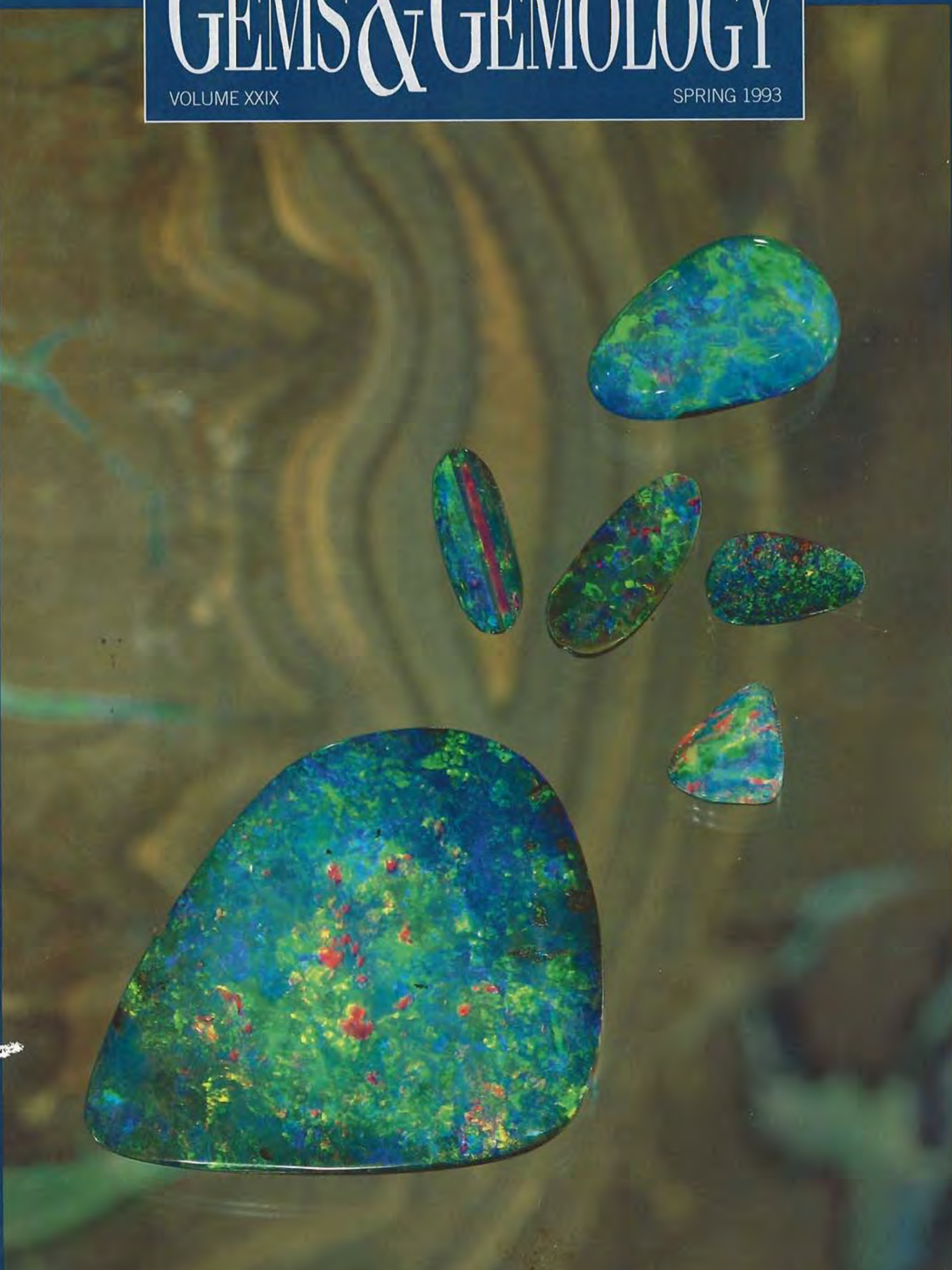
GEMS & GEMOLOGY

VOLUME XXIX
SPRING 1993



THE QUARTERLY JOURNAL OF THE GEMOLOGICAL INSTITUTE OF AMERICA

GEMS & GEMOLOGY

SPRING 1993 VOLUME 29 NO. 1

TABLE OF CONTENTS

EDITORIAL

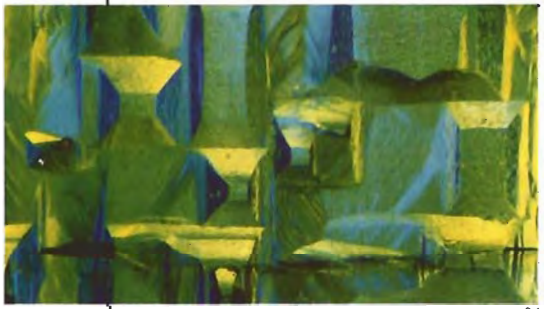
FEATURE ARTICLES

NOTES AND NEW TECHNIQUES

REGULAR FEATURES

p. 11

p. 23



p. 34

p. 52

ABOUT THE COVER: Australia is the world leader in opal production. Some of the most attractive Australian opals are those typically formed in ironstone boulders in the state of Queensland. The article by Richard Wise in this issue provides an overview of Queensland boulder opal, with specific information from an active operation, the Cragg mine. The opals illustrated here—shown on a classic opal-bearing Queensland boulder—all have some of the ironstone matrix as a backing. The large gem opal is 47.05 × 37.65 × 8.36 mm thick; the smallest piece is 13.44 × 8.55 × 2.00 mm thick. All are from the collection of George Brooks, Santa Barbara, CA.

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

*Typesetting for Gems & Gemology is by Graphix Express, Santa Monica, CA.
Color separations are by Effective Graphics, Compton, CA.
Printing is by Waverly Press, Easton, MD.*

ISSN 0016-626X

GEMS & GEMOLOGY

EDITORIAL STAFF

Editor-in-Chief
Richard T. Liddicoat

Associate Editors
William E. Boyajian
D. Vincent Manson
John Sinkankas

Technical Editor
Carol M. Stockton

Assistant Editor
Irv Dierdorff

Editorial Assistant
Denise Heyl

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

Subscriptions
Gail Young
Jin Lim
Telephone: (800) 421-7250 x201
FAX: (310) 453-4478

Contributing Editor
John I. Koivula

Editor, Gem Trade Lab Notes
C. W. Fryer

Editor, Gemological Abstracts
Dona M. Dirlam

Editors, Book Reviews
Elise B. Misiorowski
Susan B. Johnson

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

PRODUCTION STAFF

Art Director
Lisa Joko

Production Artist
Carol Silver

Word Processor
Ruth Patchick

SUBSCRIPTIONS

Subscriptions in the U.S.A. are priced as follows: $54.95 for one year (4 issues), $134.95 for three years (12 issues). Subscriptions sent elsewhere are $65.00 for one year, $165.00 for three years.

Special annual subscription rates are available for all students actively involved in a GIA program: $44.95 U.S.A., $55.00 elsewhere. Your student number *must* be listed at the time your subscription is entered.

Single issues may be purchased for $14.00 in the U.S.A., $17.00 elsewhere. Discounts are given for bulk orders of 10 or more of any one issue. A limited number of back issues of G&G are also available for purchase.

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

To obtain a Japanese translation of Gems & Gemology, contact the Association of Japan Gem Trust, Okachimachi Cy Bldg., 5-15-14 Ueno, Taito-ku, Tokyo 110, Japan. Our Canadian goods and service registration number is R126142892.

MANUSCRIPT SUBMISSIONS

Gems & Gemology welcomes the submission of articles on all aspects of the field. Please see the Suggestions for Authors in this 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.

COPYRIGHT AND REPRINT PERMISSIONS

Abstracting is permitted with credit to the source. Libraries are permitted to photocopy beyond the limits of U.S. copyright law for private use of patrons. Instructors are permitted to photocopy isolated articles for noncommercial classroom use without fee. Copying of the photographs by any means other than traditional photocopying techniques (Xerox, etc.) is prohibited without the express permission of the photographer (where listed) or author of the article in which the photo appears (where no photographer is listed). For other copying, reprint, or republication permission, please contact the editor.

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

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

THE GEMS & GEMOLOGY MOST VALUABLE ARTICLE AWARD

Alice S. Keller, Editor

It is with great pleasure that I announce the results of this year's "Most Valuable Article" contest. For the first time, all three winning articles were in the same general category: gem sources. The first-place award goes to the excellent review by Alfred A. Levinson, John J. Gurney, and Melissa B. Kirkley, "Diamond Sources and Production: Past, Present, and Future." Second place goes to the comprehensive "Gem Wealth of Tanzania," by Dona M. Dirlam, Elise B. Misiorowski, Rosemary Tozer, Karen B. Stark, and Allen M. Bassett. The first contemporary report from the legendary ruby mines of Burma (now Myanmar) won third place: "Status of Ruby and Sapphire Mining in the Mogok Stone Tract," by Robert E. Kane and Robert C. Kammerling.

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 John D. Edwards of Boulder, Colorado, whose ballot was randomly chosen to win the three-year subscription to *Gems & Gemology*.

FIRST PLACE

Alfred A. Levinson · John J. Gurney · Melissa B. Kirkley

Alfred A. Levinson is a professor in the Department of Geology and Geophysics at the University of Calgary, Alberta, Canada. He received his undergraduate and graduate degrees from the University of Michigan. A former editor of *Geochimica et Cosmochimica Acta*, Dr. Levinson has also written and edited a number of books on geochemistry. **John J. Gurney**, who holds a personal chair in geochemistry at the University of Cape Town (UCT), South Africa, from which he also received his Ph.D., has published widely in his main research fields of diamonds and upper mantle petrology. A post-doctoral research officer in the Geochemistry Department of UCT, **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.

Dr. Alfred A. Levinson

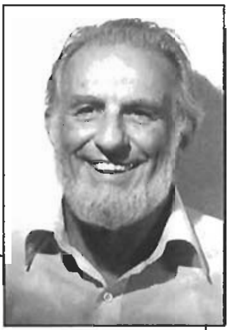
Dr. Melissa B. Kirkley and Dr. John J. Gurney

SECOND PLACE

Dona M. Dirlam · Elise B. Misiorowski · Rosemary Tozer
Karen B. Stark · Allen M. Bassett

Dona M. Dirlam is senior librarian and manager, **Elise B. Misiorowski** and **Rosemary Tozer** are research librarians, and **Karen B. Stark** is slide librarian, at the Richard T. Liddicoat Gemological Library and

Information Center, GIA, Santa Monica. A native of Minnesota, Ms. Dirlam has a B.S. from the University of Minnesota, Minneapolis, and an M.S. in geology and geophysics from the University of Wisconsin, Madison. She is editor of the Gemological Abstracts section of *Gems & Gemology* and has coauthored several articles for the journal. She is also on the board of directors of the Gem and Mineral Council of the Los Angeles County Museum of Natural History. Also a prolific author and formerly a diamond grader in the West Coast GIA Gem Trade Laboratory, Ms. Misiorowski is coeditor of the Book Reviews section of *Gems & Gemology*. Ms. Tozer, who has over eight years of library experience, is currently cataloging the Sinkankas Rare Book Collection. She has a Bachelor of Arts in Library Media from Chadron State College, Nebraska. Ms. Stark attended college in Texas and worked in a jewelry store in Ithaca, New York, prior to coming to GIA. With Ms. Misiorowski and Ms. Tozer, she is a member of the Gemological Abstracts Review Board. **Allen M. Bassett** is chief gemologist/geologist for Tan-Minerals Mining Co. in Tanzania. A native of New York, he obtained his B.S. from Amherst College and his M.S. and Ph.D. in economic geology from Columbia University. He has worked for the U.S. Geological Survey and taught at universities in Ohio and California. Dr. Bassett spent 19 years in Nepal establishing a gem industry and developing ruby mines, before turning to ruby mining in Tanzania in 1989. He has authored over 50 articles and books.



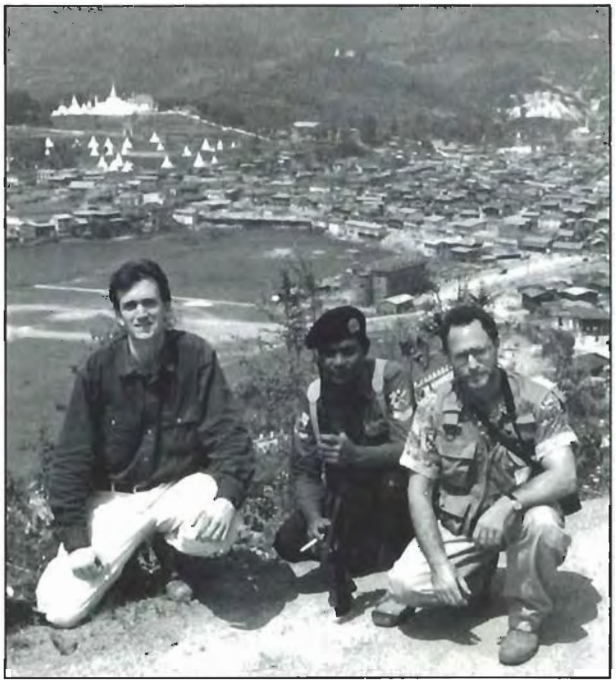
Allen M. Bassett

From left — Rosemary Tozer, Dona M. Dirlam, Elise B. Misiorowski, Karen B. Stark

THIRD PLACE

Robert E. Kane · Robert C. Kammerling

Robert E. Kane is former manager of identification at the GIA Gem Trade Laboratory in Santa Monica. A prolific author, he is currently researching and writing a book on gemstones. With 15 years of laboratory experience, Mr. Kane's research specialties include the identification of natural, synthetic and treated gems, colored diamonds, and rare collector gems. **Robert C. Kammerling** is director of identification and research at the GIA Gem Trade Laboratory in Santa Monica. He also coedits the Gem News and Lab Notes sections 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.



Robert E. Kane (left) and Robert C. Kammerling pose with a guard in Mogok.

LETTERS

CAN A DICHROSCOPE SEPARATE DYED CORUNDUM FROM RUBY?

The interesting article "Dyed Natural Corundum as a Ruby Imitation" (K. Schmetzer, H. A. Hänni, E. P. Jegge, and F.-J. Schupp, Summer 1992, pp. 112–115) mentioned several tests to reveal that corundum had been dyed. It appears to me that when U.V. radiation and some of the more sophisticated tests mentioned are not available, testing for pleochroism with a dichroscope should reveal that something is wrong. I would appreciate learning if this test was tried and, if so, what the results were.

HENRY WILKINS
Sarasota, Florida

In Reply

Mr. Wilkins is correct that simple instruments should be used if they can make the required identification, which would be the case with transparent ruby that occurs as untwinned, single crystals. However, most East African rubies are composed of a multitude of twinning lamellae that, due to their different orientation within the host crystal, produce different twin colors that distort the pleochroism and instead give the overall appearance of an isotropic material. As explained in our article, the cabochon-quality material used for dyeing is also heavily twinned. Therefore, it is not safe to use the dichroscope to differentiate ruby from this type of dyed corundum, just as it cannot be used to separate spinel and twinned ruby.

We suggest instead that the pocket spectroscope is another simple instrument that most gemologists possess and know how to use. The spectroscope can easily demonstrate, by the presence or absence of the chromium (fluorescence) lines, if the stone in question is a ruby (natural or synthetic) or other red stone such as dyed corundum or red spinel. Therefore, we have proposed the use of spectroscopy, together with magnification, for the easy separation of red-dyed corundum from natural-color ruby.

H. A. HÄNNI, Ph.D., F.G.A.
Director, SSEF Swiss Gemmological Institute
Zürich, Switzerland

CHROMIUM AS THE PRINCIPAL COLORING AGENT IN TSAVORITE GARNETS

Regarding the occurrence of tsavorite in mafic host rocks and related coloring elements, I wish to offer some new observations. As most gemologists are aware, tsavorite typically occurs in a graphite gneiss/crystalline limestone association and is colored predominantly by vanadium with chromium as the secondary coloring element. However, two metamorphosed mafic intrusive ore bodies at the Scorpion mine location in Kenya, known respectively as the "C.W." (Central West) and "Erikon" deposits, contain pockets and small stringers of both tsavorite and ruby.

From the start I have postulated that because of their mode of occurrence in a mafic host rock, their association with ruby, and their blue-green color, these tsavorites were likely to be colored predominantly by chromium rather than vanadium.

Work carried out on numerous samples by Dr. George Rossman and myself at Caltech in November 1992, using a Kevex 700/8000 energy dispersive X-ray fluorescence spectrometer, has indeed confirmed that those tsavorites from the mafic ore bodies contain a marked preponderance of Cr^{3+} ions over V^{3+} ions, in the ratio of about 8:1, while those samples from the Scorpion no. 2 and no. 4 crystalline limestone/graphite gneiss ore bodies show a chromium-to-vanadium ratio of about 1:4.5.

Also of interest is that while the titanium content of samples from both ore types remained virtually constant, the manganese content for the "traditionally" occurring (i.e., crystalline limestone/graphite gneiss) samples was notably higher than that of the mafic ore-body samples.

There are a number of other inferences and conclusions to be drawn, but these will be presented and illustrated at a later date.

C. R. BRIDGES
Bridges Exploration Ltd.
Nairobi, Kenya

ERRATUM

The Fall 1992 issue of *Gems & Gemology* contains Carol Stockton's abstract of my paper "H_2O and All That." The abstract is careless and inaccurate, especially with regard to my hydrostatic method for approximating the weight of a mounted stone. This does not determine the specific gravity, for the nature of the stone is already known. Ms. Stockton has in fact achieved the very confusion she is trying to avoid. Since the method is both practical and, in my opinion, important, I feel a correction should be made.

R. KEITH MITCHELL, F.G.A.
Vice President, Gemmological Association of Great Britain
Kent, England

Mr. Mitchell is right in correcting my abstract of his *Journal of Gemmology* article, "H_2O and All That." The phrase "the procedure outlined for obtaining a relatively accurate determination of the specific gravity of a mounted gemstone" should have read ". . . a relatively accurate determination of the *weight* of a mounted gemstone." I regret the inadvertent error and again recommend Mr. Mitchell's article to our readers.—Carol M. Stockton

QUEENSLAND BOULDER OPAL

By Richard W. Wise

After almost 75 years of inactivity, the deposits of boulder opal in Queensland, Australia, began to attract new interest in the 1960s and 1970s. Queensland boulder opal is found associated with the Winton formation, and results from deposition and dehydration of silica-rich solutions in an iron-rich host rock. At the Cragg mine, one of 69 known opal-mining operations in Queensland in 1991, miners drill as deep as 20 m to search for a deposit and then use open-cut methods to reach the opal-bearing layer identified. In the evaluation of boulder opal, color, pattern, and "composition" are important. Most boulder opal is stable under normal wear, and it is readily separated from its simulants.

ABOUT THE AUTHOR

Mr. Wise, a Graduate Gemologist, is president of L. & R. Wise, Goldsmiths, Inc., 81 Church St., Lenox, Massachusetts.

Acknowledgments: The author thanks Rudy Weber, Australian Opal and Gemstone Photographic Library, Sydney, for providing many of the opal photos; Vince, Poss, and James Evert, Boulder Opal Enterprises, Winton, Australia, for their hospitality and information; Robin Dufty, Robin Dufty Fine Gems, for her aid in planning the author's visit to Queensland; P. M. Linn, Department of Resource Industries, Brisbane, for statistical data; Rebekah V. Wise for editorial help; Rachel Knopf for preparing the original manuscript; and Dr. A. A. Levinson for editing the section on geology, formation, and occurrence.

Gems & Gemology, Vol. 29, No. 1, pp. 4–15

Boulder opal is the term used to describe gem-quality opal that occurs in veins and pockets in ironstone concretions, and retains some portion of the ironstone when cut. Most boulder opal on the market today is found in association with the Winton formation, a broad belt of Cretaceous sedimentary rock that covers the entire center of the state of Queensland, Australia. After several years of intense mining in the late 19th century, interest in Queensland boulder opal waned as the harsh climate drove miners to more lucrative deposits in areas such as Lightning Ridge and Coober Pedy.

In the early 1970s, however, significant quantities of Queensland boulder opal again entered the gem market, and interest surged as dealers and consumers alike were drawn to the unusual shapes, intense color, and artistic qualities of the Queensland material (figure 1). With the increase in opal mining throughout Australia over the last several years, there has been a parallel increase in mining in Queensland. Government figures show that at the height of recent production, 1987–88, Queensland accounted for more than 6% (in value) of all opal produced in Australia, or Aus$6,602,000 (US$5,241,988; table 1).

This article briefly reviews the history, geology, formation, mining, and gemology of boulder opal from central Queensland. Specific reference is made to current workings at the Cragg mine, a typical open-cut opal-mining operation, which the author visited in March 1990.

HISTORY

Although Pliny, in 79 A.D., and later Tavernier in 1675, referred to ancient deposits of opal in India, the only early deposits that have been confirmed are located southwest of the northern end of the Carpathian Mountains in what is now Czechoslovakia (Loneck, 1986). This was the principal source for opal worldwide until Australian discoveries in the late 19th century revolutionized the industry.

"Precious" opal was first discovered in Australia at Listowel Downs (sedimentary) and Springside (volcanic), in

Figure 1. Over the last two decades, Queensland boulder opal has reappeared in fine jewelry in the U.S. and elsewhere. This 11.16-ct boulder opal is set with a 0.96-ct red spinel and a 2.29-ct lavender sapphire. Courtesy of Paula Crevoshay, Upton, MA; photo © Harold & Erica Van Pelt.

Queensland, in 1872 (Loneck, 1986). Commercial mining peaked in 1895, and then declined sharply when extended periods of drought made it impossible to work the fields (Jackson, 1902). Early miners valued only pipe opal and seams thick enough to cut solid opal. Boulder opal was virtually ignored. Discovery of opal elsewhere in Australia—at White Cliffs in 1890, Lightning Ridge in 1903, and particularly Coober Pedy in 1915 (Keller, 1990)—subsequently diverted the attention of miners and dealers alike.

In the 1960s, however, some independent miners began reworking old claims, now using heavy equipment that could accomplish in hours what had taken their predecessors—equipped with only hand tools—days or even weeks in the harsh climate. Mining activity increased dramatically in the early 1970s, peaking in 1974. After that, production increased only gradually, and it actually declined in the early 1980s (Krosch, 1983). Mining activity exploded again in the mid-to-late 1980s, only to slow in the current decade. All mines are privately owned. As of 1991, there were 69 individuals, partnerships, and companies officially involved in opal mining in Queensland (PGIQ, 1992).

George Cragg, who has been credited with the discovery of opal in the Winton district (V. Evert, pers. comm., 1993), discovered opal in the area of the present Cragg mine in 1888. In 1970, two 100 m^2 claims owned by George Cragg's son, Fred, were combined to form the current mine. In 1986, this claim was officially filed as part of mining lease number 17. The Cragg mine has been productive intermittently since 1970. Typically, only three people are involved in the actual recovery of opal at any one time.

LOCATION AND ACCESS

The Winton formation is a belt of Cretaceous sedimentary rock that covers an area 400,000 km^2—about the size of California—in the center of Queensland (figure 2). Key mining centers are Yowah, Toompine, Quilpie, Jundah, Opalton, Mayneside, Carbine, and Kynuna (O'Leary, 1977; QDM, 1988). Despite the introduction in the 1970s of geophysical prospecting, as well as aerial and satellite photography, most areas now being worked are part of, or adjacent to, areas mined by prospectors in the 1890s (V. Evert, pers. comm., 1993). Much of this vast, potentially rich area remains untouched (QDM, 1988).

The climate of central Queensland is semi-arid. Temperatures are subject to extreme seasonal fluctuations, with heat in excess of 50°C (122°F) recorded during summer months (October to December). The normal range in summer is 25°C at night to 40°C during the day (77°–104°F). Winter (May to August) temperatures fluctuate between 5°C at night and 20°C during the day (41°–68°F). The monsoon season usually has an even greater impact on mining than temperature does. Because nearly 70% of precipitation occurs from January through March, mining normally begins in late March and ends by early November. However, a deluge at the end of March 1990, shortly after the author's visit, forced air evacuation of many miners isolated by the rains, and halted mining activities for several weeks (V. Evert, pers. comm., 1993).

TABLE 1. Rough opal production in Queensland and in all Australia for fiscal years 1981–1992.[a]

Year	Queensland	All Australia
1981–82	Aus$ 842,000	Aus$ 45,374,000
1982–83	1,395,000	42,131,000
1983–84	955,000	45,987,000
1984–85	1,346,000	45,079,000
1985–86	2,110,000	49,950,000
1986–87	2,102,000	67,425,000
1987–88	6,602,000	106,077,000
1988–89	Not available	115,000,000
1989–90	4,250,220	117,000,000
1990–91	3,221,000	Not available
1991–92	1,269,000	Not available

[a] *Sources: ABS (1981–82, 1987–88) and* Queensland Yearbook 1992 *(1992). Figures are total production figures for all types of opal, however, the vast majority of opal from Queensland is boulder opal.*

Access to major towns such as Winton, Quilpie, Longreach, and Mt. Isa is possible via regularly scheduled regional airlines from Brisbane and Townsville. Well-maintained, tarred roads connect these population centers. The trip to the Cragg mine, 175 km southwest of Winton, took approximately two hours over an improved two-lane gravel road, followed by two hours' travel by four-wheel-drive vehicle over an unimproved dirt road. Because of the harsh climate, the Queensland government strongly urges motorists to use caution when traveling in these regions. Readers are advised not to attempt access to the mining areas unless accompanied by a guide well versed in local conditions.

GEOLOGY, FORMATION, AND OCCURRENCE

Opal is silicon dioxide with water, with the general formula $SiO_2 \cdot nH_2O$. Silica actually represents 85%–90% of the composition of opal. Scanning electron microscope studies of gem opal have shown that the phenomenon called play-of-color is the result of a regular arrangement of silica spheres that form a sort of honeycomb pattern, with uniform gaps between the spheres. These gaps create a three-dimensional diffraction grating (Darragh and Sanders, 1965), and variations in the sizes of spheres and gaps result in different colors. Evidence suggests that these spheres form and accumulate by colloidal aggregation. The essential preconditions for the formation of these grids are: (1) a clean silica solution, (2) an undisturbed cavity in which the solution can accumulate, and (3) time for water to evaporate and the spheres to line up at the bottom of a cavity (Darragh et al., 1976).

The vast majority of Australian opal formed under very specialized conditions from aqueous silica gels derived from the intense weathering of feldspathic sedimentary rocks under the action of percolating groundwater. In Queensland, gem-quality opal occurs erratically within the Winton formation. Before 1964, no systematic geologic work had been carried out in the Winton area. Jackson (1902) described opal workings at Opalton, and Cribb (1948) reported on opal production at Hayricks. In 1964, however, the Manaroo sheet, an area that includes the Winton formation, was mapped and was subsequently described by Jauncey (1967). More recently, the geology of these opal deposits has been discussed in detail by Senior et al. (1977) and summarized by the Queensland

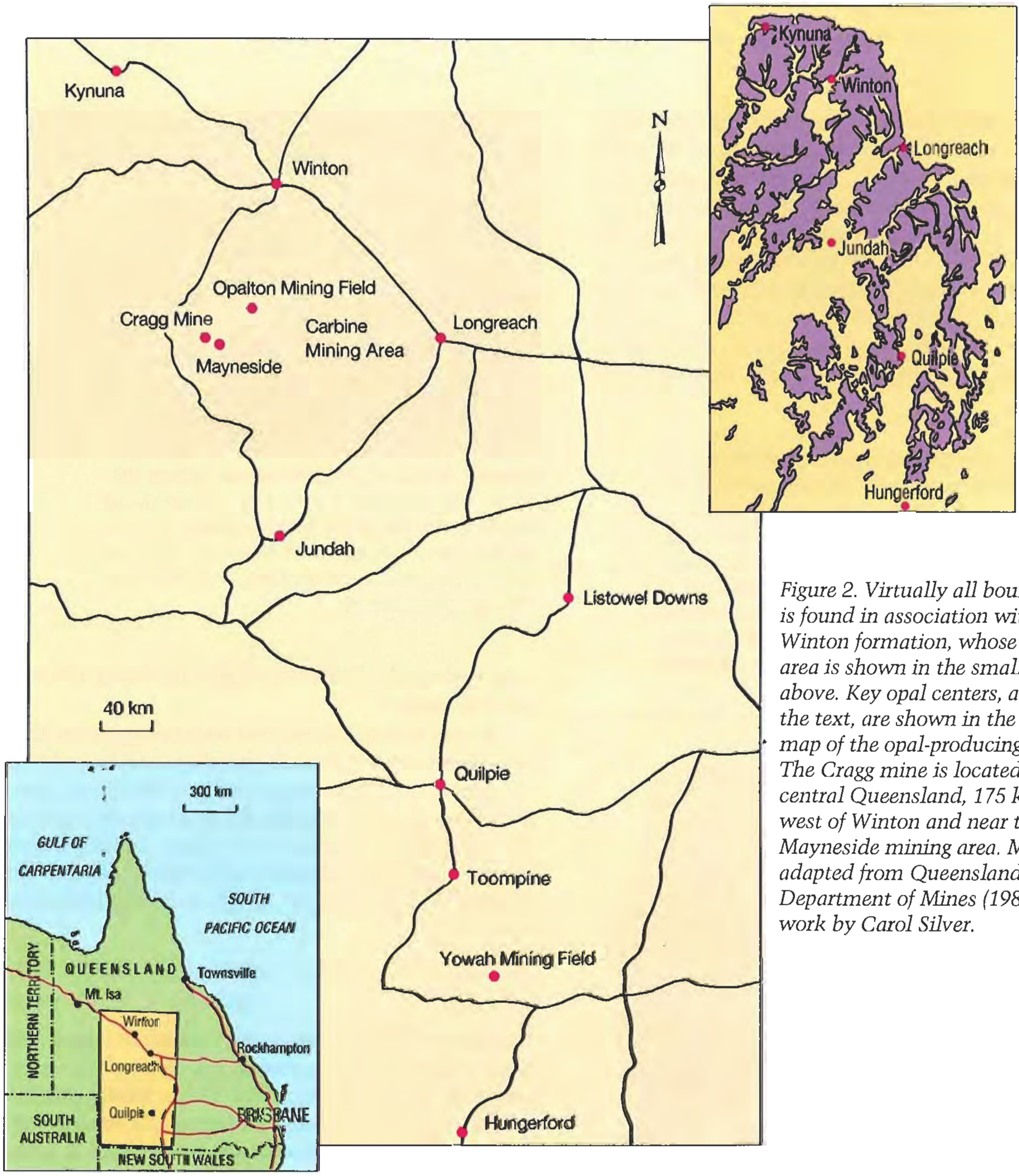


Figure 2. Virtually all boulder opal is found in association with the Winton formation, whose outcrop area is shown in the small map above. Key opal centers, as noted in the text, are shown in the larger map of the opal-producing area. The Cragg mine is located in west-central Queensland, 175 km southwest of Winton and near the Mayneside mining area. Maps adapted from Queensland Department of Mines (1988); artwork by Carol Silver.

Department of Mines (1988) and Keller (1990); these references have been used extensively in the following summary.

The Winton formation extends from the southern border of Queensland northwest to the vicinity of Kynuna (again, see figure 2). The feldspathic sandstones, siltstones, and mudstones that comprise the Winton formation first accumulated during Cretaceous times, about 80–100 million years (My) ago, when a shallow inland sea—the Great Artesian Basin—occupied much of central Australia. During the latest Cretaceous to Eocene time (70–50 My ago), after the basin's rocks had been uplifted, a tropical climate produced the first of two periods of intense chemical weathering. This first period resulted in the formation of the Morney profile, a three-layered weathering sequence more than 90 m thick (figure 3). In this profile, an upper siliceous zone overlies a varicolored zone which, in turn, overlies a basal ferruginous zone. Ironstone concretions (composed chiefly of goethite, limonite, and hematite; Senior et al., 1977) formed in the basal ferruginous zone from iron oxides that had been chemically leached from the overlying rocks. Subsequently, drainage patterns developed, followed by sedimentation along the river systems, and minor erosion of the Morney profile occurred in certain areas.

A second chemical-weathering event in the late Oligocene (about 25 My ago) resulted in the formation of the morphologically distinct, four-layered Canaway profile (again, see figure 3). This later formation consists of an indurated, highly kaolinitic crust over a mottled zone that grades down into varying thicknesses of residual Morney profile; in places, the two profiles merge.

Figure 3. *Two weathering profiles characterize the Winton formation: (left) the Morney profile, which consists of three layers of approximately equal thickness (more than 90 m total) and was formed 50–70 million years ago; and (right) the Canaway profile, which consists of four layers of unequal thickness (a maximum of 45 m total) and formed about 25 million years ago. Note that the vertical scales for the two profiles differ; see text for further details. After Senior et al. (1977).*

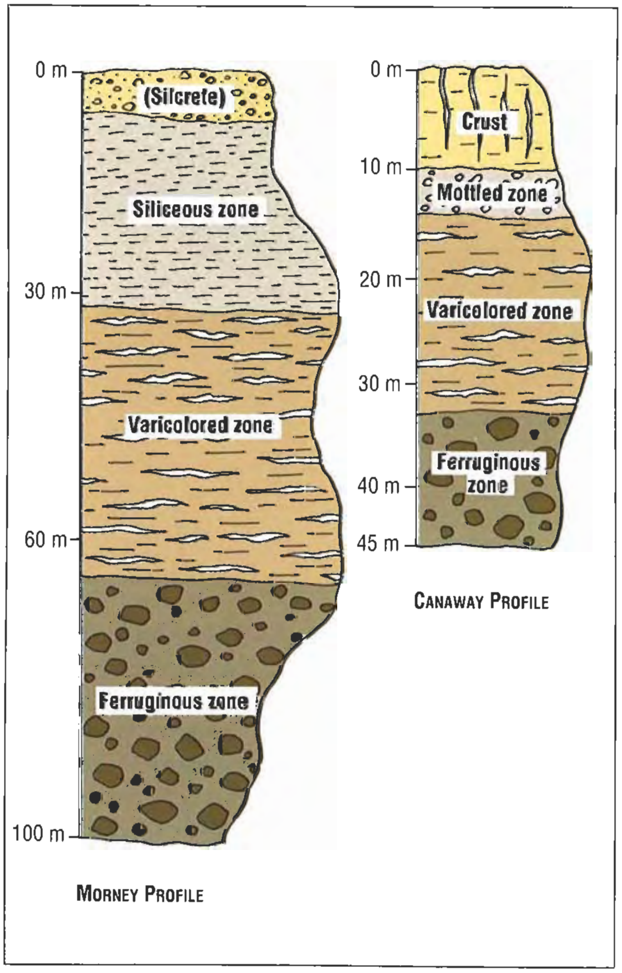


Figure 4. *Just as it precipitated throughout the Winton formation, opal can be seen here filling cracks and voids in the host ironstone. Specimen is approximately 75 mm × 28 mm wide. Photo by Rudy Weber; © Australian Opal and Gemstone Photographic Library.*

It was during this second weathering event that opal began to precipitate in shrinkage cracks and other voids within the ironstone bodies of the Morney profile (figure 4). Erosion of the feldspathic sediments in the upper siliceous zone of the Morney profile began breaking down the feldspar into kaolinite, which then released silica in solution, as shown by the following equation:

$$\underset{\text{(feldspar)}}{2KAlSi_3O_8} + H_2CO_3 + H_2O \longrightarrow \underset{\text{(kaolinite)}}{Al_2Si_2O_5(OH)_4} + K_2CO_3 + \underset{\text{(silica)}}{4SiO_2}$$

The silica solution subsequently migrated downward in groundwater as an aqueous gel, often along lineaments or smaller faults called slides, which provide natural pathways through nonpermeable or semi-permeable strata. The gel eventually precipitated in voids in the ironstone, in those localities where weathering and erosion had removed enough of the older, Morney profile to bring the basal ferruginous zone to within 40 m of the surface. A fluctuating water table, with periods of downward infiltration and upward evaporation of groundwater, was also critical for the deposition and dehydration of the silica gel, respectively. The opal accumulated slowly, the product of many successive cycles of saturation and dehydration. In fact, the voids in some boulders are only partially filled with opal because the process stopped. Winton opal is believed to be between 15 and 32 My old (Senior et al., 1977).

In the area of the Cragg mine, opal is commonly found at the base of red (ferruginous) sandstone layers

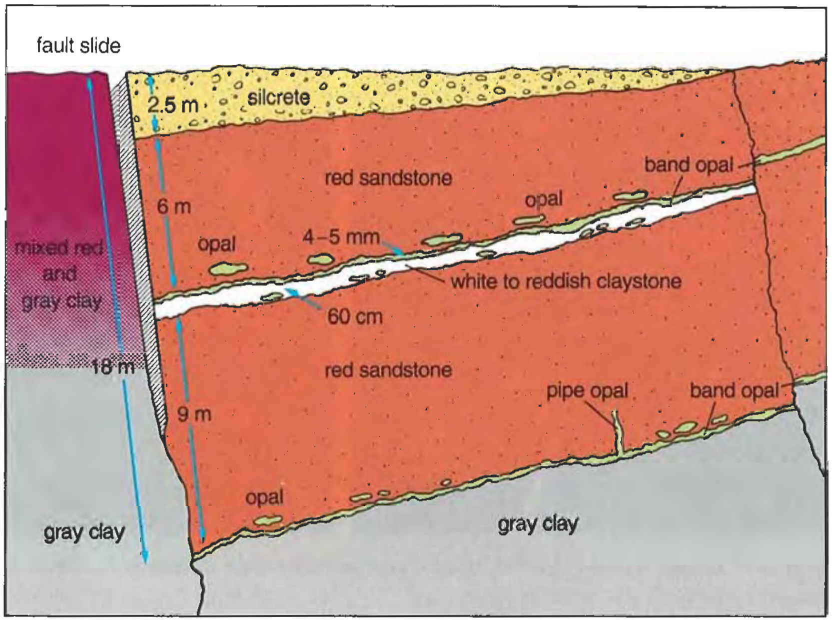


Figure 5. This idealized cross-section shows the various layers in which opal has been found in the Winton district, where the Cragg mine is located. Drawing by Richard Wise; after V. Evert and J. Evert (pers. comm., 1990–1993). Artwork by Carol Silver.

at a depth of no more than 20 m from the surface (V. Evert, pers. comm., 1993; see figure 5 for an idealized diagram of the occurrence of opal in this region). The sandstone is usually overlain by a silcrete cap (soil, sand, and gravel cemented by silica) that is called "shincracker" by local miners; in some areas, a collapsed silcrete overburden may merge laterally into red sandstone at a slide. Often an underlying layer of white fine-grained claystone forms the lower limits of the opal deposits. However, miners sometimes encounter a false bottom—that is, a layer of white to reddish claystone 15–60 cm (6–24 in.) thick—which covers a second red sandstone layer that may be opal bearing. Opal may also occur within the "false bottom." Once a second layer of pink, lateritic sandstone is encountered, however, downward mining is stopped.

