Tucson this year.

**Chrysocolla-colored chalcedony from Mexico.** One of the more vividly colored varieties of chalcedony is the slightly greenish blue material colored by finely disseminated inclusions of the copper mineral chrysocolla. Much of the fine-quality material we have seen has come from copper-mining areas of Arizona.

This year, in addition to the Arizona material, we saw large quantities from a locality in central Mexico. According to two California dealers, Michael Randall of Gem



Figure 3. This exceptional axinite crystal, 36.6 mm long, is from Russia. Courtesy of William W. Pinch; photo by Maha Smith.

Reflections and Glenn Lehrer of Lehrer Designs, the material is recovered from a large copper mine, on a level some 350 m below the surface.

The material we saw was semi-transparent—some facet quality (figure 4)—to almost opaque. Generally, the Mexican chrysocolla appears evenly colored, although examination in strong transmitted light revealed a mottled texture in several specimens.

One interesting feature of this Mexican material is its porosity. Both color intensity and transparency can be

Figure 4. Mexico is reportedly the source of this 0.82-ct faceted chrysocolla chalcedony. Photo by Maha Smith.





Figure 5. The 9.456-ct chrysocolla cabochon on the left is untreated; the 9.319-ct one on the right was soaked in water for several hours, with an apparent improvement in color and diaphaneity. Courtesy of Chris Boyd, CB Gems, Scottsdale, Arizona; photo by Maha Smith.

improved by leaving the stones in water from one to several hours, similar to the effect observed in hydrophane opal. To illustrate this effect, the editors borrowed two bullet cabochons of nearly identical size and color. They retained one cabochon as the control sample (figure 5, left) and immersed the other in water for several hours. The water produced a notable change in both color and diaphaneity (figure 5, right) as well as an approximately 0.25% increase in weight (from 9.296 ct to 9.319 ct). Some dealers said they were experimenting with polymer impregnation to produce a more permanent enhancement.

**Commercial "fantasy" cuts.** Gems that combine faceting and carving techniques, known as "fantasy" cuts, were again prevalent. This year, though, these included not only the typical one-of-a-kind miniature works of art, but also large quantities of calibrated, commercial-quality gems such as blue topaz and amethyst. Some hybrid cuts were very simple, with traditional outlines, modified faceting styles, and a series of grooves cut into their pavilion facets (figure 6).

**Cat's-eye emerald.** Although usually quite rare, cat's-eye emerald was offered by a number of dealers. David Kaassamani and Co. brought a collection of 75 cat's-eye green beryls and emeralds that ranged from a few points up to approximately 6 ct. Mr. Kaassamani reported that all had been mined within the last six months at Santa Terezinha de Goiás, Brazil. James T. Drew, Jr., of Star Gem, who was also offering some of these stones, added that

most of the chatoyant material is found in isolated pockets in what is known as "area 67" of Santa Terezinha.

**Moldavite plentiful.** Czechoslovakian moldavite tektites seemed more plentiful this year, with several dealers specializing in this material. One notable specimen contained an exceptionally long (8 mm) bubble (figure 7).

**Fire opal from Mexico.** Faceted opal from Querétero, Mexico, in colors ranging from orange to orangy red, was being offered by several dealers. CB Gems of Scottsdale, Arizona, was selling cut gems as large as 71.92 ct. Rough material was also available, with one dealer offering matrix specimens.

**Update on peridot.** An unusual number of large, good-color peridots were available this year. In the past, relatively few faceted stones over 2 ct have been offered, with many of the larger ones having a strong, undesirable brown component.

One dealer explained that these larger stones come from a new area of the San Carlos deposits. Traditionally, much of the peridot in the market was extracted from diggings at the top of a basalt mesa on the San Carlos Apache Reservation. Recently, however, Apache miners started working new deposits in a canyon below the mesa. First, they remove the overburden with a bulldozer. Then, they use drills and explosives to extract large blocks of basalt. Last, they break the blocks open with sledgehammers and pry bars, revealing pockets that sometimes contain better-color pieces in the 5- to 35-ct range.

Some very nice peridots from China were also available, notable for their "purer" green color. Also, Rudi Cullman of Idar-Oberstein indicated that peridot, mixed with yellow feldspar, is being smuggled out of Ethiopia. The color of the Ethiopian peridot is yellowish green, comparable to average Arizona material.

Figure 6. These two amethysts (1.46 and 2.85 ct) and blue topaz (2.90 ct) are examples of some of the commercial "fantasy" cuts available at Tucson. Photo by Maha Smith.



**Pietersite from Namibia.** Hawk's-eye is a dark blue, silicified form of the fibrous asbestos mineral crocidolite. It often contains oxidized yellowish brown areas of tiger's-eye where the crocidolite has been replaced by quartz. When cut *en cabochon*, this material displays chatoyancy. One major source of hawk's-eye is South Africa.

Pietersite is a lesser-known dark blue, silicified variety of crocidolite. Unlike hawk's-eye, the fibers in pietersite are not parallel but rather form an irregular patchwork of "bundles," some of which exhibit sheen (figure 8).

According to Hannes Kleynhans of Tiger-Eye Manufacturing, Hermanus, South Africa, pietersite is a brecciated form of hawk's-eye. It is named after Syd Pieters, who discovered the source in 1962 at a locality called Outjo approximately 350 km northwest of Windhoek, Namibia. Approximately 2.5 metric tons of the material was recovered over the past two years.

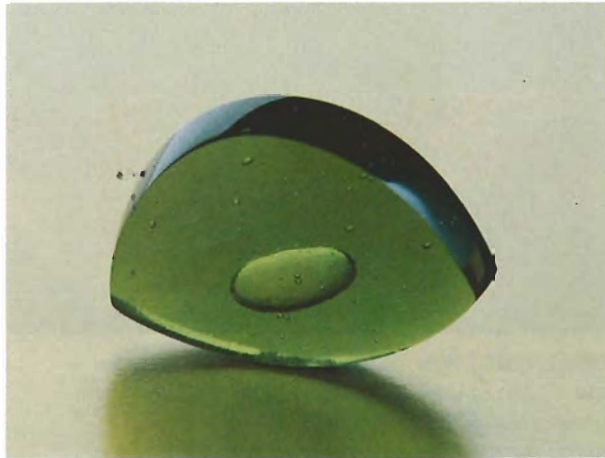


Figure 7. This 14.65-ct fashioned moldavite tektite contains a remarkable 8-mm-long bubble. Photo by Maha Smith.

**Rubies and sapphires from Vietnam.** Probably the most talked-about new source this past year, Vietnamese rubies and sapphires seemed to be everywhere. GIA staff members noted at least a dozen different dealers, with rubies and pink sapphires ranging from melee sizes to around 3 ct. The largest stone seen was a 7.18-ct oval-mixed-cut pink sapphire. One vendor had 11 faceted rubies in the 2- to 3-ct range; the largest weighed 3.14 ct and was of exceptional color and clarity. Also available were green and dark blue sapphires from Vietnam.

**New ruby deposit in Namibia.** Dr. Madan Aggarwal of Nairobi, Kenya, informed us that a new ruby deposit has been discovered near Wentrop, Namibia. The rock association is similar in appearance to that found in Longido,



Figure 8. Pietersite (17.26 ct, left) is a brecciated form of hawk's-eye (19.23 ct, right). Courtesy of Hannes Kleynhans; photo by Maha Smith.

Tanzania: Large ruby crystals with gemmy areas are enclosed in a gray-green mica. Some of the crystals reach several centimeters in their longest dimension. Faceted, transparent stones of up to one carat could be cut from the gemmy areas.

**Australian ruby.** The Queensland Opal Corp. displayed several samples of pink sapphire and ruby from a mine they recently acquired in central Australia. These included several well-formed, platy, hexagonal crystals that were essentially opaque but contained some transparent areas. The largest crystal, although not of gem quality, was almost 7.5 cm (3 in.) long. Fashioned material displayed included three ruby cabochons in the 1- to 1.5-ct range and two relatively transparent star rubies in the 1-ct range.

**Rubies and pink sapphires from Azad Kashmir, Pakistan.** Shams-Ur-Rehman, a recent GIA graduate from Peshawar, Pakistan, had a large selection of mineral-specimen-quality, translucent to semi-translucent ruby and pink sapphire crystals in matrix from Nagi Mali, a remote area of northern Azad Kashmir, Pakistan. This relatively new locality is reportedly only a few hundred kilometers from the famous blue sapphire source in neighboring Kashmir, India.

**Ruby in zoisite.** This ornamental material from Longido, Tanzania, consists of opaque crystals of hexagonal ruby and pinkish purple sapphire in a green chromian zoisite matrix. Several dealers offered large quantities as irregular blocks of rough or as cabochons and beads, small carvings, spheres, and eggs (see figure 2 of the article on green zoisite in this issue for a photo of this material). According to one vendor, the mine continues in full production.

**Chinese blue spinel.** China continues to produce small quantities of interesting natural gems. Pete and Bobbi

Flusser of Overland Gems, Los Angeles, offered several medium-dark violetish blue "cobalt" spinels from China. All pieces were fairly large, from 4 to 14 ct. One contained unusual whitish needles that appeared to be oriented at 90° degrees to each other.

**Tourmaline from Paraíba, Brazil.** Although the saturated tourmalines from Paraíba, Brazil, were available from many different dealers this year, there were significantly fewer stones than in the previous two years. However, a knowledgeable source reported that the conflict over mining rights has been resolved and mining has been resumed.