In this part of Queensland, opal is typically found in horizontal bands between layers of ironstone, at the point where sandstone meets clay. Often the opal seam is split, and both halves of the "split" are polished for jewelry (figure 6). Opal-bearing ironstone nodules (figure 7)—some more than 30 cm (12 in.) in diameter—may also be found at the base of a slide or within a claystone layer. However, Queensland opal is also found in pipes (long, stick-like structures) and seams in sandstone, as well as in sandshot (sand mixed with opal) layers or in ironstone nodules with a sandstone core. Note that the finest color is usually found at the bottom of the seam or void, in the material that precipitated earliest (G. Brooks, pers. comm., 1993).

At the Cragg mine, most of the opal is found where sandstone meets clay, with more being trapped in the sandstone than in the clay (V. Evert, pers. comm., 1993). The ironstone "boulders" at Cragg are composed of concentric bands of hydrated iron oxide (again, see figure 6). The seams of band opal found there are typically only 4–5 mm thick, but at least one band 25 cm thick has been recovered. At Cragg, as elsewhere in Queensland, the upper surface of the seam may have rounded botryoidal protrusions called "nobbies" up to a few centimeters in diameter (QDM, 1988).

Note that the term *boulder opal* is typically applied only to opal deposited in veins or pockets, or between concentric bands of hydrated iron oxide, in ironstone concretions—not to opal that forms in sandstone or in more unusual forms such as filling cracks in petrified wood. Even if the opal originally formed on an ironstone base, if it is thick enough to produce cabochons without supporting matrix, by definition it is not called *boulder opal.*

PROSPECTING AND MINING

Opal prospecting has changed little since the 1880s. Despite the Australian government's experimentation with aerial and satellite photography, prospecting is still largely a hit-or-miss affair, with miners relying mainly on surface indicators (e.g., geobotanical exploration) to determine likely deposits (V. Evert, pers. comm., 1993).

Areas at the bases of buttes and areas with dark red sandstone are believed to have good potential. In addition, prospectors look for certain species of trees that historically have been associated with opal. For example, malleebush trees grow in red sandstone; and

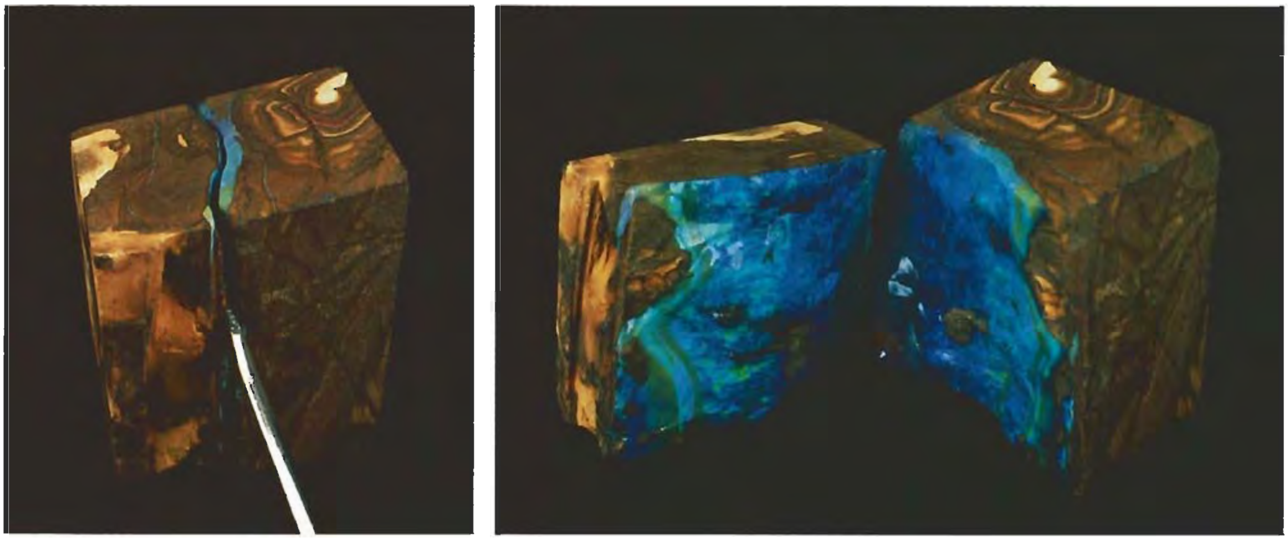
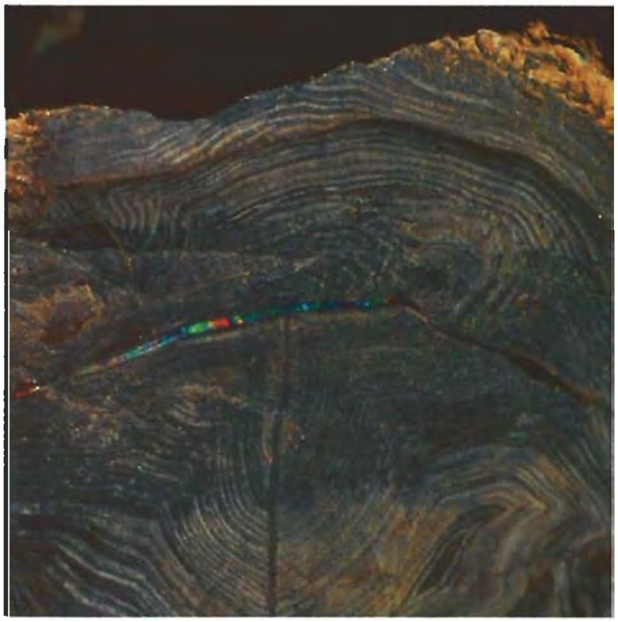


Figure 6. In the Winton district, opal is commonly found in bands between layers of ironstone (left). To recover the opal, the seam is often "split" (right), with both halves potentially useful for jewelry. Photos by Rudy Weber; © Australian Opal and Gemstone Photographic Library.

lapinga trees, which have deep roots, tend to cluster along lineaments and slides. Both are considered good indicators of opal mineralization. Even so, as noted above, most current opal production is in or adjacent to areas originally discovered and worked in the 1880s (V. Evert, pers. comm., 1993).

Figure 7. Opal-bearing ironstone nodules are common throughout Queensland, with the opal often trapped within concentric bands of hydrated iron oxide. Photo by Rudy Weber; © Australian Opal and Gemstone Photographic Library.



Today, most mining operations in Queensland, including the Cragg mine, are mechanized. According to the Queensland Department of Mines, as of December 1992 Queensland mines averaged three miners for each machine, with 41 machines and approximately 123 people currently working the opal fields.

Although there is some tunneling to mine for opal in Queensland, the Cragg operation—like most mines in that area (the author visited four other sites around Mayneside)—is open cut. First, a truck-mounted auger drills a hole 75 cm (30 in.) in diameter and up to 20 m deep, through layers of silt, sandstone, and claystone (figure 8). If signs of opal are found, a crew member is lowered by rope to check for traces of "color." Once an opal-producing area is located, a bulldozer carefully cuts open a section of ground, removing overburden down to the opal-bearing stratum. A cut will be at least 60 × 15 m (about 200 × 50 ft.), usually with a depth between 2.5 and 12 m (8 and 40 ft.), depending on the depths of the different strata (figure 9). As opal is encountered, the shape of the pit is altered to follow the opal run. While the bulldozer opens the cut, another crew member walks behind it, scanning for nodules. Miners must be alert, as color is not immediately evident in many gem-grade nodules (figure 10). Modern mining is very different from the methods of the 1890s, when prospectors with colorful names like Jundah Jack and Silk Shirt Joe roamed the outback with little more than their swag and tucker, a pick, and a shovel.

Of the opal produced to date at the Cragg operation, approximately 90% has been ironstone boulder, 8% sandstone "boulder," 1.5% ironstone matrix (e.g., band opal), and 0.5% pipe opal. The largest opal that has been found at Cragg is a piece of band opal approximately 1 m × 60 cm × 25 cm thick (3 ft. × 2 ft. × 10 in.), which was uncovered in 1987. Several gem-quality cabochons were cut from this piece (V. Evert, pers. comm., 1993).

VISUAL APPEARANCE AND GEMOLOGICAL PROPERTIES

As previously stated, boulder opal has a singular appearance that makes it easily separated visually from other types of opal. Simply stated, polished boulder opal—by definition—will always contain some ironstone as part of the finished gem. Cut boulder opal is usually divided into two types: (1) opal *with* matrix—that is, a thin layer of gem opal overlying an ironstone back that is not visible faceup (figures 1 and 11); and (2) opal *in* matrix—that is, where parts of the host ironstone are visible in the faceup portion of the gem (figure 12). Many seams of boulder opal are so thin that more than half of the finished gem is matrix.

Most boulder opal from the Cragg mine has a dark brown or black background (figure 13). The dark color is caused by a thin, sometimes microscopic layer of black potch (nongem) opal sandwiched between the ironstone matrix and the translucent layer of gem

Figure 8. To locate opal at the Cragg mine, a large truck-mounted augur drills as deep as 20 m to remove samples of the various levels in search of signs of opal. Photo by Richard Wise.

Figure 9. Open-cut operations at the Cragg mine have exposed these layers of lateritic sandstone and claystone, which are typical of the Winton district. Photo by Andrea Williamson.

Figure 10. This nodule is typical of those recovered from the Cragg mine. Only a small portion of the nodules are opal bearing, and many of those that contain gem opal do not show color until they are cleaned or cracked open. Photo by Andrea Williamson.

opal (P. Downing, pers. comm., 1993). However, the background color of Queensland boulder opal may also be gray, brown, orange, or even white (Downing, 1992). The dark-hued stones known as "boulder blacks" normally appear to have the most intense, highly saturated play-of-color, because the dark background contrasts with the phenomenal colors of the gem material. The predominant phenomenal colors in gem-quality Queensland boulder opal are intense hues of red, blue, and green (Senior et al., 1977). Stones from the Cragg mine follow this pattern (again, see figure 13), although red and green predominate.

The author recorded the gemological properties of five cabochons of opal with matrix from Queensland, which weighed 1.42 to 6.54 ct (note that because of the varying amounts of matrix that may be present, boulder opal is usually sold by the piece rather than by weight). Spot refractive-index readings, taken with a Duplex II refractometer with a monochromatic light source, were consistently in the 1.42–1.43 range, or approximately 0.02–0.03 below the average reading expected of opal (1.45; Liddicoat, 1990) and toward the low end of its possible (1.40–1.50) range. All of the samples were inert to both long- and short-wave ultraviolet radiation. Because of natural variations in the ironstone:opal ratio from one cabochon to the next, specific-gravity measurements would not be useful and therefore were not taken.

Figure 11. In fine boulder opal with *matrix, the matrix provides the backing for the opal but is not visible faceup. This 19 × 12 mm opal with matrix is accented by yellow diamonds and tourmalines. Jewelry designed and executed by Laurie M. Donovan; courtesy of L. & R. Wise, Goldsmiths. Photo © GIA and Tino Hammid.*

Figure 12. In boulder opal in *matrix, parts of the host ironstone are visible in the faceup portion of the gem—often, as illustrated here, enhancing the overall composition of the piece. Note that these two opals (each approximately 10 × 30 mm) are actually halves of the same "split." Jewelry courtesy of Nanette Forester, American Lapidary Artists, Los Angeles, CA; photo © Harold & Erica Van Pelt.*

AESTHETICS AND QUALITY EVALUATION

Judging the quality of opal—and particularly boulder opal—is in some ways simple and in others difficult. It is simple because, in the words of one prominent dealer, "the brighter it is, the better it is." In more technical terms, color saturation or intensity is the main criterion for evaluation (Wise, 1991). Two additional criteria are common to all types of opal: color and pattern (see, e.g., O'Leary, 1977; Downing, 1992).

Most experts feel that a top-grade stone must be a multicolor, that is, display three or more colors. In addition, some colors are considered more desirable than others, with red at the top of the list. For example, In *Gemworld Pricing Guide* (1991), author R. B. Drucker reserves his highest rating for a stone that shows 75% red plus two additional colors (see, e.g., figure 14). Among the great variety of patterns in which the play-of-color appears, harlequin (a display of medium-to-large angular blocks of color; see, e.g., figure 15) is often considered the most valuable, and pinfire (a pattern of tiny points of color) is usually the least. The difficult part of judging boulder opal, specifically the opal-in-matrix type (ironstone visibly mixed with opal), is an additional factor that might best be termed *composition*.

In the evaluation of boulder opal, composition refers to the overall distribution of visual elements. Because composition is qualitative, it is also subjective. It is tempting to reduce the relative size, shape, and juxtaposition of opal and ironstone to a question of "flaws": that is, the greater the proportion of matrix, the poorer the quality of the gem (Downing, 1992). However, the dramatic increase in popularity of boulder opal in recent years is due in part to increased interest by designers and craftspeople who have been drawn to the painterly qualities of this Queensland gem. They view and value the stone much as a critic views a painting—as a balanced combination of elements.

The total composition of opal and matrix should, like a good abstract painting, be pleasing to the eye. For example, a squarish cabochon with small splashes of

Figure 13. Cragg-mine boulder opal, like these two pieces (19 mm and 14 mm in longest dimension, respectively), usually has a dark brown or black background. Note also the intense green, blue, and red play-of-color displayed. Jewelry by John Iskendrian; courtesy of Boulder Opal Enterprises, Winton, Qld., Australia; photo by Doug Drummond.

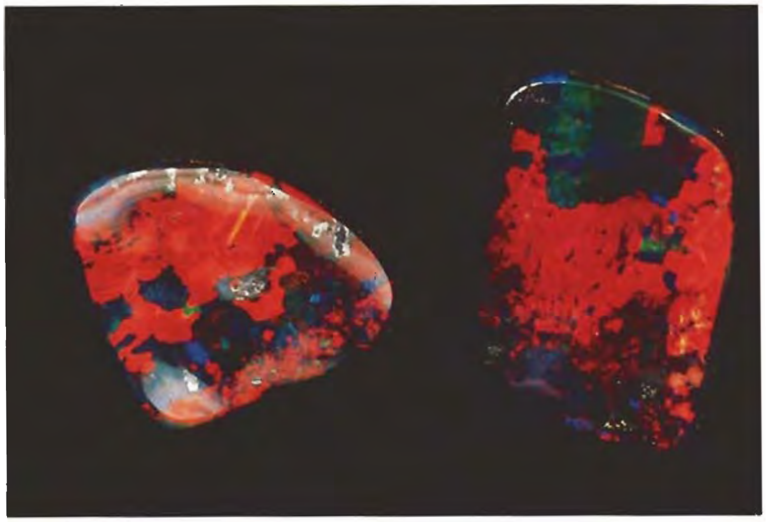


Figure 14. These two samples of boulder opal show the highly saturated, predominantly red play-of-color (with some blue and green) that is favored by many opal enthusiasts. Photo by Rudy Weber; © Australian Opal and Gemstone Photographic Library.

Figure 15. Large, angular patches of color characterize the boulder opals on the left and right as harlequins; the stone in the center shows pinfire play-of-color. The composition of all three is attractive. Courtesy of the Weber Karl Lehman Collection; photo by Rudy Weber; © Australian Opal and Gemstone Photographic Library.

color only at the corners may appear unbalanced and unattractive, whereas gems with a major portion of color toward the center (again, see figure 12) will generally be attractive. Occasionally one sees fashioned matrix opal—a stone that is primarily composed of matrix with bright flashes of opal throughout. As boulder opal is often cut freeform, the overall shape of the stone is also important.

DURABILITY

Boulder opal has a reputation for durability. Samples of opal with matrix and opal in matrix obtained by the author from the Cragg mine have been on constant display under high-intensity jewelry store lights for approximately two years with no evidence of cracking or crazing. However, another boulder matrix specimen, purchased in the rough by the author at Opalton, 32 km northeast of Cragg, initially showed intense fiery veins of opal that turned opaque white within days after the stone was set. This phenomenon, called cottoning, has been reported previously in Queensland boulder opal (Loneck, 1986).

Because of its generally high degree of stability, boulder opal from Queensland is believed to be lower in water content than opal from other parts of the continent. Shrinkage and cracking are virtually unknown (Senior et al., 1977), especially in the boulder blacks. "Lifting" (whereby the opal layer detaches itself from the matrix backing) is reported in approximately 2% of the material mined at Cragg; a thin layer of gypsum between the ironstone and opal layers causes the separation (J. Evert, pers. comm., 1993). Other cutters have reported lifting in 4%–5%, and crazing in approximately 6% (predominantly in the white opal) of Queensland stones (George Brooks, pers. comm., 1993).

SIMULANTS AND TREATMENTS

The most common boulder-opal simulants encountered in the trade are doublets of ironstone topped with a thin layer of opal. Usually this simulant is easily distinguished from natural boulder opal by the very straight dividing line between the top and bottom layers, although occasionally doublets with a natural-appearing undulating join between opal and matrix are seen. While such doublets can fool even experts if examined only with the unaided eye, close examination of the seam under low magnification will reveal a thin line of epoxy—commonly dyed to resemble the ironstone—that sometimes contains spherical cavities, probably the remains of gas bubbles (figure 16; Fryer, 1982). Although a thermal reaction tester will cause the cement layer to flow, this test is emphatically *not* recommended because of opal's extreme sensitivity to heat. Boulder opal is readily separated from treated Andamooka matrix opal by the presence of the black particulate carbon impregnator in the treated material, which can be seen at 10× magnification (see Brown, 1991).

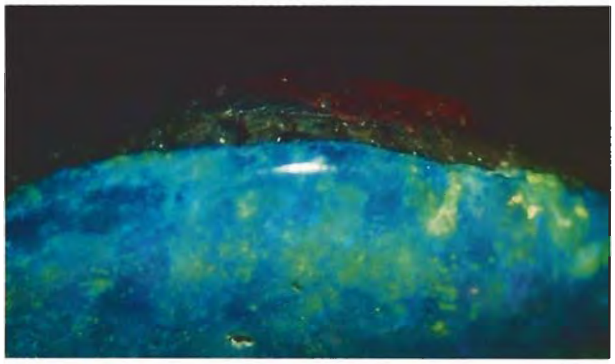


Figure 16. The most common simulant of boulder opal is manufactured by "cementing" a thin layer of opal to an ironstone backing. In the stone shown here, hemispherical cavities, probably formed by gas bubbles, reveal the thin line of epoxy that joins the two materials. Photomicrograph by Robert E. Kane; magnified 12×.

MANUFACTURING AND DISTRIBUTION

Opal manufacturing in Queensland is very much a cottage industry. No operations in the state are known to survive from income generated by cutting alone (PGIQ, 1992). Because opal mining is so expensive, most operations in Queensland are vertically integrated. To maximize their profits from the rough material, mine owners typically have in-house cutting facilities and very often their own wholesale and/or retailing operations as well. While this situation assures domestic supplies and allows much greater local control over prices, it may limit exportable supplies in times of slow production.

The distribution of boulder opal is, therefore, entirely in the hands of private miners and cutters. In 1988–89, exports of cut Queensland boulder opal totaled Aus$11,606,000 (US$8,766,012); they grew to Aus$12,074,000 (US$9,526,386) in 1989–90 (ABS, 1992). Miners report that demand for boulder opal remained strong through most of 1991 (Wise, 1991).

As of late 1992, the newly formed Queensland Boulder Opal Association (QBOA) had scheduled a series of "trade only" auctions to take place in the town of Winton during May, July, August, and October of 1993. In the past, visiting dealers have had to travel long distances between the fields and local trading centers to seek out miners and cutters and then arrange purchases. The auctions should act to centralize buying, stabilize prices, and expedite trading (QBOA press release, 1992).

FUTURE PRODUCTION

With the advent of mechanized mining, exploration and production costs have soared. Heavy equipment, fuel, and water must be trucked over long distances in an isolated and hostile environment. These factors have placed great stress on opal-mining operations during periods of economic recession. However, the vast size and unexplored potential of the Winton formation should assure significant production into the foreseeable future.

REFERENCES

Australian Bureau of Statistics, Distribution and Composition of Employee Earnings and Hours, Australia [ABS] (1981–82, 1987–88) Australian Bureau of Statistics, Belconnen, Australia.

Brown G. (1991) Treated Andamooka matrix opal. *Gems & Gemology*, Vol. 27, No. 2, pp. 100–106.

Cribb H.G.S. (1948) Opal deposits and the Hayricks mine. *Queensland Government Mining Journal*, Vol. 49, pp. 48–51.

Darragh P.J., Gaskin A.J., Sanders J.V. (1976) Opals. *Scientific American*, Vol. 234, No. 4, pp. 84–95.

Darragh P.J., Sanders J.V. (1965) The origin of color in opal. *Australian Gemmologist*, April 1965, No. 46, pp. 9–12.

Downing P.B. (1992) *Opal Identification and Value.* Majestic Press, Tallahassee, FL, and Estes Park, CO, pp. 131–137.

Drucker R.B. (1991) *Gemworld Pricing Guide*, Vol. 9. Gemworld International, Chicago, IL.

Fryer C., Ed. (1982) Gem trade lab notes. *Gems & Gemology*, Vol. 18, No. 2, p. 105.

Jackson C.F.V. (1902) The opal mining industry and the distribution of opal deposits in Queensland. *Geological Survey*, Queensland Publication 177 (reprinted in 1958 as Publication 291), pp. 112–114.

Jauncey W. (1967) *Maneroo, Queensland* (map) *1:250,000 scale, Geological Series, with Explanatory Notes Sheet SF/54–16.* Department of National Development, Bureau of Mineral Resources, Geology and Geophysics, Canberra, Australia.

Keller P.C. (1990) *Gemstones and Their Origins.* Van Nostrand Reinhold, New York.

Krosch N.J. (1983) A summary of opal mining activity, western Queensland 1970–1983. *Queensland Government Mining Journal 1983*, Brisbane, Australia, p. 273.

Liddicoat R.T. Jr. (1990) *Handbook of Gem Identification*, 12th ed. rev. Gemological Institute of America, Santa Monica, CA, p. 196.

Loneck A. (1986) *Opals, Rivers of Illusions.* Gemcraft Publications, Victoria, Australia, p. 2.

O'Leary B. (1977) *A Field Guide to Australian Opals.* Gemcraft Publications, Victoria, Australia.

Profile of the Gemstone Industry in Queensland [PGIQ] (1992) Department of Industry and Regional Development, Brisbane, Australia.

Queensland Department of Mines [QDM] (1988) *Mapping Series: Queensland Opal.* Queensland Department of Mines, Brisbane, Australia.

Queensland Yearbook 1992 (1992) Queensland Department of Resource Industries, Brisbane, Australia.

Senior B.R., McColl D.H., Cong B.E., Whiteley R.J. (1977) The geology and magnetic characteristics of precious opal deposits, southwest Queensland. *BMR Journal of Australian Geology and Geophysics*, Vol. 2, pp. 241–251.

Tavernier J.B. (1675) *Travels in India*, Vol. II. As translated in 1977 by V. Ball, Oriental Books Reprint, New Delhi, India, p. 81.

Wise R.W. (1991) Australia thy name is opal. *Colored Stone*, Vol. 4, No. 2, p. 9.

UPDATE ON DIFFUSION-TREATED CORUNDUM: RED AND OTHER COLORS

By Shane F. McClure, Robert C. Kammerling, and Emmanuel Fritsch

Blue diffusion-treated sapphires have become a subject of considerable controversy since their introduction in significant quantities a few years ago. Now it appears that diffusion-treated corundum in additional colors, including red, may also be a commercial reality in the near future. At the request of the treater, the authors examined faceted specimens in a range of colors to document their gemological properties and determine identification criteria prior to any commercial release. Diagnostic features include unusually high refractive-index readings, atypical dichroism, atypical luminescence, patchy surface coloration, color concentrations along facet junctions, and spherical voids just below the surface.

ABOUT THE AUTHORS

Mr. McClure is supervisor of identification services, and Mr. Kammerling is director of identification and research, at the GIA Gem Trade Laboratory, Santa Monica, California. Dr. Fritsch is manager of GIA research,Santa Monica.

Acknowledgments: Richard Pollack, of United Radiant Applications, Del Mar, CA, provided the diffusion-treated corundums used in this study. Gene Dente, of Park International, San Diego, CA, gave valuable information. Gustave Calderon, Patricia Maddison, and Cheryl Wentzell, of the West Coast GIA Gem Trade Laboratory (GIA-GTL), helped with the gemological investigation; and Sam Muhlmeister, of GIA Research, did the EDXRF analyses. Microprobe analyses were by Paul Carpenter, Division of Geology and Planetary Sciences, California Institute of Technology, Pasadena.

Gems & Gemology, *Vol. 29, No. 1, pp. 16–28*

Blue diffusion-treated sapphires, little more than a gemological curiosity in the late 1970s and early 1980s, became a significant—and controversial—commercial reality at the start of this decade (Kammerling et al., 1990; Koivula and Kammerling, 1990). A detailed study of these stones was reported in Kane et al. (1990).

Since then, there have been a number of developments in the area of blue diffusion-treated sapphires. First, a significant amount of the material has reportedly entered the trade ("Diffusion: 80,000 carats in Asia," 1991; Koivula et al., 1992a). Second, the strong demand for calibrated stones in a number of traditional cuts indicates an acceptance of the product by at least some large-scale manufacturing jewelers and retailers (Koivula and Kammerling, 1991a; Koivula et al., 1992a; Federman, 1992). Blue diffusion-treated stones have also become available commercially in a broad range of sizes, from 0.12 ct (3 mm rounds) to over 50 ct (Koivula et al., 1992a). The GIA Gem Trade Laboratory has seen some diffusion-treated sapphires set in fine jewelry (see, e.g., Hargett, 1991). Although pale-to-colorless corundum from Sri Lanka has been the preferred starting material for diffusion-treated stones, gem-testing laboratories have recently examined treated faceted stones from Montana and flame-fusion synthetic material (Kammerling et al., 1992; Lithiby, 1992) that has been diffusion treated blue.

Not all developments in diffusion treatment, however, have been restricted to producing blue stones. Experiments related to U.S. Patent 3,897,529 (Carr and Nisevich, 1975; reviewed in Kane et al., 1990) describe "ruby red," "salmon pink," and pink colors, among others, being produced by diffusion treatment of various pale or unevenly colored specimens of corundum. In fact, the first example of diffusion-treated corundum examined in the GIA Gem Trade Laboratory was red-orange (Crowningshield, 1979).

More recently, in early 1991, Jeffrey Bergman of Gem Source reported that attempts to produce red colors by the

Figure 1. These stones, ranging from 0.55 to 5.67 ct, represent a range of colors that are now being produced by diffusion treatment of corundum. This material is being processed for eventual release to the jewelry trade. Photo by Shane F. McClure.

diffusion process had been unsuccessful: The result was very shallow penetration of the red-producing chromophore, as well as the development of an unwanted blue component (Koivula and Kammerling, 1991a,c). Other dealers involved in red diffusion-treatment experimentation have reported similar difficulties, producing at best a pink overall body color after the necessary repolishing (Koivula et al., 1992a). Most recently, however, an isolated 0.48-ct corundum reportedly diffusion treated to a "rich cherry-red colour" was identified at the Asian Gemmological Laboratory in Hong Kong ("Diffusion-treated red corundum in HK," 1992).

In late 1992, the authors were contacted by Richard Pollack, of United Radiant Applications, who has been involved in the commercial production of blue diffusion-treated sapphires since 1989 (and was responsible for producing many of the stones examined in the Kane et al., 1990, study). He informed us that he had succeeded in producing diffusion-treated corundum in the pink-to-red color range (figure 1) and that such stones might soon be commercially viable. Before they were released into the trade, however, Mr. Pollack wished to have the product thoroughly documented gemologically and identification criteria established to discourage any subsequent misrepresentation of loose or jewelry-set stones (figure 2). At the time he provided the research samples, he reaffirmed that he would not distribute this material commercially until the report had been published.

THE DIFFUSION-TREATMENT PROCESS

The process used to diffuse surface color into corundum is reviewed in Kane et al. (1990). In the most basic terms, the process usually involves embedding fashioned stones in a powder consisting of aluminum oxide plus coloring agent(s) within an alumina crucible. Extended heating of the crucible in a furnace at elevated temperatures—typically 1600°C–1850°C, but at times approaching the melting point of corundum

Figure 2. The jewelry potential of red diffusion-treated corundum is well illustrated by this mounted 4+-ct stone. Photo by Shane F. McClure.

(2050°C)—results in a zone of treated color near the surface of the stone.

To produce a blue diffusion layer, oxides of iron and titanium are typically used, although cobalt has been used at least experimentally (Kane et al., 1990). Chromium oxide would appear to be the most logical chromophore for producing pink to red, as Cr^{3+} is the principal coloring agent in ruby and pink sapphire (Fritsch and Rossman, 1988). Among the early diffusion-treatment experiments that resulted in pink to red colors, one used a combination of 3%–6% chromium oxide and 22%–24% titanium oxide (Carr and Nisevich, 1975).

DISCLOSURE AND NOMENCLATURE ISSUES

Although there is no unanimity in the gem trade concerning proper nomenclature for disclosing diffusion treatment, there is general agreement that the treatment should be disclosed. The GIA Gem Trade Laboratory currently uses the following wording in the conclusion of an identification report for a blue diffusion-treated sapphire:

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

The word *natural* is used to avoid confusion with synthetic sapphires which, as noted above, may also be diffusion treated. Furthermore, the word *sapphire* refers to the starting material, which—regardless of its color—would be classified as such.

Red diffusion-treated material, however, presents a more complicated situation. Although the starting gem material is sapphire, the end product may resemble ruby. To call such material "diffusion-treated ruby" misrepresents the starting material; yet to call it "diffusion-treated sapphire" would be confusing at best. Should such a stone be submitted to the GIA Gem Trade Laboratory, we would probably use the more generic term *diffusion-treated corundum.*

MATERIALS AND METHODS

The study sample on which this report is based included 43 faceted stones ranging from 0.41 to 5.67 ct. Twelve of the stones were "ruby color," according to GIA Gem Trade Laboratory criteria (i.e., predominantly red in hue and of sufficient tone and saturation). Fifteen samples were either too light in tone (i.e., pink) or were predominantly purple and, therefore, not ruby color in our opinion. Some of these latter stones exhibited a weak color change, typically pinkish purple in fluorescent light and purplish pink under incandescent lighting. These 27 stones (0.55–5.67 ct) represent the core sample on which our detailed gemological study was carried out, as this was the material that we felt to be potentially most significant from a commercial standpoint.

The remaining 16 stones represented a wide range of colors (including violet, violetish blue, reddish purple, and pinkish purple faceup, most with a distinct unevenness of color—e.g., light blue with patches of pink, violet with purplish pink areas, and yellow with pink patches; figure 3). According to Mr. Pollack, these were the unsatisfactory results of early experi-

Figure 3. These stones, ranging from 0.55 to 3.35 ct, represent some of the less successful results of early experimentation to produce pink-to-red diffused color in corundum. Photo by Shane F. McClure.

mentation. Although the gemological properties of all were tested, they are not part of the core sample and will be mentioned only briefly where appropriate in the following discussion.

The 27 core samples were first subjected to standard gemological testing. Refractive-index readings were taken on the table facets with a Duplex II refractometer and a near sodium-equivalent light source. Stones exhibiting readings over the limit (1.80+) of the conventional refractometer were tested on a refractometer fitted with a cubic zirconia hemicylinder and using an appropriate contact fluid. Stones in the core sample were examined with a polarizing filter dichroscope, and all test stones were examined in transmitted light with a Chelsea filter. Four-watt long- and short-wave lamps in a controlled, darkened environment were used to determine the ultraviolet luminescence behavior of the test stones. Specific gravity was determined using the hydrostatic weighing method, with three separate sets of readings taken on each stone. The stones were also examined with a microscope in conjunction with diffused, transmitted illumination and immersion (as described by Kane et al., 1990). Use of a GIA GEM Instruments illuminated immersion cell produced comparable results.

In addition, we selected seven samples (representing the range of refractive indices observed, with five of "ruby" color) for more sophisticated testing. Energy-dispersive X-ray fluorescence (EDXRF) was performed at GIA using a Spectrace 5000 spectrometer (for more details on the technique see, e.g., Fritsch and Rossman, 1990). The standard conditions for analysis were a tube voltage of 25 kV, a current of 0.25 mA, an aluminum filter, and a 200-second life time. For the detection of aluminum, no filter was used, the voltage was 15 kV, and the current was 0.15 mA. Electron microprobe (EMP) analyses were performed on these stones at the California Institute of Technology by Paul Carpenter. Optical absorption spectra were recorded on a Hitachi U4001 spectrophotometer, at a resolution of 0.5 nm. X-ray powder diffraction analyses were performed on two of the stones, at a voltage of 50 kV and a current of 40 mA.

GEMOLOGICAL PROPERTIES

Visual Appearance. The 27 stones in the core sample ranged from medium to dark in tone and included purplish pink, reddish purple to purplish red, and orangy red hues. Faceup, some of the stones appear uniform in color, while others display varying degrees of uneven color distribution (figure 4). The unevenness appears to be the result of a complete absence of color on some pavilion facets, probably because of partial removal of the diffusion layer during repolishing.

Figure 4. The uneven faceup color of some of the test stones is evident in this 1.60-ct specimen. Photo by Shane F. McClure.

Some stones displayed a strong orange component when examined in other than the faceup position, for example, through the girdle or the pavilion. This appearance, which in our experience is not typical of either natural or synthetic corundums of similar faceup color, can be attributed to the inherent yellow body color of these stones. In a few instances this yellow substrate color was strong enough to influence the faceup appearance of the stone, making it an orangy red. A similar effect was previously noted where an inherent blue body color underlying a red diffusion layer resulted in a predominantly violet faceup appearance (Koivula and Kammerling, 1991b).

In most cases, the faceup appearance of the 16 "experimental" stones could be explained in large measure by the amount and distribution of the diffusion-produced color. In the case of stones that appeared violet, a thin red diffused layer covered much of the pavilion surface of a stone with a light blue body color. In the case of stones with patchy faceup color, it appeared that much of the diffused color layer had been removed during repolishing. The predominantly yellow stone had so little diffused color that, for the most part, only the original body color was visible.

Refractive Indices. As this property is generally not affected by enhancement processes, we were surprised to find that values for the test samples varied significantly from those expected for corundum (typically 1.762–1.770). Of the 27 samples, only one had readings in the normal range. Two gave abnormally high readings that were still within the limits of the refractometer (1.770–1.779 and 1.788–1.798).

A small group (five stones) actually displayed two distinct sets of readings on the table facets. For example, one stone exhibited a distinct set of normal corundum readings (1.762–1.770), but another set of shadow edges gave values of 1.779–1.789. Another such stone gave readings of 1.760–1.768, and also showed a distinct shadow edge at the upper limit of the instrument. It is possible that the dual readings result from different concentrations of the diffused chromium ion on different areas of the facets being tested. Alternatively, the higher readings may be for the very thin, chromium-rich diffused layer, while the lower—typical corundum—readings are for the untreated substrate just below that layer. A similar situation is sometimes encountered with garnet and glass doublets that have very thin garnet "caps," where both garnet and "substrate" glass readings are observed at the same time.

Significantly, 19 of the stones had values over the limits of the refractometer, that is, 1.80+. Six of these were tested on a refractometer with a cubic zirconia hemicylinder, which produced readings in the 1.81 to 1.84 range. Although the readings were not distinct enough to permit accurate determinations of birefringence, this appeared to be approximately 0.01. One of the six stones exhibited a dual reading, that is, one that was over the limits and one that was typical of corundum.

It is interesting to note here that five of the 16 "experimental" stones exhibited refractometer readings within the normal range for corundum, apparently due to the relatively thin diffused color layer on the facet tested. Three stones exhibited two distinct readings, while the remaining eight had single, over-the-limits values. Again, those with the higher readings had a more pronounced diffusion-induced color layer on the surface tested. Although the R.I. values varied significantly, the birefringence was relatively constant and within the range expected of corundum, 0.008–0.010.

Pleochroism. While some of the stones exhibited pleochroism typical of both natural and synthetic corundum of comparable colors, the majority showed atypical dichroism. In most of the "ruby color" stones, in particular, one dichroic color was purplish pink to purplish red and the other was brownish yellow. In our experience, the second pleochroic color of comparably colored natural and synthetic rubies ranges from orangy red to orange. It was further noted that the pleochroism was sometimes quite inhomogeneous, with adjacent areas displaying distinctly different pleochroic colors. This inhomogeneity appeared to correlate with variations in the depth of the diffused layer of color due to uneven repolishing.

Figure 5. When exposed to short-wave U.V. radiation, all but one of the stones exhibited some degree of patchy surface luminescence, as seen in these 2.25- to 2.81-ct samples. Photo by Shane F. McClure.

Chelsea Filter Reaction. All 27 core-sample stones gave a weak to moderate red reaction to the Chelsea color filter, virtually identical to what would be expected of untreated natural or synthetic corundums of comparable body color.

Ultraviolet Luminescence. The 27 core samples had very consistent reactions to long- and short-wave ultraviolet radiation. When exposed to long-wave U.V., most of the stones luminesced a faint to weak orangy red to red. In the authors' experience, these reactions overlap those of natural rubies from various localities as well as those of some flux-grown synthetic rubies. One stone showed a moderate orange fluorescence, a second fluoresced a weak reddish orange, and a third was inert. A close examination of these reactions revealed that the orange component of the luminescence came primarily from the body of the stones, while the red component originated at or near the surface (i.e., from the diffused layer). While this reaction is unlike any we have noted in either natural or synthetic rubies, the underlying orange luminescence was identical to that reported for some blue diffusion-treated sapphires (Kane et al., 1990), as well as for many natural sapphires from Sri Lanka (Webster, 1983).

Short-wave U.V. reactions were even more consistent. The interiors of the vast majority (25) of the sample stones were inert; two luminesced a faint red. However, all but one of the stones exhibited unusual patches of weak to moderate chalky bluish white to yellowish white luminescence at the surface (figure 5). In some instances, these luminescent patches were seen to be clearly confined to—and paralleling—the shapes of facets, either singly or in small groups. This is in contrast to the chalky greenish white short-wave U.V. luminescence sometimes displayed by blue diffusion-treated as well as heat-treated sapphires, where the reaction emanates from the entire stone or from irregular areas that do not correspond to specific facets. Patchy blue short-wave luminescence has been noted by the authors in some rubies suspected of having been subjected to high-temperature treatment. In these instances, however, the patchy luminescence was not confined to specific facets or groups of facets.