**Fine tourmalines from Africa.** GIA staff members noted attractive tourmalines from various African sources. Carl Friedrich Arnoldi displayed medium-light to medium-dark pink tourmalines—many resembling fine kunzite—from Nigeria. The stones averaged 2 ct and appeared to be relatively clean.

Both Bill Barker and Pala International offered nice-color rubellite from a recently discovered gem pocket in Namibia. They reported that a few hundred kilos of gem-quality material from this find was being fashioned.

Also noted were some vividly colored pink tourmalines from Madagascar, in sizes averaging 2 ct. The dealer who had them indicated, however, that he suspected the unusual color was due to artificial irradiation.

**Green zoisite from East Africa.** Green zoisite was the subject of considerable interest, but only a few faceted stones were available. Many were brownish green; only a few were the much-publicized "emerald" green. [Editor's note: See the article by N. R. Barot and E. Boehm in this issue for a detailed discussion of green zoisite.]

**Rare gemstones from Mont St.-Hilaire.** Art Grant of Hannibal, New York, and Gilles Haineault of Montreal, Canada, had some rare faceted gemstones from the famed Poudrette quarry in Mont St.-Hilaire, Quebec. These included very brilliant, near-colorless cryolites up to 1.35 ct, and yellow to green, somewhat cloudy, shortites up to 2.37 ct. Faceted colorless pectolite as large as 0.85 ct represents the rare transparent variety of this gem species, which is best known for its opaque-to-translucent blue variety (sold under the trade name "Larimar"). Also notable were a 1.49-ct included, "pistachio" green leucophanite with strong pink luminescence and two rare, transparent, predominantly orange serandites, 1.36- and 1.38-ct emerald cuts. Most interesting was burbankite, a newcomer to the gem world, which shows a remarkable color change from greenish brown in fluorescent light to reddish brown in incandescent light. The largest piece weighed 6.62 ct and was very clean.

## ENHANCEMENTS

**Update on diffusion-treated sapphires.** Blue diffusion-treated sapphires were the most talked-about enhanced gem at

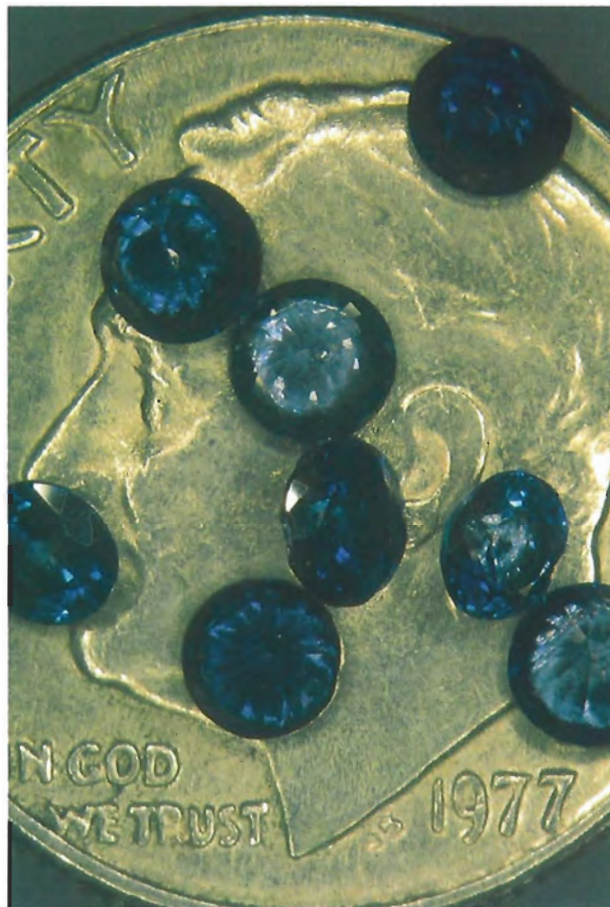


Figure 9. At 3 mm in diameter and with an average weight of 0.12 ct, these were the smallest commercially produced blue diffusion-treated sapphires encountered by the editors. Photo by John I. Koivula.

Tucson this year, with significant quantities available. Joseph A. Rott of Sabeena International, New York City, told the editors that he had approximately 12,000 ct at the show, with a total of 120,000 ct of fashioned goods in inventory.

Apparently, production has been geared to meet the needs of large-scale jewelry manufacturers. For example, Novastar Corp. of Fairfield, Iowa, was offering a number of traditional cuts—rounds, ovals, marquises, pear shapes, heart shapes, and emerald cuts—in a range of calibrated sizes. Stones were also available in a variety of weights, from under 20 points to over 50 ct.

The smallest commercially available stones we saw were 3-mm rounds, weighing an average of 0.12 ct (figure 9). According to Joseph Rott, this is the smallest size his firm markets, because anything smaller cannot be priced competitively against natural-color stones. Jeffrey Bergman of Gem Source, Las Vegas and Bangkok, further explained that the surface layer damaged by the diffusion-treatment heat



is essentially the same depth regardless of the size of the stone. Stones smaller than 3 mm are uneconomical because more than half the weight of the stone would be lost in repolishing. However, Mr. Bergman showed the editors a number of diffusion-treated stones approximately 2 mm in diameter that he had produced for experimental purposes.

Although rumors abounded of diffusion-treated sapphires with a much greater depth of color penetration, we were shown no stones that were reported to have been so treated. Using a portable instrument designed to detect diffusion treatment (see entry below), GIA researchers performed spot-checks on the full range of sizes of blue diffusion-treated sapphires offered by various firms. These examinations revealed diagnostic features consistent with those previously reported in the literature for diffusion-treated sapphires.

We saw no diffusion-treated corundum in colors other than blue, although more than one dealer stated that they were experimenting with other hues, including red and yellow. Two dealers reported some success in diffusing a red layer into the surface, but penetration was shallow and produced only a pink overall body color after repolishing.

**Blue enhanced opal.** Gerard and Joyce Raney of Redwood City, California, showed one of the editors some unusual enhanced opals that resembled Australian black opals. They reported that the starting material, from Brazil, is a highly porous, chalky white, hydrophane opal with a weak play-of-color (figure 10, left). The rough material is first soaked in a chemical mixture of potassium ferrocyanide and ferric sulfate to produce a dark "Prussian blue" color throughout. Once it is dry, the rough is placed in a slightly warmed plasticizing liquid that is composed of methyl methacrylate with a small amount of benzoyl peroxide catalyst. This step seals the pores and clarifies the opals to the point where they are almost transparent. Before the mixture solidifies completely, the now-treated rough is removed and cleaned in preparation for fashioning into polished cabochons. The end result is an enhanced opal with a blue body color so dark that it is almost black (figure 10, right). Regardless of their outward appearance, these opals should offer no identification problem for jewelers and gemologists: The treated opals generally seem too light for their size, have a slightly plastic feel, and, most importantly, reveal their intense, deep blue body color when examined under the microscope or in transmitted light.

**Irradiated green topaz.** Artificially irradiated blue topaz, in a range of tones and saturation levels, has long been a staple of the colored-stone market. At Tucson, however, we saw green irradiated topaz. Advertised as "Ocean Green Topaz," this irradiated topaz is reportedly from Sri Lanka. It was offered by a few firms.

The material the editors saw ranged from light to medium tones and from yellowish and brownish green through more saturated green to slightly bluish green hues. The



Figure 10. Brazilian hydrophane opal before (left) and after enhancement (right). The cabochon weighs 2.43 ct and measures 10.98 mm in longest dimension. Opals courtesy of Gerard and Joyce Raney; photo by Maha Smith.

smallest stone we saw measured 7 × 9 mm; the largest, 25 × 40 mm. GIA researchers are currently investigating this material.

## SYNTHETICS AND SIMULANTS

**Synthetic alexandrite gets new name.** In the Spring 1991 Gem News column we reported on a Czochralski-pulled synthetic alexandrite marketed by J.O. Crystals that debuted at Tucson last year. This year, considerably more material was available, in darker colors with a more pronounced color change. This product is now being promoted as "Nicholas Created Alexandrite." Judith Osmer of J.O. Crystals reported that the chromium content has been adjusted to create a better change of color. The center part of the Czochralski rod contains myriads of small "bubbles" that are actually crystallographically oriented gaps or negative crystals. When viewed with lateral lighting, the effect is similar to the "rain" in Kashan synthetic rubies. The center of the rod is used primarily for cabochons; faceted stones are cut from the periphery.

**More on hydrothermal synthetic beryls.** This year, we again saw hydrothermal synthetic beryls from Russia and Australia [see Gem News, Winter 1988, p. 253, and Spring 1991, p. 54]. The Russian material, in a range of colors, was shown by Kyle Christianson Ltd., of Sylvania, Ohio, a firm that markets a number of laboratory-grown gem materials produced in Novosibirsk (see CZ entry below). Although these synthetic beryls were for display only, we learned that they may become a commercial reality in the near future.

Kimberley Created Emeralds markets the Biron synthetic pink beryl, an Australian product; at the show, they were offering approximately a dozen faceted stones in the 2-ct range. They also had two bicolored, "watermelon,"

synthetic beryls. These square step cuts consisted predominantly of synthetic pink beryl with a green (synthetic emerald) zone at the culet, which produced distinct pink and green zones face-up. These synthetic beryls are currently being investigated by GIA researchers.

**Colored CZ plentiful.** Although relatively little colorless cubic zirconia was seen this year, many color varieties were found in abundance in both rough and cut form. These included green, blue, orange, orangy red, yellow, and purple varieties in predominantly high saturations. One of the more frequently seen colors was a medium light to medium tone of purple, sometimes being sold as "Lavender Ice."