Absorption Spectra. In general, the absorption features noted with the desk-model spectroscope were similar to those of both natural and synthetic corundums in the pink-to-red-to-purple color range. There were, however, two notable differences. First, the sharp absorption lines at approximately 468.5, 475.0, and 476.5 nm (Webster, 1983) that are generally pronounced in even medium-toned corundum of these colors were very weak or absent. In addition, the fine absorption lines in the red portion of the spectrum at 659.2, 668.0, and 697.5 nm (Webster, 1983) were weaker than would be expected in stones with comparable depths of color.

Specific Gravity. The specific-gravity values obtained—3.99 to 4.01—were well within the range for corundum, both natural and synthetic.

Figure 6. Discoid fractures in several of the sample stones provided evidence of high-temperature treatment in general, but they are not specific to the diffusion process. Photomicrograph by Shane F. McClure; magnified 15×.

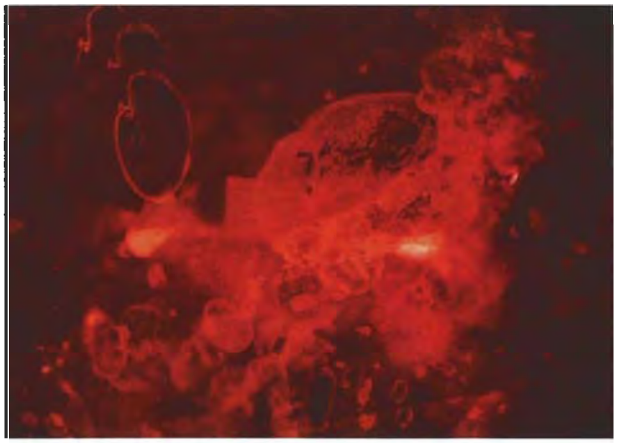


Figure 7. Uneven coloration from one facet to another was the most prevalent feature noted—with low magnification or, in some cases, with the unaided eye—in the diffusion-treated corundums in this study. Photo, taken in diffused transmitted light without immersion, by Shane F. McClure.

Magnification. Examination of these stones with magnification proved to be one of the most valuable and consistent tests for detecting treatment. We observed features typical of high-temperature corundum enhancements in general, as well as those associated with diffusion treatment in particular. We also noted characteristics that had not previously been reported in blue diffusion-treated stones.

The features typical of heat treatment—that is, discoid fractures (figure 6), melted crystal inclusions, and sintered surfaces—were seen in many of the samples. In the authors' experience, such features are significantly less common in heat-treated rubies than in heat-treated sapphires. However, we do not feel that this observation could be used effectively as a criterion for the identification of diffusion treatment because they only indicate that the stones have been exposed to high temperatures.

Among the features specifically associated with diffusion treatment (see, e.g., Kane et al., 1990), most prevalent was uneven coloration from one facet to another. Whereas most blue diffusion-treated sapphires reveal this patchiness only with immersion, we observed it easily in many—but not all—of the pink-to-red sample stones using only diffused transmitted light (and, in some cases, even without magnification; figure 7). We also noted that the unevenness of color was more pronounced than is usually apparent in most blue-treated stones, with relatively more

Figure 8. In general, the predominantly pink-to-red-to-purple diffusion-treated stones showed more areas that were totally devoid of diffused color than have been noted in blue diffusion-treated stones. Photomicrograph by Shane F. McClure; magnified 28×.

facets being totally devoid of color (figure 8). This is due to a relatively thinner layer of diffused color and/or excessive repolishing.

As with blue diffusion-treated corundum, stones in our test sample displayed "bleeding"—concentrations of color in surface-reaching cavities and fractures (figure 9). One stone had a fracture extending from the table to the surface of the pavilion near the culet that exhibited such diffused color along its entire length (figure 10).

Figure 10. A concentration of diffused color is quite apparent in the large fracture that traverses this stone from the table to near the culet. Photomicrograph by Shane F. McClure; magnified 17×.

Many of the stones also displayed varying degrees of surface and near-surface damage that has not been seen in the blue diffusion-treated sapphires examined to date. Most common were small groups of minute spherical voids visible just below the surface (figure 11). Where these broke the surface, small pits resulted (figure 12). In addition, these clusters of voids and pits were invariably surrounded by concentrations of the diffused color (figure 13). Note that Brown et al. (1990) reported the presence of numerous small "bubbles" in the diffusion layers on a sample of red diffusion-treated flame-fusion synthetic sapphires.

Figure 9. Some of the stones in the test sample displayed "bleeding," or concentrations of color, in surface-reaching cavities. Photomicrograph by Shane F. McClure; magnified 28×.

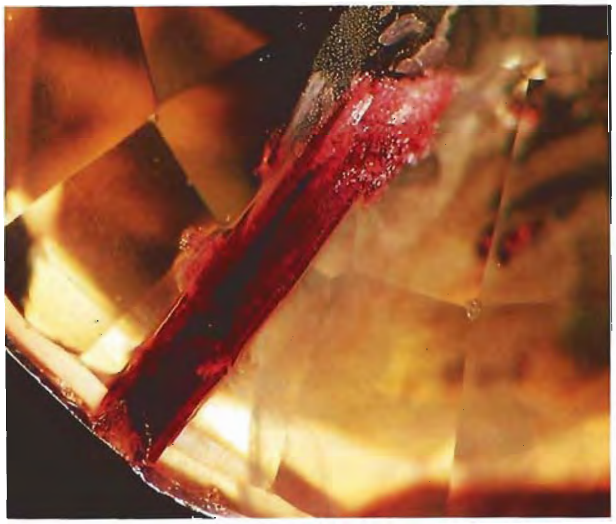
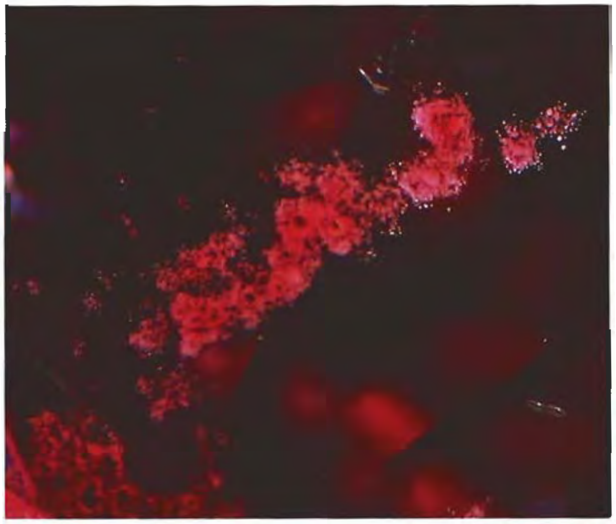


Figure 11. Small groups of minute spherical voids within the diffused color layer were visible in many of these stones. Photomicrograph by Shane F. McClure; magnified 40×.



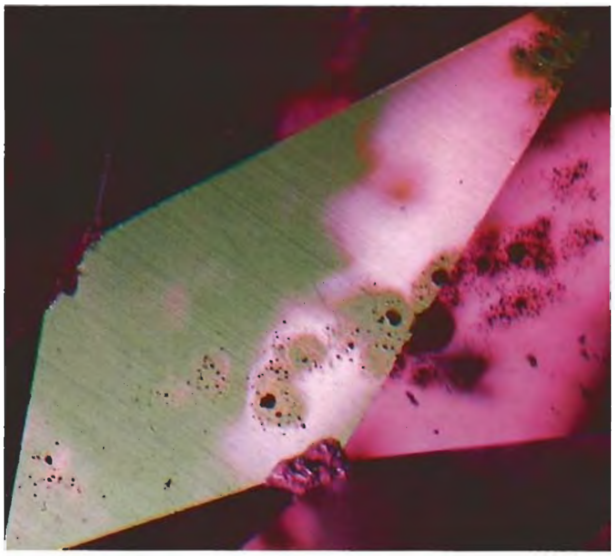
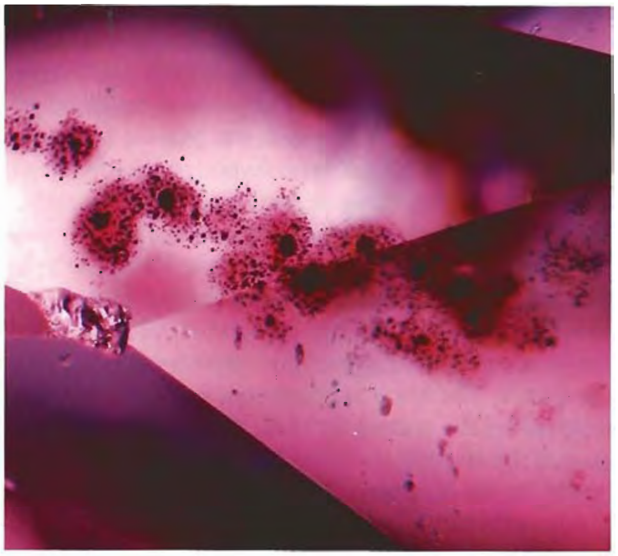


Figure 12. With reflected light, pits can be seen where small voids like those shown in figure 11 break the surface of the stone. Photomicrograph by Shane F. McClure; magnified 28×.

Figure 13. Concentrations of diffused color invariably surrounded the small pits and spherical voids in the diffused layer. Photomicrograph by Shane F. McClure; magnified 40×.



Also in the near-surface area, we saw dense concentrations of very small, white inclusions covering entire facets (figure 14). To the unaided eye, these gave the appearance of a poor polish, although in reflected light the other-than-surface nature became evident.

Figure 14. Dense concentrations of very small, white inclusions were often noted in the near-surface areas, covering entire facets. Photomicrograph by Shane F. McClure; magnified 27×.

Immersion. With this technique, uneven coloration was revealed in those stones where it was not evident with magnification only, and it became much more evident in the others (figure 15). We also noted, however, that the color reinforcement of facet junctions was significantly more subtle than in blue diffusion-treated corundum (Kane et al., 1990). In some instances, virtually no color outlining was observed. This occurred with stones that retained a fairly even diffused layer after repolishing. The stones in the core sample that fit this description were predominantly dark red, although this could conceivably also be the case with evenly treated pink or purple stones. The

Figure 15. The uneven distribution of diffused color in many of the test stones was easily seen when immersion (here, in methylene iodide) was used in conjunction with diffused transmitted light. Photo by Shane F. McClure.

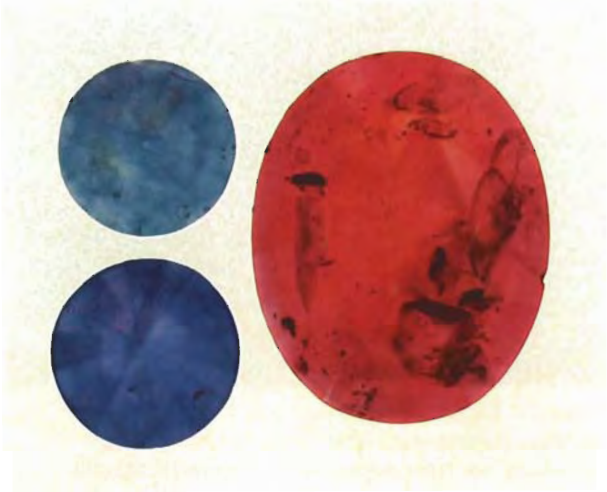


Figure 16. Color reinforcement of facet junctions is much more subtle—and, in some cases, completely absent—in predominantly pink, red, and purple diffusion-treated stones when compared to typical blue diffusion-treated sapphires. Photo by Shane F. McClure.

subtlety or absence of this feature is particularly evident when a red diffusion-treated stone is examined next to a blue diffusion-treated one (figure 16).

Several features we observed in these stones while they were immersed were similar to ones reported for blue diffusion-treated sapphires. The most notable of these was the much higher relief of the diffusion-treated stones when compared to natural or synthetic rubies (figure 17). This feature is extremely helpful in identifying this material when comparison stones are available. Also seen in this material, as it is in the blue, is a dark ring around the girdle of some of the stones (figure 18).

Figure 17. With immersion (here, in methylene iodide), the significantly greater relief of the diffusion-treated stone (center) as compared to synthetic (left) and natural (right) ruby is readily apparent. Photo by Shane F. McClure

Figure 18. A dark ring of color is visible around the girdle of this 0.56-ct mounted diffusion-treated stone immersed (in methylene iodide). Note that some patchiness of color can also be seen between the prongs of the mounting. Photo by Shane F. McClure.

As was the case with the blue diffusion-treated sapphires examined by Kane et al. (1990), methylene iodide was the most effective immersion medium for detecting diagnostic features in the current test sample. However, we also obtained good results for most stones with water and glycerine (see, e.g., figure 19).

One curious feature noted in several stones was the presence of a relatively deep, pale blue or purple diffused layer underlying the near-surface pink to red diffusion color (figure 20). Immersion also revealed the presence of irregular yellow zones within some of the stones. The latter is consistent with information supplied by the treater that pale yellow sapphires are used as the starting material, but we do not know the reason for the blue layer. Koivula et al. (1992b) recently reported that yellow sapphires are being purchased in large quantities in Sri Lanka for use in both heat and diffusion treatment. During a visit to Sri Lanka in mid-1992, the senior author was told that demand for these stones had resulted in significant price increases.

CHEMICAL ANALYSIS, OPTICAL ABSORPTION, AND X-RAY POWDER DIFFRACTION

Chemical Analysis. We compared chemical analyses obtained using EDXRF and electron microprobe techniques on the seven samples mentioned earlier (table

1). Besides aluminum and oxygen, the other elements present in concentrations that can be reliably measured with both techniques are chromium, iron, and titanium. Small amounts of gallium were detected in all samples by EDXRF. Silicon, magnesium, and vanadium were analyzed for but not detected.

The major finding is that chromium concentrations for these stones—from more than 7 wt.% to almost 17 wt.% Cr_2O_3 as measured by EMP—are much higher than those measured for natural or synthetic ruby (which, in our experience, are typically 0.2–2.0 wt.% Cr_2O_3). Although some natural or synthetic stones might have higher chromium concentrations (see, e.g., Henn et al., 1990), such stones are usually very dark, significantly darker than any of our diffusion-treated samples. The high chromium content measured in the diffusion-treated stones is easily explained: The apparent color is not homogeneously distributed throughout the stone; rather, it is limited to a very thin layer in which the coloring agent—chromium—must be concentrated. Concentrations of other elements such as Ga, Fe, and Ti, which do not participate in the red coloration, are typical of those measured in some natural rubies. Therefore, EDXRF is helpful in proving that the diffusion treatment was applied to natural—not synthetic—sapphires.

A significant difference between the two methods of chemical analysis used for this study, and one that proved uniquely valuable in this application, is that the microprobe takes measurements at a much shallower depth (only a few micrometers) than does EDXRF (about 100 micrometers). Thus, the EDXRF results reflect an average composition for the surface diffusion layer, where most of the chromium is concentrated, plus the region beneath, where less of the chromium has penetrated. Consequently, the microprobe results show values appreciably higher for Cr_2O_3 (7.42–16.83 wt.%) and lower for Al_2O_3 (83.25–92.60 wt.%) than those revealed by EDXRF (4.18–13.16 wt.% and 85.85–95.49 wt.%, respectively).

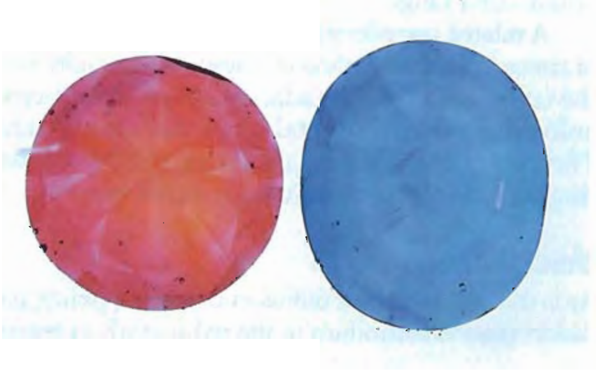


Figure 19. With immersion in water, the patchiness of color typical of diffusion treatment is readily apparent in the 1.96-ct red stone, but is very subtle in the 2.14-ct blue diffusion-treated stone. Photo by Shane F. McClure.

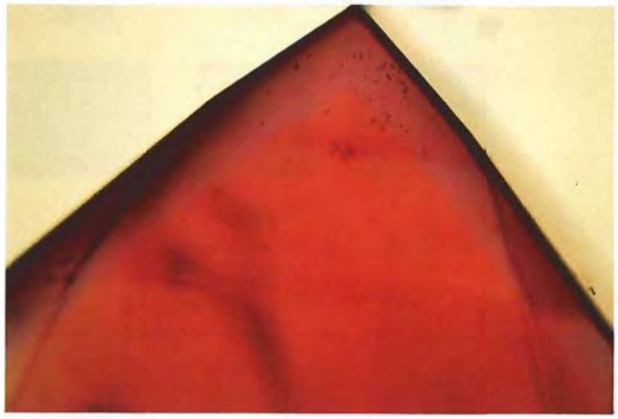


Figure 20. Several of the sample stones revealed a relatively deep, pale blue or purple diffused layer underlying the near-surface pink-to-red diffusion color. Photomicrograph by Shane F. McClure; magnified 30×.

Note also the variation in EMP:EDXRF chromium concentration ratios for different stones. This is not necessarily caused by a variation from stone to stone in the speed of diffusion; a more likely explanation is that more material was removed during repolishing from the tables of certain stones.

The titanium concentrations measured by the two techniques are basically comparable. However, the iron concentrations determined by EDXRF are greater than (sometimes only marginally, but up to almost double) those measured with the electron microprobe. This is opposite the behavior of the chromium concentrations. Although several explanations could be ventured, we are not certain of the cause of this difference.

Optical Absorption. Optical absorption spectra of three "ruby-color" samples of diffusion-treated corundum were taken in a random orientation. The broad bands centered at approximately 410 and 560 nm, which determine the color of the stone, are similar to those observed in natural and synthetic rubies. The most distinct "chromium lines"—at 692 and 694 nm—and other sharp bands seem weaker and wider than in the spectra of natural rubies. The sharp features seen in all naturally colored rubies at about 467 and 474 nm are difficult to discern, and those expected

TABLE 1. Electron microprobe[a] and EDXRF analyses of seven selected diffusion-treated corundums.

	R01711		R01712		R01713		R01714		R01715		R01716		R01717	
														
	2.55 ct R.I. 1.83-1.84[b]		1.96 ct R.I. 1.82-1.83		4.32 ct R.I. 1.81-1.82		2.62 ct R.I. 1.81-1.82 & 1.760-1.768		2.33 ct R.I. 1.84		2.81 ct R.I. 1.788-1.798		0.56 ct R.I. 1.83-1.84	
Oxide	EMP[c]	EDXRF[d]	EMP	EDXRF	EMP	EDXRF	EMP	EDXRF	EMP	EDXRF	EMP	EDXRF	EMP	EDXRF
Al_2O_3	83.25	88.74	84.36	85.85	86.25	88.03	86.84	93.26	82.78	91.25	92.60	95.49	86.96	92.07
Cr_2O_3	16.05	10.39	15.42	13.16	13.81	11.22	12.44	6.11	16.83	8.06	7.42	4.18	12.68	7.28
FeO	0.07	0.11	0.11	0.20	0.06	0.09	0.12	0.19	0.07	0.08	0.09	0.10	0.10	0.14
TiO_2	0.43	0.48	0.31	0.48	0.36	0.38	0.27	0.28	0.44	0.42	0.13	0.17	0.29	0.30
Others[e]	0.26	0.27	0.02	0.30	0.01	0.29	0.01	0.17	0.02	0.18	0.01	0.11	0.01	0.21
Total	100.06	99.99	100.22	99.99	100.49	100.01	99.68	100.01	100.14	99.99	100.25	100.05	100.04	100.00

[a] *Electron microprobe analyses were performed on an automated, five-crystal JEOL 733 spectrometer operating at a beam accelerating potential of 20 kV, a current of 35 nA, a 30-second counting time, and a spot size of 10 μm. Three points were selected on the table of each sample; the average of the three points is given here. K-alpha lines were analyzed for each element. Standards include: (Mg)—Boyd forsterite; (Al)—Al_2O_3; (Si)—anorthite; (Ca)—anorthite; (Ti)—TiO_2; (V)—V_2O_5; (Cr)—Cr_2O_3; (Fe)—Fayalite; (Ga)—GaP. The microprobe data were corrected using the program CITZAF (Armstrong, 1988) employing the absorption correction of Armstrong (1982), the atomic number correction of Love et al. (1978), and the fluorescence correction of Reed (1965, as modified by Armstrong, 1988).*

[b] *Refractive-index readings over 1.81 are approximate and, therefore, are given only to two decimal places.*

[c] *EMP: Electron microprobe.*

[d] *EDXRF: Energy dispersive X-ray fluorescence.*

[e] *Includes the following: MgO, SiO_2, CaO, V_2O_3, and Ga_2O_3.*

at 658 and 668 nm are not detectable. In two of the three samples, there seems to be some absorption on the low-energy side of the 692–694 nm doublet, with an apparent maximum at about 700 nm—a feature that has never been reported in untreated rubies.

X-ray Powder Diffraction. Because of the exceptionally high chromium concentrations detected in the near-surface areas, the question arose as to whether this layer still retained the structure of corundum. Therefore, we selected two stones for X-ray powder diffraction analysis. For the scrapings, we chose areas with relatively deep color penetration to insure that the powder sample was removed from a treated portion. In both instances, the resulting patterns were identical to standard patterns for corundum.

DURABILITY AND STABILITY

In the Kane et al. (1990) study of blue diffusion-treated sapphires, the treatment layer was shown to be unaffected by such standard cleaning procedures as ultrasonic and steam cleaning, and boiling in a detergent solution. That investigation also showed that the heat and chemicals used in jewelry repair procedures could result in minor to moderate surface etching, as would be expected with corundum generally. Given the findings of this study, it can be expected that the diffusion-treated stones described herein would exhibit similar durability and stability results.

Of particular importance with any diffusion-treated stone is the fact that repolishing or recutting could remove some or all of the diffused layer, resulting in a lightening or total loss of color. Given the observed shallowness of color penetration in the present study stones—as well as the many areas where the diffused color layer has apparently been completely removed in repolishing—this precaution is especially pertinent to diffusion-treated stones in the pink-to-red-to-purple color range.

A related consideration is that the removal of color zones from the pavilion of a stone—especially near the culet—generally has a far greater effect on faceup color than their removal from the crown area. Therefore, we recommend against repolishing or recutting pavilion facets on diffusion-treated stones.

DISCUSSION

As is the case with blue diffusion-treated sapphires, diffusion-treated corundum in the red-to-pink-to-purple color range can also be readily identified by standard gemological testing.

As with blue diffusion-treated stones, an important diagnostic feature is the uneven coloration from one facet to another, including areas where the diffused color layer has been completely removed in repolishing. Because this type of color anomaly was easier to detect in the current test sample than it has been with blue diffusion-treated stones, immersion was less critical, although in all three media used, it did make the patchiness more obvious. However, several stones in this sample showed very little patchiness and facet reinforcement. Moreover, because refinements in the treatment process are inevitable, all corundums—regardless of color—should be routinely examined in immersion. Also typical of the treatment is a bleeding of diffused color in surface cavities and surface-reaching fractures.

Concentrations of color along facet junctions may be seen in diffusion-treated stones in the color range covered by this study, but they are likely to be more subtle or even absent in some instances, making this a less reliable diagnostic feature. When present, however, such concentrations do provide proof of diffusion treatment.

Also noted with magnification were small voids within the color-diffused layer, just below and/or breaking the surface of the stones. Similar features have been noted in stones with orange faceup color, resulting from a red diffusion color overlying yellow synthetic sapphire (Brown et al. 1990). The presence of such voids in a surface color layer—especially where they are surrounded by concentrations of color—can also be considered diagnostic of diffusion treatment.

Unlike blue diffusion-treated stones, anomalous refractometer readings can provide additional evidence of diffusion treatment where chromium is the diffused chromophore. Such readings include atypically higher values than expected of corundum, including over-the-limits readings, as well as multiple readings on a single facet. Such anomalous readings may be quite confusing to some gemologists. The high R.I. values are most likely due to the unusually high chromium concentrations in the surface-diffused layers. Relatively high refractive indices have also been found to correlate with high chromium concentrations in natural ruby from Malawi, which were very dark (Henn et al., 1990), and emeralds (e.g., those from the Swat Valley of Pakistan—Gübelin, 1982; Bowersox and Anwar, 1989).

The high chromium concentration measured near the surface of these diffusion-treated rubies also explains their very weak luminescence. Extremely high chromium concentrations are responsible for what is known as "concentration quenching" of luminescence (Waychunas, 1988). This phenomenon occurs when Cr_2O_3 exceeds 0.6 wt.% in corundum, with a corresponding decrease in luminescence as the Cr^{3+} concentration increases (Dubois-Fournier, 1989).

The subdued luminescence is not diagnostic of these treated stones, since natural rubies from several localities (e.g., Umba Valley, Tanzania) may also show very weak reactions. What is indicative of the treatment when present, however, is a superficial, chalky bluish white to yellowish white short-wave luminescence confined to and paralleling individual facets or groups of facets.

Also of value in detecting Cr^{3+}-diffusion treatment are the abnormally weak spectral absorption features for the respective apparent depths of color. These include weak or absent lines in the 475-nm area and in the far red.

CONCLUSIONS

It is important to keep in mind that the properties described in this report are based on a relatively small sample of diffusion-treated faceted stones in the pink-to-red-to-purple color range. Furthermore, the treater, Richard Pollack, has indicated that experimentation is continuing with the goal of both increasing the depth of penetration of the diffused color layer and minimizing surface damage. It is believed that other laboratories are also experimenting with diffusion treatment in this color range. Therefore, the extent and/or presence of many of the above features—especially those noted with magnification—may vary. For example, deeper penetration of the color-causing chromium ion, coupled with careful repolishing, could result in stones with little or no patchiness of color; that is, there might be no facets that are devoid of diffusion color. A deeper diffusion layer could also facilitate the removal during repolishing of the surface damage noted herein. Color reinforcement along facet junctions might be altered as well. Variations in the depth of penetration would, in turn, quite possibly alter the ultraviolet luminescent reactions, for example, perhaps partially or totally masking the underlying orange fluorescence to long-wave U.V. seen in some of the test stones.

With the above caveats in mind, the diffusion-treated corundums described in this article are not difficult to identify. Diagnostic features include the following (at least one of which was present in all stones examined):

- Uneven or patchy facet-to-facet coloration and a dark ring around the girdle. In many cases, this was noted without magnification, with only immersion and diffused transmitted light.
- Color concentrations along facet junctions and/or in surface-reaching fractures and cavities, noted with magnification. This feature was best noted with diffused transmitted illumination.
- Spherical voids just below the surface and within the diffusion layer, usually surrounded by color concentrations and seen with magnification.
- Dense concentrations of very small, white inclusions just under the surface of the stones and covering entire facets. This feature is best seen with magnification and darkfield illumination.
- High relief of diffused stones when compared to natural or synthetic rubies in immersion.

Other key features noted in the test sample include the following:

- Weak to moderate, chalky bluish white to yellowish white short-wave ultraviolet surface luminescence. This reaction may be clearly confined to and parallel individual facets or groups of facets.
- Anomalous refractive index readings, including multiple readings on individual facets and readings overthe limits of the conventional refractometer (1.80+).
- Atypical dichroism, with one color being a distinct brownish yellow as opposed to the expected orangy red to orange.
- Absorption characteristics that are weaker than what would be expected for either natural or synthetic rubies or fancy sapphires of comparable depth of color.

REFERENCES

Armstrong J.T. (1982) New ZAF and alpha-factor correction procedures for the quantitative analysis of individual microparticles. In K.F.J. Heinrich, Ed., *Microbeam Analysis—1982*, San Francisco Press, San Francisco, CA, pp. 175–180.

Armstrong J.T. (1988) Quantitative analysis of silicate and oxide materials: Comparison of Monte Carlo, ZAF and Phi (rho z) procedures. In D.E. Newbury, Ed., *Microbeam Analysis—1988*, San Francisco Press, San Francisco, CA, pp. 239–246.

Bowersox G.W., Anwar J. (1989) The Gujar Killi emerald deposit, Northwest Frontier Province, Pakistan. *Gems & Gemology*, Vol. 25, No. 1, pp. 16-24.

Brown G., Kelly S.M.B., Beattie R., Bracewell H. (1990) Gemmology study club lab reports: Diffusion coated synthetic sapphire. *Australian Gemmologist*, Vol. 17, No. 8, pp. 326–328.

Carr R.R., Nisevich S.D. (1975) Altering the appearance of sapphire crystals. United States patent 3,897,529, filed December 15, 1969, issued July 29, 1975.

Crowningshield R. (1979) Developments and highlights at GIA's lab in New York. *Gems & Gemology*, Vol. 16, No. 7, pp. 194-196.

Diffusion: 80,000 carats in Asia (1991). *Jewellery News Asia*, No. 87, November, p. 77.

Diffusion-treated red corundum in HK (1992). *Jewellery News Asia*, No. 96, August, pp. 96, 98.

Dubois-Fournier J. (1989) *A contribution to the identification of ruby by detecting various trace elements* [in French]. D.U.G. report, Nantes University, 201 pp.

Federman D. (1992) Diffusion sapphire, beyond the pale. *Modern Jeweler*, Vol. 91, No. 2, February, pp. 76–79.

Fritsch E., Rossman G.R. (1988) An update on color in gems, part 3: Colors caused by band gaps and physical phenomena. *Gems & Gemology*, Vol. 24, No. 2, pp. 81–102.

Fritsch E., Rossman G.R. (1990) New technologies of the 1980s. *Gems & Gemology*, Vol. 26, No. 1, pp. 64–75.

Gübelin E.J. (1982) Gemstones of Pakistan: Emerald, ruby, and spinel. *Gems & Gemology*, Vol. 18, No. 3, pp. 123–139.

Hargett D. (1991) Gem trade lab notes: Diffusion-treated sapphires in fine jewelry. *Gems & Gemology*, Vol. 27, No. 3, pp. 178–179.

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

Kammerling R.C., Koivula J.I., Kane R.E. (1990) "Deep" diffusion treatment of corundum. *ICA Early Warning Laboratory Alert*, No. 32, February 16.

Kammerling R.C., Moses T., Kane R.E. (1992) Blue diffusion-treated synthetic sapphires. *ICA Early Warning Laboratory Alert*, No. 55, June 2.

Kane R.E., Kammerling R.C., Koivula J.I., Shigley J.E., Fritsch E. (1990) The identification of blue diffusion-treated sapphires. *Gems & Gemology*, Vol. 26, No. 2, pp. 115–133.

Koivula J.I., Kammerling R.C. (1990) Gem news: Diffusion-treated corundum. *Gems & Gemology*, Vol. 26, No. 1, pp. 100–101.

Koivula J.I., Kammerling R.C. (1991a) Gem News: More on diffusion-treated sapphires. *Gems & Gemology*, Vol. 27, No. 1, p. 53.

Koivula J.I., Kammerling R.C. (1991b) Gem News: More experimentation with blue diffusion-treated sapphires. *Gems & Gemology*, Vol. 27, No. 3, p. 187.

Koivula J.I., Kammerling R.C. (1991c) Gem News: ...and red stones too. *Gems & Gemology*, Vol. 27, No. 3, pp. 187–188.

Koivula J.I., Kammerling R.C., Fritsch E. (1992a) Gem News: Update on diffusion-treated sapphires. *Gems & Gemology*, Vol. 28, No. 1, pp. 62–63.

Koivula J.I., Kammerling R.C., Fritsch E. (1992b) Gem News: Sri Lanka: Update on gem production. *Gems & Gemology*, Vol. 28, No. 4, pp. 273–274.

Lithiby J. (1992) Lab report: Surface-diffused synthetic sapphire. *JewelSiam*, Vol. 3, No. 5, September–October, p. 78.

Love G., Cox M.G., Scott V.D. (1978) A versatile atomic number correction for electron-probe microanalysis. *Journal of Physics D*, Vol. 11, pp. 7–27.

Reed S.J.B. (1965) Characteristic fluorescence correction in electron-probe microanalysis. *British Journal of Applied Physics*, Vol. 16, pp. 913–926.

Waychunas G.A. (1988) Luminescence, X-ray emission and new spectroscopies. In F. Hawthorne, Ed., *Reviews in Mineralogy, Vol. 18: Spectroscopic Methods in Mineralogy and Geology*. Mineralogical Society of America, Washington, DC, pp. 639–698.

Webster R. (1983) *Gems, Their Sources, Descriptions and Identification*, 4th ed. Revised by B.W. Anderson, Butterworths, London.

NOTES AND NEW TECHNIQUES

A NEW GEM BERYL LOCALITY: LUUMÄKI, FINLAND

By Seppo I. Lahti and Kari A. Kinnunen

Strongly etched prismatic crystals of yellow, green, and pale blue gem beryl have been quarried from a pegmatite dike in Luumäki, Finland. To date, the pegmatite has yielded about 15 kg of gem beryl, minor amounts of facet-grade topaz, and many varieties of quartz. The gem beryls from Luumäki are similar in gemological properties and chemical composition to other pegmatitic beryls, such as those from Brazil and the Ukraine. Large primary fluid inclusions surrounded by micro-fracture halos may be diagnostic of the new locality.

In 1982, mineral enthusiast Kauko Sairanen noticed a quartz outcrop near a small road in Luumäki, a commune in southeast Finland. Of particular interest were elongated pockets that were lined with quartz crystals and contained a pale yellow transparent mineral that was later identified as beryl. Subsequent geologic mapping showed that the outcrop represented the core of a small pegmatite dike, which had intruded a coarse-grained rapakivi granite (i.e., a granite that contains large potassium feldspar crystals surrounded by a plagioclase shell).

Mr. Sairanen and some friends took out a mining claim in 1986 and formed a company to work the pegmatite. At first the outcrop seemed promising, and several gem-quality crystals—some quite large—were recovered; many have since been faceted (figure 1). However, the small-scale mining conducted to date indicates that the gem beryl occurs sporadically, so the claim owners have continued their work only intermittently.

Luumäki is about 180 km northeast of Finland's capital, Helsinki, and less than 40 km from the Russian border (figure 2). Public access to the quarry is possible with permission from the owners. For this study, we visited the site and collected specimens several times during the last five years. We also studied the gemological properties of several gem beryl crystals and cut stones provided by the mining company.

GEOLOGY AND OCCURRENCE

Although numerous complex pegmatites occur in the Precambrian rocks of southern Finland, gem minerals have been found only occasionally. In addition to several quartz varieties, small amounts of topaz, kunzite, morganite, yellow beryl, and colored tourmalines have been recovered in the course of feldspar mining (Haapala, 1966; Erämetsä et al., 1973; Lahti, 1981; Lahti and Saikkonen, 1986).

The Luumäki pegmatite is situated in the northern corner of the large Wiborg rapakivi granite complex, which consists of several granite as well as minor anorthosite (some of which contains the local

ABOUT THE AUTHORS

Dr. Lahti is state geologist in the Petrology Department, and Dr. Kinnunen is special research scientist in the Economic Geology Department, at the Geological Survey of Finland, Espoo, Finland.

Acknowledgments: The authors thank the owners of Suomen Jalokivikaivos Oy (The Precious Stone Mine of Finland Co.)—Matti Lång, Risto Pitkänen, and Kauko Sairanen—for help and information. They also thank their colleagues at the Geological Survey: Mirja Saarinen and Leena Järvinen, for help with the mineralogical studies; and Christian Backman, Riitta Juvonen, Maija Ilmasti, and Lasse Pakkanen, for chemical analyses of the beryls.

Gems & Gemology, *Vol. 29, No. 1, pp. 30–37*

Figure 1. This pendant features three faceted Luumäki beryls connected by natural gold nuggets from northern Finland. The largest stone weighs about 8.6 ct and is 17.71 mm long. Pendant designed by Aarne Alhonen; photo by Jari Väätäinen.

labradorite often called spectrolite) intrusions. The Wiborg complex covers an area about 100 × 180 km that extends from southeastern Finland to nearby Karelia, Russia. The different rapakivi granites in the region vary between 1,650 and 1,700 million years (My) old (Vaasjoki, 1977); the pegmatites might be somewhat younger. The Svecokarelian granitoids, schists, metavolcanics, and gneisses into which the rapakivi granites were intruded are 1,800–1,900 My.

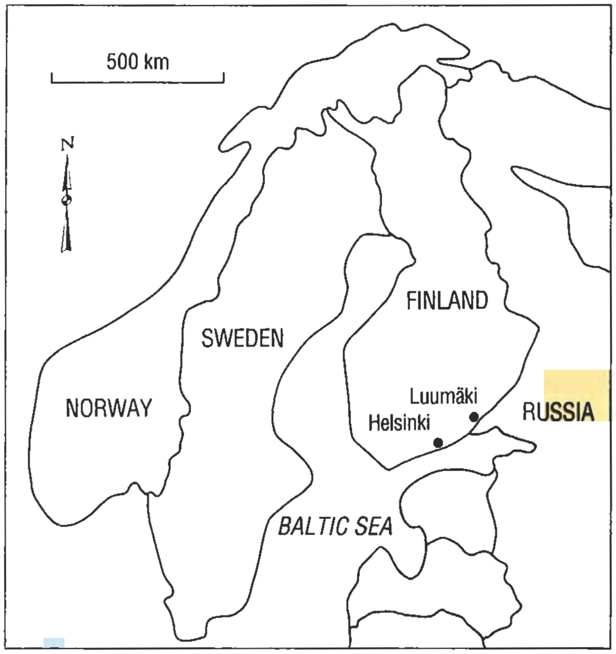
Geologic mapping by one of the authors (SIL) revealed that the pegmatite is a poorly exposed dike about 20 m wide in granite (figure 3). A massive quartz core, about 10 m wide, makes up the central part of the dike. It is surrounded by three feldspar-mica-quartz pegmatite zones referred to here as intermediate, wall, and border. The grain size of the pegmatite increases gradually from the narrow, fine-grained border zone nearest the host granite to the quartz core. The transitions between the zones are also gradual.

The main minerals in the pegmatite, in addition to quartz, are reddish brown microcline, albite, quartz, biotite, and, locally, muscovite. The mineralogy of both the border and wall zones is simple, but the intermediate zone contains a number of rare minerals (table 1). Very large crystals of common beryl, topaz (not of gem quality), and monazite-(Ce) are characteristic in the intermediate zone in particular.

Pockets are abundant in the central parts—the core and intermediate zones—of the dike; they range in diameter from several centimeters to several tenths of a meter. The pockets may contain crystals of quartz, albite, microcline, orthoclase, and gem beryl; locally, bertrandite, goethite, and fluorite are common. The bottom of a pocket is usually covered by a layer of red-brown clay minerals and crystal fragments loosened from the walls.

Two generations of beryl can be distinguished in

Figure 2. The commune of Luumäki, where the gem beryl pegmatite was found, is located about 40 km (25 miles) from Finland's border with Russia.



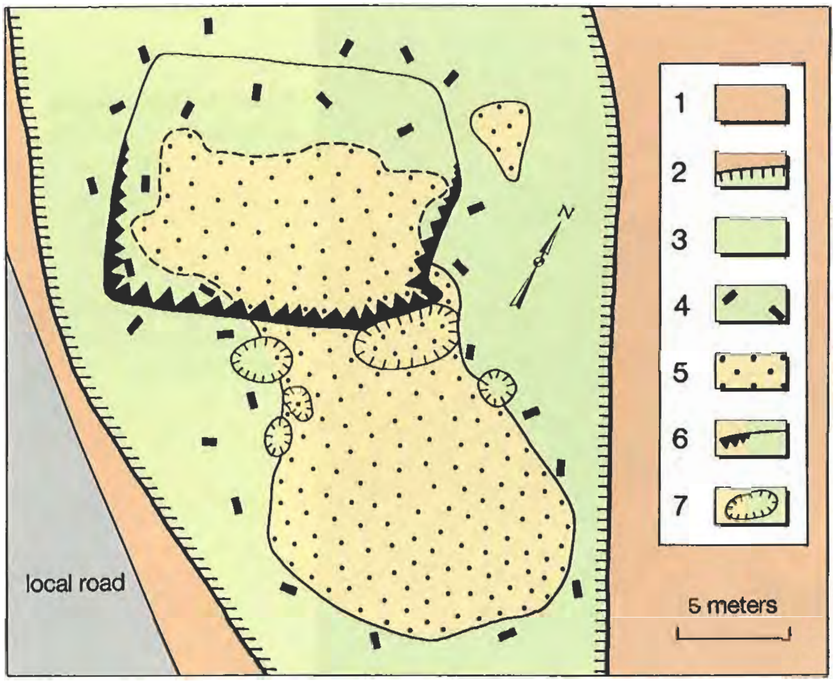


Figure 3. Geologic map of the Luumäki gem beryl pegmatite. The colors represent: (1) rapakivi granite, country rock; (2) fine-grained border zone of the pegmatite dike; (3) wall zone of the pegmatite; (4) very coarse intermediate zone of the pegmatite; (5) quartz core; (6) gem beryl quarry; and (7) larger cavities or crystal pockets observed on the surface, partly abraded and polished during glacial time. Gem beryl has been found in the pockets within the quarry, whereas crystals of common beryl sporadically occur in the intermediate zone around the quartz core. The road on the left joins the village of Jurvala (by the main road no. 6 at Luumäki) to the village of Tuukainen.

the pegmatite: The older is opaque, common beryl (not gem quality), and the younger is transparent, gem beryl. The common beryl is yellow, often strongly altered by hydrothermal solutions, and usually stained and impregnated brown by iron compounds. The crystals of common beryl, which usually range from 5 to 15 cm (up to 30 cm) in diameter, have well-developed first-order prism faces and, occasionally, basal pinacoids (Pitkänen, 1991).

Common beryl occurs in the intermediate zone of the pegmatite, while gem beryl is found only in pockets, either associated with common beryl or embedded in the microcrystalline reddish quartz (jasper) that locally fills the pockets and fractures (figure 4).

The gem beryl crystals usually range in weight from a few grams to several tens of grams. The largest and most attractive crystals found to date are "Mrs. Ellie" and "Mr. Jock," which weigh 450 and 950 grams, respectively. Both are high gem-quality green beryl (figure 5). "Mrs. Ellie" is now in the collection of Finland's Central Museum of Natural History, housed in the Department of Geology and Mineralogy, University of Helsinki.

MINING AND PRODUCTION

The Luumäki pegmatite is mined by a small Finnish company, Suomen Jalokivikaivos Oy, intermittently during the summer months from May to September. The three owners have contracted with a local construction firm for help with heavier mining chores. After blasting with forcite (a slow-detonating type of dynamite), the owners collect the gem material by hand. They use hammers and chisels to empty the pockets and then screen the clay-rich material in water to reveal any gem beryl (figure 6). Currently the pit is 20 m long, 10 m wide, and 5 m deep.

Of the 15 kg of gem beryl found thus far, approximately 40% is facet grade. The gem beryl usually ranges from pale yellow to greenish yellow to yellowish green; rarely, the material is a bright "golden" yellow (figure 7). Approximately 10%–15% of the total would be considered aquamarine, with various shades of blue. Although the mine owners maintain that they have not traded in treated beryl, experiments by the authors have shown that blue aquamarine can also be produced by heating pale green or yellow green beryl from this locality (see Ehrnrooth and Tuovinen, 1989).

TABLE 1. Minerals identified in the intermediate zone of the Luumäki beryl pegmatite.

Silicates		Oxides and others
K-feldspar:	Margarite	Quartz
- Microcline	Illite	Monazite-(Ce)
- Orthoclase	Kaolinite	Goethite
Albite	Smectite	Hematite
Biotite	Vermiculite	Columbite
Muscovite		Microlite-Pyrochlore
Chlorite		Euxenite
Beryl		Fluorite
Topaz		Calcite
Bertrandite		Gypsum

Figure 4. A 5-cm-long cigar–shaped crystal of yellowish green beryl is shown here in the massive reddish brown microcrystalline quartz (jasper) in which it was found at Luumäki. Photo by Jari Väätäinen.

Facet-quality pieces of blue, pale pink, or colorless topaz (0.5–8 ct), as well as smoky, rock crystal, brownish green (praseolite-like), and red (ferruginous, resembling fire opal) quartz have also been found. In addition, much of the quartz recovered can be used for cabochons or tumbling material.

MATERIALS AND METHODS

The Test Sample. The study included about 2 kg of gem beryl rough: numerous crystals or fragments of various sizes and colors—some self-collected and others obtained from the mining company—and 20 faceted stones of various colors that were provided by the mining company. Physical, gemological, and chemical properties were determined on seven (about 1–4 cm) rough pieces of yellow and pale green beryl and on 15 faceted green, yellow, and pale blue stones (1–41.7 ct).

The beryl crystals studied were typical of the locality: prismatic, usually cylindrical or cigar shaped; some were strongly etched and quite irregular in form (again, see figures 4, 5, and 7). The round or oval brilliant-cut, step-cut, and antique-cut stones were fashioned in Finland (by K. Sairanen, M. Lång, and S. I. Lahti) and abroad.

Methods. Gemological properties were determined for the seven rough and 15 faceted beryls, following the routine procedures described in Liddicoat (1989) and Read (1991). Refractive indices were measured with a Rayner refractometer with a sodium light source, and optical absorption spectra were investigated with both a prism and a diffraction-grating spectroscope. Specific gravity was measured in a sodium polytungstate-water solution.

A Philips X-ray diffractometer and Debye-Scherrer camera were used in the X-ray powder diffraction analyses of the beryl samples and in the identification of associated minerals, with reference to the JCPDS (International Center for Diffraction Data) files. Unit-cell dimensions were computed from the indexed X-ray powder diffraction patterns using the computer program of Appleman and Evans (1973). The chemical composition of the gem beryl specimens was determined—using a combination of microprobe analysis, atomic absorption spectroscopy (AAS), and inductively coupled plasma–atomic emission spectroscopy (ICP-AES)—at the Chemical Laboratory of the Geological Survey of Finland.

Solid inclusions were identified by means of polarized microscopy. Gemologically characteristic inclusions were determined from the seven natural-color yellow and pale green beryl crystals and one heat-treated yellow beryl specimen, following the methods outlined by Gübelin and Koivula (1986). The 20 faceted stones were also examined with the microscope; however, most of these were clean, without any inclusions. Fluid inclusions in one rough yellow beryl sample were studied with microscope heating and freezing stages using doubly polished thick sections, (Roedder, 1984; essentially the same techniques and

Figure 5. These three crystals are typical of the high-quality green beryl recovered from the Luumäki pegmatite. The large crystal at the rear, known as "Mrs. Ellie," is 14 cm long and weighs 450 grams. Photo by Jari Väätäinen.

Figure 6. The beryl crystals at Luumäki are usually found embedded in a reddish-brown clay. Here, the miners wash clay removed from pockets in the pegmatite to reveal any beryl crystals present. Photo by Matti Lång.

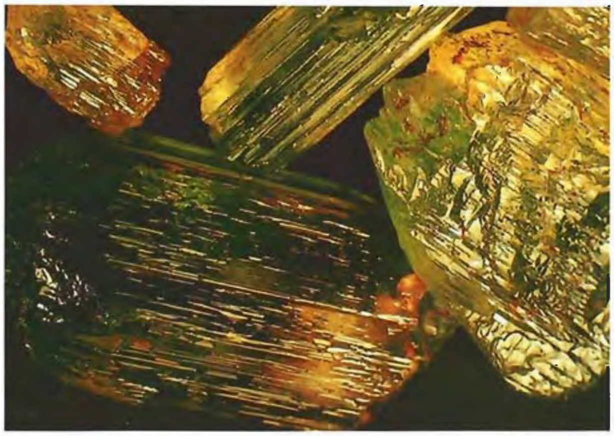


Figure 7. Most gem beryl crystals from the Luumäki pegmatite range from yellow to greenish yellow and yellowish green. The largest crystal, in the front, is 7.2 cm wide and weighs 110 grams. Note the "golden" yellow crystal in the upper left. Photo by Kari A. Kinnunen.

equipment as described in Spencer et al., 1992). The photomicrography employed new illumination methods and instruments designed by Kinnunen (1991a, b).

PHYSICAL APPEARANCE AND GEMOLOGICAL PROPERTIES

The strongly etched crystals showed prism faces that were striated and/or full of individual rectangular pits, complex groups of pits, or strings of pits along the c-axis (figure 8). The surfaces along the basal pinacoids were full of hexagonal etch pits. The pits varied greatly in area and depth; some had stepped walls.

Figure 8. The surface texture on the prism face of this Luumäki yellow beryl crystal is typical of the material found at this locality. Prolonged natural etching has produced the stepped, mosaic-like surface features, with etch pits and hillocks. Photomicrograph by Kari A. Kinnunen; transmitted Rheinberg illumination (blue/yellow dual-circular filter to enhance the three-dimensional effect) and shadowing; magnified 8×.

The gem beryls examined ranged in color from pale yellow to "golden" yellow, pale yellow-green to pale green, and pale blue (see, e.g., figure 9). The gemological properties, as described in table 2, appear to be consistent with gem beryls in these color varieties from other localities (Liddicoat, 1989; Sinkankas, 1989). Note that the specific gravity is slightly higher than that given for pure $Be_3Al_2Si_6O_{18}$ (2.62–2.66), but corresponds well to the values given for aquamarine and other pale beryls (2.628–2.730) with a low alkali content (see, e.g., Sinkankas, 1989, p. 191).

INTERNAL CHARACTERISTICS

The mineral inclusions identified in the Luumäki beryls—small albite crystals, mica, quartz, beryl (observable only with crossed polarizers), and clay and a hematite-like material filling fractures and growth tubes—are known to occur in beryls from other localities (see, e.g., Gübelin and Koivula, 1986; Sinkankas, 1989). However, certain other internal features appear to be distinctive of this occurrence. Growth tubes and corrosion tubes were common near the basal planes of the crystals examined (figure 10). They were observed to run parallel to the c-axis and usually to widen as they approached the surface of the crystal, similar to the "trumpet-like" inclusions described in the pegmatitic beryls from the Ukraine (Bartoshinskiy et al., 1969; Sinkankas, 1989, p. 245). In cut stones, however, the terminations may be thin. These inclusions are similar to the growth tubes in aquamarines known as "rain" (see Gübelin and Koivula, 1986). In Luumäki beryls, however, the inclusions appeared wider than is typical for "rain," main-

Figure 9. Luumäki gem beryls in a wide range of colors have been faceted. The large oval stone at the top weighs 41.7 ct and is 27 mm wide. All of these stones are of natural color. Photo by Jari Väätäinen.

TABLE 2. Gemological properties of gem beryl from a pegmatite in Luumäki, Finland.[a]

Color	Transparent "golden" yellow, pale yellow, pale yellow-green, pale green, medium green or—rarely—natural (pale blue) aquamarine
Refractive indices	
Pale green and golden yellow	ϵ = 1.566-1.568, ω = 1.574-1.575
Aquamarine (natural blue)	ϵ = 1.564, ω = 1.572
Luminescence	Inert to both long- and short-wave U.V. radiation
Specific gravity	2.685–2.688
Optical absorption spectrum	No specific lines or bands
Dichroism	Green: bluish green/pale yellow green; in heat-treated aquamarine, pale blue-green/blue
Polariscope	Slight anisotropism in the direction of the c-axis
Chelsea filter reaction	Pale green
Internal characteristics	Mineral inclusions—albite, mica, beryl, quartz (all identified with polarized microscopy), clay and hematite-like material in some fractures and growth tubes; large primary fluid inclusions almost always surrounded by micro-fracture halos formed by natural decrepitation may be diagnostic of this locality
Thermal reaction	Strong decrepitation of fluid inclusions at 400°–460°C

[a] *Properties listed were obtained from seven pieces of rough—six yellow and one pale green—and 15 faceted stones. With the exception of dichroism, the gemological properties of the heat-treated material were not tested. See text for methods used.*

ly because of the etching phenomena; some are more properly classified as corrosion tubes.

Primary fluid inclusions (three-phase type) were found in negative crystals along former growth zones, in irregular cavities, and in tube-like channels along the c-axis of the gem beryl. Pseudosecondary and secondary fluid inclusions were found in partially healed fracture planes with a random orientation, commonly as "veils" showing fingerprint-like healing patterns.

Study of the primary and secondary fluid inclusions with microscope heating and freezing stages revealed the following characteristics for the Luumäki beryls: phase composition at room temperature—water 52%–76%, vapor 24%–48%, daughter minerals 2%–3% (one isotropic, two anisotropic, and one nonmagnetic opaque); homogenization temperature—370°–390°C; salinity—7.3%–7.5% NaCl equivalent; density—0.7; pressure estimate—0.2 to1.0 kbar (see Kinnunen et al., 1987); and pressure-corrected crystallization temperature—400° to 490°C. These char-

Figure 10. Growth tubes parallel to the c-axis were found to be characteristic of Luumäki beryl. Small syngenetic mineral inclusions (albite) can be seen here in the ends of the needles. Photomicrograph by Kari A. Kinnunen; transmitted crossed polarized light, magnified 20×.

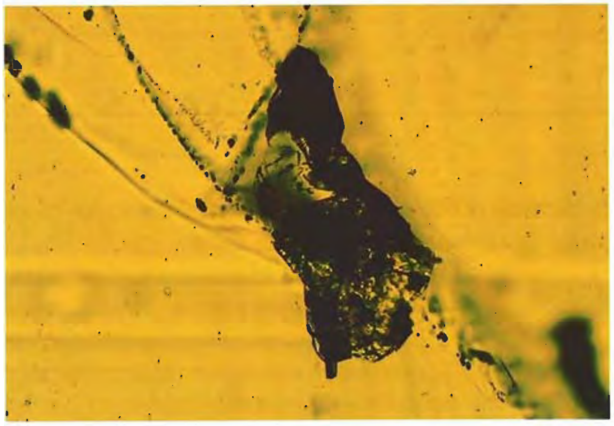


Figure 11. Large, naturally decrepitated fluid inclusions, like those shown here, appear to be diagnostic of Luumäki gem beryls The small cracks incorporate submicroscopic fluid inclusions as a result of healing during recrystallization. Photomicrograph by Kari A. Kinnunen; darkfield illumination, magnified 32×.

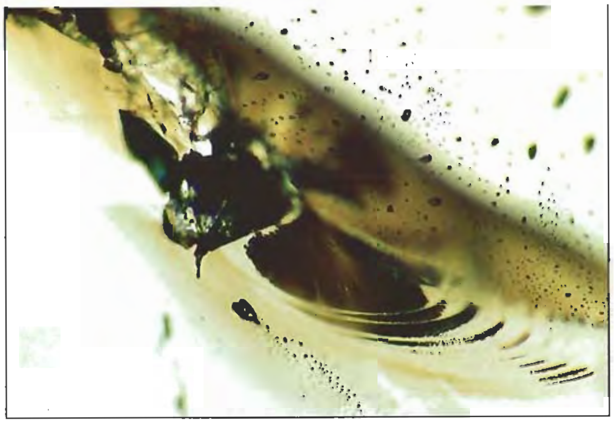


Figure 12. In this heat-treated yellow beryl from Luumäki, the once fluid-containing cavities are now empty. They appear dark because of total reflection of transmitted light. Note, too, the different appearance of the micro-fractures that surround the inclusion. Photomicrograph by Kari A. Kinnunen; magnified 32×.

acteristics are typical of late aqueous fluids from pegmatitic environments (cf. Roedder, 1984).

Many of the large fluid inclusions seen in the Luumäki gem beryls were surrounded by networks of micro-fractures (figure 11), small cracks that formed during natural decrepitation. These micro-fractures healed in recrystallization, at which time small secondary fluid inclusions were trapped. A few of the cut stones also showed these inclusions, which have not been reported in beryls from other localities. When the inclusions were examined with a stereomicroscope and pinpoint lighting, they closely resembled the flower-like discs, or "sun-spangle" inclusions, found in treated amber (see Gübelin and Koivula, 1986). Note that the fractures formed during the heat treatment of beryl are different (air filled) and show no healing textures (figure 12).

CHEMICAL COMPOSITION

The chemical composition of the Luumäki gem beryls (table 3) closely resembles that of certain Ukrainian and Brazilian gem beryls (see, e.g., Bartoshinskiy et al., 1969; Correia-Neves et al., 1984). Both the green and "golden" yellow varieties were found to be poor in alkali and earth alkali metals compared to pegmatite beryl in general (Černý, 1975), but they contained minor concentrations of iron and water. Beryls found in crystal pockets in pegmatites and granites are typically low in alkalis (Černý, 1975).

Unit-cell data for the "golden" yellow beryl are as follows: the space group P6/mcc, a = 9.203 (1) Å and c = 9.192 (2) Å, vol. = 672.68 Å^3, c:a = 0.999. The values agree with those calculated from the chemical data. The lengths of both crystallographic axes are close to those of pure $Be_3Al_2Si_6O_{18}$, or of Brazilian and Ukrainian beryls that contain minor amounts of water in addition to the major elements (see, e.g., Bakakin et al., 1970; Sinkankas, 1989; Correia-Neves et al., 1984). The unit-cell dimensions of the various color varieties did not differ markedly from one another.

HEAT TREATMENT

According to Nassau (1988), the yellow color of beryl is caused by ferric iron (Fe^{3+}) that substitutes for alu-

TABLE 3. Chemical composition of Luumäki gem beryl.[a]

	Yellow		Green	
	Range	Average	Range	Average
Oxide[a] (wt. %)				
SiO_2	64.32–66.09	65.08	64.16–65.44	64.87
Al_2O_3	16.55–17.44	16.86	16.50–17.30	16.86
BeO	13.71		13.32	
Fe_2O_3	0.33–0.48	0.41	0.47–0.68	0.56
Na_2O	0.02–0.06	0.04	0.03–0.08	0.06
Li_2O	0.01		n.d.	
MgO	0.00–0.07	0.02	0.00–0.18	0.05
CaO	0.00–0.02	0.01	0.00–0.04	0.02
H_2O_+	1.02		n.d.	
Trace element (ppm)				
Co		293		438
Cs		278		122
Zn		69		91
Sc		49		29
Cr		18		23
Ni		16		13
V		19		11

[a] *SiO_2, Al_2O_3, Fe_2O_3 (= total iron), Na_2O, MgO, and CaO were analyzed by microprobe techniques from a thin section of each crystal; the average is based on nine determinations. BeO, Li_2O, and Cs were assayed from a dissolved beryl sample with atomic absorption spectroscopy (AAS). The other trace elements were determined from the dissolved beryl with inductively coupled plasma-atomic emission spectrometry (ICP-AES): H_2O_+ was determined with a Leco RMC-100 rapid moisture determinator. All of the determinations are from the same two specimens. n.d. = not determined.*

minum in the structure of the mineral. In green beryl, iron occurs partly in the channel position and partly replaces aluminum. Heat treatment fades the yellow color and changes green varieties to blue.

Heating experiments with Luumäki beryl gave similar results. The "golden" yellow beryl faded to nearly colorless if the stones were kept two to five hours in an oven at temperatures between 400° and 500° C. Green beryl became blue when heated under the same conditions. The specific hue and saturation of the heat-treated blue color varied from one sample to the next, in direct relationship to the intensity and shade of the original green material (see Ehrnrooth and Tuovinen, 1989).

CONCLUSION

The Luumäki pegmatite shows features typical of miarolitic pegmatites (i.e., those with crystal-lined cavities; Černý, 1991), which are important sources of gem minerals. To date, however, mining has produced relatively little gem-quality beryl. Because only a small portion of the dike is visible on the surface, though, the economic significance of the occurrence is impossible to estimate without further study, further exposure of the pegmatite, and/or core drilling.

The complex rapakivi granite–anorthosite intrusions seem to have potential as sources of gem minerals in Finland. In addition to the known spectrolite deposits, the authors have found minor pockets of gem minerals. The mineralogic and geologic similarities between the Luumäki pegmatite and the productive Ukrainian gem beryl and topaz pegmatites, which occur in a rapakivi-type granite of the same age (Bartoshinskiy, 1969; Sinkankas, 1989; Koshil et al., 1991), also favor this conclusion. In addition, pegmatites usually occur in groups or clusters (i.e., pegmatite districts), so it is likely that there may be more gem-bearing pegmatites in this region of Finland.

REFERENCES

Appleman D.E., Evans H.T. (1973) Job 9214: Indexing and least-squares refinement of powder diffraction data. In *U.S. Geological Survey, Computer Contribution 20*, U.S. National Technical Information Service, Document PB2-16188, 62 pp.

Bakakin V.V., Rylov G.M., Belov N.V. (1970) X-ray diffraction data for identification of beryl isomorphs. *Geochemistry International*, Vol. 7, No. 6, pp. 924–933.

Bartoshinskiy Z.V., Matkovskiy O.I., Srebrodolskiy B.I. (1969) Aktsessornyy berill iz kamernykh pegmatitov Ukrainy (Accessory beryl from the chamber pegmatites of the Ukraine). *Mineralogitcheskiy Sbornik*, Vol. 23, pp. 382–397.

Černý P. (1975) Alkali variations in pegmatitic beryl and their petrogenetic implications. *Neues Jahrbuch für Mineralogie, Abhandlungen*, Vol. 123, No. 1, pp. 198–212.

Černý P. (1991) Rare element granitic pegmatites. Part 1: Anatomy and internal evolution of pegmatite deposits. *Geoscience Canada*, Vol. 18, No. 2, pp. 49–67.

Correia-Neves J.M., Monteiro R.L.B.B., Dutra C.V. (1984) Composição química de berilos pegmatíticos do Brasil e seu significado petrológico e metalogenético (Chemical composition of pegmatitic beryls in Brazil and their petrological significance). *Revista Brasileira de Geociencas*, Vol. 14, No. 3, pp. 137–146.

Ehrnrooth E.-K., Tuovinen P. (1989) Luumäen beryllien lämpökäsittely (Heat treatment of the Luumäki beryls). *Gemmologian Työsaralta* (publication of the Gemmological Society of Finland), No. 18, pp. 4–19.

Erämetsä O., Nieminen K., Niinistö L. (1973) Two transparent beryl varieties from the Kaatiala pegmatite, Finland. *Bulletin of the Geological Society of Finland*, Vol. 45, Part 2, pp. 125–130.

Gübelin E.J., Koivula J.I. (1986) *Photoatlas of Inclusions in Gemstones*. ABC Edition, Zürich, 532 pp.

Haapala I. (1966) On the granitic pegmatites of the Peräseinäjoki-Alavus area, South Pohjanmaa, Finland. *Bulletin de la Commission Géologique de la Finlande*, Vol. 224, 98 pp.

Kinnunen K.A. (1991a) Three-dimensional microscope image using anaglyphic filters: A new aid to fluid inclusion petrography. *American Mineralogist*, Vol. 76, pp. 657–658.

Kinnunen K.A. (1991b) Parempia valokuvia stereomikroskoopilla (High-quality photomicrographs with the stereomicroscope). *Geologi* (publication of the Geological Society of Finland), Vol. 43, No. 6, pp. 113–114.

Kinnunen K.A., Lindqvist K., Lahtinen R. (1987) Fluid history from crystal cavities in rapakivi, Pyterlahti, southeastern Finland. *Bulletin of the Geological Society of Finland*, Vol. 59, Part 1, pp. 35–44.

Koshil I.M., Vasilishin I.S., Pavlishin V.I., Panchenko V.I. (1991) Wolodarsk-Wolynskii Geologischer Aufbau und Mineralogie der Pegmatite in Wolynien, Ukraine (Geology of Wolodarsk-Wolynski; and the mineralogy of the pegmatites in Wolhynia, Ukraine). *Lapis*, Vol. 10, No. 10, pp. 27–40.

Lahti S.I. (1981) On the granitic pegmatites of the Eräjärvi area in Orivesi, southern Finland. *Geological Survey of Finland Bulletin*, Vol. 314, 82 pp. (monograph).

Lahti S.I., Saikkonen R. (1986) Kunzite from the Haapaluoma pegmatite quarry, western Finland. *Bulletin of the Geological Society of Finland*, Vol. 58, No. 2, pp. 47–52.

Liddicoat R.T. Jr. (1989) *Handbook of Gem Identification*, 12th ed. Gemological Institute of America, Santa Monica, CA.

Nassau K. (1988) *Gemstone Enhancement*. Butterworths, London.

Pitkänen R. (1991) Luumäen jalokivipegmatiitti (The Luumäki gem beryl pegmatite). *Kivi* (publication of the Finnish Gem Hobbyists' Society), Vol. 9, No. 1, pp. 27–29.

Read P.G. (1991) *Gemmology*. Butterworth-Heinemann, Oxford.

Roedder E. (1984) Fluid inclusions. In P.H. Ribbe, Ed., *Reviews in Mineralogy*, Vol. 12, Mineralogical Society of America, Washington, DC, 644 pp.

Sinkankas J. (1989) *Emerald and Other Beryls*. Geoscience Press, Prescott, AZ.

Spencer R.J., Levinson A.A., Koivula J.I. (1992) Opal from Querétaro, Mexico: Fluid inclusion study. *Gems & Gemology*, Vol. 28, No. 1, pp. 28–34.

Vaasjoki M. (1977) Rapakivi granites and other postorogenic rocks in Finland: Their age and the lead isotopic composition of certain associated galena mineralizations. *Geological Survey of Finland Bulletin*, Vol. 294, 64 pp. (monograph).

DE BEERS NEAR COLORLESS-TO-BLUE EXPERIMENTAL GEM-QUALITY SYNTHETIC DIAMONDS

By Marie-Line T. Rooney, C. M. Welbourn, James E. Shigley, Emmanuel Fritsch, and Ilene Reinitz

Examination of five small boron-doped synthetic diamonds, grown by De Beers researchers for experimental purposes, reveals some diagnostic features not reported in previous studies of gem-quality synthetic diamonds. The presence of internal growth sectors that are blue, yellow, or near colorless has produced faceup colors in three faceted stones that vary from near colorless to bluish-greenish gray to blue. Because they look so different from previously reported De Beers synthetic diamonds, such faceted synthetics could go unrecognized without careful gemological testing should they ever become commercially available.

Previous articles on gem-quality synthetic diamonds have reported the visible zoning of certain features such as color, ultraviolet luminescence, and graining, and their importance as identification criteria for this material (see Shigley et al., 1986, 1987, 1992). Recently, we examined two small crystals (0.12 and 0.20 ct) and three faceted De Beers synthetic diamonds (0.05 to 0.07 ct) that are interesting examples of a kind of internal color zoning that produces a variable overall color appearance (figure 1). Several polished plates of this same kind of synthetic diamond were described by two of us (MLTR and CMW) in recent reports on the development of internal growth sectors in synthetic diamonds (see Burns et al., 1990; Rooney, 1992).

Single-crystal synthetic diamonds normally are yellow, which results from the incorporation of nitrogen atoms from the surrounding environment into the diamond (by substitution as isolated atoms for carbon atoms) at the time of growth. The presence of nitrogen as an impurity reportedly aids in the growth of larger, higher-quality crystals. In the case of the samples studied here, the yellow color was reduced by using a nitrogen getter (an element that acts to bond with the nitrogen outside of the growing diamond crystal, and thereby reduces its incorporation within the crystal) in the synthesis capsule. Also, varying amounts of boron—known to be responsible for the blue color in many natural and synthetic diamonds—were added to the synthesis capsule in the growth runs.

During rapid growth under laboratory conditions, synthetic diamond crystals can develop octahedral, cube, dodecahedral, and trapezohedral external crystal faces and corresponding internal growth sectors. As the different internal sectors grow, they tend to incorporate certain impurities in different amounts. Thus, the resulting synthetic diamond crystal is partially inhomogeneous in chemical composition. In particular, nitrogen and boron are incorporated to a varying

ABOUT THE AUTHORS

Mrs. Rooney and Dr. Welbourn are research scientists at the De Beers Diamond Trading Company (DTC) Research Centre in Maidenhead, United Kingdom. Dr. Shigley is director of research, Dr. Fritsch is manager of research, and Dr. Reinitz is a research scientist, at the Gemological Institute of America, Santa Monica and New York.

Acknowledgments: The authors thank Dr. R. J. Caveney, director of research at the De Beers Industrial Diamond Division (Pty.) Ltd. Diamond Research Laboratory (DRL), Johannesburg, South Africa, for the loan to GIA of the boron-doped synthetic diamonds. Vesna Cvetkovic of the DRL grew the synthetic diamonds discussed in this article. Karin Hurwit of the GIA Gem Trade Laboratory provided the color and clarity descriptions of the three faceted stones. Mike Moon and Sam Muhlmeister of GIA Research prepared the visible and infrared absorption spectra.

Gems & Gemology, *Vol. 29, No. 1, pp. 38–45*

extent into the several growth sectors in a synthetic diamond (see, e.g., Nassau and Nassau, 1978, p. 496, figure 2; Koivula and Fryer, 1984; Burns et al., 1990; Rooney, 1992).

Internal growth sectors that differ from one another in impurity content give rise to the zoning of certain visible features reported in the large synthetic diamonds we have seen. In contrast, the vast majority of natural diamonds grow as octahedron-shaped crystals, with crystallization in only one dominant octahedral growth sector (except for rare mixed-growth natural crystals; see Welbourn et al., 1989). Although zoning of either color or ultraviolet luminescence does occur in some natural diamond crystals, in general it is not related to the development of various internal growth sectors, and thus has a different appearance. For a review comparing the external morphology and internal zoning in natural and synthetic diamond crystals, see Sunagawa (1984).

Differences in relative amounts of boron and nitrogen impurities can produce blue, yellow, or near-colorless internal growth sectors in synthetic diamond crystals. When such crystals are faceted, a variety of potential color appearances could result. For example, the light bluish-greenish gray faceup appearance of one of the faceted stones examined for this study is very different from the color of synthetic diamonds described previously (Crowningshield, 1971; Koivula and Fryer, 1984; Shigley et al., 1992). Such a small, light-colored faceted stone might not be readily recognized as synthetic if it were to become commercially available, because to the unaided eye it resembles many faceted natural diamonds seen in the market.

The synthetic diamonds described here were produced for experimental purposes at the De Beers Diamond Research Laboratory in Johannesburg, South Africa, as part of ongoing research into the physical properties of synthetic diamonds. The objective of these particular experiments was to investigate the properties of low-nitrogen, boron-doped synthetic diamonds, not to see how large they could be made, so only small samples—like those described here—were produced originally. However, researchers at the DRL have recently grown synthetic diamond crystals of this kind as large as about 1 ct. The samples examined for this study had been grown onto small synthetic diamond seed crystals by the temperature-gradient method in a high-pressure/high-temperature apparatus using a metal solvent/catalyst (for further information, see Bundy et al., 1973; Burns et al., 1990).

Yellow, and to a lesser extent blue and colorless, synthetic diamonds have been described in the gemological literature (Crowningshield, 1971; Koivula and Fryer, 1984; Shigley et al., 1986, 1987). GIA researchers recently reported on a 5-ct Sumitomo synthetic diamond crystal section that contained yellow, blue, and colorless internal growth sectors (Shigley et al., 1992). However, the De Beers samples described here are the first faceted stones we have seen that contain similarly colored growth sectors. Thus, they do not look like other faceted synthetic diamonds we have described. This article documents the gemological properties of these synthetic diamonds, and compares them to those of synthetic diamonds reported previously in the gemological literature. A new type of crystal face first reported on these synthetic diamonds is briefly discussed.

Figure 1. The three small boron-doped faceted synthetic diamonds examined for this study—from left to right, 0.063 ct (sample 2), 0.049 ct (sample 3), and 0.075 ct (sample 1)—and the 0.197-ct crystal were grown at the De Beers Diamond Research Laboratory. Photo by Robert Weldon.

MATERIALS AND METHODS

The two synthetic diamond crystals, both cuboctahedra, weigh 0.197 and 0.116 ct. The three faceted samples are round modified brilliants weighing 0.075 (sample 1), 0.063 (sample 2), and 0.049 (sample 3) ct, respectively. The three stones are light bluish-greenish gray, dark blue, and near colorless, respectively. Their approximate clarity grades (as determined by the GIA system) are VS_1, SI_2, and SI_1, respectively. In addition, two polished plates and about a dozen other crystals of this kind of synthetic diamond had previously been studied by two of us (MLTR and CMW) to provide data on the development of internal growth sectors in this material (see again, Burns et al., 1990; Rooney, 1992).

The GIA researchers used standard gemological

TABLE 1. Luminescence of De Beers boron-doped experimental synthetic diamonds.

Luminescence behavior	Sample 1	Sample 2	Sample 3
Long-wave U.V. fluorescence			
Color	Orange	Slightly yellowish orange	Orange
Intensity	Weak	Moderate	Very weak
Appearance	Chalky, turbid	Chalky, turbid	
Distribution	Uneven; narrow, inert cross-shaped area seen under crown facets	Uneven; narrow, inert straight band seen across crown facets	Uneven
Long-wave U.V. phosphorescence			
Color	Orange	Yellowish orange	Inert
Intensity	Weak	Strong	
Duration	1–5 minutes	1–5 minutes	
Short-wave U.V. fluorescence			
Color	Slightly greenish yellow	Slightly greenish yellow (plus minor orange)	Slightly greenish yellow
Intensity	Strong	Strong	Strong
Appearance	Chalky, turbid	Chalky, turbid	Chalky, turbid
Distribution	Uneven; narrow, inert cross-shaped area seen under crown facets	Uneven; narrow, inert straight band seen across crown facets	Uneven; small, angular, inert areas
Short-wave U.V. phosphorescence			
Color	Greenish yellow	Yellow	Yellow
Intensity	Very strong	Very strong	Very strong
Duration	1–5 minutes	1–5 minutes	1–5 minutes
Cathodoluminescence			
Color	Yellow	Yellow	Yellow
Intensity	Strong	Strong	Strong
Distribution	Uneven	Uneven	Uneven

testing equipment as well as other laboratory instrumentation. The former included a gemological microscope, a long-wave (366 nm) and short-wave (254 nm) ultraviolet lamp unit, a Beck prism spectroscope, a DISCAN digital-scanning diffraction-grating spectroscope, and a GIA GEM electrical conductometer with sharp probes to allow testing of specific locations on a sample. Our examination was hindered by the small size of the faceted stones (diameter less than 3 mm) which made observation and photography of some of the gemological features difficult. A Pye-Unicam 8800 spectrophotometer was used to record absorption spectra at liquid-nitrogen temperature over the range 250–850 nm. A Nicolet 60SX Fourier-Transform infrared spectrometer was used to record infrared spectra over the range 400–16,000 cm^{-1}. Observations of cathodoluminescence were made using a Nuclide ELM-2B luminoscope.

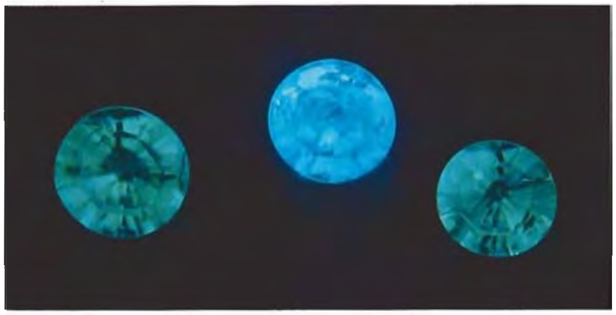


Figure 2. The intense cathodoluminescence of the three faceted synthetic diamonds is characteristic of other synthetic diamonds we have studied. As can be seen here, this luminescence is unevenly distributed. A dark, cross-shaped area that does not luminesce is visible in two of the stones. Photo by Maha DeMaggio.

In the study of crystal morphology, a Huber 302 two-circle optical-reflection goniometer was used to measure interfacial angles on several crystals. A Cambridge Instruments Stereoscan 360 scanning electron microscope (SEM) was used to produce micrographs of the small crystals.

OBSERVATIONS

Overall Faceup Color. The variation in appearance from near-colorless to blue among the faceted samples results from differences in the relative size, arrangement, and color of their internal growth sectors (see figure 1). When the blue and yellow sectors are relatively equal in volume and lighter in color, the overall faceup appearance of a faceted stone is more "grayish" or "greenish" (such as sample 1). Both crystals appear blue.

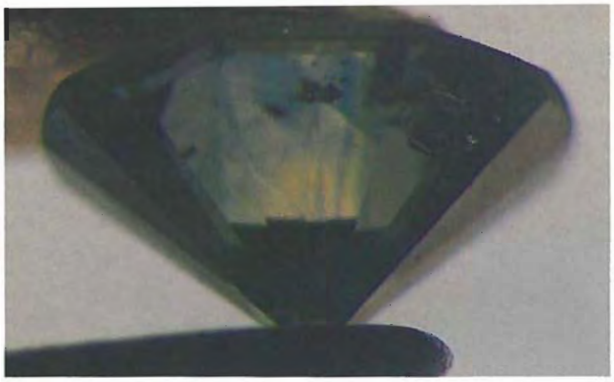


Figure 3. The arrangement of darker blue, lighter yellow, and near-colorless internal growth sectors in sample 2 is seen here with diffused light. The small opaque areas represent metallic flux inclusions. The arrangement of internal growth sectors is less obvious in the other two faceted stones. Photomicrograph by John I. Koivula.