Most prevalent, however, were light to medium tones of pink, heavily promoted under such names as "Pink Ice" and "Nouveau Rosé." They were commonly set in sterling silver and gold-electroplated fashion jewelry. One randomly chosen faceted piece was purchased for gemological examination. It revealed a Chelsea color filter reaction, long- and short-wave U.V. luminescence, and absorption spectrum

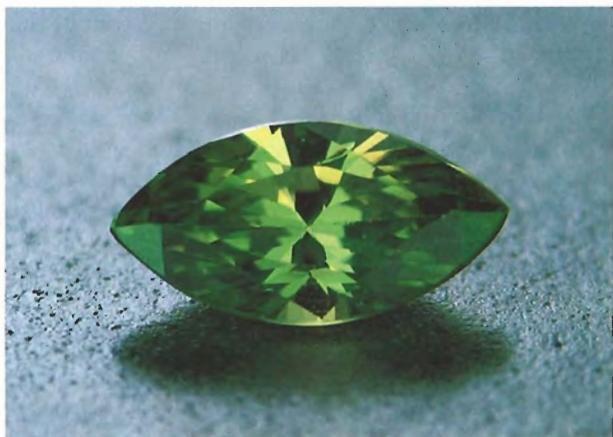


Figure 11. The color of this 2.00-ct cubic zirconia from Russia is similar to that of some dark green tourmaline. Photo by Maha Smith.

(as seen with a desk-model spectroscope) that were essentially the same as those noted for the pink nontransparent "CZ" recently investigated by the editors and colleagues (see *Gems & Gemology*, Winter 1991, p. 240). These non-transparent varieties were also available at Tucson for the first time this year.

Kyle Christianson Ltd. was marketing a new, dark yellowish green CZ—reminiscent of some fine iron-colored tourmaline—that reportedly was obtained only recently in Russia. The 2.00-ct marquis cut shown in figure 11 was subsequently examined; it appeared green through the Chelsea color filter, was inert to long-wave U.V. and fluoresced a weak yellow-green to short-wave, and showed absorption bands at 443–450, 472, 483, 583, and 607 nm.

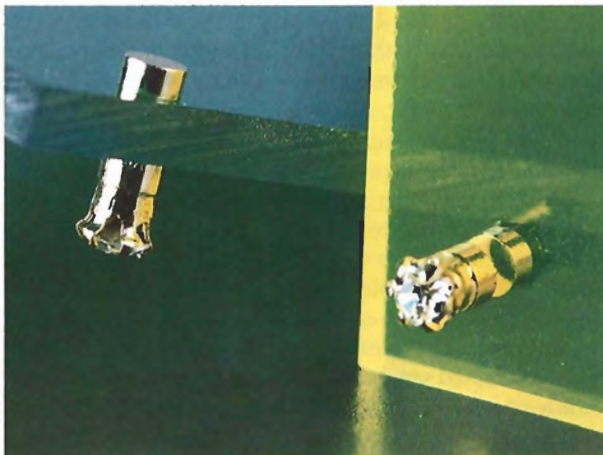


Figure 12. These glass imitation-diamond ear studs are held in place with tiny magnets. Photo by Maha Smith.

**Rare laboratory-grown crystals.** In addition to the large quantities of such well-known laboratory-grown gem materials as CZ, YAG, and synthetic corundum, emerald, and quartz, we also came across faceted samples of some very unusual laboratory-grown materials. These included germanium bismuth oxide, lead molybdate (synthetic wulfenite), and tellurium dioxide. Some older diamond simulants, not seen in the market for a long time, included strontium titanate and lithium niobate.

**Magnetic "pierceless earrings."** One jewelry item we came across was unusual not for the gem materials but for the method in which they were used. Marketed as "pierceless earrings" (figure 12), these were colorless-glass diamond simulants and imitation-pearl ear studs held in place by tiny magnetic "clips." They were promoted for use by those who do not wish to pierce their ears, especially for the multiple-earring look.

**Another chatoyant glass.** For several years, we have seen a semitranslucent, chatoyant glass composed of parallel optical fibers. Sometimes this material is deformed to produce a wavy reflective band when cut *en cabochon*. With both types, the cat's-eye effect is very pronounced, contributing to the rather unnatural appearance of the fashioned gems (see *Gem News*, Summer 1991, p. 123).

This year we encountered a more transparent variety of chatoyant glass with a less pronounced (i.e., more natural-appearing) "eye." When viewed face-up, the chatoyant band is seen to be intersected at right angles by a series of evenly spaced dark "lines" (figure 13).

Microscopic examination from the side and perpendicular to the chatoyant band revealed the expected honeycomb structure, with the individual cells having hexagonal outlines. The individual fibers were thicker than



Figure 13. The reflective band on this 11.00-ct cat's-eye glass cabochon is less distinct than that usually noted on this type of manufactured gem. Photo by Maha Smith.

those noted in the materials mentioned above and exhibited nontransparent peripheries. Both these features contributed to the less distinct chatoyancy. Magnification also revealed that the dark parallel lines were slender, parallel, dark brown "inclusions" of square cross-section. When taking an R.I. on the cab's dome, we noticed that the parallel fibrous structure produced two separate "striped" spot readings of about 1.48 and 1.62.

**Novel crystal opal imitation.** One of the more interesting novelty "gems" at Tucson was a composite product marketed by Manning International of New York and Hong Kong. Promoted under the trademark name "Gemulet," this product consists of colorless glass in which small fragments of synthetic opal have been embedded (figure 14). Because the glass used has a refractive index (1.47) that is very close to that of the synthetic opal (1.45), the latter has very low relief. Consequently, the play-of-color appears to be coming from the larger "gem," rather than from the included opaline material. The material is marketed in teardrop shapes (for pendants and earrings) and as faceted pieces.

**Faceted synthetic quartzes.** In last year's Tucson report, the editors mentioned the availability of large quantities of Russian-grown synthetic quartz in a number of colors. Most of that material was rough; this year, significantly more faceted material was seen.

Figure 15 illustrates three representative samples. The



Figure 14. This 0.83-ct "Gemulet" simulant for crystal opal consists of a single synthetic opal fragment embedded in colorless glass. Specimen courtesy of Manning International; photo by Maha Smith.

yellow specimen shown is a synthetic citrine; we also saw some synthetic yellowish brown quartzes that were reminiscent of "sherry" topaz. The green specimen, which is darker and more saturated than any natural single-crystal quartz we have encountered, could be an effective simulant for green tourmaline. Both the yellow and green varieties owe their color to the presence of iron. The blue synthetic quartz, also with no natural counterpart, is reminiscent of some irradiated blue topaz. The most popular variety of synthetic quartz remains synthetic amethyst.

Figure 15. These Russian-grown hydrothermal synthetic quartzes (left to right: 6.18, 6.42, and 6.20 ct) are representative of some of the faceted material now available. Photo by Maha Smith.





Figure 16. Titanium is the coloring agent of this 2.40-ct Czochralski-pulled synthetic pink sapphire. Photo by Maha Smith.

**Knischka synthetic rubies.** Knischka synthetic ruby, a flux-growth product of Paul O. Knischka of Austria, was marketed at Tucson this year by the Argos Group of Los Angeles, California. According to a recent news release, Argos has been appointed the exclusive North American distributor of Professor Knischka's products.

**Synthetic blue and green sapphires grown by Czochralski pulling.** The Washougal plant of Union Carbide in Washington state produces blue and green Czochralski-pulled synthetic sapphire. The rod fragments that we examined exhibited concentric color zoning from the core to the rim, similar to that observed in flame-fusion synthetic blue sapphire. Medium-tone, slightly violetish blue faceted stones were available through the Argos Group of Los Angeles and were loupe clean.

Figure 17. These YAGs (2.44–3.53 ct) represent some of the colors seen as faceted stones at Tucson. Photo by Maha Smith.



**Titanium-doped synthetic pink sapphire.** Flame-fusion synthetic pink sapphire has long been available in the gem trade. It typically owes its color to chromium. These synthetic pink sapphires characteristically appear red through the Chelsea filter, fluoresce red to long-wave—and pinkish purple to pink to short-wave—U.V. radiation, and reveal a "chromium" absorption spectrum.

A number of vendors at Tucson were marketing another type of synthetic pink sapphire (figure 16). Produced by the Czochralski method, this material owes its color to doping with titanium (as confirmed by GIA Research). This "titanium sapphire" is grown in large amounts by companies such as Union Carbide for use in the laser industry. Preliminary gemological testing revealed a strong orangy red color through the Chelsea filter, a moderate orange fluorescence to long-wave—and a very strong bluish violet fluorescence to short-wave—U.V., and no distinct absorption features in the spectrum obtained with a desk-model spectroscope. GIA researchers are currently conducting a more detailed study of this material.

**Imitations of sugilite and other nontransparent gems.** In the Spring 1991 Gem News section, we reported on a convincing lapis lazuli imitation that consisted of barium sulfate in a polymer matrix with pyrite inclusions. We also regularly see rectangular blocks of a reportedly similar composition in colors that imitate coral, turquoise, sugilite, black "onyx," malachite, and azurite-malachite.

Such "rough" material was again at Tucson, but this year a large number of fashioned pieces were also available. Most prevalent were necklaces of beads in various shapes, sizes, and colors. Especially prevalent were imitations of azurite-malachite, but these were only moderately convincing.