Luminescence. In contrast to behavior reported previously (Shigley et al., 1986, 1987, 1992), the three faceted synthetic diamonds described here luminesced to both long- and short-wave ultraviolet radiation (see table 1). However, the long-wave U.V. fluorescence—weak to moderate—was weaker in intensity than the short-wave U.V. response. Most U.V.-luminescing natural diamonds react more strongly to long-wave U.V. In all five study samples, the luminescence to U.V. radiation was uneven, and sometimes clearly zoned, as has been the case with other synthetic diamonds. When viewed faceup, all three faceted stones exhibited narrow linear, angular, or cross-shaped areas that did not fluoresce, surrounded by larger areas that fluoresced brightly. In most cases, when the lamp was turned off, the stones exhibited very persistent, very strong, yellow (to short-wave U.V.) or orange (to long-wave U.V.) phosphorescence lasting from one to five minutes.

The three faceted stones displayed cathodoluminescence when they were exposed to an electron beam. This luminescence was quite intense, and—as has been noted in previous studies of synthetic diamonds (Woods and Lang, 1975; Shigley et al., 1987; Ponahlo, 1992)—it was also zoned in color and intensity (see table 1). To the unaided eye, the luminescence appears yellow, but photography recorded more blue than yellow for one sample (figure 2). Although difficult to see in figure 2, the uneven pattern of cathodoluminescence—bright areas separated by narrow inert areas, both of which can be observed with magnification—duplicates the uneven pattern of ultraviolet luminescence in these samples. Cathodoluminescence provides an additional means of distinguishing synthetic from natural diamonds, because it reveals the differing patterns of internal growth sectors characteristic of the two (see Shigley et al., 1987; Burns et al., 1990; Ponahlo, 1992). This test is particularly useful where no other diagnostic properties are visible.

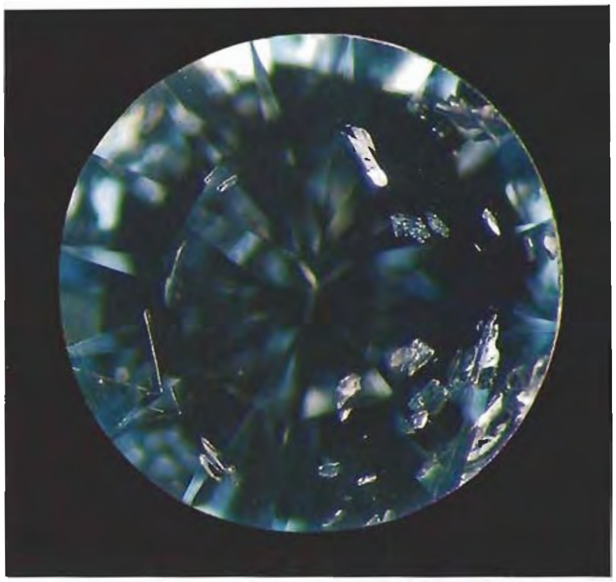


Figure 4. Numerous metallic flux inclusions can be seen through the crown facets of sample 2. Photomicrograph by John I. Koivula; reflected light.

Microscopy. When viewed with a gemological microscope, the three faceted stones revealed several interesting features. In diffused transmitted light, all three were seen to consist of darker to lighter blue, light yellow, and near-colorless internal growth sectors in varying arrangements (see, e.g., figure 3). The blue sectors display a more distinct shape, and appear as wedge- or parallelogram-shaped, lath-like zones bounded by sharp edges and having angular corners. In sample 1, near-colorless to yellow funnel-shaped areas occur between these blue sectors. The outlines of the yellow and near-colorless growth sectors are not as distinct. Thus, the shape of the blue sectors is more readily apparent. This is also the case for the two crystals, where the blue sectors were observed to lie beneath the cube crystal faces.

All five samples contain inclusions, but these are most abundant in sample 2 (see figure 4). Various numbers of both large and smaller "pinpoint" flux (i.e., metal solvent) inclusions were observed in the three faceted stones. The larger inclusions have a shiny, metallic appearance, and in some cases seem to be oriented parallel both to one another and to the octahedral faces of the original crystal. Similar inclusions in other gem-quality synthetic diamonds have previously been reported (Shigley et al., 1986, 1987).

When viewed between crossed polarizing filters, the five samples exhibited anomalous birefringence ("strain") with weak (first-order) interference colors. Near the larger flux inclusions, the strain formed a more radial pattern with slightly stronger first-order interference colors (see figure 5). The overall weakness of this birefringence is typical of that observed in other synthetic diamonds, and it differs in intensity and pattern from the more intense anomalous birefringence typically seen in natural diamonds.

Figure 5. A pattern of weak anomalous birefringence ("strain") was seen in sample 3 when it was viewed between crossed polarizing filters. The small area of blue birefringence is an area of greater strain surrounding a metallic flux inclusion. Photomicrograph by John Koivula; magnified 10×.

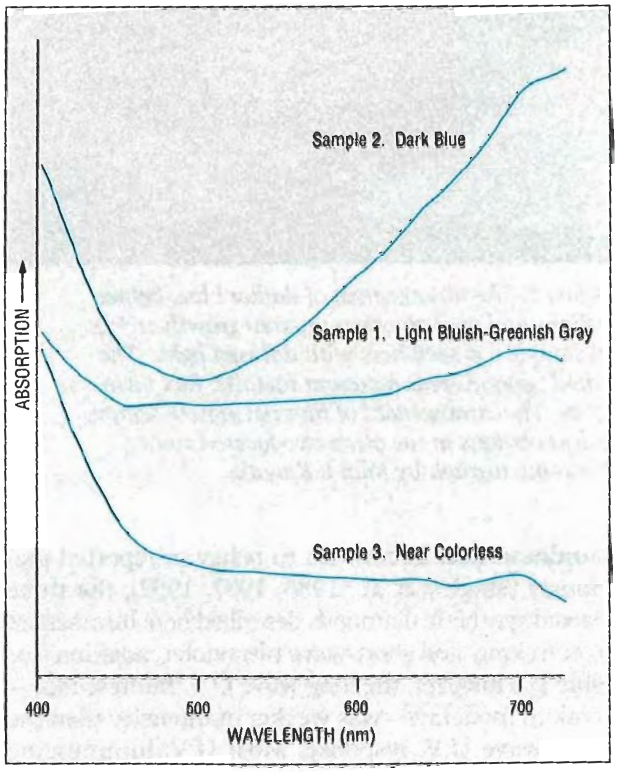


Figure 6. The visible spectra of all three faceted synthetic diamonds, recorded at liquid-nitrogen temperature, show increasing absorption toward the ultraviolet. For samples 1 and 2, weak or moderate increasing absorption is also evident toward the infrared. In contrast to the other two samples, the stronger increasing absorption at the long-wavelength end of its spectrum gives rise to the darker blue color of sample 2.

We saw little distinct graining in any of the three faceted stones, and none in the two crystals, although in some instances, the relatively sharp edges of the darker blue internal growth sectors were marked by visible graining. These synthetic diamonds lack the pattern of internal graining observed in yellow synthetic diamonds (Shigley et al., 1986, 1987), possibly because they contain less nitrogen.

Electrical Conductivity. The three faceted samples exhibited a range of conductive behavior: Sample 1 was electrically conductive (with instrument readings similar to those for natural type IIb diamonds), sample 2 proved to be conductive only in certain areas of the crown and pavilion facets, and sample 3 was not conductive. Both crystals were conductive, with various readings depending on where on their surfaces they were tested.

Spectroscopy. We did not observe any sharp absorption bands in the optical absorption spectra of the five samples with a Beck desk-model spectroscope. Because of the small size of these samples and the fact that three were faceted, it was impossible to record spectral curves with the spectrophotometer that would represent individual blue, yellow, or colorless growth sectors. The spectrophotometer traces for all three faceted samples showed increasing absorption toward the ultraviolet (figure 6). The spectra of samples 1 and 2 also showed weak to moderate increasing absorption toward the infrared, especially in the dark blue faceted stone (sample 2). There is a weak, broad absorption feature at about 700 nm in the spectra of samples 1 and 3, which we have seen in many spectra of both natural and synthetic diamonds, but we are uncertain of its interpretation. In comparison, natural colorless or yellow type Ia diamonds often have sharp absorption bands due to the N3 color center (the Cape lines). Neither natural nor synthetic blue type IIb and yellow type Ib diamonds show any sharp bands in the visible-range spectrum.

The diamond type of a particular stone can be identified by its infrared spectrum (see, e.g., Fritsch and Scarratt, 1992, pp. 38–39). The infrared spectra of the three faceted stones (figure 7) suggest that sample 1 is a mixed type IIb plus IIa diamond, while sample 2 is a type IIb. This is consistent with their observed electrical conductivity. Sample 3 is a type IIa plus IIb. Because the three faceted samples are so small, the infrared spectrum of each represents contributions from various growth sectors throughout the entire sample. Given the size of the yellow growth sectors in each of the three samples, together with the unfavorable measurement geometry for recording spectra from small faceted stones, it is not surprising that we do not see the 1344 and the 1130 cm^{-1} infrared features in these spectra that distinguish type Ib diamond. However, infrared spectra of individual yellow growth sectors recorded by Rooney (1992, p. 18, figure 3) in a polished section of one of these boron-doped synthetic diamonds indicates that these growth sectors are type Ib diamond. Thus, it is likely that all synthetic diamonds of this kind are actually a mixed type IIa plus IIb plus Ib.

Crystal Form and the Nature of Internal Growth Sectors. Previous articles (e.g., Shigley et al., 1986, 1987, 1992; Burns et al., 1990) have described the basic growth shape of a synthetic diamond crystal as that of a cuboctahedron, which can be modified by the presence of minor dodecahedral and trapezohedral faces. The presence of true cube {100}, dodecahedral {110}, and trapezohedral {113} faces is characteristic of synthetic diamond crystals; genuine crystallographic faces with these Miller indices are not found on natural diamond crystals.* The presence of these faces on the surface of a crystal is generally accompanied by distinctive internal growth sectors also not seen in natural stones. Gemological features associated with this kind of more complicated growth and the presence of one or more growth sectors—e.g., zoning of color and luminescence—are, therefore, important for the identification of synthetic diamonds.

A number of these boron-doped synthetic diamonds, in uncut form, have been studied at the DTC Research Centre. Some were found to have a new kind (not previously seen on natural or synthetic diamonds) of trapezohedral growth face in addition to {113}. Figure 8 shows an SEM micrograph and corresponding labeled line drawing of one of these crystals. Note in this figure that there are additional trapezohedral faces lying between the {113} faces and the top (001) face. In a recent report on these boron-doped synthetic diamonds, Rooney (1992) demonstrated (by measurement of the angles between crystal faces) that these new faces are {115} faces. Subsequently, these faces were reported on a Sumitomo synthetic diamond by Shigley et al. (1992). Again, the presence of nonoctahedral crystal faces—which might be present on unpolished portions of a faceted synthetic diamond—is further evidence of the difference between natural and laboratory growth environments for diamonds.

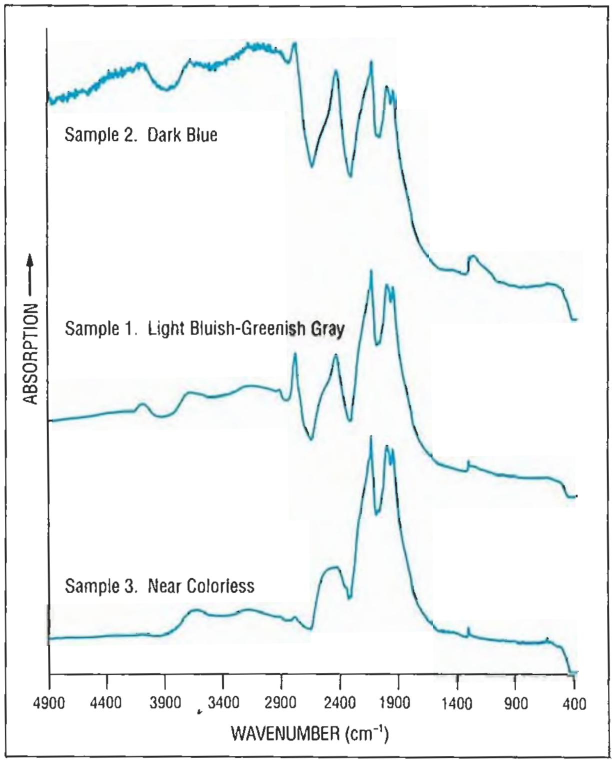


Figure 7. Because the internal growth zones are so small, it was impossible to record infrared spectra from individual zones; thus, these curves represent composite spectra for the three faceted synthetic diamond samples. According to these spectra, sample 2 is a type IIb diamond, sample 1 is a mixed type IIb+IIa diamond, and sample 3 is a mixed type IIa+IIb diamond. The type Ib component related to the yellow growth sectors could not be resolved.

Rooney's (1992) description of two other boron-doped synthetic diamonds, prepared as thin polished plates, confirmed the presence of internal {115} growth sectors corresponding to external faces on this kind of synthetic diamond. Optical micrographs of these two samples (with corresponding line drawings of their growth sector arrangement) are shown in figures 9 and 10, respectively. The samples were polished parallel to the (110) dodecahedral plane so as to expose individual growth sectors. These two samples show clearly how measured differences in impurity content lead to visible differences in color and other gemological properties.

**The generalized symbol {hkl} refers to the Miller indices, a nomenclature system that crystallographers use to designate crystallographic planes (or faces) and to calculate the angles between them. When these Miller indices are surrounded by braces {}, they represent a crystal form, which is a group of crystal faces that all have the same position with respect to the symmetry elements of the crystal. For example, all crystal faces on a cube with Miller indices (100), (010), and (001), can be described by the one symbol {100}.*

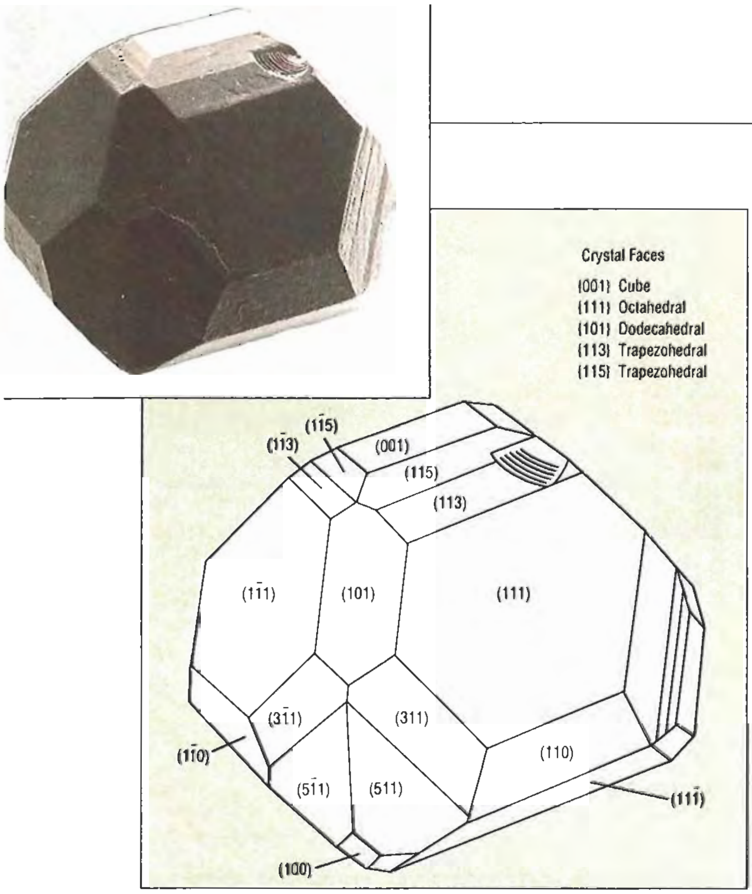


Figure 8. This low-magnification scanning electron micrograph and line drawing of a small boron-doped synthetic diamond crystal show the arrangement of crystal faces. Note the additional {115} trapezohedral faces lying between the {113} faces and the top (001) face.

Cube and octahedral growth faces are always present on synthetic diamonds. The presence of the minor growth forms (dodecahedral and trapezohedral) depends on the solvent/catalyst chemistry. When present, their location, number, and relative size tend to be rather haphazard, presumably reflecting the details of the local growth conditions within the synthesis capsule. This seems to be especially true of these particular boron-doped synthetic diamonds, where there can be very large differences in the relative development of sectors of similar type.

DISCUSSION

In some respects, the gemological properties of these three faceted stones are similar to those of other synthetic diamonds: internal color zoning, strong short-wave U.V. fluorescence and cathodoluminescence that are unevenly distributed, metallic flux inclusions, and weak anomalous birefringence ("strain"). In contrast to other synthetic diamonds studied by GIA researchers, however, these five samples exhibit some, albeit weak, long-wave U.V. fluorescence. However, the short-wave response was more intense than the long-wave response, which differs significantly from the stronger long-wave fluorescence typical of natural diamonds that fluoresce to U.V. radiation. In addition, the three stones lacked the prominent graining noted in yellow synthetic diamonds (see Shigley et al., 1986, 1987).

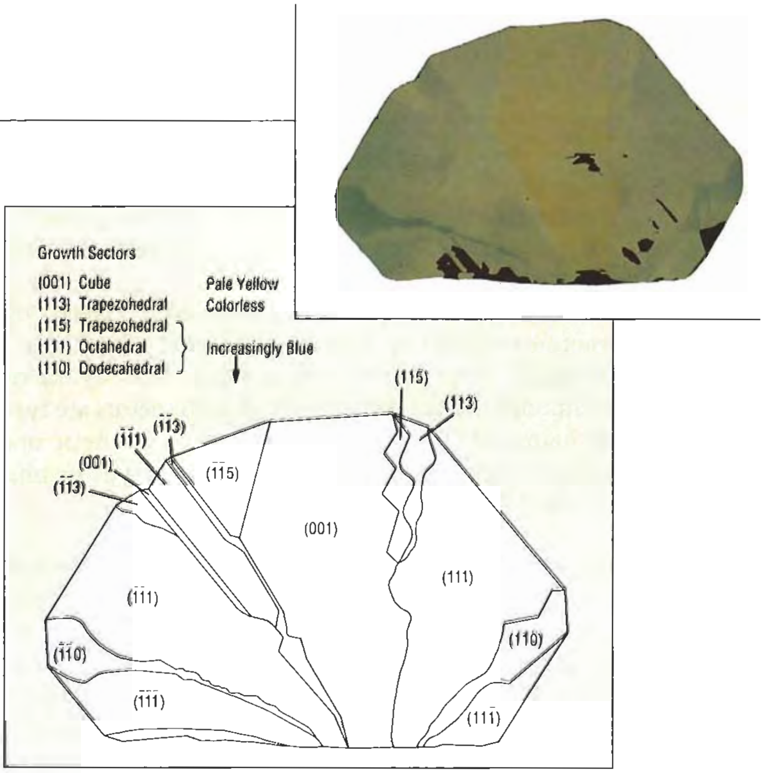


***Figure** 9. A transmission optical photomicrograph **and gr**owth-sector line drawing of a 0.075-ct boron-**doped** synthetic diamond in the form of a polished plate (0.55 mm thick, 3.9 mm wide). The {001} growth sector is pale yellow. The {113} sectors are essentially colorless. The remaining sector types are all blue, with the intensity of color increasing in the order {115}, {111}, {110}. Infrared measurements (Rooney, 1992) indicate that the yellow color in the {001} sectors resulted from its being type Ib (nitrogen concentration of about 11 ppm). For the blue type IIb regions, the concentration of uncompensated boron was approximately 0.55 ppm for {115}, 1.1 ppm for {111}, and 2.2 ppm for {110} sectors. Photo by C. M. Welbourn.*

The most interesting aspect of these synthetic diamonds is their mixed IIa, IIb, and Ib character, which has never been reported for natural diamond crystals (although it was noted in a large Sumitomo synthetic diamond crystal; Shigley et al., 1992). The differing incorporation of boron and nitrogen in the internal growth sectors causes the variation in color from one sector to another. Because the degree to which impurities are incorporated can also vary from one crystal to another, this kind of synthetic diamond could vary greatly in color from near-colorless to gray (or green) to blue and to yellow (and thus also in some properties, such as electrical conductivity and luminescence). Crystals in which the color sectors are of

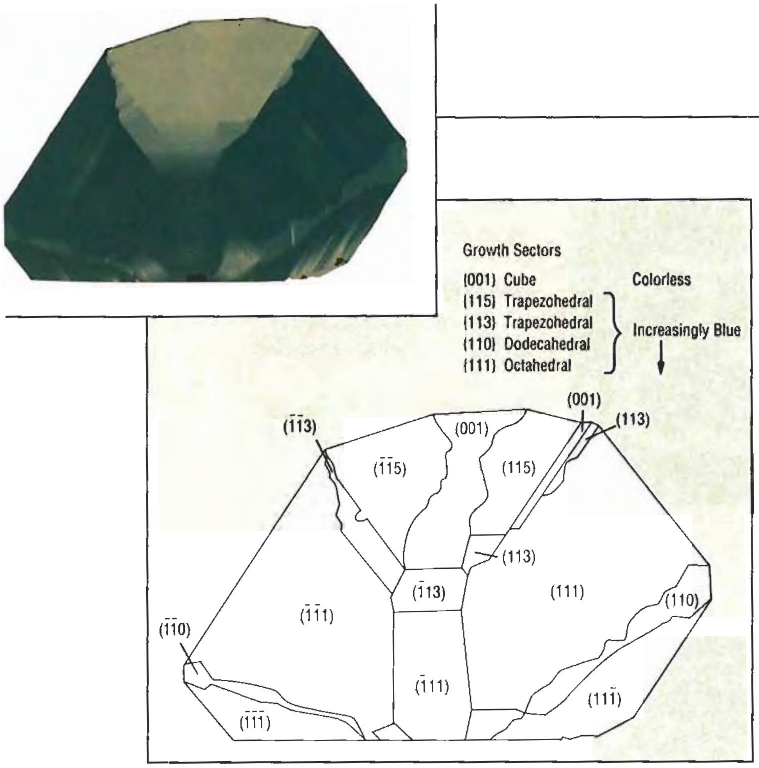


Figure 10. The 0.014-ct synthetic diamond (shown here in the form of a polished plate 0.19 mm thick and 4.2 mm wide) in this transmission optical photomicrograph and growth-sector line drawing was doped with 14 times as much boron as the one shown in figure 9. Infrared spectra (Rooney, 1992) indicate no nitrogen but 0.08 ppm uncompensated boron in the {001} sectors. Similar boron concentrations in other sectors are: {111}—40 ppm, {110}—25 ppm, {113}—9 ppm, and {115}—4 ppm. Photo by C. M. Welbourn.

relatively equal proportions could appear grayish or slightly greenish, and thus may not look like other synthetic diamonds to the unaided eye. However, examination with a gemological microscope should quickly reveal the presence of the kind of color zoning illustrated in figure 3, which has never been encountered in natural diamond crystals.

CONCLUSION

Examination of three small faceted De Beers synthetic diamonds and two small crystals reveals that they are a mixed type. The presence of different proportions of three distinct—blue, yellow, and near-colorless—growth sectors affects the faceup color of each finished stone. Because of this combination of colors, these synthetic diamonds look more like natural diamonds than most other synthetic diamonds reported in the gemological literature. The presence of nonoctahedral faces unique to synthetic diamonds is another feature by which they can be distinguished from their natural counterparts. Furthermore, since it is much more economical to grow small rather than large synthetic diamonds, it is possible that small (0.10 ct or less) faceted synthetic diamonds will appear first in the jewelry industry. Nonetheless, documentation of the gemological properties of these De Beers synthetic diamonds—e.g., metal inclusions, generally strong zoned short-wave U.V. fluorescence and phosphorescence, weak birefringence, and the color zoning itself—indicates that identification should be easy, since these properties do not correspond to those of any known natural diamonds. However, this could require that small near colorless-to-blue faceted diamonds that are suspect be gemologically tested—a practice that is not commonly followed now.

REFERENCES

Bundy F.P., Strong H.M., Wentorf R.H. Jr. (1973) Methods and mechanisms of synthetic diamond growth. *Chemistry and Physics of Carbon*, Vol. 10, pp. 213–263.

Burns R.C., Cvetkovic V., Dodge C.N., Evans D.J.F., Rooney M-L.T., Spear P.M., Welbourn C.M. (1990) Growth-sector dependence of optical features in large synthetic diamonds. *Journal of Crystal Growth*, Vol. 104, pp. 257–279.

Crowningshield R. (1971) General Electric's cuttable synthetic diamonds. *Gems & Gemology*, Vol. 13, No. 10, pp. 302–314.

Fritsch E., Scarratt K. (1992) Natural-color nonconductive gray-to-blue diamonds. *Gems & Gemology*, Vol. 28, No. 1, pp. 35–42.

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

Nassau K., Nassau J. (1978) The history and present status of synthetic diamond: Part II. *Lapidary Journal*, Vol. 32, No. 2, pp. 490–508.

Ponahlo J. (1992) Cathodoluminescence (CL) and CL spectra of De Beers' experimental synthetic diamonds. *Journal of Gemmology*, Vol. 23, No. 1, pp. 3–17.

Rooney M-L.T. (1992) {115} Growth in boron-doped synthetic diamonds. *Journal of Crystal Growth*, Vol. 116, pp. 15–21.

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

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

Shigley J.E., Fritsch E., Reinitz I., Moon M. (1992) An update on Sumitomo gem-quality synthetic diamonds. *Gems & Gemology*, Vol. 28, No. 2, pp. 116–122.

Sunagawa I. (1984) Morphology of natural and synthetic diamond crystals. In I. Sunagawa, Ed., *Materials Science of the Earth's Interior*, Terra Scientific Publishing Co., Tokyo, pp. 303–330.

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

Woods G.S., Lang A.R. (1975) Cathodoluminescence, optical absorption, and X-ray topographic studies of synthetic diamonds. *Journal of Crystal Growth*, Vol. 28, pp. 215–226.

GEM TRADE LAB NOTES

EDITOR
C.W. Fryer *Gem Trade Laboratory, West Coast*

CONTRIBUTING EDITORS
GIA Gem Trade Laboratory, East Coast
G. Robert Crowningshield • Thomas Moses

GIA Gem Trade Laboratory, West Coast
Karin Hurwit • Robert C. Kammerling •
Shane F. McClure

SYNTHETIC ALEXANDRITE

With Needle-Like Inclusions

Examination with magnification is usually the most important gemological technique for separating natural gem materials from their synthetic counterparts. Therefore, the presence of ambiguous internal features can make such separations especially challenging.

Recently, the West Coast lab was asked to identify a 3.59-ct mixed-cut pear shape that exhibited a distinct color change, appearing red-purple in incandescent illumination and displaying both green and purple in fluorescent light. Standard gemological testing showed properties consistent with the alexandrite variety of chrysoberyl, both natural and synthetic.

Magnification revealed an abundance of dust-like pinpoint inclusions, as well as numerous short, thin, highly reflective, needle-like inclusions. Most of the latter appeared to be straight, although some were slightly curved (figure 1). When the stone was immersed in methylene iodide, we also noted a slightly curved color banding parallel to the girdle plane (figure 2). However, the curvature was so slight that it could have been due to an optical distortion. Furthermore, the banding appeared to be asymmetric: very straight through one end and the center of the stone, but slightly curved at the other end. Because of the needle-like inclusions and the unusual banding, we asked GIA Research to perform additional testing. Energy-dispersive X-ray fluorescence (EDXRF) analysis detected chromium and vanadium in proportions very similar to those in reference samples of synthetic alexandrite produced by the Czochralski-pulling method. Infrared spectroscopy indicated a mid-infrared spectrum typical of melt-type synthetics, that is, one that lacked water-related absorption bands.

Figure 1. These short, needle-like inclusions were observed in a synthetic alexandrite that may have been grown by the Czochralski-pulling method. Magnified 40×.

Figure 2. Slightly curved color banding, typical of a melt-grown synthetic, was detected in this 3.59-ct synthetic alexandrite with magnification and immersion in methylene iodide. Magnified 15×.

On the basis of these tests, we identified the stone as synthetic alexandrite. We speculate that the needle-like inclusions may be a platinum-group metal, inasmuch as platinum, iridium, and rhodium are commonly used for the crucibles in which synthetic crystals are grown by the Czochralski-pulling method. *SFM and RCK*

BERYL

"Coated" Beryl

Before the commercial introduction of synthetic emerald in the 1930s, methods used to mimic natural emeralds ranged from dyeing or coating pale beryls and other less expensive gem materials, to glass imitations, to a wide selection of doublets and triplets. The earliest technique was undoubtedly painting or coating. Benvenuto Cellini detailed many of these early methods in his book, *Treatise on Goldsmithing*, originally published in 1568 (for extracts, see K. Nassau, *Gemstone Enhancement*, Butterworths, 1984, p. 14).

A 4.39-ct emerald-cut stone submitted to the East Coast lab for identification is an example of a natural beryl that owed most, if not all, of its color to a green coating that covered the entire pavilion of the stone. The Chelsea col-

---

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

Gems & Gemology, Vol. 29, No. 1, pp. 46-51

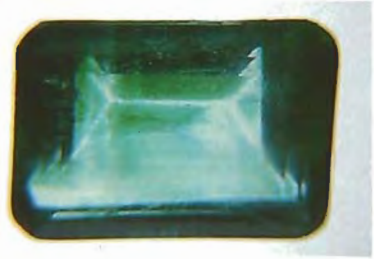


Figure 3. When this 4.39-ct coated beryl was viewed at 10× magnification in transmitted light, the lack of color at the facet junctions (where the coating has worn off) is evident.

or filter revealed a red reaction that, with only cursory examination, could be misleading. (This is an excellent reason why one should NEVER make an identification based only on a color-filter reaction.) In addition, numerous two-phase inclusions and long, fine needles—together with properties consistent with natural beryl—identified the substrate material. Because the coating had worn off the facet junctions, however, the treatment was evident in diffused transmitted light (figure 3). In addition, the coating melted when touched with a hot point, consistent with a coated beryl reported 10 years ago (see *Gems & Gemology*, Spring 1983, p. 44). A broad absorption band between 660 nm and 690 nm was visible in a Beck desk-model prism spectroscope. This band, which is related to the presence of dye, was superimposed over the spectral region where emerald chromium lines usually appear. Thus, we could not determine if the beryl itself contained chromium.

Although methods of gemstone enhancement continue to get more sophisticated, one cannot dismiss the more primitive techniques which still appear in the marketplace. *TM*

Irradiated Beryl of a Rare Color

The East Coast lab was asked to identify six yellow-green stones that ranged from about 12 to 35 ct (figure 4). Standard testing proved that all were beryl, but with some unusual characteristics.

Figure 4. The uniformity of color, and the fact that the optic axes of all six yellow-green beryls (12–35 ct) are perpendicular to the table, suggests that all may have been cut from the same piece of rough.

The first unusual feature noted was that the optic axis was perpendicular to the table in each stone, which—along with the uniformity of color from one stone to the next—suggests that all may have been cut from the same crystal. With a desk-model prism spectroscope, we also observed a series of lines in the red portion of the absorption spectrum that resembled those seen in chromium-bearing minerals. On closer examination, however, we noted that the absorption bands (figure 5) were close to those we first saw in 1972, in a Maxixe-type blue beryl. In fact, the spectrum was seen and recorded four years earlier (*Gems & Gemology*, Summer 1968, pp. 315–316) in a grayish blue beryl known to have been produced by irradiating a morganite. However, the significance of the distinctive appearance of this spectrum was not recognized until attractive dark blue beryls began to appear on the market (*Gems & Gemology*, Summer 1973, pp. 172–175). Although these spectral lines are diagnostic for all Maxixe-type beryls, the overall color of any particular stone (from dark blue to greenish yellow) will depend on broad absorption features visible only with a spectrophotometer.

In their initial investigation of Maxixe-type beryl, K. Nassau and D. L. Wood (*Lapidary Journal*, October 1973, pp. 1032–1058) determined that irradiation treatment of beryl may produce several colors, including the yellow-green seen in these six stones. It is possible that these stones have been irradiated only, and that with appropriate heat treatment they would become a purer yellow, as did such stones in the original Nassau and Wood experiments. The effects of irradiation in beryl are further described by W. J. Rink, P. J. Gielisse, and H. S. Plendl in "Coloration in Electron-Irradiated Beryl" (*Journal of Gemmology*, Vol. 22, No. 1, 1990, pp. 33–37). *GRC*

DIAMOND

Blue Diamond with Unusual Inclusions

Figure 6 shows an inclusion consisting of strings of small crystals of an uniden-

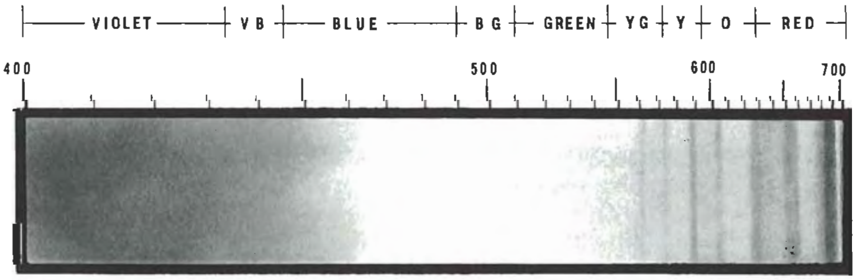


Figure 5. The absorption pattern of the yellow-green beryls shown in figure 4 closely resembles that of irradiated blue Maxixe-type beryl.

Figure 6. Although a black fingerprint-like inclusion in a blue stone suggests sapphire, here it occurs in a blue diamond. Magnified 40×.

tified black material, arranged in a fingerprint-like pattern. Such a pattern in a blue gemstone would ordinarily suggest a sapphire and prove its natural origin. In this instance, however, the stone was a 1.02-ct fancy blue, marquise-shaped, brilliant-cut diamond. We established that the color was natural on the basis of the stone's electrical conductivity and its typical reaction to short-wave ultraviolet radiation.

Although such inclusions are very rare in diamonds, a colorless diamond with a similar inclusion was illustrated in the Spring 1968 Lab Notes section (pp. 278–279). *GRC*

Diamond Laser Drilled for Mounting

Today, laser drilling is commonly used in the clarity enhancement of diamonds. In simple terms, a focused laser beam is used to drill a narrow hole from the surface of a diamond to a dark inclusion. The beam may vaporize the inclusion, or the inclusion may be subsequently leached with acid. As noted in the next entry, laser drill holes have even been used as a conduit for filling a fracture that does not reach the surface of the stone.

Still another use of laser drilling was brought to the attention of the East Coast lab by Yoshiko Doi, president of the AGT Gem Laboratory, the GIA Gem Trade Laboratory's affiliate in Tokyo. She shared with us a 0.32-ct round brilliant (figure 7) that was pierced from the crown to the pavilion by two relatively large drill holes, and a second round brilliant pierced with one such hole. The purpose of the drilling reportedly was to prepare the diamonds for a special mounting. The process presented an interesting question—How should such diamonds be clarity graded?—inasmuch as laser drill holes are typically treated as clarity features associated with inclusions.

Such diamonds are not, however, without precedent. For example, briolette-cut stones are occasionally drilled for the purpose of mounting. Although mechanical drilling was used historically for that purpose, this diamond was laser drilled with the same intent. GIA Gem Trade Laboratory policy has been to treat such drilling as something performed to facilitate mounting rather than for clarity purposes, so we graded this laser-drilled diamond similarly. Note, however, that if the drilling were to impart clarity characteristics, such as hairline fractures extending from the laser drill hole, they would be considered in the final grade determination. In this instance, however, no such features were induced.

Figure 7. The large laser drill holes in this 0.32-ct diamond were made to prepare the stone for mounting, not to enhance its apparent clarity. Magnified 10×.

At the same time, Ms. Doi also showed us diamonds that had been grooved or notched on their pavilion facets, apparently to prepare them for use in "invisible" settings (figure 8). Here, too, for grading purposes this feature was treated as part of the fashioning process.

Edward Schwartz and RCK

Figure 8. Large grooves have been cut into the pavilion of this 0.27-ct diamond, apparently so it could be used in an "invisible" setting. Magnified 10×.

Laser-Assisted Filling in Diamond

A faint white cloud near the culet, just barely visible in figure 9, is the only indication of a filled fracture in this view of a 2.51-ct diamond submitted to the East Coast lab. The unusual feature of this filled fracture is that it

Figure 9. Barely visible in this faceup view of a 2.51-ct diamond is a filled fracture near the culet. Note the minute laser drill holes at three o'clock and (a fainter one) at nine o'clock on each side of the culet. Magnified 12×.

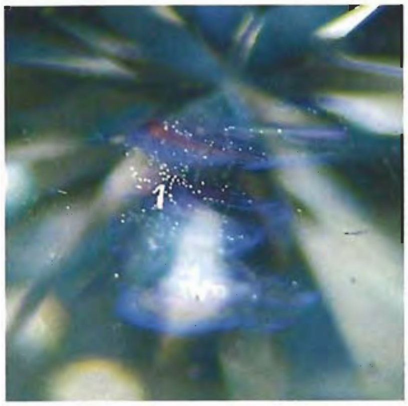


Figure 10. The purple flash effect and the presence of trapped bubbles prove that this fracture has been filled. Note the laser drill hole, through which the filler was introduced into the fracture. Magnified 33×.

appeared to be wholly internal. We could not discern any evidence that the fracture itself reached the surface. However, two laser drill holes (just visible in figure 9 at the three and nine o'clock positions on either side of and near the culet) provided access to the fracture for the filling material. Figure 10 shows one of the laser drill holes as well as the purple flash and trapped bubbles that are characteristic of some filled fractures. *GRC*

Another Radioactive Diamond

Occasionally, the lab detects residual radioactivity in green-to-black color-enhanced diamonds. The 2.51-ct greenish yellow round brilliant cut shown in figure 11 revealed a mottled green coloration on the crown with a distinctive blotchy pattern (of lighter and darker areas) on the table, when viewed with diffused lighting. With a Victoreen 290 survey meter, we recorded a residual radiation dose rate of 0.1 mR per hour (2–3 times background at the East Coast lab) on the table. This confirmed that the coloration was due in part to some form of radiation treatment.

Gemological analysis revealed some interesting characteristics. There was no phosphorescence, but the stone fluoresced a strong chalky green to long-wave—with a slightly weaker reaction to short-wave—ultraviolet radiation. The desk-model spectroscope revealed a Cape spectrum of moderate strength, as well as absorption bands at 498, 504, and 595 nm, which suggests that the initial color of the diamond was light yellow. Testing with a Pye-Unicam SP8-400 ultraviolet-visible spectrophotometer confirmed these absorption bands, which are typical of radiation and heat treatment.