We purchased a 2.52-ct square tablet resembling sugilite for examination. Gemological testing revealed a vague spot R.I. in the mid-1.50s and an S.G. of 2.26. When the surface was gently rubbed with an acetone-dipped cotton swab, it became dull and appeared to "lose" its polish; a thermal reaction tester ("hot point") applied to the base caused white discolorations and produced an acrid odor. All these properties are similar to those of the imitation lapis mentioned above.

Examination with ultraviolet radiation produced interesting reactions: a strong chalky orange luminescence to long-wave and a weak to moderate chalky orangy red luminescence to short-wave. These reminded us of the reactions we have noted in some jadeite dyed to imitate natural-color "lavender" material. The color concentrated in fractures of such material is very similar to the body color of this sugilite imitation.

**Faceted colored YAG.** Also seen in far greater quantities than in past years were various colors of YAG (figure 17), manufactured yttrium aluminum 'garnet' being sold in both rough and cut forms.



Figure 18. Standing approximately 6.25-in. (15.9 cm) tall, this cored crystal section of colored YAG was marketed as a "pencil holder." Photo by Maha Smith.

One notable color was a highly saturated, "fluorescent"-appearing yellow. Gemological examination of a 3.16-ct faceted sample revealed total absorption from 400 to 500 nm (in a desk-model spectroscope) and very strong yellow luminescence to both long- and short-wave U.V. radiation. EDXRF analysis revealed the presence of cerium as the coloring agent. Another type, colored by neodymium, had a light pink to purple color change.

Some samples were a saturated medium-dark, slightly violetish blue similar to some irradiated topaz. This material appeared red through the Chelsea color filter and showed a typical cobalt-type absorption pattern, with bands at approximately 560, 595 and 640 nm. EDXRF analysis confirmed the presence of cobalt as the coloring agent. Interestingly, the material was inert to both long- and short-wave U.V., perhaps because of a trace presence of iron. We also saw greenish blue material that resembled some cuprian tourmaline from Paraíba, Brazil (one large section weighed 2,310 ct). EDXRF analysis established the presence of both chromium and thulium (a rare-earth element), which are presumed to be the cause of color.

Saturated greens ranged in tone from medium to very dark. EDXRF analysis of a lighter-toned yellowish green specimen revealed the presence of chromium, thulium, and holmium, all believed to contribute to the color. Similar examination of one of the darker, very slightly bluish green stones, however, revealed the presence of chromium alone as the chromophore.

Although these or similar colors are also available in CZ, the lower dispersion of YAG makes it perhaps a more

effective simulant for some colored stones, most of which typically display little or no eye-visible dispersion.

**YAG as an "ornamental" material.** One interesting item was an unusual use for sections of Czochralski-pulled crystals of neodymium-doped YAG. Grown for laser rods, these large crystals had been extensively cored, typically leaving 12 or more holes of varying diameter running the length of the crystal sections. One enterprising vendor was marketing these as "synthetic garnet pencil holders" (figure 18).

## INSTRUMENTATION

**Instrument for detecting diffusion treatment.** As previously noted, blue diffusion-treated sapphires are becoming increasingly prevalent. While thus far detection of this treatment has been relatively straightforward, the equipment required is not always conveniently available.

In response to this challenge, GIA GEM Instruments developed the Illuminated Immersion Cell (figure 19), a portable instrument that provides all the tools needed to detect diffusion treatment. Debuted at Tucson, it features a battery-powered, high-intensity krypton light source and reflector contained within the base of an immersion cell. This provides diffused transmitted light, the best illumination for detecting the diagnostic color inhomogeneities of the treatment. The instrument also features a 2 × lens, fitted into the screw cap of the immersion cell, which enables a magnified view of a stone's features. It can be used with a variety of liquids, including water, glycerine, or methylene iodide.

Although designed primarily for the detection of diffusion treatment in corundum, the instrument is also useful for observing other types of color zoning, including the curved color banding of flame-fusion synthetic sapphires. Additional uses include detecting assembled stones and carrying out relative relief tests (e.g., in the separation of diamond from its simulants).

Figure 19. GIA GEM Instruments' new portable Illuminated Immersion Cell is designed to detect diffusion treatment. Photo by Maha Smith.



# Gems & Gemology

# C · H · A · L · L · E · N · G · E

The pace of developments in gemology is accelerating. Over the last year alone, *Gems & Gemology* has reported on exciting new ruby finds in Vietnam and Tanzania, renewed mining for emeralds in Russia and Afghanistan, as well as new theories on the formation of diamonds and new techniques for their recovery from vast offshore deposits. We have also looked at new synthetic gem materials, new treatment processes, and new cutting techniques.

We've met our 1991 challenge. Now, with GIA's Continuing Education Department, *Gems & Gemology* challenges you.

The following 25 questions are based on articles published in the four 1991 issues of *Gems & Gemology*. Please refer to those issues to find the *single best answer*; then mark the appropriate letter in the card provided in this issue (photocopies or facsimiles will not be accepted). Mail the card with your answers by Monday, August 24, and be sure to include your name and address. All entries will be acknowledged with a letter and an answer key.

Score 75% or better, and you will receive a GIA Continuing Education certificate testifying to your accomplishment. Score a perfect 100%, and your name will also appear in the Fall issue of *Gems & Gemology*.



*Note: Questions are taken from only the four 1991 issues. Choose the single best answer for each question.*

- Separating Morogoro rubies from Mogok rubies is difficult because they share
  - a marble-related origin.
  - a similar gallium content.
  - a similar vanadium content.
  - the presence of two or three systems of twin lamellae.
- Andamooka matrix opal has been color enhanced by carbon impregnation since the
  - late 1930s.
  - mid-1950s.
  - mid-1960s.
  - early 1970s.
- In 1990, the value of emeralds produced in the Panjshir Valley of Afghanistan was approximately
  - \$5 million.
  - \$10 million.
  - \$10-\$20 million.
  - more than \$20 million.
- The proportion of marine diamonds that are gem quality is about
  - 10%.
  - 25%.
  - 50%.
  - 90%.
- Red garnets have been mined in Czechoslovakia since the
  - 16th century.
  - 17th century.
  - 18th century.
  - 19th century.
- From November 1989 through March 1990, a deposit of pink sapphire and ruby in the Luc Yen district of Vietnam produced more than
  - 500,000 carats.
  - one million carats.
  - three million carats.
  - five million carats.
- "Pearl CZ" can best be separated from natural and cultured pearls by
  - the "candling" effect seen in strong transmitted light.
  - its significantly higher R.I. and S.G.
  - its color in transmitted light.
  - its fluorescence reaction to U.V. radiation.

8. Opticon may improve the apparent clarity of an emerald better than "traditional" oils because
- it is more durable.
  - it contains fewer bubbles.
  - its R.I. is closer to that of natural emerald.
  - its color is closer to that of natural emerald.
9. Rubies from Morogoro, Tanzania, have been found mixed in parcels of
- garnets.
  - tourmalines.
  - Burma rubies.
  - spinel.
10. The rarest color of labradorite from the Ponderosa mine is
- pink.
  - deep red.
  - pale yellowish orange.
  - bright saturated green.
11. Emeralds were first discovered in Russia in
- 1780.
  - 1830.
  - 1860.
  - 1910.
12. All gem-quality labradorite crystals from the Ponderosa mine exhibit
- aventurescence.
  - Carlsbad twinning.
  - Albite twin lamellae.
  - dendritic manganese staining.
13. Treatment of matrix opal from Andamooka can be identified by
- the black particulate carbon visible with  $10\times$  magnification.
  - its patchy blue-white fluorescence to long-wave U.V. radiation.
  - its pronounced play-of-color.
  - the presence of siliceous matrix visible with  $10\times$  magnification.
14. Marine diamond deposits are only now considered feasible because
- of the greater demand for industrial diamonds.
  - exploration for new land sources is expensive.
  - deep-sea diving apparatus is now relatively inexpensive.
  - sea levels have recently dropped.
15. The "open table" style of cutting has been used primarily
- to cut small diamonds.
  - to repair badly damaged diamonds.
  - to fashion transparent colored stones.
  - as a modification of cabochon cutting.
16. Some of the oldest diamonds dated so far are from the
- Kuruman kimberlite.
  - Argyle lamproite.
  - Premier kimberlite.
  - Kimberley kimberlite.
17. Chemically, emeralds from the Panjshir Valley most closely resemble those from
- Russia.
  - Brazil.
  - Pakistan.
  - Colombia.
18. The great majority of diamonds in South Africa will probably be discovered
- along the river basins.
  - at their lamproite sources.
  - at their kimberlite sources.
  - submerged along the continental shelf.
19. The most appropriate indication of the origin of Uralian emeralds is
- color analysis.
  - growth structures.
  - refractive indices.
  - optical microscopy.
20. The garnet industry in Czechoslovakia today employs
- about 5,000 persons.
  - 5,000 to 7,500 persons.
  - 9,000 to 10,000 persons.
  - well over 10,000 persons.
21. The first step in detecting filled fractures in emeralds is
- immersion microscopy.
  - locating surface breaks.
  - locating flow structure.
  - identifying inclusions.
22. The gemological characteristics of rubies from Vietnam overlap those of rubies from other localities, except for
- reaction to U.V. radiation.
  - the presence of nordstrandite inclusions.
  - distinct lines at 692.8 and 694.2 nm in their absorption spectrum.
  - irregular, "swirled" growth features.
23. A rock fragment that may bear diamonds and is foreign to the igneous mass in which it is found is
- ultramafic.
  - an eclogite.
  - a xenolith.
  - a peridotite.
24. Annual production of cubic zirconia
- is about half a billion carats.
  - approaches one billion carats.
  - is greater than one billion carats.
  - is as much as one and a half billion carats.
25. It is believed that diamonds are transported by kimberlite from 110 km below the surface to the surface
- in less than one day.
  - in about a year.
  - over hundreds of years.
  - over thousands of years.

# Reviews

ELISE B. MISIOROWSKI AND LORETTA LOEB, EDITORS

## CAMEOS OLD AND NEW

By Anna M. Miller, 216 pp., illus., publ. by Van Nostrand Reinhold, New York, 1991. US\$39.95\*

This well-organized book begins by reviewing the history of cameo carving and its evolution from the cylinder seals of Mesopotamia to the scarab seals of Egypt and then to the naturalistic engravings and portraits of ancient Greece and Rome. Detailed explanations are given of the powerful myths of the various periods, which were commonly depicted in the cameo jewelry. Later, intarsia during the Dark Ages would reflect the odd mixture of pagan beliefs and Christian symbolism of Medieval Europe.

The renewed interest in art during the Renaissance influenced the use of perspective and light in the cameo carvings of that time, and materials other than chalcedony, such as shell, gained popularity. The romanticism of the 18th century led to an obsessive desire for cameos in the upper and newly emerging middle classes of the 19th century. Thus, a busy market in fraudulent "ancient" cameos was spawned. By the end of the 1800s, these forgeries had successfully doused the flames of interest in this art form, and it has never fully recovered.

The chapter on cameo production compares ancient tools and techniques to modern carving methods. A valuable portion of this chapter provides criteria to separate hand-carved cameos from those mass-produced today by ultrasonic machines. Ms. Miller explains the "fresh-fallen snow" char-

acteristic (recognized by the absence of undercutting or tool marks, a matte finish, and repetitive texture and design) that readily identifies ultrasonically carved cameos. Another clue is provided by the surface of the carving: The hand-carved piece feels smooth, whereas the machine-carved cameo feels slightly rough to the experienced touch. A short discussion covers the materials employed and the use of color in planning a carving. This is followed by a step-by-step description of the cutting process. The chapter concludes with information on major carving centers and master carvers associated with those centers.

A chapter on distinguishing ancient from modern cameos examines the difficulties involved in circa-dating cameos (i.e., assigning an approximate date of manufacture) and notes the importance of signatures in authenticating a piece. To help the reader identify legitimate carvers, Ms. Miller provides information on the signatures of the major carvers and where they are typically located on given pieces. She emphasizes, however, that fraudulent cameos of period and signature abound, as do assembled carvings.

Various glass cameos are discussed, as are Wedgewood, sulphide, and plastic cameo imitators. Ms. Miller also discusses cameo wax portraits (a totally new cameo form for this reviewer) along with plaster-of-paris and sulphur-cast cameos.

The book concludes with discussions on appreciating the artistic aspects of cameos and the factors

involved in building one's own cameo collection. Ms. Miller cites a number of historic public and private collections.

A series of appendices includes a fairly extensive glossary; helpful lists of auctioneers, booksellers, retail sources, and suggested reading; and a bibliography. Particularly useful is the compact information provided in the "Instant Expert" portions, which cover common cameo subjects and materials, as well as what features to look for when circa-dating cameos.

Ms. Miller's *Cameos* is easy to read and comprehend. It will undoubtedly prove useful to appraisers, collectors, and admirers of this art form.

JO ELLEN COLE  
GIA Research Librarian  
Santa Monica, California

## BASIC WAX MODELING: AN ADVENTURE IN CREATIVITY

By Hiroshi Tsuyuki, 106 pp., illus., publ. by Matsubara-Kashiwa Books, Japan, 1990. US\$25.00\*

Directed toward the novice, this book is a wonderful step-by-step guide to carving wax for jewelry casting. It discusses the various techniques as well as commonly

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



used tools and the wide variety of waxes that are available.

The greater part of the book is dedicated to 11 wax-carving projects, which are laid out in an easy-to-read photo/text format. Covered are hard-wax carving, wax buildup, sheet-wax work, and texturing and welding techniques. Beginning with simple skills and working progressively to more complicated levels, the author illustrates each project with black-and-white photos, line drawings and close-up views of the actual piece being worked. At the end of each project, additional sketches illustrate the types of rings or jewelry that could be created using the skills learned in that particular exercise.

Some of the projects include useful tips or "tricks of the trade," such as using an ink eraser to clean up deep grooves. Similarly, the author does a nice job of including cautions in especially critical areas. Overall, the book is well presented and easy to comprehend. There are occasional typographical or translation errors, but they are minor and do not detract from the usefulness of the book.

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*S. Alexis Co. Manufacturing  
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## THE ENCYCLOPEDIA OF GEMSTONES AND MINERALS

*By Martin Holden, 303 pp., illus., publ.  
by Michael Friedman Publishing  
Group, 1991. US\$45.00.*

Although from the title one might expect a book that contains all the information from both the *Encyclopedia of Minerals* and the *Color Encyclopedia of Gemstones*, this is not the case. Rather, this is a good, comprehensible book about most minerals and gem materials that the average collector or gemologist is apt to see. Also

included are a number of related topics, such as atomic structure, cleavage, polymorphism, and sedimentary rocks.

Each mineral or gem entry includes, in list form: classification (e.g., carbonate, native metal, organic gem material, etc.), chemical composition, crystal system, hardness, and specific gravity. Some of the important properties of each material are also discussed, as are how the material is formed and major localities, primary uses, and name origin. Unfortunately, there is little mention of optical properties, including refractive index, which would have made this book even more useful for gemologists.

Most of the 340-plus photographs are very good, and many minerals are complimented by crystal drawings from Viktor Goldschmidt's classic work, *Atlas der Krystallformen*.

However, the book does contain a few notable errors. In the discussion on diamonds, for example, the dark yellow color is erroneously attributed to iron rather than nitrogen, and the pink color is attributed to manganese rather than structural defects. Also, play-of-color in opal is wrongly referred to as "opalescence." Under corundum, the only method of synthesis mentioned is the Verneuil process, and the discussion of topaz includes no mention of the irradiation treatment that has produced millions of carats of blue topaz.

Despite these shortcomings, collectors, students, and general readers will find this book a useful introduction to the world of gems and minerals.

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## ANCESTRAL JEWELS

*By Diana Scarisbrick, 191 pp., illus.,  
publ. by Vendome Press, New York,  
1991. US\$37.50\**

This book presents a brilliant study of

heirloom jewelry as it relates to British aristocracy. Beginning with traditions of late Medieval and Renaissance times, and continuing into the 20th century, Ms. Scarisbrick examines ancestral jewels in a way that successfully enables the reader to understand their historic significance. She also exquisitely illuminates the circumstances of their creation and use.

Fantastic portraits of bejeweled nobility mark each of the six chapters that detail the loves and lives of Britain's most illustrious bloodlines—Tudors, Stuarts, both early and later Georgians, Victorians, Edwardians, and their successors. Ms. Scarisbrick's research is meticulous, with specific dates and events referenced and cross-referenced. Detailed explanations not only describe the physical aspects of a particular jewel, but also discuss precisely the way it was worn or kept—often coupled with an anecdote relating to its presentation. A great deal of rare information has been compiled to give the reader these new perspectives on the past.

The appendix titled "Where Are They Now?" further explores the dispersal, transformation, or theft of some of these exquisite objects. The brief glossary that follows is particularly helpful for those who are unfamiliar with certain terms.

Most of the illustrations are in black and white, which is probably due to the limited accessibility of the actual pieces and the age of the photos themselves. Where possible, contemporary color photos are provided. A nice balance is achieved by including historic color portraits that show the owners wearing their jewels.

I highly recommend this well-written, reasonably priced book to anyone interested in augmenting their knowledge of antique and period jewelry.

CAROL P. ELKINS  
*Assistant Vice President, Jewelry  
Sotheby's  
Los Angeles, California*

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# LETTERS

## GROWTH OF SYNTHETIC RED SPINEL FROM NATURAL SPINEL

In a letter quoted in the Summer 1991 issue of *Gems & Gemology* (Gem News, p. 125), Dr. G. V. Bukin states that flux-grown synthetic red spinels are produced at his institute (in Novosibirsk, Russia) using "defective crystals" from the Pamir Mountains as feedstock, so the properties of the finished material are very similar to those of natural Pamir spinel. This type of claim usually implies that the product has at least some of the aspects of a "regrown" or "reconstructed" one.

Such claims frequently have been made over the years, usually as a form of advertising "puffery," by which the marketer intends to convince the customer that his synthetic product is to be preferred over that of others. Examples that come to mind range from the Geneva Rubies of about 1885 (Nassau, *Gems Made by Man*, p. 42ff) to the quite recent Biron synthetic emerald (Nassau, *Gems & Gemology*, Spring 1990, pp. 55-56). These claims are usually withdrawn eventually, often when close examination shows them to be false. Curiously enough, no one has yet tried to make such a claim for synthetic quartz, where natural quartz is indeed used as feed.