The diamond was forwarded to GTL's West Coast radiation-testing facility for radionuclide identification. First, the diamond was vigorously wiped with filter paper to remove any radioactive surface contamination. Radiation testing of the filter paper proved negative: There was no removable contamination on the stone. The high-purity germanium detector (HPGe) revealed a residual radionuclide concentration of 1.25 nanocuries of americium-241 per gram of diamond. This is 10 times the concentration found in the americium-treated diamond described in the Summer 1992 issue of *Gems & Gemology* (pp. 104–111). Inasmuch as all known americium-treated diamonds came from one source and were treated according to a patented procedure (see U.S. Patent 3,616,357), it is highly probable that this 2.51-ct diamond was subjected to the same process. According to the patent, the treatment involves embedding the diamond in a powdered americium-241 oxide compound for one to two weeks, then soaking and washing it in three separate baths of concentrated nitric acid, with a final washing in detergent followed by rinsing in water.

Figure 11. Because of the radionuclide responsible for the radioactivity in this 2.51-ct diamond, a legal (U.S.) release date of approximately 6507 A.D. was calculated.

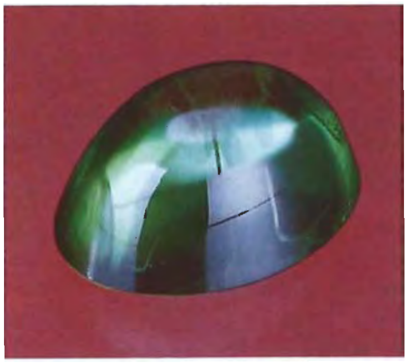
Because americium-241 has such a long half-life and the U.S. concentration limit for this radionuclide is extremely low, the diamond's legal release date—as specified by U.S. law—was calculated to be sometime in 6507 A.D. (4,514 years ± 7%). The diamond was returned to the client, as permitted by GIA's California State Radioactive Materials Licence (which applies in this instance), with the required warning and educational material.

Charles E. Ashbaugh and TM

SYNTHETIC EMERALD, Cabochon Cut

Almost all the synthetic emeralds seen in the GIA Gem Trade Laboratory are in the form of faceted stones. It was thus unusual that the 0.78-ct oval cabochon shown in figure 12, which was submitted to the West Coast lab, proved to be synthetic. The identification was made on the basis of the low refractive indices and birefringence, weak red flu-

Figure 12. This 0.78-ct oval cabochon (approximately 6.90 × 5.03 × 3.33 mm) was identified as flux-grown synthetic emerald; the properties were similar to Russian material.



orescence to long-wave U.V. radiation, and yellowish orange-to-brown flux inclusions. The properties are similar to those of flux-grown synthetic emeralds of Russian manufacture (see, e.g., "Russian Flux-Grown Synthetic Emeralds," *Gems & Gemology*, Summer 1985, pp. 79–85).

We cannot emphasize enough for our readers that the shape in which a gem material is fashioned should not be considered a diagnostic feature in its identification. *RCK and SFM*

Imitation LAPIS LAZULI, an Update

The Spring 1992 Lab Notes section (p. 55) reported on a most unusual lapis lazuli imitation seen in the West Coast lab. In addition to describing the gemological properties of this product, the entry noted that X-ray diffraction analysis revealed patterns that matched phlogopite mica. We concluded that this manufactured product might be a phlogopite ceramic.

Since publication of that report, this lapis simulant was tested further. Examination of a thin section between crossed polarizers confirmed that it was predominantly a strongly birefringent mica-type material, with high-order interference colors (figure 13). However, we also noted minor dark blue, singly refractive zones that appeared black when the stone was viewed with crossed polarizers.

A sawn section of the sample was next studied by Paul Carpenter at the California Institute of Technology, using a scanning electron microscope (SEM) with energy dispersive spectrometer (EDS). The SEM revealed that the material consisted primarily of crystals with a roughly rectangular outline and lamellar structure, as would be expected of a mica, while the EDS spectrum was typical of phlogopite, with Mg, Al, Si, and K as major elements.

Also detected with the SEM were a very few grains, 10 to 50 μm in longest dimension, that lacked the lamellar structure typical of phlogopite. We estimated that these represented no more than 5% of the overall volume of the specimen, which could explain why they were not detected during the earlier X-ray diffraction analysis. We determined that these grains were two distinct materials: (1) a silicate of calcium and magnesium (identity as yet undetermined), and (2) the mineral lazurite (an aluminosilicate of sodium and calcium that contains significant sulfur and is the blue component in lapis lazuli). As a result of this further investigation, we hypothesize that the blue coloration of this simulant is due, at least in part, to the presence of lazurite inclusions. As further substantiation, the U.V.–visible reflectance spectrum of this imitation (as taken with an Hitachi U4001 spectrophotometer) is basically identical to that of a piece of natural lapis lazuli from Afghanistan.

Emmanuel Fritsch and RCK

Figure 13. At least two different components can be seen in this thin section of the lapis lazuli imitation illustrated in the Spring 1992 Lab Notes section (p. 55) when it is viewed between crossed polarizers. Magnified 80×.

Large Faceted LAZULITE

An attractive collector's stone, faceted lazulite is only rarely encountered in the lab. While its typically dark, saturated blue color is quite similar to that of some apatite, the combination of refractive indices in the low 1.60s and a high birefringence (typically 0.031–0.036) might cause some gemologists to confuse it with tourmaline.

Faceted lazulites are usually small. Those we have examined are typically under a half carat. Although stones 0.5–2.0 ct are seen, clean lazulites over 5 ct are extremely rare, according to the second edition of Joel Arem's *Color Encyclopedia of Gemstones* (Van Nostrand Reinhold, New York, 1987). Thus, staff members of the West Coast lab were pleasantly surprised to receive for identification the 5.85-ct modified emerald cut shown in figure 14. All of the gemological properties were consistent with those reported in the literature for lazulite, including the strong trichroism (slightly violetish blue, light green, and near colorless). Magnification revealed one- and two-phase fluid and gas inclusions, partially healed fracture planes, and—as would be expected given the relatively high birefringence—strong doubling. *SFM and RCK*

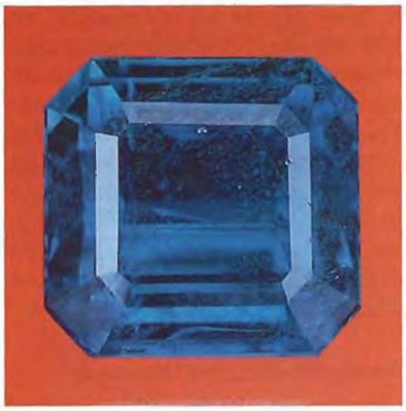


Figure 14. At 5.85 ct (10.60× 10.10 × 6.12 mm), this is an unusually large faceted lazulite.

Cat's-Eye ORTHOCLASE

Although the Gem Trade Laboratory sees many phenomenal stones, the 6.54-ct cat's-eye orthoclase identified by the East Coast lab was unusual because of its yellow color and the fact that it was chatoyant but lacked adularescence (fig-

Figure 15. This 6.54-ct cat's-eye orthoclase is unusual both because of its yellow color and because it shows chatoyancy, but no adularescence.

Figure 16. Notice the unusual shape, color, and luster of these attractive abalone pearls, each approximately 20 × 18 × 12 mm.

ure 15). The chatoyant orthoclase commonly seen in the trade is cat's-eye moonstone, which is both adularescent and white to grayish white (see, e.g., *Gems & Gemology*, Spring 1963, p. 23).

Examination with a microscope revealed cleavage planes in two directions. This and the results of standard gemological testing (refractive index, optic figure, and fluorescence) distinguish cat's-eye orthoclase from similar-appearing stones, such as scapolite and quartz. *Nicholas DelRe*

Abalone PEARLS from North America

Figure 16 illustrates one of the most unusual pairs of abalone pearls ever examined in the West Coast lab. According to the owner, the pearls were recovered from the abalone (*Haliotis rufescens*) that were once abundant off the Pacific coast of North America. The multicolored pearls, each approximately 20 × 18 × 12 mm, are roughly a cushion shape, rather than the conical or horn-shaped concretions usually formed by this univalve mollusk. Both appeared to be completely covered with nacreous layers that had an almost metallic luster. The dominant colors were vivid green and blue, with pink, purple, and violet overtones. X-radiography (figure 17) revealed the internal structure, a multitude of concentric layers that echoed the external shape of these pearls. *KH*

Figure 17. This X-radiograph clearly shows the hollow center and concentric layers of conchiolin in the abalone pearls illustrated in figure 16.

PHOTO CREDITS

Shane F. McClure took the photos in figures 1, 2, 12, and 14. Nicholas DelRe supplied figures 3, 4, 6, 9, 10, and 15. Bob Crowningshield drew the absorption spectrum diagram in figure 5. Maha DeMaggio took the photo in figure 11. John I. Koivula took the photomicrographs in figures 7, 8, and 13. Figure 16 is © GIA and Tino Hammid; the X-radiograph in figure 17 was taken by Karin Hurwit.

GEMNEWS

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

TUCSON '93

Early February is always an exciting time for the gem community, as the many concurrent gem and mineral shows take place in Tucson, Arizona. These presentations, held in hotels, motels, and other locations throughout the city, attract jewelers, dealers, and mineral and gem enthusiasts from all over the world. As in years past, this Spring issue Gem News column focuses on highlights of this important event, based on observations by the editors and many of their colleagues at GIA and the GIA Gem Trade Laboratory.

DIAMONDS

Show update. Although the Tucson shows collectively are noted for colored stones, mineral specimens, and fossils, diamonds are being seen in ever-increasing quantities. This year, Malhotra Inc. of New York was offering natural green transmitters (diamonds that show green luminescence excited by visible light) from the Panna mine in India. We also saw two nice chameleon diamonds, one over 7 ct and the other approximately 2.5 ct.

One firm was marketing diamond briolettes, including a crudely strung necklace containing over 60 stones. All of the pieces (none of which appeared to be larger than 1 ct) were of fairly low clarity with a brown body color; they were identified as having come from India.

We were also pleased to note that companies offering clarity-enhanced diamonds were openly disclosing the fact of enhancement.

Figure 1. These "Diamond Stars" are fashioned in Israel. The stones shown here range from about 3 to 5 mm in diameter. Courtesy of Fancoldi Registered Trust; photo by Tino Hammid.

Star-cut diamonds. Although we have seen some successful attempts to cut and facet diamonds into five-pointed stars, we were impressed with the brilliancy and consistency of workmanship in the fashioned stones offered by Jeff Pancis of Pancis Inc., Morris Plains, New Jersey, who is the U.S. agent for the Fancoldi Registered Trust, the Swiss company offering the new cut (figure 1). Not only are the diamonds themselves of unusually good quality, but the patented star design incorporates 66 to 76 facets, depending on the size of the stone. The star cuts are also available in fancy colors.

Because as much as 80% of the stone's original weight may be lost during fashioning, the stars are sold by clarity and diameter (i.e., approximating that of a circle drawn around the five points), not by weight. The stones on display at Tucson ranged from 3 mm to 9.7 mm in diameter and averaged about 5 mm.

Marketed under the trademark "Diamond Stars," the stones are all fashioned in Tel Aviv, Israel, and have been in production only since September 1992, according to a Fancoldi spokesman. He added that lasers are sometimes, but not always, used in the cutting process. However, finishing—especially polishing the junctions between points—is the most difficult part of the manufacturing process.

COLORED STONES

Exceptional iris agates. Iris agate is one of the rarest phenomenal gem materials. When viewed at certain angles in transmitted white light, this gem exhibits spectral colors that are caused by diffraction from the many fine, closely packed parallel layers of chalcedony that comprise this material.

At Tucson, we saw several fine iris agates (figure 2), fashioned free-form pieces that ranged from roughly 10 to 25 ct. According to Michael Randall of Crystal Reflections, he had 32 matched pairs and 16 single pieces of this material cut from a single piece of Oregon rough that had been obtained some three years earlier. The phenomenal nature of the material was discovered by accident, when the rough was dropped and the iris effect noted in a small fragment.

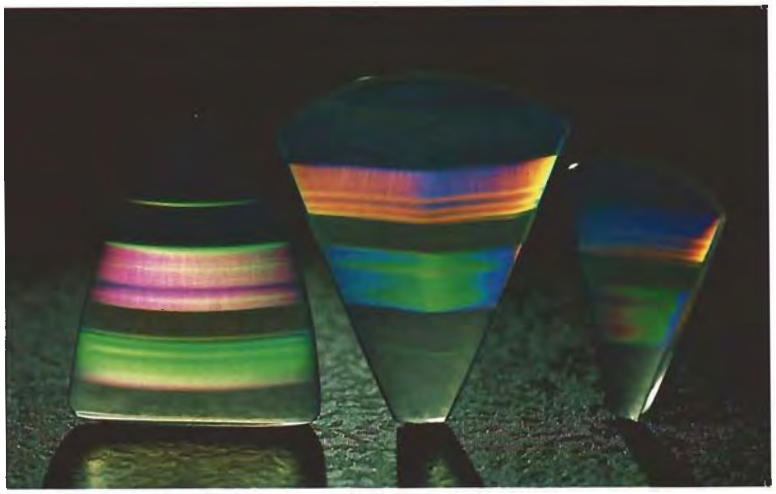


Figure 2. These three tongue-shaped cabochons (13.56–25.61 ct) of iris agate were among several fashioned from a single piece of Oregon rough. Courtesy of Michael Randall; photo by Robert Weldon.

Baltic amber. Several kilograms of Baltic amber were being marketed by Polish dealers, many of whom were attending Tucson for the first time. On display were some large pieces, up to 30 cm in length. It would appear from the quantities available at Tucson, as well as from those reported previously (see, e.g., entries in the Fall and Winter 1992 Gem News columns) that there are still considerable reserves of this material.

Our readers should note that one dealer from Warsaw maintained that it is an accepted trade practice in some countries to treat Baltic amber (including clarification and pressing) without disclosing the enhancement.

Amethyst from Uruguay . . . The Winter 1992 Gem News included a brief entry on Uruguay as a commercial source of agate and amethyst. At Tucson, we visited the booths of firms marketing Uruguayan amethyst in either specimen or fashioned form. The mineral specimens we saw consisted primarily of aggregates of small (approximately 1 cm wide) crystals of good color. We also saw slices consisting of amethyst peripheries and agate cores. The faceted stones we saw were also deeply colored—no light-toned material—and in a range of sizes appropriate for jewelry use.

One of the editors also met Eduardo Casabo, director of the New York–based Economic and Commercial Department of the Uruguayan Government Trade Bureau. This gentleman was in Tucson to learn first-hand about the gem industry, as well as to make available brochures containing useful information relating to such areas as demographics, foreign trade regulations, and foreign trade services in Uruguay.

. . . and amethyst-citrine from Bolivia. For more than a decade, quartz gems displaying distinct amethyst and citrine color components have been available in fashioned form. Because of the lack of rough crystals in the trade, there was some question when this material was first introduced as to whether or not some or all of it had not been produced by heat and/or irradiation treatment of amethyst (see, e.g., K. Nassau, "Artificially Induced Color in Amethyst-Citrine Quartz," *Gems & Gemology*, Spring 1981).

This year at Tucson, however, rough as well as fashioned material was being offered. All reportedly comes from the Anahi mine in eastern Bolivia, close to the border with Brazil. Joseph A. Rott of Tropical Imports, New York, had 50 kg of facet-grade rough and 20 kg of mineral specimen–quality material. Mine owner Ramiro Rivero, of Minerales y Metales del Oriente S.R.L. (Santa Cruz, Bolivia), was showing several faceted specimens as well as some rough crystals.

Some of the crystals were fairly well formed, singly terminated prisms; others appeared to have been strongly etched (see, e.g., figure 3). The color zoning ranged from moderate to distinct and in some cases clearly ran the length of the crystal. The presence of so much rough material and the first-hand information from reliable professionals who have visited the source provides abundant evidence that amethyst-citrine occurs naturally.

Apatite from Brazil and Madagascar. We saw approximately 100–200 ct of an intense, dark greenish blue apatite that the dealer, Luizhélio Barreto da Silva Nen, reported was discovered in 1992 at Ibira, a locality near the town of Jacobina in Bahia, Brazil. The material occurs as heavily etched crystals in association with jasper and feldspar. Mr. Barreto also showed us crystal fragments of a very dark, saturated blue apatite from this same locality that, he indicated, has been available for about three years.

We saw greater amounts, both rough and cut, of the bright greenish blue to bluish green apatite from

Figure 3. This strongly etched 836.5-ct amethyst-citrine crystal and 22.32-ct faceted stone are from the Anahi mine, in eastern Bolivia. Crystal courtesy of Joseph A. Rott; stone courtesy of Ramiro Rivero; photo by Maha DeMaggio.

Madagascar that we first noted in the Summer 1990 Gem News section. One dealer was marketing it as "Paraibite." Rudi Cullmann, of Idar-Oberstein, reported that the same area of Madagascar was producing a dark, slightly bluish green apatite that is generally very clean and exhibits no change in color with heat treatment up to 450°C. Subsequent gemological testing on one sample obtained for study revealed properties within the published ranges for this gem material.

Uncommon cat's-eye gems. One firm was offering a 10.90-ct cat's-eye alexandrite (reportedly from Brazil) that exhibited an attractive color change. Another showed a 7.55-ct stone with an attractive, though somewhat less spectacular, color change that is reportedly from Orissa, India. Also seen was a 9.40-ct bicolored tourmaline with the eye centered down the middle of the stone at the junction of the red and green halves.

Gems with natural crystal surfaces. Our Spring 1991 show report included an entry on drusy gems—fashioned gem materials that prominently displayed natural surfaces of minute crystal faces. Drusy gems noted this year include chrysocolla in quartz, sphaerocobaltite, and a bright white pectolite from New Jersey. We noted other materials prepared for gem use with one or more natural surfaces intact. These included a fine-grained black schist embedded with small pyrite crystals and a pyrite with iridescence produced by an intentional acid treatment (according to Bill Heher of Rare Earth Gallery, West Redding, Connecticut; figure 4).

Beryls from the Ukraine. Our Spring 1992 Tucson report contained a brief entry on golden beryl and aquamarine identified as being of Russian origin. This year, some exceptionally large (up to 0.5 m long), transparent yellowish green to greenish yellow beryl crystals and faceted stones, along with rough and cut aquamarine produced by heat treatment, were being offered by Wicast Ltd., Norman, Oklahoma, with the source identified as a large pegmatite at Wolodarsk in the Ukraine.

According to an article in the October 1991 issue of *Mineralien Magazin Lapis*, the pegmatites around Wolodarsk have been known for about 100 years. A Polish geologist, Gottfried Ossovski, was the first to find beryl as well as topaz in these deposits; mining began about 60 years ago. At the time this report was published, the large pegmatites producing gem-quality crystals were being worked at depths of 100 to 150 m. Ninety-six different minerals have been found, although topaz, quartz, and beryl remain the most important. All can occur as large single crystals, some as long as 2 m.

The distinctive surfaces of the beryl crystals (see, e.g., figure 5) are, according to the above-referenced report, the

Figure 4. This 83.29-ct pyrite section was fashioned to display its natural surfaces and then acid treated to induce an attractive iridescence. Courtesy of Bill Heher; photo by Maha DeMaggio.

Figure 5. A large pegmatite at Wolodarsk, Ukraine, produced this 314-gram beryl crystal. Courtesy of Wicast Ltd.; photo by Sky Hall.

result of secondary crystallization. We also learned through a colleague the heat-treatment conditions being used to produce blue stones from the greenish yellow to yellowish green material. First the stones are slowly heated in air to 350°C. This temperature is maintained for roughly 12 hours, at which time the oven is turned off and the stones are allowed to cool slowly. A dealer involved in the treatment and marketing of this material indicated that it is very consistent in its response to heat. It is therefore possible to predict fairly accurately the color that will result by the depth of color and strength of the green component prior to heating.

One of the editors (EF) had been shown similar beryl crystals of Ukrainian origin in Idar-Oberstein, Germany, a few years ago. This material reportedly has been making its way to Europe for several years. What we saw this year at Tucson appears to be the beginning of a serious promotional effort in the United States.

Miscellaneous notes on emeralds. A number of dealers exhibited fine-quality Zambian emeralds, which were deep, slightly yellowish green and had fewer eye-visible inclusions than is typically seen in this material. Most of these stones are said to come from a new vein. Idar-Oberstein dealer Rudi Cullmann reports that the Nigerian "emerald" deposit, which created a debate in the trade over the nomenclature of the green beryls found there, is temporarily inactive.

We also saw emerald from Madagascar. This material, available for some time in Europe, is only starting to surface in the United States. It is slightly darker than average, and slightly yellowish green with a "brightness" that one dealer compared to green cubic zirconia. Specimens examined by one of the editors were relatively clean, with the feldspar inclusions that seemed so prominent in early material from this source conspicuously absent.

Extraterrestrial gem materials. Many collectors find the most fascinating of gem materials to be those that originate from beyond our own planet. At the 1992 Tucson show, we noted jewelry set with "Gibeon class" iron-nickel meteorite from Namibia (Gem News, Summer 1992). There was even more of this material this year, being sold as acid-etched blocks and plates ranging from a few grams to over a kilogram.

Although the editors saw only a few faceted pallasitic peridots like those featured in the article by Sinkankas et al. (*Gems & Gemology*, Spring 1992), at least two vendors were selling free-form "gems" of nickel-iron with peridot (see, e.g., figure 6). This material was reportedly fashioned

Figure 6. This 29.99-ct tongue-shaped cabochon was fashioned from a pallasitic meteorite. Photo by Maha DeMaggio.

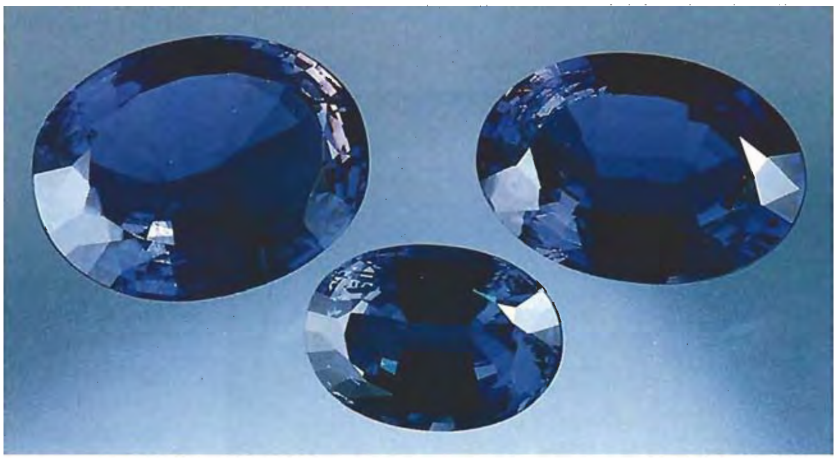
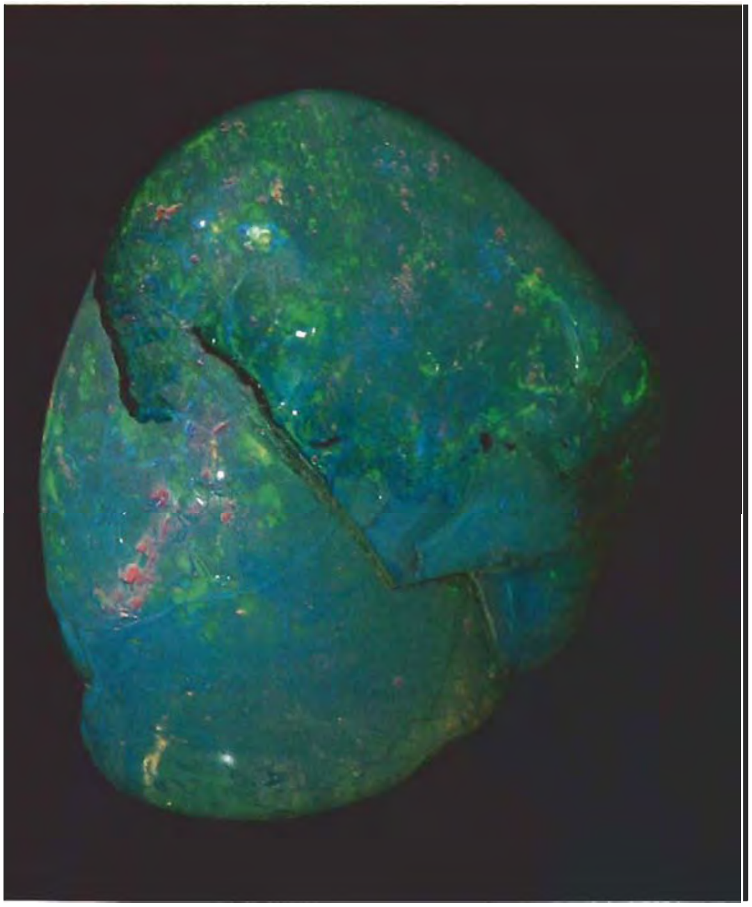


Figure 7. At 43.69, 97.78, and 111.02 ct, these Indian iolites are exceptionally large. Courtesy of Anil B. Dholakia, Adris Oriental Gem & Art Corp.; photo by Nicholas DelRe.

from parts of the large pallasite found in Esquel, Argentina, that was mentioned in the above-referenced article.

A number of natural glasses (known as tektites) were also available. While there is still debate as to whether these are of extraterrestrial origin, it is now more widely accepted that other-worldly forces were involved in their formation (e.g., the impact of meteors). Moldavite was again present in both rough and fashioned form, while tektites such as the black "Indochinites" from Thailand and a similar-appearing material from neighboring China were seen as rough. Also noted were irregular lumps of light yellow Libyan desert glass.

Figure 8. This 600-ct opal was found in northern New South Wales, Australia. Courtesy of Robert and Brendon Cleaver, Silver Orchid, Australia; photo by Robert Weldon.



Some unusually large gems. We saw a number of exceptionally large gemstones this year. Mark Smith from Bangkok had one of the largest faceted sinhalites the editors have seen, an attractive 240.60-ct light brown cushion shape that reportedly was cut from a 465-ct piece of rough recovered at Elapata Village, approximately 6 km north of Ratnapura, in Sri Lanka. The stone is so large that one can actually see doubling of the pavilion facet junctions through the table with the unaided eye.

A number of dealers offered large (up to 17 ct), clean, brown faceted sphenes (titanites) from Sri Lanka. The strong dispersion was nicely enhanced by the medium dark brown body color.

Art Grant, of Coast-to-Coast Rare Stones, Martville, New York, exhibited a fine 673.14-ct faceted pink fluorite from Pakistan that was cut in a modified hexagon. Mr. Grant did not know of any larger faceted pink fluorite from this locality.

The editors have seen few faceted iolites larger than about 10 ct. It was thus with some surprise that we came across three very large stones at one exhibitor's booth. The 43.69-, 97.78-, and 111.02-ct stones (figure 7) reportedly were all cut from a single crystal of Indian origin.

Also seen was an approximately 600-ct opal found in the 1920s at Tintenbar, in northern New South Wales, Australia (figure 8). This unusually large piece of white opal, which shows good play-of-color, formed in a basaltic environment.

Jadeite from the Russian Federation. Although Myanmar (formerly Burma) is the best known and commercially the most important source of jadeite, other localities (e.g., Guatemala) have also produced this gem material. This year at Tucson we were shown jadeite from the Russian

Figure 9. These jadeite cabochons (15.92 and 18.44 ct) were cut from material mined in the Sajany Mountains of the Russian Federation. Photo by Maha DeMaggio.

Federation. Representatives of the renowned Fersman Mineralogical Museum in Moscow were offering some semitranslucent, strongly mottled, grayish green cabochons that resembled Guatemalan material (figure 9), which reportedly came from the Sajany Mountains. The firm White Nights/USIM had small slabs of semitranslucent green jadeite with a very saturated color that a representative identified as coming from south-central Siberia, near Lake Baikal, which is just east of the Sajany Mountains. Therefore, the different specimens may actually originate from the same source.

Gemological testing of a 15.92-ct grayish green round cabochon obtained from the Fersman representatives revealed properties consistent with those published for jadeite, including a strong 437-nm absorption line. X-ray diffraction analysis then confirmed the identification. Examination of a small fragment of the more saturated green material with a desk-model spectroscope revealed the strong absorption lines in the red that are attributed to chromium in jadeite.

Lapidary art. Among the large number of excellent gemstone carvings available at Tucson this year, of particular interest were those that took advantage of the internal features of the host gem to add significantly to its appearance.

Judith Whitehead, of San Francisco, had a pair of 33-mm-long oval cabochons of rock crystal quartz that had been fashioned to place a prominent band of bright red inclusions right down the center of each (figure 10). Magnification revealed the inclusions to be transparent, with the general appearance of hematite or lepidocrocite.

Kusum S. Naotunne, of Ratnapura, Sri Lanka, showed us the unique 14.19-ct zircon illustrated in figure 11. The numerous iridescent discoid fractures that create the aventurescent effect resulted from metamict breakdown of the host. In this instance, the lapidary very carefully placed this layer under the table facet and at an angle just off parallel to the table plane so that the aventurescence would be seen without distracting light reflections from the table surface itself.

Opal from Canada. The February 1993 issue of *Lapidary Journal* contains an article by Paul B. Downing on a recent find of opal in British Columbia, Canada. At Tucson, one of the editors examined some of this material and spoke with Professor Downing and Robert Yorke-Hardy. The latter is involved in the prospecting and recovery of the opal.

The material is found in basalt—sometimes with chalcedony—at a site within approximately 40 km (25 mi.) of the town of Vernon. The opal ranges from transparent to opaque; most exhibits a yellow-to-brown body color reminiscent of material from Mexico, although colorless opal with strong play-of-color has also been found (see, e.g., figure 12), as well as much common opal. Mr. Yorke-Hardy volunteered that most of the effort to date has gone into exploration rather than recovery, and that the true extent of the opal field has yet to be determined.

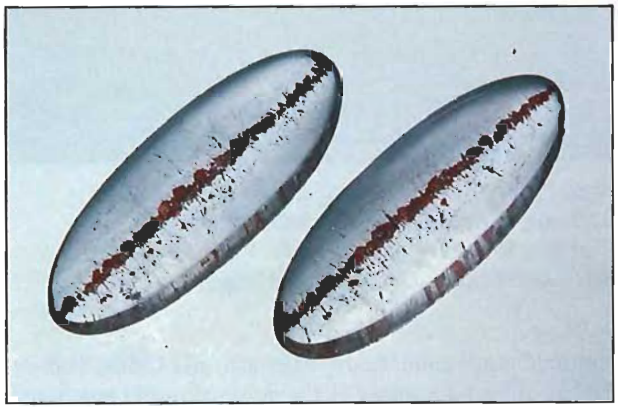


Figure 10. Each of these 33-mm-long quartz cabochons is highlighted by a distinctive band of bright red inclusions. Photo by Maha DeMaggio.

Figure 11. The aventurescence in this 14.19-ct zircon was created through careful orientation of the inclusions. Photo by Maha DeMaggio.

Figure 12. This opal in basalt matrix (32.5 × 29.3 × 31.5 mm) is from British Columbia, Canada. Courtesy Robert W. Yorke-Hardy, Y-H Technical Services Ltd.; photo by Maha DeMaggio.

Cultured pearls from Tahiti, Australia, and China. Tucson dealers offered a number of the cultured pearls purchased at the October 9–10, 1992, auction held in Papeete, Tahiti. This auction is held annually by G.I.E. Poe Rava Nui, an organization that represents several hundred family and cooperative pearl farms in French Polynesia. Approximately 50,000 Tahitian cultured pearls, divided into 120 lots, were offered; all but one lot sold. The average price per cultured pearl was US$100, with the highest price—US$445 each—paid for a lot of 411 pearls in the 10–13 mm range. The success of the auction was primarily attributed to G.I.E.'s emphasis on quality over quantity in their selection of materials. They also limited each lot to one shape (rounds, ovals, etc.) and to goods of comparable value. On our return from Tucson, however, we learned that a devastating cyclone hit French Polynesia in the Tuamotu Archipelago on February 10, causing extensive damage to the cultured pearl industry.

Large, white baroque cultured pearls from Australia were also available, as were high-quality tissue-nucleated cultured pearls from China. The Chinese are working to develop perfectly spherical cultured pearls by means of tissue nucleation.

Figure 13. These natural freshwater pearls and non-nacreous concretions (5.5–8.5 mm in diameter) are from Quebec, Canada. Courtesy of Claudette Bouchard; photo by Robert Weldon.

Natural freshwater pearls from Quebec. Claudette Bouchard and Jean Boisvert, of Aux Pierres Fines Enr., Alma, Quebec, loaned the editors seven natural freshwater pearls and nonnacreous concretions from Quebec (figure 13). These ranged in diameter from 5.5 to 8.5 mm. Some of the concretions were only partially covered with nacre, and a reddish brown one had none. The nacreous parts and pearls showed white to pinkish white body color, and one was purplish pink. All had very high luster. Some had minor holes, indentations, and blemishes; some were "circled" or "ringed." The largest Quebec pearls documented thus far are 9.8 and 10.5 mm in diameter. One pearl and one concretion had been sawn in half; note in figure 13 the concentric-layer structure typical of natural pearls. The X-ray luminescence of these pearls was a weak white glow, as would be expected from river pearls of these body colors.

All of these pearls and concretions had been harvested during the preceding few summers, initially by chance and then by curiosity. They form in a freshwater mollusk from the *Unio* family, which is found in the waterways north of the Lac St. Jean area, around the 50th parallel. These mussels measure between 15 and 20 cm and generally show barbs on their shells. The temperature in this area is known to dip as low as –40°C, and one wonders how these mollusks can survive in such an extreme environment.

"Peeling" pearls. Charles Yousling, of Charles of Fairhaven in Burlington, Washington, encountered uncommon success at Tucson in finding and extracting spherical black cultured pearls—from within their baroque casings. Mr. Yousling recovered the 10.5-mm round pearl illustrated in figure 14 by carefully peeling (with a knife) a baroque Tahitian cultured pearl similar to that shown in the upper left-hand corner. He repeated his success only a few days later, as evidenced by the partially peeled pearl on the right. The "shell" of nacre removed from that specimen is

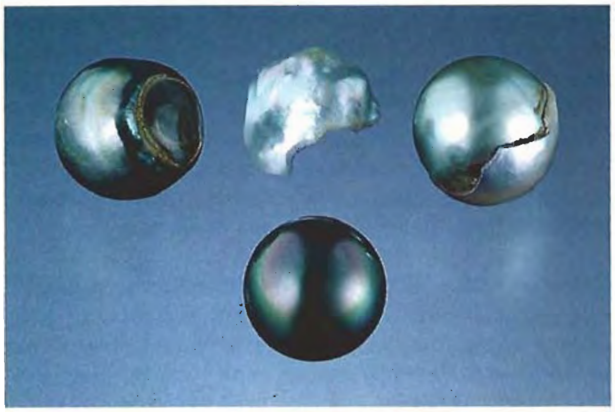


Figure 14. The 10.5-mm round black cultured pearl at the bottom was recovered by peeling a baroque cultured pearl similar to the one at the upper left. Another round cultured pearl (far right) is in the process of being peeled, with the original "skin" shown here in the upper center. Courtesy of Charles Yousling; photo © GIA and Tino Hammid.

shown here in the center. Of the 80–100 baroque Tahitian cultured pearls Mr. Yousling has peeled over the past five years, he has uncovered 10 round pearls. In selecting a possible candidate, he first looks for one that has enough weight to justify the peeling and does not rattle when shaken. Another clue is the ability to transmit light through the first translucent layer of nacre to the one below. A small flashlight is a great help here and, surprisingly, a toothpick: Sometimes the round pearl inside the top layer of nacre can be rotated by careful manipulation through a surface flaw with a toothpick—the trick Mr. Yousling used to find the 10.5-mm pearl. He only selects relatively inexpensive pearls (the one that produced the round bead shown here cost US$20) because of the uncertain outcome of the peeling process. Note from the exposed seed on the baroque cultured pearl in the upper left of figure 14 that the nacre was too thin to enclose a nacreous round bead.

Peridot from Ethiopia. One of the benefits of attending Tucson is the opportunity to see gem materials from new localities. This year proved no exception, with peridot from Ethiopia making its "Tucson debut." Among other dealers, Rudi Cullmann was offering rough that he had received via Nairobi. He and a colleague indicated that the material had first become available in mid-1992.

According to a brief report by Dr. N. R. Barot in the February 1993 issue of the *ICA Gazette* ("Gem deposits discovered in Ethiopia and Somalia"), the peridot was found near the villages of Mega and Magado in the far south of Ethiopia, within the Mega escarpment and about 110 km northeast of Lake Turkana. This represents the northernmost gem deposit found to date in the Mozambique orogenic belt, which runs from Mozambique, through the gem-rich areas of East Africa, to Somalia on the Gulf of Aden. The peridot occurs in basalt "balls" that are scattered on a desert plain. Dr. Barot states that clean, facetable material over 2 grams is rare, an observation consistent with what we saw in Tucson.

In terms of color and the irregular shape of the rough, the material is reminiscent of peridot from the San Carlos Apache Indian Reservation in Arizona. Unlike San Carlos material, however, the Ethiopian rough appears more consistent in color from piece to piece. Seven rough pieces and seven faceted stones were purchased for further investigation (see, e.g., figure 15). Gemological testing revealed properties consistent with peridot from other localities. With magnification, we noted the following internal features in one or more of the fashioned stones: roughly circular decrepitation halo cleavages ("lily pads"); partially healed fractures, some with yellowish staining (possibly limonite); nearly opaque, dark reddish brown octahedra (possibly chromian spinel); and translucent, somewhat brown inclusions, possibly distorted spinel crystals. Also noted were wisp-like streamers that, when abundant, imparted a hazy appearance to the host that was different from a similar effect sometimes seen in peridot because of its strong doubling. All of these internal features have been noted in peridot that formed in similar environments such as Arizona and China.

Red quartz from Mexico. David R. Hargett of New York showed the editors some unusually bright, slightly brown-

Figure 15. Southern Ethiopia is the reported source of these three faceted peridots (the square-cut stone is 2.76 ct). Photo © GIA and Tino Hammid.

Figure 16. This 8.65-ct partially polished piece of red quartz and the accompanying faceted stone appear to be colored by inclusions of the fibrous form of cuprite known as chalcotrichite. Courtesy of David Hargett; photo © GIA and Tino Hammid.

ish red quartz (figure 16) from Mexico. With magnification, we saw a multitude of tiny, randomly oriented red fibers throughout this material. The appearance of the inclusions and the fact that the red quartz was found in the walls of a copper mine in Zacatecas, suggests that they might be the fibrous form of the copper oxide cuprite known as chalcotrichite. EDXRF analysis showed a very high copper content and virtually no iron in the quartz. Previous examples of red quartz have been found to be colored by some type of iron compound such as hematite-stained limonite.

Mr. Hargett indicated that the supply of this red quartz seems to be quite limited, but the actual reserves are not known. Mining for copper minerals is ongoing in the area.