Three considerations are relevant. *First*, crystal growth is strongly influenced by trace impurities. Therefore, crystal growers use highly purified materials to yield reproducible results; they would not permit entry into their flux or melt of unknown quantities of unknown types of inclusion impurities that would accompany "defective crystals." Only in quartz is a very pure natural substance available in quantity at a sufficiently low cost. *Second*, the form and structural defects of a crystal are lost when it dissolves in a flux or melt, so the form and structural defects of the synthetic derive from the process and not from the feed. *Third*, those impurities that might be deemed characteristic of a specific locality have distribution coefficients that differ from one another, so the locality impurity distribution fingerprint would not be carried over into the synthetic even if the natural mineral was used as feed.

Any one of these considerations is sufficient to discount Dr. Bukin's claim. The reason for this claim undoubtedly does not derive from his undisputed technical

competence, but may be found in his concern for "marketing and trade" aspects, to which he refers in his letter.

KURT NASSAU, PhD  
*Lebanon, New Jersey*

## DR. BUKIN REPLIES

I enjoy reading Dr. Nassau's reviews on gem growth and find them very useful. But real experimentation is much more complicated. I wish to note the following regarding Dr. Nassau's remarks.

Hydrothermal and flux crystals are grown at high temperatures (400°–600°C for hydrothermal, 1000°–1250°C for flux) in very complex compositions of fluxes and melts. The final product is affected not only by the original raw materials, but also by the solutions and fluxes themselves as well as by the material of the container in which the process occurs.

Because of the solvents my colleagues and I have developed, microimpurities in the raw materials have an extremely negligible effect on crystallization. So we can produce gems that are very similar in composition and properties regardless of the deposit from which the initial raw material came.

Moreover, for industrial production it is more economical to employ cheap chemicals with impurity contents up to several percentage points. Pure chemicals, which are quite expensive, have no advantage as the raw material, while defective crystals and cutting scraps of emerald, other beryls, and spinel are cheap and readily available.

If one were to make a school experiment of halite (NaCl) recrystallization, one would never think to use Na<sub>2</sub>CO<sub>3</sub> and HCl as raw materials; rather, one would simply dissolve common table salt in hot water and then grow the halite crystals by cooling the solution or by temperature-gradient technique. We use the same approach. We have succeeded in obtaining the solvents (flux and hydrothermal) in which natural materials dissolve well enough at some higher temperatures, and we constantly provide stoichiometric saturation of the solution relative to the growing crystals in a colder growth zone. That is how the process of recrystallization of natural defective material into high-quality crystals takes place.

Only with the growth of synthetic alexandrite and synthetic emerald for laser applications do we employ pure chemicals (including some rather toxic beryl compounds). Even in these cases, we use pure chemicals only to avoid contamination of the grown crystals with Fe ions that might badly influence spectral and generating characteristics of the final product.

As for Dr. Nassau's second and third considerations, they do not contradict our methods of growth. Indeed, the process of recrystallization of the initial natural raw material takes place throughout the solution stage, with subsequent crystal growth on seeds or spontaneous nucleation of higher-quality crystals with different contents of microimpurities. The desired color characteristics are produced by small admixtures of transition metal ions—mainly of Cr, V, Fe, Ni, and Co—that are obtained by the growing crystals from the "mother" solutions and melts. All the above data are reported in my published works, which at this time are available only in Russian.

G. V. BUKIN, PhD  
*Design Technological Institute  
of Monocrystals (Siberian Branch)  
Novosibirsk, Russia*

### HOLLOW HEXAGONAL COLUMNS IN DIAMOND NOT ETCH PITS

I read with interest the Gem Trade Lab Notes entry on hexagonal etches in diamond (Fall 1991, p. 174). However, the feature described is a very well-shaped hexagon with a straightness and depth that are inconsistent with other natural etch pits in diamond. I would like to suggest, therefore, that this feature is not an etch pit, but rather the result of a needle crystal that has been etched out by the acid-cleaning process to which diamonds are subjected.

On one occasion, I recorded a group of similar features

in a rough diamond that, of significance here, were crystals rather than holes. Each one protruded a bit above the diamond's surface, exhibiting a crystal "roof" structure. I think you will agree that there is an association between our two observations. I enclose my original photographs for comparison [figure 1]; perhaps someone can speculate as to the identity of the original needle crystals.

JOHN CHAPMAN  
*Argyle Diamonds  
West Perth, Western Australia*

### LOWER THE HEATING TEMPERATURE FOR OPTICON

We enjoyed the article on our product, Opticon 224<sup>2</sup>, in the Summer 1991 issue of *Gems & Gemology*. Not only was this new application of our product of interest to us, but we also appreciate the exposure and increased business that the article has provided. In fact, the product was not designed for the treatment or enhancement of faceted gemstones; it was designed to seal fractures in slabs of agate and other gem materials and to stabilize rough turquoise and other soft stones to reduce waste during the cutting process.

My intention in writing is to pass on an important point that was brought to our attention by one of our customers. On page 72 of the article, the authors state that one user recommended a heating point of 203°F. However, the flash point of Opticon is 164°F! Since publication of the article, we have already received one report of the product burning and turning black. This could not only ruin the material being treated, but it could also present a serious fire hazard to the user. Our directions on the product package now suggest a warming temperature no higher than 150°F.

MARY A. HULLSIEK  
*Hughes Associates  
Victoria, Minnesota*

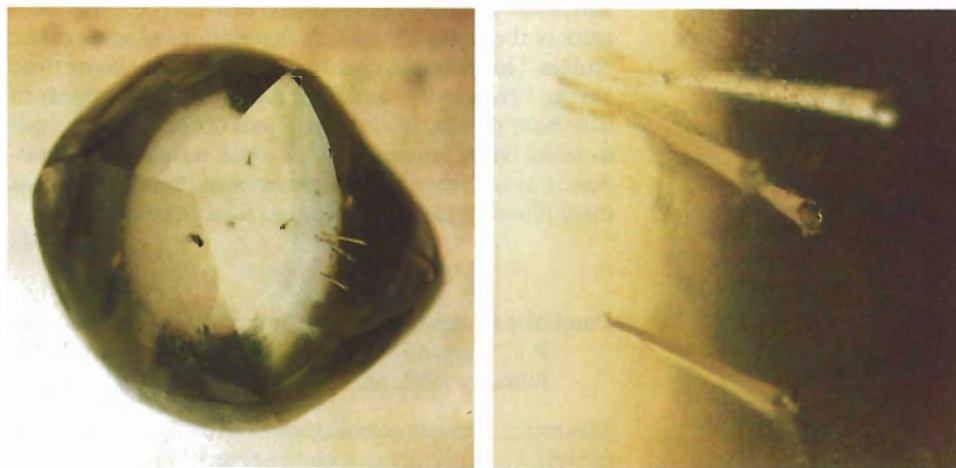


Figure 1. These "needle crystals" in diamond may be etched out during the cleaning processes that diamonds undergo, leaving "holes" in the finished stone. Photos by John Chapman.

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# GEMOLOGICAL ABSTRACTS

DONA M. DIRLAM, EDITOR

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## COLORED STONES AND ORGANIC MATERIALS

**Contributions to a history of gemmology—Carl Peter Thunberg and Ceylon gemstones.** J. Sinkankas, *Journal of Gemmology*, Vol. 22, No. 8, 1991, pp. 463–470.

Technology has made gemology an increasingly complex area of study, but it has also brought much greater understanding of gem materials. A glance at the history of gemology—such as Dr. Sinkankas provides in this article—reveals just how confusing it was before the advent of technology.

This article opens with a brief biography of 18th-cen-

tury Swedish naturalist Carl Peter Thunberg. Primarily a botanist and physician, Thunberg dabbled briefly in gems after a few weeks' visit to the island of Ceylon (now Sri Lanka) in 1777. By that time, Ceylon was long famous as a source of gemstones, notably since Marco Polo's reports in the 14th century. In the 17th century, Jean-Baptiste Tavernier cited Ceylon as one of only two sources of colored stones in the East (the other being Burma).

From Thunberg's writings, Dr. Sinkankas provides a list of 19 gem materials with names in English, Malabarese, Sinhalese, and Swedish and with brief descriptions. The remainder of the article is a discussion in which Dr. Sinkankas attempts (convincingly) to unravel the true identities of the gems. Thunberg's descriptions of some of the "rubies," for example, clearly fit what we now know to be zircon. "Hyacinths" and "red turmalins" also appear to have been zircons, while descriptions of "blue sapphire" call to mind iolite, aquamarine, or topaz rather than corundum. Europe's then-fledgling science of chemical analysis more often clouded identification than clarified it.

CMS

**Turquoise in Pre-Columbian America.** G. Harbottle and P. C. Weigand, *Scientific American*, Vol. 266, No. 2, February 1992, pp. 78–85.

This article presents gemology from an archaeological point of view. Pre-Columbian societies revered turquoise above even jade. Holding great social and religious value, arti-

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

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facts of worked turquoise have been found throughout Mesoamerica. Yet the only sources of turquoise in this area are in what is today the American Southwest. The movement of turquoise from the Southwest throughout Mexico helps identify the apparently extensive contacts between the Mesoamerican and Southwest cultures.

The earliest evidence of turquoise in Mesoamerican culture dates from approximately 600 B.C., but it was not used widely until 900–1200 A.D. We know that raw turquoise was imported from the Cerrillos area of what is now New Mexico in 700 A.D. for use in religious ceremonies. Eventually, the Chaco Canyon settlement of New Mexico developed into the major manufacturing and distribution center for turquoise. The ceremonial use of turquoise reached its zenith between 975 and 1130 A.D.

Gradually, use of turquoise expanded beyond the religious leaders and rulers to the middle and lower classes. As consumption of turquoise in Mesoamerica increased, though, Chaco Canyon appeared to lose its monopoly of the turquoise trade. The greater demand led to the opening of other sources—and trade routes—in the Southwest. By the 13th century, demand for turquoise had never been stronger, but Chaco Canyon was no longer the single major center.

The isolation of the deposits and hardships of retrieving the turquoise must have been extremely challenging to ancient miners. Simple single-shaft chamber mines were most common, although sometimes these mines were expanded to huge open pits. Tools recovered from the mine sites show little technical expertise. Most common are double-sided hammer stones of heavy throw weight. The strength required to wield them must have been considerable.

*Jo Ellen Cole*

## GEM LOCALITIES

**Volodarsk-Wolynskii. Geologischer Aufbau und Mineralogie der Pegmatite in Wolynien, Ukraine (Volodarsk-Volynsky. Geological structure and mineralogy of the pegmatites of Volynya, Ukraine).** I. M. Koshil, I. S. Vasilishin, V. I. Pavlishin, and V. I. Panchenko, *Lapis*, Vol. 16, No. 10, October 1991, pp. 24–40, 82.

In recent years, larger quantities of beryls and topazes from Volodarsk, Ukraine, have become available than ever before. However, what little has been written about this locality is mostly in Russian. In this article, Koshil et al. describe (in German) the geology at Volynya and the minerals found there.

The gem crystals are found in granites and pegmatites related to the Korosten pluton. On the basis of structure and mineral content, several types of pegmatites can be distinguished. The type called "chamber pegmatite" (*Kammerpegmatit*) generally contains the widest range of minerals (over 90 species are listed in the article). This type is also the main source of gem specimens (primarily beryl and topaz, along with smoky quartz and some amethyst, citrine, and phenakite).

Beryl occurs in opaque to transparent, often large, columnar crystals up to about 30 cm (12 in.). They are predominantly green to yellowish green, but golden yellow and blue stones are also found. Most crystals show etched faces, and specimens corroded to absolutely irregular forms are not rare. Topaz occurs in etched crystals, too, but for the most part they are well formed and resemble the topazes from Ilmen and Adun-Chilon. Crystals can reach considerable sizes (the largest on record weighed 117 kg). The topazes occur in various pale to intense hues (colorless, blue, pink, red, yellow), some of which will be affected by heat treatment or irradiation.

The article contains a geologic map, several cross-section sketches of typical pegmatites, and 29 beautiful color photographs of gem and mineral specimens.

*Rolf Tatje*

## INSTRUMENTS AND TECHNIQUES

**The microscopic determination of structural properties for the characterization of optical uniaxial natural and synthetic gemstones. Part 3: Examples for the applicability of structural features for the distinction of natural and synthetic sapphire, ruby, amethyst and citrine.** L. Kiefert and K. Schmetzer, *Journal of Gemmology*, Vol. 22, No. 8, 1991, pp. 471–482.

Using the techniques outlined in part 1 of this series, the authors examined a variety of natural and synthetic corundums, as well as natural and synthetic amethyst and citrine, to determine characteristic structural features useful for identification. They found that the internal growth features of alkali-basalt sapphires parallel the characteristic crystal habit for corundum from this type of source—i.e., with basal pinacoid  $c$  {0001} and hexagonal dipyrmaid  $z$  {22 $\bar{4}$ 1} dominant, often accompanied by the positive rhombohedron  $r$  {10 $\bar{1}$ 1}. Also observed, though less commonly, were growth features parallel to the second-order hexagonal prism  $a$  {22 $\bar{4}$ 3} and to hexagonal dipyrramids  $n$  {22 $\bar{4}$ 3},  $w$  {11 $\bar{2}$ 1},  $v$  {44 $\bar{8}$ 3}, and  $v$  {44 $\bar{8}$ 1}. As yet, the authors have not encountered  $a$  {11 $\bar{2}$ 0} and hexagonal dipyrramids other than  $n$  {22 $\bar{4}$ 3} in flux-grown synthetic sapphire. Chatham flux-grown synthetic blue sapphires are discussed in some depth.

The techniques used here are particularly effective with natural and synthetic rubies that lack any other internal features—a problem that has plagued gemology for some time. Examples provided include recent production of natural rubies from Malawi and Knischka synthetic rubies marketed since 1987. Both exhibit features that reflect their respective origins.

Structural characteristics that distinguish natural from synthetic amethyst and citrine have been established previously; here, the authors illustrate how their recently developed techniques can be used to reveal these features.

One addition that would have been extremely useful, given the complex and diverse nature of the material covered in this trilogy of articles, is a table of the characteristic features discussed. Without it, the reader must juggle an

almost unmanageable quantity of technical information. Moreover, much of the discussion in the text assumes a working knowledge of crystallography. However, even the gemologist whose crystallography is rusty—or essentially nonexistent—will appreciate the information provided by the numerous photomicrographs. CMS

## JEWELRY MANUFACTURING ARTS

**Golden hoard from a lost tribe.** P. Dragadze, *Connoisseur*, Vol. 221, No. 950, March 1991, pp. 94–97, p. 120.

In the late summer of 1987, Soviet archaeologist Vladimir Guguev excavated the burial mound of a high-ranking Sarmatian woman. The Sarmatians were a nomadic tribe of Indo-Iranian descent who made their home in southern Russian between 400 B.C. and 400 A.D.

Among the treasures found in the grave were gold bracelets, a ring, a diadem decorated with stags, and a turquoise-encrusted torque showing a seated Oriental warrior flanked by dragons. This necklace of stamped and chased gold weighs over 2 kg. The male figure, sitting with his legs crossed, dates the piece to the first century A.D.; the style of his sword places its manufacture somewhere in Central Asia.

The Sarmatians left no written record; the objects buried with this noblewoman offer some of the first insights into their spiritual life. Much more archaeological work remains to be done in Rostov. Excavations have been limited by the lack of modern equipment and funding, but local experts feel that the area contains a wealth of other artifacts. LS

**Menuki: The magnificent miniatures of Japan.** R. B. Caldwell, *Arts of Asia*, Vol. 22, No. 1, 1992, pp. 70–77.

Menuki are the paired ornaments that fill the grips of Japanese samurai swords. Their importance is two-fold: They are exceptional works by recognized artists, and their ties to the sword give them a place at the center of traditional Japanese culture. In this article, the author discusses the collecting of menuki from both of these perspectives.

The sword was a symbol of absolute authority in Japan from the 13th century onward; during the 14th century, some of the country's most skilled artisans began to devote themselves exclusively to its ornamentation. The Goto clan, in particular, became known for their menuki. Menuki are unique as works of art in that they reflect the wearer, rather than the artist. In his advice to collectors, the author states that one should get a clear sense of the man for whom the menuki were made, and only then search for the tiny details that identify the maker.

The earliest of these tiny sculptures were made of *shakudo*—a mixture of copper, gold, and other metals that developed a black patina. Advances in metalsmithing over the centuries have changed the composition of the metal and thus its color, providing the collector with a means of dating unsigned pieces. Very often, menuki are decorated

with gold or silver, and occasionally one sees pieces made entirely of gold.

The most popular images were dragons and lions, or the lion-like Chinese Foo dogs. The author provides a wide range of examples—from the traditional cranes, monkeys, and bats to an extraordinary pair showing all 12 creatures of the zodiac.

In describing menuki as “functional works of art created to fill a need in the most artistic fashion . . . they can convey a concept of beauty or of purpose and tradition,” the author makes a strong case for collecting these extraordinary works. LS

**Mr. Stuart and his laser: The industry's best-kept secret.** R. Weldon, *Jewelers' Circular-Keystone*, Vol. 163, No. 3, March 1992, pp. 84–86.

Martin Stuart of Martin Stuart and Co., Lakeview Terrace, California, has developed a way to repair jewelry by using a laser instead of the more conventional jeweler's torch. The process has been compared to a microwave. “When using a typical jeweler's torch, you heat from the outside inward,” he says. “When using a laser, you heat from the inside outwards. It works by selective absorption of light, leaving a 3/4 to 1 mm focal spot for the weld.” The weld occurs within 1/1000 to 1/20,000 of a second, so the heat to which the piece of jewelry is subjected is thousands of times less than that from a jeweler's torch. Mr. Stuart has successfully worked on antiques, enameled pieces, and costume jewelry. This technique also has proved effective on jewelry containing heat-sensitive stones. Because the laser works so fast, most stones need not be removed before the jewelry is repaired. KBS

**The watering hole: A detailed look at water pollution sources and permit requirements for the jewelry manufacturing industry.** Mabbett, Capaccio & Associates, *American Jewelry Manufacturer*, Vol. 40, No. 3, March 1992, pp. 148–152.