Miscellaneous fashioned curiosities. Art Grant, of Coast-to-Coast Rare Stones, again offered a number of unusual faceted materials, including: a 2.45-ct near-colorless faceted ezcurrite from Argentina (difficult to cut because it "shreds" on the lap); a 2.00-ct probertite from Germany; a 0.14-ct light brown mooreite (as slippery as mica); and a 20.18-ct near-colorless brucite from the Russian Federation.

Gilles Haineault, from Montreal, Quebec, had a roughly square-shaped 1.22-ct faceted leifeite from Mont St. Hilaire, Quebec. Although relatively abundant at Mont St. Hilaire, leifite rarely occurs in transparent pieces.

Transparent rhodochrosite from Colorado. One of the most spectacular gem materials seen at Tucson was rhodochrosite from the recently reopened Sweet Home mine near Alma, Colorado. According to a representative of The Collector's Edge, a firm displaying and marketing this material in both mineral specimen and faceted form, some very rich pockets were uncovered in the latter half of 1992. One of these (the Good Luck pocket, found in September) produced some 500 pieces. Among the faceted stones were a 51.58-ct cushion shape, a 33.39-ct rectangular brilliant, and a 21.51-ct round brilliant, all cut by Michael Gray. These stones were not only exceptionally large, but they were also lighter in tone and more transparent than is typically seen in such material (figure 17). Among the unfashioned specimens was a euhedral crystal, measuring about 10.5 × 10.5 × 6.0 cm, on matrix.

Update on rubies. Rubies from Myanmar (Burma) appeared to be more available this year than last, with several dealers even offering calibrated Burmese melee, a sure sign that the material is abundant. Rubies from Vietnam were also more widely available this year, and the overall quality appeared to be higher. In addition, we saw more truly red stones than previously, when a significant number of the Vietnamese "rubies" offered were actually pink sapphires.

Several dealers had very attractive Afghan stones, some truly red, up to approximately 1.5 ct. These came from renewed production at the well-known Jegdalek locality. Many specimens on matrix were available at the mineral shows. Gary Bowersox, of GeoVision Inc., had one cabochon that was bicolored blue and red, indicating that blue sapphire might be present at the same locality.

South India has long been known as a source of a generally low-end commercial grade of star corundum. This material, which typically shows pronounced hexagonal zoning and a pale brownish red to purple color, is sometimes referred to as "mud ruby" in the gem industry. This year we saw for the first time another type of red to pink

Figure 17. This 5.87-ct rhodochrosite was fashioned by Michael Gray from material recovered in 1992 from the Sweet Home mine near Alma, Colorado. Courtesy of Ralph Mueller and Assocs., Scottsdale, Arizona; photo by Maha DeMaggio.

Figure 18. These ruby and pink sapphire cabochons, ranging from 2.72 to 3.44 ct, are from southern India. Courtesy of Ketan and Anil B. Dholakia, Adris Oriental Gem & Art Corp.; photo by Maha DeMaggio.

corundum, reportedly from Karnataka, about 160 km (100 mi.) south of Mysore in southern India. Although no better than translucent in diaphaneity, the material appeared evenly colored and was a far more attractive, saturated color (figure 18) than the asteriated stones described above.

Miscellaneous notes on sapphires. As one of the most popular of colored stones, sapphires were abundant in Tucson. Thailand, Australia, and Sri Lanka were well represented, with smaller amounts from sources such as Colombia, Montana, Tanzania, and Vietnam.

The firm Gemstone International was offering 20 color-change sapphires, most in the 1- to 3-ct range, although the largest was 7.16 ct. Uncut black "star" sapphires from Mato Grosso, Brazil were also seen this year, as was an unusual collection of parti-colored sapphires from Montana that had been cut to emphasize the color zoning.

Spessartine garnet from Africa. Also introduced at Tucson this year was an intense orange garnet from a locality in Africa. Various dealers identified the source as Namibia or the Kunene River (which runs along the border between Namibia and Angola). At one of the shows, mineral specimens of this material were labeled "Marienfluss," reportedly the name of a town in northern Namibia.

The vast majority of the material we saw was being marketed by Colgem Ltd. of Ramat-Gan, Israel. It was represented as "Hollandine" in honor of the House of Orange, the royal family of the Netherlands. According to information provided by Israel Eliezri of Colgem, the material was originally found in the late 1800s, by a Dutch adventurer who died before he could start mining. Subsequently forgotten, the locality was only rediscovered recently.

The euhedral crystals typically exhibit 24 faces, with either gyroidal or trapezohedral morphology. Cut stones average 2 ct, with the largest fashioned gem to date weighing 13.77 ct. Two crystals and one fashioned gem (figure 19) were subsequently loaned to the editors for examination. Gemological properties determined on the fashioned piece were as follows: R.I. of 1.791; S.G. of 4.10; and a weak, desaturated orange appearance through the Chelsea filter. Absorption features noted with a desk-model prism spectroscope were an absorption cutoff at about 445 nm, a distinct diffused band just above 460 nm, a stronger and wider diffused band between 480 and 490 nm, and a weak diffused bank from about 525 to 545 nm. Magnification revealed angular and roiled graining throughout the stone; semiparallel, curved fibrous inclusions resembling bysso-

Figure 19. These two well-formed crystals (8.62 and 8.38 ct) and faceted stone (3.93 ct) of spessartine garnet are from a recently rediscovered source in Africa. Courtesy of Israel Eliezri, Colgem Ltd.; photo by Maha DeMaggio.

Figure 20. Note the three distinct color zones in this 21.88-ct zoisite. Courtesy of Cynthia Renée; photo by Shane F. McClure.

Figure 21. This unit, the larger of two "LubriGem" systems, was developed in Israel to fill fractures in emeralds.

lite asbestos; and somewhat rounded, transparent, near-colorless crystals (possibly apatite) in a cluster and in association with dark, opaque angular crystals, possibly a manganese oxide.

On the basis of the criteria established by Stockton and Manson (see *Gems & Gemology*, Winter 1985), this garnet should be classified as spessartine. Note, however, that it is not a pure spessartine, as EDXRF analysis identified the presence of a significant amount of Fe and traces of Ti. The very saturated color, which led a number of gemologists at the show to hypothesize that this was pure spessartine, is actually due to Fe–Ti charge transfer absorbing considerable blue light, in addition to the expected Mn features.

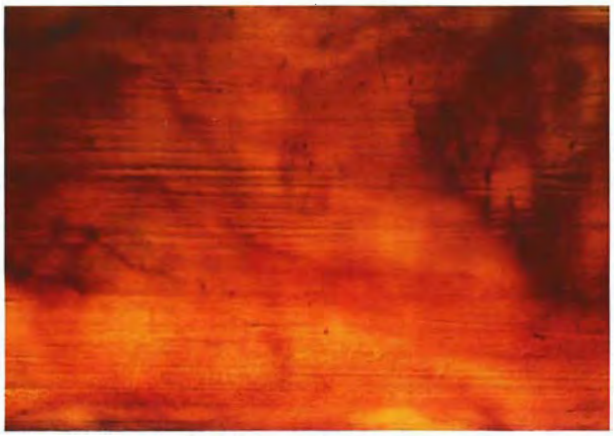


Figure 22. Grain boundaries are evident in this 62-gram reconstructed amber produced in Czechoslovakia. Photo by Maha DeMaggio.

Tourmaline from Paraíba, Brazil. The distinctive cuprian tourmaline from Paraíba, Brazil, was again available, although not in great quantities. Most of the stones we saw were small, less than 1 ct. For example, the firm Organizaçóes Manoel Nogueira Ltda. of Minas Gerais, Brazil, had about 1,000 ct of round melee 2.6–3.5 mm. This firm also had an exceptional 4.80-gram bicolored—violetish blue and blue-green—crystal with no eye-visible inclusions, although the well-formed prism faces exhibited distinct striations. A number of dealers had slices of concentrically zoned—watermelon-type—material from Paraíba. We did see some faceted stones in the 2- to 4+-ct range, some reportedly of natural color and others identified by the vendors as having been heat treated.

We also saw crystals of dark yellowish green tourmaline with highly reflective, yellow metallic-appearing

Figure 23. Crystal-pulling techniques are being used increasingly to produce materials with gem applications, such as these specimens of synthetic corundum (e.g., the red boule, 18 cm long × 7.5 cm in diameter) and YAG (e.g., the blue wedges, 2.8 cm long × 1 cm thick). Courtesy of Manning International; photo by Nicholas DelRe.

inclusions (see Gem News, Fall 1992, p. 205, for a faceted example). According to Luizhélio Barreto da Silva Nen of Recife, Brazil, this material is found below the levels from which the brightly colored crystals are recovered. Further down, only black schorl is found.

Staff members were also shown some blue-green Paraíba-like tourmaline—the largest, a 52.96-ct pear shape—that was said to come from a new find near Araçuaí in northeast Minas Gerais. A knowledgeable dealer informed one of the editors that tourmaline recently discovered from another locality was being misrepresented as Paraíba material. Although this newer material might resemble that from Paraíba, it reportedly does not respond as well to heat treatment; that is, the resulting colors are not as saturated.

Parti-colored zoisites. A Gem Trade Lab Note in the Winter 1992 *Gems & Gemology* describes and illustrates a distinctly bicolored (violetish blue/yellowish green) 2.52-ct zoisite. We saw a small number of similar-appearing fashioned stones this year at Tucson. One firm, DW Enterprises of Boulder, Colorado, had four faceted stones ranging from 1.50 to 4.29 ct. We also saw a distinctive 21.88-ct cabochon that displayed a green section between two blue zones (figure 20).

When GIA staff members examined some of the rough material described in the article "Gem-Quality Green Zoisite" (N. R. Barot and E. W. Boehm, *Gems & Gemology*, Spring 1992), they noted blue zones in several pieces. Thus, it is quite possible that additional bicolored stones will appear in the trade.

ENHANCEMENTS

Apparatus for fracture filling gems. The Fall 1992 Gem News section contained an entry on a kit for color treating emeralds. This system included a green oil-based dye and used heat—but no pressure or vacuum apparatus—to facilitate penetration into surface-reaching breaks.

This year we saw another system being promoted to enhance the appearance of emeralds (figure 21). Marketed as "LubriGem," it was developed by Zvi Domb, an engineer from Ramat-Hasharon, Israel.

The apparatus uses a thick-walled metal cylinder that is filled to about 50%-60% of its volume with the substance of choice. Mr. Domb has found that cedarwood oil works best with Colombian emeralds, and paraffin works well with Zambian stones. He indicated that synthetic polymers such as Opticon can also be used in his system.

After the filler has been melted and/or reduced in viscosity through heating in the cylinder to approximately 95°–100°C, the stones to be treated are placed in a perforated glass cup and immersed in the filling medium. A spring-driven metal piston is then inserted into the top of the cylinder and tightened by hand to pressurize the contents. Stones are treated from 30 minutes to 12 hours (longer times are recommended for better results), after which the heating element is turned off, and the stones are removed and cleaned with a piece of cloth. The system is available in two sizes, one that accommodates several small cups at a single time, and the other—a portable unit—that can handle only one cup.

SYNTHETICS AND SIMULANTS

Reconstructed amber. Amber was abundant at the shows this year. One substitute for natural block amber seen was reconstructed amber, also known as "pressed amber" and "ambroid." This material, marketed by the firm Solar-X International, was available as unfinished cylinders and blocks, as well as in sectional bracelets. According to a representative of the firm, the material is produced in Czechoslovakia from Baltic amber recovered from the Kaliningrad region of Russia. The representative also volunteered that nothing was added to the amber during reconstruction (R. T. Liddicoat's *Handbook of Gem Identification* [1989] indicates that linseed oil is usually added).

One sample, a 62-gram cylinder (figure 22), was purchased for examination. The material exhibited an aggregate reaction between crossed polarizers and no strain colors; a variegated luminescence to U.V. radiation (long wave—weak to strong chalky bluish white and faint to weak dull brownish yellow; short wave—faint to weak, dull chalky brownish yellowish green); 1.53 spot R.I.; and 1.06 S.G. In addition to enhancing the veil-like brown outlines of the individual pieces of amber (which can also be seen with the unaided eye), magnification revealed several small, round gas bubbles. However, no stretched gas bubbles, which are sometimes associated with pressed amber, were noted.

More "pulled" synthetic materials available. As noted in the Winter 1992 Gem News column, much of the crystal-growth research that has potential relevance to the gem industry involves Czochralski and other pulling techniques. Last year at Tucson, we saw "pulled" blue, green, and pink synthetic sapphires; yttrium aluminum garnet (YAG) in a number of colors; and synthetic alexandrite.

This year the above materials were again being offered, as were synthetic ruby and synthetic pink sapphire in a wider range of tones. According to one vendor, such pulling techniques generally produce large crystals of very uniform color. He indicated that his firm had sold 400,000 carats of "rough" synthetics during the first two months of 1993. Some representative colors of synthetic corundum and YAG are shown in figure 23.

Miscellaneous emerald simulants. Emerald is typically one of the more highly included single-crystal gem materials, and lower-quality stones often exhibit reduced diaphaneity. Therefore, materials with aggregate structures can be faceted to imitate translucent emeralds. Three such materials were seen at Tucson this year: chrysoprase chalcedony from Australia, dyed green chalcedony, and aventurine quartz from India. In particular, about 200 carats of the quartz were being offered by one firm, all emerald cut. The uneven color distribution might cause someone to believe that the stones were low-quality emerald or beryl that had been treated with a colored fracture filler.

UPDATE

1993 Burma Emporium. Prior to making a return visit to the Mogok Stone Tract, Robert E. Kane and Dr. Edward Gübelin attended the 30th annual Gems, Jade, and Pearl Emporium, which was held February 18–28, 1993, in Yangon, Myanmar (formerly Rangoon, Burma). They provided Gem News with the following report.

The Myanma Gems Enterprise (MGE) 30th Emporium concluded with total sales of US$14,657,185, just short of the record $14,839,891 sales at the 27th (1990) Emporium. A total of 654 people, from 16 countries, attended the 1993 Emporium.

Jadeite jade attracted the majority of buyers (458 from Hong Kong alone) and commanded the highest dollar amount, with total sales of $11,472,889. Of the 540 jade lots offered, 343 sold; the reserve asking price was not met on the other 197 lots. It is interesting that this year's auction also featured a small selection of rough maw-sit-sit from the Tawmaw area, in the jadeite-mining district of upper Myanmar.

Pearls cultured in the Mergui Archipelago region of southern Myanmar brought in $642,255. The 179 lots of "gems," the Emporium's third auction category, sold for a total of $1,008,629. These lots were primarily composed of rubies and sapphires (most already cut, although some rough was offered). This year the auction also included small quantities of peridot, various colors of spinel, green tourmaline, danburite, almandine garnet, aquamarine, diopside, enstatite, zircon, colorless topaz, and scapolite. A 21-kg piece of lapis lazuli that sold reportedly came from a deposit just beyond the Dat Taw ruby mine in Mogok. Thirty-three lots comprising 106 faceted diamonds were offered, but only 61 stones in 17 lots sold.

As reported in the article "Status of Ruby and Sapphire Mining in the Mogok Stone Tract," which appeared in the Fall 1992 issue of *Gems & Gemology*, there is an important new mining district in Myanmar, at Monghsu. At the 30th Emporium, 14 lots of Monghsu ruby were offered. Three lots each contained 1,000 carats of small (1,033 pieces in one lot, 1,300 in each of the other two), untreated ruby rough from this exciting new locality. Because the MGE had always taken pride in the fact that none of the rubies and sapphires offered at the Emporium had been subjected to heat treatment, the fact that the 11 remaining lots of faceted Monghsu ruby were prominently labeled as heat treated represented a historic first for the MGE Emporium. However, heat treatment of these stones is necessary to remove the distinct blue, hexagonal zoning (which is oriented down the center of the crystal, along the c-axis) in this naturally dark to very dark, slightly purplish red material. The resulting color is a very attractive medium to dark red that is comparable to fine rubies from Mogok. Mr. Kane and Dr. Gübelin also saw a great deal of faceted, heat-treated Monghsu ruby in Bangkok.

ANNOUNCEMENTS

We are proud to report that *Gems & Gemology* won first place for best professional journal in the 1992 Gold Circle Awards competition sponsored by the American Society of Association Executives (ASAE). In addition, the article "Rubies and Fancy Sapphires from Vietnam" was awarded a certificate of achievement in feature writing—scientific/education, the second highest award in that category. Authored 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 article appeared in the Fall 1991 issue of *Gems & Gemology.* Of particular interest, given the journal's reputation for fine graphics and color reproduction, is the fact that the "feature writing" award was awarded on the basis of the text only, as required by the rules of the contest.

Editor Alice S. Keller traveled to Washington, D.C., to accept the two awards at the ASAE's 10th Management Conference (figure 24).

Figure 24. Gems & Gemology *Editor Alice Keller (right) accepts the 1992 ASAE award for best professional journal from ASAE Executive Director Quincalee Brown.*

Acknowledgments: The editors thank the following individuals for contributing information and/or assisting in testing items described herein: Gustave P. Calderon, Karin Hurwit, Patricia Maddison, Shane F. McClure, and Cheryl Wentzell of the GIA Gem Trade Laboratory, Santa Monica; and Nicholas DelRe and Kenneth V. G. Scarratt of the GIA Gem Trade Laboratory, New York.

Gems & Gemology

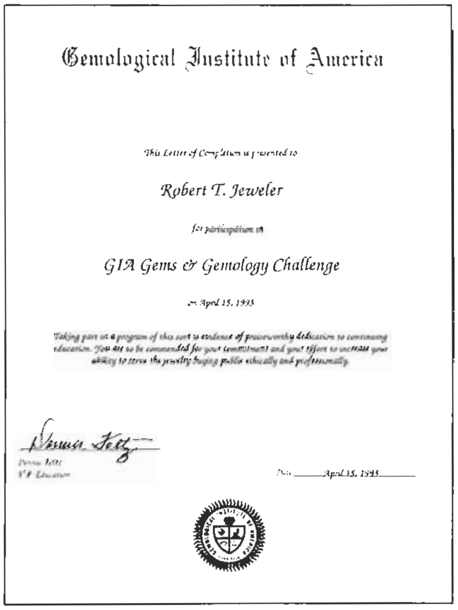
C·H·A·L·L·E·N·G·E

Diamond exploration in Canada and the Russian Federation, the vast gem potential of Tanzania, advances in diamond synthesis, the identification of "bleached" jadeite, the resurgence of ruby mining at Mogok. . . . It's been an exciting year in the world of gemology, and we've worked to uphold *our* commitment to keep you well informed on every new development.

Now, along with GIA's Continuing Education Department, *Gems & Gemology* challenges *you*.

Based on information from the four 1992 issues of *Gems & Gemology*, the following 25 questions call on you to demonstrate your knowledge of this dynamic field. Refer to the feature articles and Notes and New Techniques in these issues to find the *single best answer* for each question, then mark your letter choice on the response card provided in this issue. Mail the card to us by Friday, August 20, 1993. 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 in recognition of your achievement. Earn a perfect score of 100% and your name will also appear "in lights" in the Fall 1993 issue of *Gems & Gemology*. Good luck!



Gemological Institute of America

This Letter of Completion is presented to

Robert T. Jeweler

for participation in

GIA Gems & Gemology Challenge

on April 15, 1993

Taking part in a program of this sort is evidence of praiseworthy dedication to continuing education. You are to be commended for your commitment and your effort to increase your ability to serve the jewelry-buying public ethically and professionally.

Date April 15, 1993

Note: Questions are taken from only the four 1992 issues. Choose the single best answer for each question.

1. An inexpensive, accurate, reliable, and easily operable gold testing method is
   - A. capacitive decay.
   - B. X-ray fluorescence.
   - C. chemical reactivity.
   - D. not presently available.

2. A new ruby imitation that was first reported in 1991 appears to be produced by subjecting natural corundum to
   - A. heat treatment.
   - B. quench crackling and dyeing.
   - C. electrolysis.
   - D. coating and fracture filling.

3. Kilbourne Hole is the site of an
   - A. alkaline lake.
   - B. extinct volcano.
   - C. ancient meteorite.
   - D. ancient mining camp.

4. Bleached and polymer impregnated jadeite is sometimes referred to as
   - A. coated jade.
   - B. grade A jade.
   - C. grade B jade.
   - D. grade C jade.

5. The simplest mining method throughout Myanmar is
   - A. tunneling.
   - B. open-pit mining.
   - C. sluice operations.
   - D. the washing of gravels along waterways.

6. The primary coloring agent of gem-quality green tanzanite is
   - A. iron.
   - B. chromium.
   - C. vanadium.
   - D. nickel.

7. The Changle sapphire deposit is unique among basaltic sapphire deposits because
   - A. it produces a large number of color-change stones.
   - B. it produces many large (5+ ct) stones.
   - C. significant amounts of sapphire have been identified *in situ*.
   - D. significant amounts of blue and green sapphires have been recovered.

8. It is unlikely that many radiation-colored grossular garnets will be encountered in the trade often because
   - A. of FTC regulations.
   - B. their colors fade rapidly.
   - C. of their high levels of radioactivity.
   - D. they are heavily fractured.

9. To determine if a diamond is synthetic, a good starting point is testing its
   - A. radioactivity.
   - B. specific gravity.
   - C. thermal conductivity.
   - D. luminescence behavior.

10. The "fire" opals from Querétaro, Mexico, were probably formed at temperatures near or above
   - A. 160°C.
   - B. 300°C.
   - C. 800°C.
   - D. 1100°C.

11. The only confirmed locality for change-of-color garnets in Tanzania is at
   - A. Umba.
   - B. Morogoro.
   - C. Lake Manyara.
   - D. Longido Mountain.

12. The total production of diamonds from antiquity through 1990 is estimated to be on the order of
   - A. 1,000,000,000 carats.
   - B. 1,750,000,000 carats.
   - C. 2,000,000,000 carats.
   - D. 2,250,000,000 carats.

13. Gem-quality green tanzanite can be separated from tsavorite, "chrome" tourmaline, and apatite through the use of a
   - A. microscope.
   - B. polariscope.
   - C. dichroscope.
   - D. refractometer.

14. According to recent research, when a gray-to-grayish blue diamond does not test as electrically conductive, then the diamond
   - A. is type IIa.
   - B. is type IIb.
   - C. is probably not natural.
   - D. should be tested for luminescence.

15. The R.I. of bleached/polymer-impregnated jadeite compared with untreated jadeite is
   - A. slightly higher.
   - B. significantly lower.
   - C. significantly greater.
   - D. not significantly different.

16. The gold content of 10K gold is
   - A. 178 parts per thousand.
   - B. 417 parts per thousand.
   - C. 375 parts per thousand.
   - D. 483 parts per thousand.

17. The one inclusion typical of Kilbourne Hole peridot that has not been found in peridot from other sources is
   - A. biotite.
   - B. diopside.
   - C. hercynite.
   - D. forsterite.

18. To date, the only method known to provide conclusive evidence of polymer impregnation of jadeite is
   - A. specific gravity.
   - B. infrared spectroscopy.
   - C. a handheld spectroscope.
   - D. ultraviolet luminescence.

19. The dramatic fall of ruby prices in 1908 was due to
   - A. new discoveries of ruby.
   - B. the commercial availability of synthetic rubies.
   - C. a failed attempt to "corner" the market.
   - D. the political situation leading to the World War.

20. Ruby from Tanzania was first discovered in the early 1900s
   - A. at Morogoro.
   - B. near Longido Mountain.
   - C. along the Umba river.
   - D. in the Merelani Hills.

21. The vast majority of gem diamonds are type
   - A. Ia.
   - B. Ib.
   - C. IIa.
   - D. IIb.

22. Over the next ten years, the most likely major source for greatly increased diamond production will be
   - A. Sakha.
   - B. Canada.
   - C. Australia.
   - D. Antarctica.

23. The type and amount of radionuclides causing radioactivity in a gemstone can be determined
   - A. with U.V. testing.
   - B. with a Geiger counter.
   - C. through X-ray diffraction.
   - D. by gamma-ray spectroscopy.

24. The percentage of diamonds from the Argyle mine that are gem quality is about
   - A. 5%.
   - B. 15%.
   - C. 20%.
   - D. 25%.

25. Unlike typical peridot, peridot from the Esquel meteorite was found to contain
   - A. "lily pad" inclusions.
   - B. acicular inclusions oriented 90° to one another.
   - C. protogenetic plates of biotite.
   - D. distinct crystals of chromite.

BOOK Reviews

ELISE B. MISIOROWSKI AND SUSAN B. JOHNSON, EDITORS

THE HEAT TREATMENT OF RUBY AND SAPPHIRE

*By Ted Themelis, 236 pp., illus., publ. by Gemlab, Inc., Clearwater, FL, 1992. US$90.00**

One of the most arcane aspects of jewels is the art and alchemy of gem enhancement. The creation of a vivid blue sapphire from an otherwise unattractive chunk of corundum stirs both our aesthetic longing for beauty and our practical desire for profit. These processes traditionally have been developed by trial and error, and have been kept secret within a family or business. This secrecy has given rise to a raging curiosity among both those who treat corundum and those who would like to understand the treated stones that they buy or sell. Into this vacuum of information falls this book by experienced heat treater Ted Themelis.

The book is intended for those already familiar with heat treatment and, to a lesser extent, to explain the complexities of treatment to gemologists and retail jewelers. In chapter 1, Mr. Themelis presents some technical data useful for heat treatment of corundum. The causes of color in ruby and sapphire, and the general heat-treatment methods one might wish to apply for a given color enhancement, are listed in chapter 2, with examples of heat-treatment experiments very briefly described. This is followed by a discussion of the effect of heat treatment on inclusions in chapter 3, and the identification of corundum in chapter 4.

The most useful and informative chapters are 5, which gives specific details of preparations for heat treatment, and 6, a survey of heat-treatment equipment. Also very valuable is an extensive listing of worldwide ruby and sapphire localities in chapter 7, with general notes on heat treatment of corundums from each area. The final chapter briefly discusses commercial issues such as value and disclosure.

The organization of the book could be improved by first describing treatment, and then its effects. For example, chapters 3 and 4 might be combined, refocused to concentrate on the identification of heat treatment in corundum, and moved to the end of the book, next to the discussion of value and disclosure. Much of the information presented in chapter 4 is better covered in the many other publications specializing in the separation of corundum from other stones.

The descriptions of heat-treatment processes in chapters 2 and 7 are inadequate, and they suffer from being divided between the chapter organized by color and the chapter organized by locality. There is in these two chapters, as elsewhere, a great deal of redundancy. At 256 pages, the book is not overlong, but one feels that the information could have been presented more succinctly.

In addition, the book appears to be entirely unedited, and reads much like a first draft. The English grammar, style, and punctuation are so poor as to interfere with the readability of the text, and there are many obvious typographical errors. Perhaps the most glaring example is a procedure for removing calcite crystals from the surface of rough given as: "The corundums are embedded in a highly concentrated solution of hydrochloric acid and heated slowly to 1500°C on a hot plate for several hours." Unless Mr. Themelis has hot plates of extraordinary capability, one would assume this was intended to read 150°C.

Many of Mr. Themelis's statements are unclear, and a quotation from chapter 1 almost defies analysis: "Lightening the dark red color in many rubies, usually from various African localities, requires changing the valence of the Cr^{+3}, resulting in partial evaporation of the chromium. It is not possible to change the valence of the Cr^{+3}, because: the chromium in the ruby substance is always in solution, the very high melting point of Cr_2O_3, its diffusion coefficient, and other parameters." The author may have intended to say that red color in ruby cannot be lightened by heat treatment, because no process is known that can alter the valence state of chromium in solution in corundum. Many nonstandard terms, such as "overcast" color, are undefined. Others are misused, such as "secondary deposits" as an alternative term for iron stains.

There are extensive line drawings and black-and-white illustrations, but sometimes these are inadequately explained or unclear. The very useful listing of localities in chapter 7 has no specific maps to help us locate the places described.

In addition to the mechanical problems listed above, the book is quite uneven in the presentation of specific technical information. The information that is given is frequently incorrect. For instance, the method quoted above for removing calcite from the surface of corundums presumably instructs the reader to heat hydrochloric acid to 150°C. This is well above the 110°C boiling point of HCl, and the fumes that HCl would give off at and near the boiling point are toxic (Don't try this at home, kids!).

Much useful information about Mr. Themelis's previously unpublished work is included here, but it is intermixed with the work of others, and frequently the distinction between his work and the work of others is not made clear. An extensive bibliography is given, but most of the citations are in chapter 1, while the work of others in the remainder of the text is left unattributed.

The author's deliberate decision to discuss heat-treatment parameters only in general terms is understandable as a means of protecting his livelihood, but it is frustrating to see all experiments described only in terms of the number and color of stones treated, the treatment time, and whether the atmosphere was "reducing" or "oxidizing."

---

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

Nowhere is given even one detailed account of treatment, including heating and cooling ramp rates, oxygen partial pressure, specific sample preparation methods, and specific results. Nor are Mr. Themelis's results related to the scientific theory presented in chapter 1.

At $90.00, this book seems expensive, but small printings of specialized monographs usually have high per-volume prices.

Despite its many problems, this book is useful as a survey of corundum heat treatment. It could be of value to anyone currently involved in heat treatment, as it does provide some clues and "know-how." It will also help interested nontreaters learn more about the practice of heat treating sapphires, although it may not deepen their understanding. Because of the potentially dangerous errors, it should not be used by the novice as a guide to experimentation.

MEREDITH MERCER
GIA Research
Santa Monica, California

JADE

*Edited by Roger Keverne, 376 pp., illus., publ. by Van Nostrand Reinhold, New York, 1991. US$90.00**

Volumes of literature have been written on the topic of jade. If one had to choose a single reference work, however, this would be a good one. The book is a compilation of chapters on the gemology, history, appraisal, and sources of jade written separately by 17 contributing authors and coauthors under the guidance of consulting editor Roger Keverne.

Although jade is most often associated with China, this book also addresses the often-ignored role jade plays in other cultures. In his introduction, Roger Keverne presents the impressive credentials and involvement of the individual contributing authors, many of whom are university professors or museum curators.

The gemological aspects of jade are covered in the first chapter, by Jill Walker. This is an expanded version of her 1982 *Gems & Gemology* article (as noted in the acknowledgments), adding mineralogic differences between jadeite and nephrite, sources for jade, and trade names to an otherwise complete gemologist's reference.

The next six chapters—by Daphne Lange Rosenzweig, Angus Forsyth (two consecutive chapters), Brian McElvey, Yang Boda, and Robert Frey, respectively—address Chinese jades from the neolithic period to post-1800. Scholarly attention is paid to developments in the uses for jade, motifs utilized, and craftsmanship in working jade. As throughout the entire book, each chapter is well illustrated in color.

The seventh chapter addresses the appraisal of Chinese jade, a subject not often discussed in written text. Daphne Lange Rosenzweig approaches this topic in terms of the physical, the aesthetic, and the extraneous properties of each piece. One expects a text to help pinpoint monetary valuation of gems on the basis of physical characteristics (identification, size, and quality), and occasionally on aesthetic properties (workmanship, subject, style, and period characteristics). However, Ms. Rosenzweig emphasizes the extraneous properties (provenance, market volatility, and local taste) and points out the need to gradually acquire connoisseurship through years of experience.

Chapters 8–14 are devoted to the appreciation of jade from other regions and cultures, including the Pacific Rim, the South Pacific, Europe, Burma, North America, Meso-America, and the Islamic and Mughal jades. Emphasis here is on the uses of jade historically in each region, as well as on the development of techniques for cutting and carving jade.

Mr. Keverne closes the text with advice for buyers and collectors. He points out considerations for the first-time buyer, including color, carving, and ornamentation, as well as the need to assess the piece for flaws, repairs, and possible alterations that make recent jade pieces appear antique.

The three appendices at the end are just as valuable as the text. They are: (1) an extensive listing of public collections of jade worldwide; (2) three all-inclusive detailed glossaries covering Chinese-language (Pinyin to Wade Giles interpretations), English, and Chinese terms; and John Sinkankas's unparalleled bibliography for jade.

Geologists may feel that the source geology information is a bit thin, but otherwise all those interested in jade will find this book a fascinating and useful reference; a welcome addition to any library.

JUNE HANANO-YURKIEWICZ
Evan Caplan & Co.
Los Angeles, California

OTHER BOOKS RECEIVED

The Regent, *by Dale Perelman, 142 pp., Fithian Press, Santa Barbara, CA, 1990, US$8.95.** The legend of France's most famous diamond is told in this biographic dramatization. Based on well-documented accounts, this re-creation follows the Regent diamond from its discovery in 1701 by a slave who paid for it with his life, through the many members of royalty who sold, pawned, murdered for, and romanced it, to its resting place today, in The Louvre Museum in Paris.

LAWRENCE E. MARMOSTEIN

Rubies & Sapphires, *by Fred Ward, 64 pp., illus., Gem Book Publishers, Bethesda, MD, 1992, US$14.95.** This book is an expanded version of an article originally published in *National Geographic* (Vol. 180, No. 4, October 1991). The author has added personal accounts of his research adventures as well as striking color photographs of gems and gem locations. Beginning with a brief chapter on "History and Lore," the author swiftly takes you to the corundum centers of the world. Mining, enhancements, cutting, jewels and artifacts, and synthetics and their uses, are all illustrated with outstanding color photographs. Unfortunately, there is no information on the Vietnamese mines and corundum. However, the final chapter contains some helpful hints for buying and caring for all of these beautiful gems. Note that the simplistic style of the text seems geared to the novice gem buyer rather than the seasoned gemologist.

LAWRENCE E. MARMOSTEIN

GEMOLOGICAL ABSTRACTS

DONA M. DIRLAM, EDITOR

COLORED STONES AND ORGANIC MATERIALS

The care and cleaning of gem materials. M. Stather, *Australian Gemmologist*, Vol. 18, No. 2, 1992, pp. 34–38.

This article gives some general tips on cleaning gems. Included are dos and don'ts relating to the types of containers, detergents, and brushes to use; water temperature; and examination of items before, during, and after cleaning. Also addressed are "mechanical" cleaning methods—such as ultrasonic and steam cleaners—followed by sections on storing gems and precautions against wearing jewelry during sports activities. The final section explains how to clean ivory and bone.

The remainder of the report is a two-page table that succinctly addresses specific gem materials: chalcedony, quartz, beryl, coral, chrysoberyl, diamond, garnet, ivory, jade, jet, kunzite, lapis lazuli, malachite, opal, pearl, peridot, corundum, shell, spinel, tanzanite, tortoise shell, topaz, turquoise, tourmaline, and zircon. For each there is an entry on cleaning techniques, followed by comments relating to other durability concerns.

The brief report should prove informative to jewelers and gemologists. In many respects it serves as a useful follow-up to the *Gems & Gemology* article "Gemstone Durability: Design to Display" (D. Martin, Summer 1987, pp. 63–77). *RCK*

The chemical properties of Colombian emeralds. D. Schwarz, *Journal of Gemmology*, Vol. 23, No. 4, 1992, pp. 225–233.

Quantitative chemical analysis was performed by microprobe on 90 samples of Colombian emeralds, 60 of known provenance. The discussion summarizes the data and compares the findings to previous work on emeralds from a variety of localities worldwide. Analyses of the data indicate how various elements substitute in the emerald structure. The findings essentially confirm previous research, but the data for samples of such precisely known provenance is a welcome addition to the literature on emeralds. Tables provide range and mean data for samples from each locality, and graphs illustrate the elemental correlations. Locality and geologic maps also accompany the text. *CMS*

Chemical, X-ray and Mössbauer investigation of a turquoise from the Vathi area volcanic rocks, Macedonia, Greece. S. Sklavounos, T. Ericsson, A. Filippidis, K. Michailidis, and C. Kougoulis, *Neues Jahrbuch für Mineralogie, Monatshefte*, No. 10, 1992, pp. 469-480.

Secondary turquoise occurs in a porphyritic trachyte-rhyodacite in the Vahti area of northern Greece, where it is found in veinlets and thin encrustations in cavities in volcanic rocks. In open spaces, it forms massive cryptocrystalline to fine granular structures. It has a "sky blue" color and a chemical formula of

$Cu_{0.96}Mn_{0.01}Ba_{0.01}Al_{5.86}Fe^{3+}_{0.13}As_{0.01}(PO_4)_4(OH)_8 \cdot 5H_2O$, with a = 7.52(Å), b = 10.24(Å), c = 7.70(Å), α = 111° 18′, β = 115° 07′, γ = 69° 19′. The Mössbauer spectrum at room temperature gave two doublets of nearly equal intensity, indicating that the Fe^{3+} is substituting for Al^{3+} in octahedral Al positions. The Cu cation influences the cell parameters c and α, while the $Fe^{3+}/(Fe^{3+} + Cu)$ ratio affects the a-parameter. A simplified geologic map, two scanning electron micrographs, microprobe analyses, and a Mössbauer spectrum accompany the article. *R. A. Howe*

Editor's Note: It should be noted that there is no discussion regarding the gemological value of this material or its commercial availability.

Examination of an unusual alexandrite. U. Henn and H. Bank, *Australian Gemmologist*, Vol. 18, No. 1, 1992, pp. 13–15.

An alexandrite examined by the authors exhibited a number of ambiguous properties. Refractive indices, birefringence, and U.V. luminescence were within the ranges for both natural and synthetic products, and the inclusions were equally inconclusive. Among the internal features were distinct growth zoning, air-filled fractures, fingerprint-like inclusions, and a single triangular platelet that could be platinum (typical of flux synthetics) or hematite or graphite (as found in some natural gem materials).

Further testing was therefore carried out using U.V.-visible, infrared, and Raman spectroscopy. The U.V.-visible spectrum was inconclusive, with features typical of both natural and flux synthetic alexandrite. Infrared spectroscopy proved diagnostic, revealing distinct vibrational bands attributable to H_2O and OH molecules in natural alexandrite. Raman spectroscopy further substantiated the identification by establishing the tabular black inclusion as hematite. *RCK*

Gemmology Study Club lab reports. G. Brown and S. M. B. Kelly, *Australian Gemmologist*, Vol. 18, No. 2, 1992, pp. 56–60.

The first of these seven brief lab reports describes a 2.60-ct faceted, medium-dark brownish red garnet, reportedly from Australia's Northern Territory. Gemological properties were determined as follows: S.G., 3.89; R.I., 1.75; optical character, singly refractive; diaphaneity, transparent; U.V. luminescence, inert to both long and short wave; and absorption spectrum, typical of almandine. Based on these properties and using criteria established by Stockton and Manson (*Gems & Gemology*, Winter 1985, pp. 205–218), the stone was identified as a pyrope-almandine garnet with no appreciable spessartine content.

Other reports cover two star spinels from Sri Lanka, one displaying four rays and the other six rays, and some yellow zircons. Additional entries describe a cameo with a black granular opaque base, to which was fused an allegedly laser-carved head, possibly made of alkyd resin-bonded or imitation turquoise; a spherical cultured pearl with a much smaller round protuberance growing on its surface; and dendritic silica gems (single-crystal quartz, chalcedony, and opal). The final report describes two Egyptian faience scarabs (Mohs hardness, 5–6; specific gravity, 2.43 and 2.44; spot R.I., 1.49; inert to U.V. radiation, and no diagnostic absorption features).