This article, written by an environmental consulting and engineering firm, outlines pollutants generated by various manufacturing processes, regulations for pollutant discharge into the water systems, and pollution prevention. Pollutants include heavy metals from base metals, plating chemicals, toxic organics from cleaning solvents, oil, grease, and petroleum hydrocarbons. Jewelry manufacturers are required to obtain pollution-control permits before they discharge any of these chemicals into the wastewater. Applicable regulations can be obtained from state and local regulatory authorities. They typically cover discharges to sewage systems, discharges to surface water and groundwater, review and approval of wastewater treatment plans, cross-connection permits, backflow prevention devices, and the oil-spill prevention control and countermeasures (SPCC) plan. The article also provides a detailed breakdown of each regulation. Discussed briefly are methods for pollution prevention. A future article will provide more

detailed information on pollution-prevention and waste-minimization techniques. *RT*

**Spirits and souls: Denise and Samuel Wallace.** C. L. E. Benesh, *Ornament*, Vol. 15, No. 2, 1991, pp. 45-49.

Denise and Samuel Wallace have created a series of bejeweled belts designed with the ethnic peoples of the Pacific Northwest as their central theme. This article focuses on the Crossroads of Continents belt. Adorned with 10 figures representing ethnic peoples throughout Siberia, Alaska, the Yukon Territory, and British Columbia, the belt is crafted from sterling silver, 14K gold, fossilized walrus tusk, scrimshaw, fossil coral, Bruneau jasper, variscite, chryso-prase, sugilite, lace agate, and chrysocholla. It is a work of art, with painstaking detail evident in the design of the costume that adorns each piece. The individual figures can be removed from the belt and worn as pendants; in addition, each one opens to reveal drawings and other detachable pieces such as earrings. This article describes each figure in detail, including its significance within the particular culture. Seven color photographs accompany the article. *RT*

## JEWELRY RETAILING

**Antique jewelry: Buying and selling in a recession.** E. Weber, *Jewelers' Circular-Keystone*, Heritage Insert, Vol. 163, No. 2, February 1992, pp. 130-134.

The current economic recession in the United States has adversely affected the antique jewelry market. Retail clients are more hesitant about buying and more practical about what they buy. Wholesale dealers have increasingly limited themselves to more discriminate, domestic purchasing and rely more on international buyers. Collectors, because of their unique, less-monetary motivation, are the least discouraged from making acquisitions during this time and are the most likely to be persuaded to make important purchases.

One positive aspect of the antique jewelry market during this recession is the auction market. This is due to its relative stability and the recent recommendations of economists to purchase antique jewelry as an investment. In addition, wholesale dealers are working to generate more activity in the market by re-evaluating their pricing structures and finding creative methods to attract new clients.

*Alicia G. Powers*

**Good appraisals can boost a jeweler's reputation, provide a competitive edge against discounters and generate profits.** R. Shor, M. Thompson, and R. Weldon, *Jewelers' Circular-Keystone*, Vol. 163, No. 4, April 1992, pp. 57-73.

This article gives a candid view of what an appraisal is, what it isn't, and what it should be. It walks the reader through the appraisal process by providing much-needed information: take-in procedures, types of appraisals, appraisal tools, product analysis, sources and resources, and legal

liability. A particularly useful section details appraisal organizations, purpose.

This is an important article for anyone thinking about becoming an appraiser. Although thorough in its attempt to educate, however, it should not be used (and is not intended) as a substitute for a formal appraisal education.

*KBS*

**Retail jewelers are top target of telephone credit-card scams.**

W. G. Shuster, *Jewelers' Circular-Keystone*, Vol. 162, No. 12, December 1991, pp. 108-109.

This article discusses the ever-increasing problem of telephone credit-card scams and its effect on several U.S. retail jewelry businesses. According to the U.S. Secret Service, "phone frauds as a whole, including those against retailers, cost \$1.2 billion a year." Even though there are no specific figures for the jewelry industry, the Jewelers' Security Alliance estimates that individual losses average \$2,000 to \$10,000. Some culprits are criminals currently incarcerated for other crimes. One such ring in Pittsburgh, Pennsylvania, had access to telephones in prison and used confederates working for them on the outside. They fraudulently ordered millions of dollars in merchandise from retailers in 30 states.

The article gives important information on recognizing telephone scams and several case histories of scams against jewelry retailers. Clues to watch for include lack of concern about price and insistence on overnight shipping. Any jeweler who suspects fraud is advised to contact the local Secret Service office or the Jewelers' Security Alliance. Precautions for preventing such problems are also listed. The article is highly recommended for anyone in the jewelry industry.

*KBS*

**R<sub>x</sub> for insurance appraisal headaches.** P. J. Geolat, C. Van Northrup, and D. Federman, *Modern Jeweler*, Vol. 91, No. 3, March 1992, pp. 38-49.

This excellent article describes the near-war between appraisers and insurance companies and details what can be done to bring about a truce.

Included are some of the possible liabilities involved in writing an insurance appraisal report. To underscore the severity of the risk, the authors cite an example whereby an appraisal written as a "freebie" by a West Coast "appraiser" earned him a conviction for fraud and a very large fine.

Partisan viewpoints are given: Jewelers see insurers as replacing jewelry at a fraction of the actual cost, and insurers see jewelers as overgrading and overvaluing the product. Both arguments carry weight.

Outlined are the basics of replacement-cost appraisals and what will cover appraisers' "fiduciary responsibilities." Proper take-in procedures are also demonstrated. A quick overview of insurance coverage helps clarify for the customer the purpose of the appraisal. Examples show how easy it is to get into trouble if the appraiser does not know what he or she is doing.

Jeweler/appraisers must realize that valuations have to reflect market reality, not dictate it. Value generally should be determined on the basis of research on actual and realized prices, not on what it would cost to manufacture the particular piece.

This article, one of the most thoroughly written on the subject, is easy to comprehend and a pleasure to read.

*Jo Ellen Cole*

## SYNTHETICS AND SIMULANTS

**An unusual assembled inclusion specimen.** R. C. Kammerling and J. I. Koivula, *Journal of Gemmology*, Vol. 22, No. 8, 1991, pp. 459–462.

Gemological pitfalls can sometimes occur in very unexpected places. Messrs. Kammerling and Koivula report on an assembled specimen of dendritic agate and glass. Although the manufactured nature of the specimen is evident from a side view, it would be less obvious if the sample were mounted in a bezel. However, magnification revealed numerous bubbles in the cement layer between the agate back and glass cap. Refractive index readings on the agate layer were ineffective because of an epoxy or resin coating on the back surface of the specimen. *CMS*

## TREATMENTS

**Dyed quartzite sold as jadeite.** *Jewellery News Asia*, No. 89, January 1992, p. 60.

Dyed quartzite is being sold as natural green jadeite in Hong Kong, Thailand, and the People's Republic of China. The Hong Kong Gems Laboratory identified both mounted and loose quartzite that had been sold as jadeite in 1991. Ou-Yang Chiu Mei, former director of the Asian Institute of Gemological Sciences, said that while dyed quartzite turned up occasionally in previous years, more pieces have been seen recently. Dyed quartzite is sometimes called Malaya jade. Quartzite is actually the recrystallization of quartz sandstone. Appreciable differences in specific gravity and refractive index, as well as dye concentrations visible with magnification, should aid in identification.

*Jana Emi Miyahira*

**Emeralds from Colombia (Part 3).** G. Bosshart, *Journal of Gemmology*, Vol. 22, No. 8, 1991, pp. 500–503.

The third (and final) part of this series on Colombian emeralds includes brief, general discussions of treatment methods and identifying characteristics. In addition, the author describes how emerald's sensitivity to heat and ultrasonic cleaning varies with the quality of the individual gem. A combination of microscopic features (spectra, refractive indices, and specific gravity) can be used to determine if an emerald is of Colombian origin, but the author finds it impossible to distinguish emeralds of one Colombian mine from those of another. Although most Colombian emeralds are

treated, usually by oiling of some kind, a major unresolved problem is the determination of the precise treatment present—a requirement under CIBJO guidelines. The article closes with the author emphasizing his position that the only non-emerald group of green beryl is the one colored solely by vanadium and/or iron with no chromium present.

*CMS*

## MISCELLANEOUS

**Hot art, cold cash.** M. van Rijn and A. Page, *Art @ Auction*, Vol. 14, No. 8, March 1992, pp. 92–99, 135–136.

This article contains an excerpt from an upcoming new book, *Hot Art, Cold Cash*, by international art dealer Michel van Rijn, on the intrigues and intricacies of the world art and auction markets. It also provides an interview with the author, and a response from Sotheby's.

The portion of the book published here tells the story of the Avar Treasure, a collection of gold and silver belt fittings, allegedly from Turkey, that was to be auctioned by Sotheby's in late 1981. The treasure, initially highly admired in the art world, mysteriously failed to sell and was subsequently "bought in" by Sotheby's for failing to meet the collection's reserves. After the auction, van Rijn revealed that the pieces were actually fakes he had commissioned to get revenge on the auction house, which he blamed for the loss of an important sale involving Japanese clients.

Van Rijn describes how he commissioned a now-deceased collector/antique dealer, Patrikiades, to forge pieces based on his own collection and pass them off as genuine. Patrikiades was not only a superb artist and craftsman, but he also knew how to duplicate the composition of ancient metals.

Van Rijn acknowledges that Sotheby's did follow proper procedures, checking with known experts for authenticity of the pieces and inquiring of various countries whether similar treasures had been documented before they were stolen. Van Rijn says he also concocted this scheme to prove how easy it is to get something of debatable origin accepted as genuine by the "experts."

Sotheby's states in its reply that the Japanese venture that Mr. van Rijn claimed was the source of his animosity toward the auction house did not take place until months after the failed Avar auction. Sotheby's goes on to point out that it did not buy back the Avar Treasure, but rather cancelled the sale of two of the items so that the collection could remain intact. *Jo Ellen Cole*

**Paper gems.** J. Eadie, *Journal of Gemmology*, Vol. 22, No. 8, 1991, pp. 498–499.

This brief note alerts gemologists to a different form of gem collecting: stamps that depict gem materials or related topics. Twenty-nine color photos illustrate the range of stamps available. Of even greater value is the author's offer to provide a list of topics and stamps that can be found; his address accompanies the article. *CMS*