Each entry is nicely illustrated with either color or black-and-white photographs. *RCK*

Notes from the laboratory—16. K. Scarratt, *Journal of Gemmology*, Vol. 23, No. 4, 1992, pp. 215–224.

Items recently encountered in the Gemmological Association of Great Britain Gem Trade Laboratory (GAGB-GTL) include a large red spinel, a treated blue diamond, bleached-and-impregnated jadeite, and cast polyester resin simulants. The 149.92-ct red spinel exhibited typical properties for natural spinel and appears to have been recut from an ancient gem. In its original form, this spinel may have been larger than the "Black Prince's Ruby" in the British Crown Jewels. The treated blue diamond (0.40 ct) has an intense "zircon" blue color with yellow patches visible from some viewing angles. Optical and infrared spectroscopy confirmed that the stone is a treated type Ia diamond, and a concentration of blue color in the culet area indicates electron irradiation.

The laboratory's observations on several samples of "bleached" jade are described, including the unusually high luster that is a good first indication of this treatment. Standard gemological properties were typical for jadeite, and hot-point testing produced no "sweating" or other indication of impregnation. Infrared spectroscopy revealed features that conclusively identify the presence of an impregnating resin.

The final note reports on cast polyester resin simulants of tortoise shell, horn, ivory, bone, and jet that are being produced in the United Kingdom. The material is available in cylinders as large as 128 mm in diameter and 1.5 m long, in rectangular blocks as large as 45 × 75 mm, and in sheet form. The material can be distinguished from its natural counterparts most readily by microscopy, as the resin shows none of the characteristic structures of the natural materials it imitates. Its R.I. and S.G. can be used as additional distinguishing properties.

All notes are well illustrated with color micro- and macro-photographs and, in some cases, with infrared spectra. A table of comparative properties also accompanies the note on polyester resin simulants.

An additional feature in this issue is "A Note from the Bahrain Laboratory," the first such to accompany "Notes from the Laboratory." This government-owned laboratory, operated with the assistance of GAGB-GTL, sent a report on an amber-bead necklace. This material is particularly popular in Bahrain for use in worry beads. S.G., hot-point, and

sectility tests all initially indicated that the beads were amber, but microscopy and immersion revealed that the beads were pale at the facet edges and the color appeared to be concentrated in the center of each facet. U.V. luminescence revealed a bright chalky bluish white fluorescence concentrated where the color was palest, i.e., at the facet edges. Additional microscopic examination revealed internal features indicating that the material had not been pressed. It was concluded that a surface color enhancement had been used, possibly as a by-product of a clarification process.
CMS

Novel assembled opals from Mexico. R. C. Kammerling and J. I. Koivula, *Australian Gemmologist,* Vol. 18, No. 1, 1992, pp. 19–21.

Opal is commonly seen in assembled stones primarily for two reasons. First, since natural opal often occurs in seams that are too thin for cutting into gems, composites are constructed to make use of these very thin layers of opal. Second, a thin layer of transparent opal can be glued to a black base to imitate highly prized black opal.

After detailing still more types of opal composites, the authors describe a new type of assembled opal, "Opal Encapsulado," reportedly from Mexico. Examination of two oval "Encapsulado" cabochons revealed that the majority of the assemblage consisted of a large transparent cap, below which is a thin slice of natural opal. A black granular substance covered the back of the opal slice. The base itself is composed of a transparent colorless material that appears similar in composition to the transparent dome.
Gustave P. Calderon

Rauchmondsteine, eine neue Mondstein-Varietät (Smoky moonstones, a new variety of moonstone). H. Harder, *Zeitschrift der Deutschen Gemmologischen Gesellschaft,* Vol. 41, No. 2/3, 1992, pp. 69–84.

"Smoky moonstone" is proposed as a suitable varietal name for a feldspar from Sri Lanka that exhibits a strong blue adularescence against a smoky body color. The occurrence, like that of other moonstone deposits in Sri Lanka, is in a decomposed pegmatitic body in which fragments of partly decomposed feldspar crystals are imbedded in clay. The locality, discovered in 1990, is near the village of Imbulpe (or Imblupe, as given by the author), near Balangoda, Sabargumava Province, to the east of the famous gem capital of Ratnapura. Chemical analyses of numerous specimens from this and other moonstone deposits on the island show that those stones displaying white sheen are higher in potassium, while those of blue sheen contain more sodium. The smoky body color is attributed to a small iron content.

While the author claims this occurrence to be unique for smoky-body-color moonstone, this abstracter notes that similar smoky-hued moonstones, also displaying fine blue adularescence, have been mined from sanidine crystals found in the Black Range, Grant County, New Mexico. They were reported as early as 1947 by V. C. Kelley and O. T. Branson (*Economic Geology,* Vol. 42, pp. 699–712), and briefly described in my book, *Gemstones of North America* (Van Nostrand Reinhold, New York, p. 74) in 1976. Aside from this, H. Harder's article is valuable for his accounts of typical moonstones from the classic locality at Metiyagoda and from other, recently developed deposits in Sri Lanka.
John Sinkankas

Strong sales at Burma emporium, but high prices put off TGJTA team. *Thailand Jewellery Review,* Vol. 5, No. 11, November 1992, pp. 34–35.

This summary of the 1992 mid-year Myanmar (Burma) Gems Emporium auction is based on information provided by a seven-member buying team of prominent gem dealers from Thailand. According to Thailand Gem and Jewelry Traders' Association (TGJTA) Honorary Advisor Thanan Maleesriprasert, the mission was concluded without a single purchase by the team because they felt the prices for rough gem material offered were unreasonably high. The dealers believe that the Burmese have abandoned any commitment to supply rough gemstones on a favorable basis to the Thais after having stockpiled material for several years without selling it through the traditional Jade, Pearl and Gemstones Emporium of the past. This is bad news for the Thai dealers, as they are finding it extremely difficult to obtain adequate rough supplies from their own country and other conventional sources such as Sri Lanka, India, and Australia.

More than 100 Thai entrepreneurs, some without connections to the Thai gem and jewelry industry, attended the event, most in the hope of meeting the appropriate Myanmar officials who could assist them with joint-venture projects in the gemstone sector and other commercial fields as well. It seems that most of the jade purchases, which accounted for the highest value of sales, were made by Taiwanese and Hong Kong Chinese, who outbid the Thai contingent. The article reports US$6.37 million in sales of jade.
JEC

Trade embargo on coral. G. Brown, *Australian Gemmologist,* Vol. 18, No. 1, 1992, pp. 5–6.

In October 1991, the Wildlife Protection Authority of Australian National Parks and Wildlife issued a notice regulating the import and export of specific types of corals. This brief article includes the exact wording of Notice 13 and, importantly, provides an interpretation of the provisions. In this regard, the author points out a number of potential problems in enforcing the controls, as well as the potential impact on those dealing in corals. Further clarification is provided through a note from the editor and text from the Wildlife Protection Agency post-dating the initial issuance.

This report should be read by anyone, including tourists, who intends to purchase Australian corals or plans to bring corals into or out of Australia.
RCK

DIAMONDS

Diamonds for connoisseurs. S. Stephenson, *Jewellery International*, No. 11, 1992, pp. 31–34, 37.

Only in the last decade has the buying public truly become acquainted with fancy-colored diamonds. This article reviews the reasons behind the new popularity now spurring sales, and how different dealers and manufacturers are developing marketing techniques for these stones. Once only within reach of the very wealthy, the greater availability of smaller, more affordable sizes has opened this market to the general retail consumer.

The author gives two reasons for this awareness. First, publicity surrounding the 1987 auction of a 0.95-ct red diamond for $880,000, the highest price per carat ever paid for a colored diamond, helped create widespread popular interest in colored diamonds. Second, the marketing campaign for Argyle's champagne diamonds has created a new niche for colored diamonds, one that is more accepted by the average, price-conscious consumer.

Stephenson reviews the current supply and demand for colored diamonds, and concludes that the potential for future growth is dependent on consumer awareness, economic conditions, and supply. A sidebar explains how deformities or impurities cause color in diamonds. Seven color photographs illustrate the article. *JEC*

Evaluation of brilliancy in relation to various combinations of the main facets angles (in Japanese). M. Kato, *Journal of the Gemmological Society of Japan*, Vol. 16, No. 1–2, 1991, pp. 15–23.

Because the accurate measurement of diamond pavilion proportions is very time consuming with the Leveridge gauge, micrometer, or ProportionScope, pavilion proportions are generally measured by visual observation. The GIA diamond-grading course teaches the table-reflection method to estimate pavilion depth. Kato maintains that the GIA method is not only too crude to estimate proportion properly, but it is also principally incorrect, because it ignores important factors like the effect of the crown main facet angle and the table percentage. He suggests that accurate measurement is particularly important for stones above 0.5 ct, F color, or VVS_2 clarity.

Kato further describes the analysis of dispersion and volume, showing that the grading of brilliancy can be improved. He has proposed the use of "F-values" to evaluate brilliancy. F-values are calculated and diagramatically presented in relation to various combinations of main facet angles of pavilion α and crown β. Kato maintains that the F-cut (crown angle 36° and pavilion angle 40.75°) described in a previous paper (*Journal of the Gemmological Society of Japan*, Vol. 9, No. 3, 1982) yields the highest brilliancy and is truly an ideal cut, as compared to the Tolkowsky cut (crown angle 34.30° and pavilion angle 40.45°). *Masao Miki*

Examination of artificial coloring of diamonds (in Japanese). I. Umeda, *Journal of the Gemmological Society of Japan*, Vol. 15, No. 1–4, 1990, pp. 3–11.

Gem diamonds have been artificially colored at the Jewelry Laboratory UMEDA in Japan. They used primarily type Ia cut stones, but also rough diamonds and type Ib synthetic diamonds.

Standard irradiation in a nuclear reactor (neutron irradiation) produced a desaturated green body color in the diamonds. This coloration is caused by extensive damage to the crystal lattice of diamond, which occurs when high-powered neutrons collide with carbon atoms. Color alterations from green to brown were observed with annealing (in an electric furnace), which heals some damage in the crystal structure, thus stabilizing the body color. The radioactivity of the diamonds treated in this manner decreased to a safe level within a few months after treatment.

Colorless diamonds were altered to blue and bluish green by bombardment with 10-MeV electrons in a linear accelerator (electron bombardment). This color change is caused by the collision of high-powered electrons and carbon atoms, which creates some voids in the diamond's crystal lattice. Annealing modifies conditions within the crystal lattice by exchanging carbon atoms and voids within the unit cell of the diamond. The temperature of annealing determines the degree of modification within the crystal system, yielding reproducible colors that vary from lemon yellow to golden yellow.

It is not feasible to alter the color of diamonds by conventional cobalt-60 gamma-ray equipment, because diamonds are nearly transparent to gamma rays.

A dual-beam spectrophotometer was used to record the spectra of the sample diamonds before and after treatment (irradiation and annealing) at room temperature. However, low-temperature spectroscopy—not performed for this study—is needed to determine differences between treated and natural-color stones. *Takashi Hiraga*

Famous diamonds of the world XLVII. I. Balfour, *Indiaqua Annual 1991*, No. 55, p. 255.

This brief article is an update on one of the most notable diamond discoveries, the Centenary diamond. In 1988, the Premier mine produced a 599-ct rough diamond, coincidentally in time to commemorate De Beers's 100-year history. Mr. Balfour also notes the timely appearance of other large stones that have marked historic events.

The delicate task of fashioning this rough was assigned to Gabi Tolkowski. The finished product, a combination heart and shield shape, is reportedly flawless. Weighing 273 ct, it is the third largest fashioned diamond "of the finest color." *Juli L. Cook*

Russia to De Beers: 'We want more control'. R. Shor, *Jewelers' Circular-Keystone*, Vol. 164, No. 1, January 1993, pp. 50–60.

Things are heating up between Russia and De Beers. Russia is not only the world's most prolific diamond producer by value, but it also claims to have huge stockpiles of rough diamonds buried in the Kremlin vaults—possibly as much as $3 billion worth. In addition, Russia is planning to open two more mines that could double production. Now, the Russians want to have more control over the diamonds they produce, but too much autonomy could put the world diamond market in jeopardy of collapsing.

The emerging strategy is that De Beers will keep control of Russia's production but will pay more and control less. Russia would like to leave distribution of the largest part of the rough to De Beers, while increasing and diversifying its production of polished goods. Leonid B. Gourevitch, one of Russia's top parliamentary officials, thinks it is time for Russia to assert itself. Gourevitch doesn't want a split from De Beers or a change in the contract, but he says "Russia must work with De Beers to maintain order in the diamond market." De Beers's concerns regarding Russia's demands include: (1) the possibility that the best rough will go to local polishers and De Beers will get only the least desirable stones; (2) the inefficiency of Russia's polishing facilities, which will be difficult to modernize; and (3) future ventures between Russia and other firms that might promote illegal sales of Russian rough in the various diamond markets.

This in-depth article covers many aspects of the Russia-De Beers contract, future deals, the Russian market, and the key players involved in what many may see as the deal of the century. The article includes a detailed flow chart showing the various channels of distribution.

KBS

GEM LOCALITIES

A deposit of greenstone, Shan State, Myanmar. T. Hlaing, *Australian Gemmologist*, Vol. 18, No. 2, 1992, p. 42.

A gem material known locally as "greenstone" is recovered both from a fresh outcrop and as water-worn pieces in the Langhko district in southern Shan State, Myanmar.

Four specimens were examined at Taunggyi Degree College, Myanmar, to characterize the material. Microscopic examination revealed that the material consists of masses and radiating aggregates of green-to-yellow long, prismatic fibrous crystals imbedded in a fine- to medium-grained limestone. X-ray diffraction analysis determined the presence of calcite and tremolite in four samples, with quartz and/or diopside in three of these, and confirmed the amphibole content of this nephritic material. In accord with the variable composition, S.G. values ranged from 2.88 to 3.10.

This gem material is marketed in both Yangon and Mandalay. It reportedly first became popular some 20 years ago and is experiencing renewed popularity today.

RCK

Gems around Australia: 7. H. Bracewell, *Australian Gemmologist*, Vol. 18, No. 2, 1992, pp. 38–39.

Continuing her narrative tour of Australia's gem-producing areas, the author begins this seventh episode with a visit to the area of Mount Goldsworthy in Western Australia. This site is known for its "tiger-iron," an ornamental gem material consisting of bands of predominantly golden silicified crocidolite set in black and red jaspilites. This latter material is described as alternating layers of fine-grained chalcedony or sediments impregnated with black hematite and silica.

The next stop was Marble Bar, the name itself a misnomer as the formation consists not of a calcium carbonate but, rather, of a fine-grained jasper. The local council has set aside an area where samples of this banded, deeply colored material can be collected.

On the outskirts of Marble Bar, the author visited the Comet gold mine, which has been in operation since 1938 and is also a tourist attraction. Sixty kilometers to the south, in the Lionel area, chlorite is mined and then marketed under the name "Pilbara Jade." Chrysotile and serpentine are also found in the Lionel area.

RCK

The Mintabie opalfield. I. J. Townsend, *Australian Gemmologist*, Vol. 18, No. 1, 1992, pp. 7–12.

This article, adapted from an earlier report by the author published by the South Australian Department of Mines and Energy, provides a good overview of what has become a significant source of gem-quality opal. Discovered in the 1920s, the Mintabie opal field has been exploited in earnest only since 1976. It is located in the far north of South Australia, approximately 1000 km northwest of Adelaide and 290 km from the famous Coober Pedy opal-mining center.

The opal occurs in a medium- to coarse-grained kaolinitic, fluvatile sandstone. Opal-bearing levels are found from the surface down to a depth of at least 25 m. Drilling is used both in grid prospecting and in sinking vertical shafts for underground mining, while bulldozers are used extensively in the open-cut mining of amalgamated claims. With either method, miners resort to simple hand tools whenever precious opal is encountered.

A great range of precious opal types is recovered at Mintabie, including black, crystal, semi-black, and white pinfire, comparing favorably with the best of these from other Australian localities. Although some Mintabie opal has a tendency to crack, this trait is believed to be confined to material recovered from below the water table.

The article also contains some general information on the formation, composition, and structure of Australian opal; production figures for Mintabie; and pricing data for the various opal types. It is nicely illustrated and is a welcome addition to the literature on Australian opal.

RCK

INSTRUMENTS AND TECHNIQUES

Determination of the age and origin of emeralds using rubidium-strontium analysis. Ph. Vidal, B. Lasnier, and J-

P. Poirot, *Journal of Gemmology*, Vol. 23, No. 4, 1992, pp. 198–200.

Age dating can be used to determine the natural or synthetic origin of emeralds and, in some cases, their locality of origin. The authors describe their study of the use of rubidium-strontium geochronology for this purpose. They found that reliable dating could not be obtained for all samples, but that isotopic ratios provided sufficient information to group the samples into three clusters: emeralds from Precambrian rock localities (Brazil, Madagascar, Zambia), emeralds from young rocks (Colombia, Pakistan, Afghanistan), and synthetic emeralds (Lennix and Gilson). A major problem with the technique, for gemological applications, is that it requires the destructive analysis of a few milligrams of powdered material, which cannot always be sacrificed from a cut gemstone. The authors conclude with suggestions for further research and improvements in analytic methodology. *CMS*

Robotic opal-cutting: An Australian solution to an old problem. A. Cody and G. Brown, *Australian Gemmologist*, Vol. 18, No. 2, 1992, pp. 40–41.

Although Australia is the major source of rough opal, relatively high labor costs result in much of the smaller rough being exported for cutting. To address this issue, an Australian opal dealer and CSIRO's Division of Manufacturing Technology have developed robotic opal-cutting equipment.

Before opal rough is processed with this equipment, it is first examined by an experienced opal cutter, who then uses hand grinding to remove any matrix, expose play-of-color on what will be the top of the stone, and prepare a flat base. This preform next goes to the robot's data-entry cell/dopping station, where another experienced cutter makes decisions as to the shape and dimensions of the finished piece, assisted by computer-generated graphics. At this station, the stone is also automatically dopped, the dop stick is bar coded, and the cutting parameters are programmed into the system. Next, the stone goes to the computer-controlled, automated grinding cell, where it is identified by the bar code and then cut to the programmed proportions. After they have been cut, the stones are tumble polished in large batches.

The system appears to be quite efficient for processing caliber-sized opals and is capable of producing approximately 480 stones in an eight-hour day. *RCK*

Simple advanced refractometer technique: Determining optic sign. A. Hodgkinson, *Canadian Gemmologist*, Vol. 13, No. 4, 1992, pp. 114–117.

This article reiterates the usefulness of determining several optical characteristics at once while taking R.I. readings with the refractometer. While most gemologists are used to measuring refractive index and birefringence, too many forget that optic character and sign can also be determined from the refractometer at the same time. Although the first logical choice of instruments might seem to be the spectroscope, the author feels that in many cases determination of optic character and sign are more diagnostic.

Mr. Hodgkinson has developed a way to determine optic character and sign even when a mounted stone is not optimally oriented, especially with notoriously difficult separations such as differentiating scapolite from quartz. A relatively simple but detailed test using Polaroid sunglasses is described thoroughly in the text and with diagrams. *JEC*

JEWELRY HISTORY

Hollywood jewels. B. Paris, *Art & Antiques*, Vol. 9, No. 8, August 1992, pp. 44–50.

Paris's article begins with a detailed history of La Peregrina—a 203.84-grain pearl now set as a pendant to a Cartier pearl, diamond, and ruby necklace—the focus of an exhibit of the jewels of Hollywood held in Los Angeles in December of 1992. Coinciding with the 1992 release of a book documenting movie jewelry, the Academy of Motion Picture Arts and Sciences sponsored an exquisite display in Los Angeles. The exhibit featured some 21 pieces designed by Cartier, Tiffany, Harry Winston, Paul Flato, and Van Cleef and Arpels that had appeared in films.

The highly visible, wealthy celebrities of Hollywood became the fashionable American royalty, setting trends with their distinctive styles. Recognized as the queen of this court for her status as a celebrity, and a connoisseur of remarkable jewelry, is Elizabeth Taylor. Several pieces in her collection are recognized for their royal associations and outstanding quality: the Peregrina pearl, the Krupp diamond, the Taylor-Burton diamond, and a heart-shaped yellow diamond. Highlights in this article include some fascinating stories that appear to have been taken from the new book, *Hollywood Jewels* (Abrams), by Penny Proddow, Debra Healy, and Marion Fasel. Most illustrations in this article are of actresses wearing the jewelry and are from this book. *AGP*

Round wire in the early Middle Ages. N. Whitfield, *Jewellery Studies*, Vol. 4, 1990, pp. 13–28.

Although various studies have been made of the techniques used in antiquity for the manufacture of round wire, only limited attention has been paid to the Early Middle Ages (roughly fifth to 10th centuries A.D.). First presented as a lecture to the Society of Antique Jewellery Historians' 10th Anniversary Conference, this paper presents the results of a detailed study of jewelry from this period. The jewelry studied is in collections at the British Museum, the Victoria and Albert Museum, the Royal Museum of Scotland, and the National Museum of Ireland. The study focuses on 0.15–0.6 mm gold and silver wire that was formed by hammering, block twisting, strip twisting, strip drawing, folding, wire drawing, casting, and/or smoothing.

The author describes these methods of manufacture, the probable tools used, and the marks that are indicative of each technique. In some cases, to prove that marks found could be linked to a specific technique, the author experimentally made wire using the technique in question. Fifteen valuable black-and-white photos illustrate the marks described. Some of the photos depict wire made by the author.

Whitfield concludes that hammering was in widespread use for making thick wires; the most common way of making finer wires appears to have been block twisting. Examples of strip twisting have thus far been found only on Merovingian jewelry of the late fifth and sixth centuries. Although drawing wire through a draw plate was known in Eastern Europe in the fifth and sixth centuries, there are no authentic examples in Western European jewelry until the eighth century.

Altogether, this report gives fascinating insight into early gold and silversmithing capabilities. *EBM*

JEWELRY MANUFACTURING ARTS

Tweaks and leaps. C. Edelstein, *Jewellery International*, No. 12, 1992/1993, pp. 61–65.

This article, which includes 10 superb color photographs, reviews recent fashion trends in jewelry. Although the global recession persists, jewelry design continues to grow and change. Designers tend to extremes—either remaining conservative and sticking with established styles, or boldly leaping into new areas of artistic expansion, using new materials and methods of fabrication. Thematic jewelry seems to be a growing trend, with equestrian, nautical, celestial, and natural motifs being the most popular.

Because clothing and jewelry fashion tend to go hand in hand, multi-layered necklaces with fringes of chain are complementing the revival of "hippie" fashions. Enamelled neon colors—hot pink, lime green, and sea blue—are in great demand for the second season, especially in "color-blocked" patterns on tubular bangle bracelets, domed rings, and fat hoop earrings. Gold granules, knots, bands, and squiggles are added for accents. Black-and-white enamel combinations are also a favorite, as is the use of inlaid opaque stones. Intarsia is slowly catching on.

Color and unusual cuts are the most important trends in gemstones themselves. The greater availability of tanzanite, tsavorite, tourmaline, and colored sapphire affords a host of new color combinations. As consumers become familiar with these unusual stones, they are expected to increase in popularity. More customers are also being introduced to fantasy cuts. The works of Bernd Munsteiner, Bart Curren, Steve Walters, and Michael Dyber have helped promote this with one-of-a-kind designs.

Emphasis on color is also showing up in mixed-metal jewelry, with the cool white of platinum accenting yellow, green, or pink gold.

The strongest sellers of late have been hoop earrings with dangling charms and stackable rings, both part of the "convertible" jewelry trend. These rings and hoops are metamorphosed by different designers into their own signature styles and mass-marketed very successfully. This kind of "convertible" jewelry has proved very popular lately, as consumers like the idea of getting multiple looks from a single purchase. *JEC*

JEWELRY RETAILING

Bulgari's new age. V. Becker, *Jewellery International*, No. 13, 1993, pp. 29–30.

Ms. Becker briefly discusses the jewelry firm Bulgari's influence on the development of the current Italian style of bold, sophisticated gold jewelry. The roots of this style can be found in the late 1960s and early 1970s, when Bulgari saw a need for versatile day jewelry for the modern woman executive. Taking their inspiration from their rich cultural heritage, brothers Nicola and Paolo Bulgari based their jewelry designs on classical Roman and opulent Italian Renaissance motifs. The now-familiar style of a bezel-set, ancient coin suspended from a heavy gold chain brought Bulgari international fame. The use of bezel-set cabochon-cut stones in a strong mix of colors, and the combination of gold and stainless steel, were other innovations introduced by Bulgari that have become signature elements for jewelry of the last decade.

The 1990s are heralding a new trend toward individuality and social consciousness. In an effort to move with the time, Bulgari has launched a new line of jewelry—called "Naturalia"—based on stylized fish, birds, and animals. The author hints at future changes in jewelry styles without elaborating further. Three examples of Bulgari's distinctive jewels are shown in color photographs. *EBM*

SYNTHETICS AND SIMULANTS

Fiber-eye: A Gemmology Study Club report. G. Brown and S. M. B. Kelly, *Australian Gemmologist*, Vol. 18, No. 2, 1992, p. 52–53.

Fiber-eye is the trade name for a laboratory-grown material consisting of fused, cubic-packed glass optical fibers. Like the hexagonally arrayed Cathay-stone, one type of Fiber-eye consists of parallel fibers. When fashioned into properly oriented cabochons, it displays strong chatoyancy. A second type of Fiber-eye, however, is composed of twisted bundles of fibers; such material displays a zigzag "lightning bolt" chatoyancy.

Gemological testing was conducted on both white and dark brown specimens. Magnification revealed the cubic symmetry of the optical fibers in both types; in the brown material, the color appeared to be caused by a brown substance surrounding bundles of colorless glass fibers. Gemological properties determined were as follows: Mohs hardness, 5.5 to 6; fracture, splintery; tenacity, very brittle; S.G., white type—4.23, brown type—3.55; optic character, singly refractive; spot R.I., over the limits (estimated at 1.86 using a reflectivity meter); diaphaneity, transparent parallel to—and opaque perpendicular to—length of fibers; U.V. luminescence—long wave, white type greenish yellow and brown type inert—short wave, white type pale green and brown type brownish green; absorption spectrum, no diagnostic features.

The report includes some speculation as to how this material is produced, and is illustrated with both black-and-white and color photos. *RCK*

Synthesis of gem-quality diopside by the floating zone method, using natural chromian diopside (in Japanese). Y. Naito, *Journal of the Gemmological Society of Japan*, Vol. 15, No. 1–4, 1990, pp. 29–36.

Kamisano, Yamanashi Prefecture, in Japan is rich in non-gem-quality green diopside. The author used this opaque material as nutrient and seed in the synthesis of gem-quality diopside by the traveling solvent, floating zone method, with an infrared-convergent-image furnace in a nitrogen atmosphere. Nutrient rods (1.5 cm in length and 0.5 cm in diameter) were prepared by hydrostatically pressing the powders of natural samples. Transparent, emerald-green, single-crystal boules of diopside were successfully synthesized. The conditions of growth and microscopic features of the resulting products are also described. The author states that synthesis had never before been attempted using natural diopside. *Masao Miki*

TREATMENTS

Diffusion-treated synthetic star detected. *Jewellery News Asia*, No. 97, September 1992, p. 184.

The Hong Kong Gems Laboratory has identified a gem that it describes as a Verneuil synthetic ruby with a diffusion-treated star. The depth of the star was less than 1 mm, according to the laboratory director, Ou-Yang Chiu Mei. While the stone looked natural, the star did not move as expected. The director also pointed out that the rays on this star were not as sharply delineated as Linde synthetic stars. Experiments at the University of Hong Kong showed a slight difference in chemical composition between the top of the stone and areas near the base. Also, curved striae were detected on the base using an electron microscope. It is believed that the star was produced by coating the stone surface with titanium oxide and then heating the stone to 1700°C. *JEM*

Identification of a dyed black cultured pearl (in Japanese). E. Ito, *Journal of the Gemmological Society of Japan*, Vol. 16, No. 1-2, 1991, pp. 50–51.

The Pearl Science Laboratory of Japan tested a black pearl, sold as a "Ryukyu black pearl," for color origin. The greenish black body color with pinkish overtones resembled that of the natural black pearl known as Ryukyu, which is found only in black-lip mollusks (*Pinctada margaritifera*). However, Ryukyu pearls usually look bluish black under a strong light source; this pearl appeared reddish purple. Further testing with a spectroscope failed to show the absorption lines at 400, 500, and 700 nm that are typical of Ryukyu pearls. Examination with a microscope revealed dye concentrations in small surface cracks. A destructive test revealed dye concentrations within the coarse parts of the nacre. *Takashi Hiraga*

Identification of fissure-treated gemstones. H. A. Hänni, *Journal of Gemmology*, Vol. 23, No. 4, 1992, pp. 201–205.

Dr. Hänni's review of fissure-treated gemstones brings together the diverse literature on this topic from the past decade and summarizes the nature, appearance, and identification of gemstones subjected to this general category of treatment. The article begins with a brief explanation of why fissure treatment works and how it is performed. Dr. Hänni focuses on the oil and epoxy-resin treatment of emerald and the glass-infilling of corundum. He provides a summary of identification features and methods, including bubbles or dendrite-like patterns, ultraviolet fluorescence, soaking in solvents, color flashes, microscopy, infrared spectroscopy, and the like. Color photomicrographs and infrared spectra illustrate the distinguishing characteristics noted. The article concludes with a brief discussion of disclosure practices. Dr. Hänni recommends that all fracture treatments be dealt with in the same way, including general disclosure to the final consumer. *CMS*

MISCELLANEOUS

Gemstone photography: Capturing the beauty. R. Weldon, *Jewelers' Circular-Keystone*, Vol. 163, No. 10, October 1992, pp. 70–72.

Mr. Weldon begins part two of his series on gemstone photography by describing a basic photography studio for gems and jewelry. He then focuses on backgrounds and props, tips on positioning the gemstone, and how to prevent the accumulation of dust. The author concludes with lighting methods, including suggestions on light diffusers and the strategic positioning of lights. Overall, this article, combined with the first (on film), gives a working knowledge of gemstone photography. It is illustrated with 10 color photographs. *KBS*

Symmetrical polyhedra for gemstones. J. Lurie, *Journal of Gemmology*, Vol. 23, No. 4, 1992, pp. 207–214.

This in-depth article about symmetrical polyhedra will be of interest primarily to crystallographers, lapidaries, and geometers. Its stated aim is to inspire gem cutters to explore faceted "spheres" as alternate designs. The various classes of symmetric polyhedra are described in considerable detail, accompanied by excellent drawings and tables of faceting angles for each of the major forms. Some fascinating and unusual patterns emerge. *CMS*

SUGGESTIONS FOR AUTHORS

The following guidelines were prepared both to introduce you to *Gems & Gemology* and to let you know how we would like a manuscript prepared for publication. No manuscript will be rejected because it does not follow these guidelines precisely, but a well-prepared manuscript helps reviewer, editor, and reader appreciate the article that much more. Please feel free to contact the Editorial Office for assistance at any stage in the development of your paper, whether to confirm the appropriateness of a topic, to help organize the presentation, or to augment the text with photographs from the extensive files at GIA.

INTRODUCTION

Gems & Gemology is an international publication of original contributions concerning the study of gemstones and research in gemology and related fields. Topics covered include (but are not limited to) colored stones, diamonds, gem instruments and identification techniques, gem localities, gem enhancements, gem substitutes (simulants and synthetics), gemstones for the collector, jewelry manufacturing arts, jewelry history, and contemporary trends in the trade. Manuscripts may be submitted as:

Original Contributions—full-length articles describing previously unpublished studies and laboratory or field research. Such articles should be no longer than 6,000 words (24 double-spaced, typewritten pages) plus tables and illustrations.

Gemology in Review—comprehensive reviews of topics in the field. A maximum of 8,000 words (32 double-spaced, typewritten pages) is recommended.

Notes & New Techniques—brief preliminary communications of recent discoveries or developments in gemology and related fields (e.g., new instruments and instrumentation techniques, gem minerals for the collector, and lapidary techniques or new uses for old techniques). Articles for this section should be approximately 1,000-3,000 words (4-12 double-spaced pages).

Gems & Gemology also includes the following regular sections: *Lab Notes* (reports of interesting or unusual gemstones, inclusions, or jewelry encountered in the Gem Trade Laboratories), *Book Reviews* (as solicited by the Book Review Editor; publishers should send one copy of each book they wish to have reviewed to the Editorial Office), *Gemological Abstracts* (summaries of important articles published recently in the gemology literature), and *Gem News* (current events in the field).

MANUSCRIPT PREPARATION

All material, including tables, legends, and references, should be typed double spaced on 8 1/2 × 11" (21 × 28 cm) sheets with 1 1/2" (3.8 cm) margins. It is preferable, but not essential, that the article be submitted (preferably in Microsoft Word or in ASCII format) on an IBM-compatible floppy disk (either 3 1/2" or 5 1/4") as well as in hard copy form. Please identify the authors on the title page only, not in the body of the manuscript or figures, so that author anonymity may be maintained with reviewers (the title page is removed before the manuscript is sent out for review). The various components of the manuscript should be prepared and arranged as follows:

Title page. Page 1 should provide: (a) the article title; (b) the full name of each author (first name, middle initial, surname), with his or her affiliation (the institution, city, and state or country where he/she was working when the article was prepared); (c) acknowledgments of persons who helped prepare the report or did the photography, where appropriate; and (d) five key words that we can use to index the article at the end of the year.

Abstract. Page 2 should repeat the title of the article followed by an abstract. The abstract (approximately 150 words for a feature article, 75 words for a note) should state the purpose of the article, what was done, and the main conclusions.

Text. Papers should follow a clear outline with appropriate heads. For example, for a research paper, the headings might be: Introduction, Previous Studies, Methods, Results, Discussion, and Conclusion. Other heads and subheads should be used as the subject matter warrants. Also, when writing your article, please try to avoid jargon, to spell out all nonstandard abbreviations the first time they are mentioned, and to present your material as clearly and concisely as possible. For general style (grammar, etc.) and additional information on preparing a manuscript for publication, *A Manual of Style* (The University of Chicago Press, Chicago) is recommended.

References. References should be used for any information that is taken directly from another publication, to document ideas and facts attributed to—or facts discovered by—another writer, and to refer the reader to other sources for additional information on a particular subject. Please cite references in the text by the last name of the author(s) and the year of publication—plus the specific page referred to, if appropriate—in parentheses (e.g., Kammerling et al., 1990, p. 33). The references listed at the end of the paper should be typed double spaced in alphabetical order by the last name of the senior author. Please list only those references actually cited in the text (or in the tables or figures).

Include the following information, in the order given here, for each reference: (a) all author names (surnames followed by initials); (b) the year of publication, in parentheses; (c) for a *journal,* the full title of the article or, for a *book,* the full title of the book cited; and (d) for a *journal,* the full title of the journal plus volume number, issue number, and inclusive page numbers of the article cited or, for a book, the publisher of the book and the city of publication. Sample references are as follows:

Kammerling R.C., Koivula J.I, Kane R.E. (1990) Gemstone enhancement and its detection in the 1980s. *Gems & Gemology,* Vol. 26, No. 1, pp. 32–49.

Armstrong J.T. (1988) Accurate quantitative analysis of oxygen and nitrogen with a Si/W multilayer crystal. In D. E. Newbury, Ed., *Microbeam Analysis—1988,* San Francisco Press, San Francisco, CA, pp. 301–304.

Liddicoat R.T. (1989) *Handbook of Gem Identification,* 12th ed., 2nd rev. printing. Gemological Institute of America, Santa Monica, CA.

Tables. Tables can be very useful in presenting a large amount of detail in a relatively small space, and should be considered whenever the bulk of information to be conveyed in a section threatens to overwhelm the text.

Type each table double spaced on a separate sheet. If the table must exceed one typewritten page, please duplicate all headings on the second sheet. Number tables in the order in which they are cited in the text. Every table should have a title; every column (including the left-hand column) should have a heading. Please make sure terms and figures used in the table are consistent with those used in the body of the text.

Figures. Please have line figures (graphs, charts, etc.) professionally drawn and photographed. High-contrast, glossy, black-and-white prints are preferred.

Submit black-and-white photographs and photomicrographs in the final desired size if possible. Where appropriate, please use a bar or other scale marker on the photo, not outside it.

Use a label on the back of each figure to indicate the article's title (or a shortened version thereof) and the top of the figure. Do not trim, mount (unless one figure is composed of two or more separate photos), clip, or staple illustrations.

Color photographs—35 mm slides or 4 × 5 transparencies—are encouraged. Please include three sets of color prints with the manuscript package submitted for publication consideration.

All figure legends should be typed double spaced on a separate page.

In each legend, clearly explain any symbols, arrows, numbers, or abbreviations used in the illustration. Where a magnification is appropriate and is not inserted on the photo, please include it in the legend.

MANUSCRIPT SUBMISSION

Please send three copies of each manuscript (and three sets of figures and labels) to the Editorial Office, in care of:

Alice S. Keller, Editor
Gems & Gemology
P.O. Box 2110
1660 Stewart Street
Santa Monica, CA 90407

In view of U.S. copyright law, we must ask that each submitted manuscript be accompanied by the following statement, signed by all authors of the work: "Upon publication of (title) in *Gems & Gemology,* I (we) transfer to the Gemological Institute of America all rights, titles, and interest to the work, including copyright, together with full right and authority to claim worldwide copyright for the work as published in this journal. As author(s), I (we) retain the right to excerpt (up to 250 words) and reprint the material on request to the Gemological Institute of America, to make copies of the work for use in classroom teaching or for internal distribution within my (our) place of employment, to use—after publication—all or part of this material in a book I (we) have authored, to present this material orally at any function, and to veto or approve permission granted by the Gemological Institute of America to a third party to republish all or a substantial part of the article. I (we) also retain all proprietary rights other than copyright (such as patent rights). I (we) agree that all copies of the article made within these terms will include notice of the copyright of the Gemological Institute of America. This transfer of rights is made in view of the Gemological Institute of America's efforts in reviewing, editing, and publishing this material.

As author(s), I (we) also warrant that this article is my (our) original work. This article has been submitted in English to this journal only and has not been published elsewhere."

No payment is made for articles published in *Gems & Gemology.* However, for each article the author(s) will receive 50 free copies of the issue in which their paper appeared.

REVIEW PROCESS

Manuscripts are examined by the Editor, the Editor-in-Chief, and at least three reviewers. The authors will remain anonymous to the reviewers. Decisions of the Editor are final. All material accepted for publication is subject to copyediting; authors will receive galley proofs for review and are held fully responsible for the content of their articles.