GEMS & GEMOLOGY

VOLUME XXVIII SUMMER 1992

THE QUARTERLY JOURNAL OF THE GEMOLOGICAL INSTITUTE OF AMERICA

GEMS & GEMOLOGY

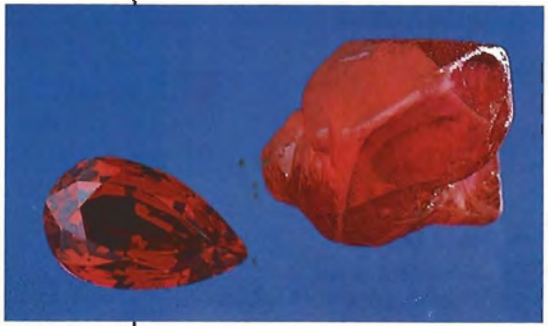
SUMMER 1992 VOLUME 28 No. 2

TABLE OF CONTENTS

p. 85

EDITORIAL

FEATURE ARTICLE



p. 89

NOTES AND NEW TECHNIQUES

p. 105

REGULAR FEATURES

p. 124

ABOUT THE COVER: Over the last three decades, Tanzania—the subject of the lead article in this issue—has emerged as one of the most important sources of fine gem materials. Although a producer of gem-quality diamonds, rubies, and sapphires, Tanzania is perhaps best known for its production of the gem variety of zoisite, tanzanite, which occurs in the Merelani Hills. The superb transparent tanzanite crystal shown here weighs 491.80 ct and measures 62 × 34 × 25 mm. The faceted tanzanites weigh 60.53 and 24.30 ct, respectively. Stones are courtesy of Michael Scott, Sunnyvale, 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.

© 1992 Gemological Institute of America All rights reserved 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
Lisa Lauderback

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
Loretta B. Loeb

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: $49.95 for one year (4 issues), $119.95 for three years (12 issues). Subscriptions sent elsewhere are $59.00 for one year, $149.00 for three years.

Special annual subscription rates are available for all students actively involved in a GIA program. $39.95 U.S.A., $49.00 elsewhere. Your student number *must* be listed at the time your subscription is entered.

Single issues may be purchased for $12.50 in the U.S.A., $16.00 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.

MANUSCRIPT SUBMISSIONS

Gems & Gemology welcomes the submission of articles on all aspects of the field. Please see the Suggestions for Authors in the Winter 1991 issue of the journal, or contact the editor for a copy. Letters on articles published in *Gems & Gemology* and other relevant matters are also welcome.

COPYRIGHT AND REPRINT PERMISSIONS

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.

THANK YOU, DONORS

The Gemological Institute of America extends its sincerest appreciation to all of the people and firms who contributed to the activities of the Institute in 1991 through donations of gems to the Gemstone Collection for reference, research, and classroom use, as well as donations of written materials to the Richard T. Liddicoat Gemological Library and Information Center. We are pleased to acknowledge many of you below.

Dale Abell
Albert F. Rhodes Jewelers
Helen Antolovich
Chuck Ashbaugh
Asian Gemmological Laboratory
Aucoin Hart Jewelers Inc.
Hans J. Bagge — In memoriam
N. R. Barot
Penny Barreto
Ronald Base
Beija-Flor Gems
K. C. Bell
Marc Bielenberg
Gary Bowersox
Chris Boyd
Daryl Bradley
Ben Bridge
Falk Burger
Alfred Campbell
Don Clary
Jo Ellen Cole
Commercial Mineral Co.
Creative Gems
Crescent Jewelers Inc.
Design and Technological Institute of Monocrystals
J. and S. S. DeYoung, Inc.
Pete J. Dunn
Robert Dunnigan
Mark and Debbie Ebert
Robert Effler — In memoriam
David Epstein
Fine Gems, Inc.
Fingems
Mary Fitzgerald
F. R. Somers & Son PTY Ltd.
C. W. Fryer
Emmanuel Fritsch
Frosette Gems Ltd.
John Fuhrbach
Gems Galore
Gellner Kollektion
Geological Museum Beijing
Golay Buchel USA Ltd. Incorporating Heller Hope
Richard Goldberg
Keith Gouverneur
Art Grant
Michael and Patricia Gray
Liu Guobin
Jim Haas
David R. Hargett
William L. Harville, Jr.
Nancy Hays
William D. Hoefer, Jr.
Harry A. Horwitz
M. A. Huebler
John Hummel
Renata de Jara
Joseph's Jewelers
A. Kalokerinos
J. K. Kalkhorst
Robert C. Kammerling
Robert E. Kane
Christopher B. Keenan
William C. Kerr
Charles L. Key
Kirsi Klein
John I. Koivula
Guy Langelier
Lelia Louise Larson
Richard Larson
Lee Frank Jewelers
Tien-Fu Lin
Jack Lowell
Lynn's Jewelry
D. Vincent Manson
Charles Mark
Marshall Martin
Mason & Kay Inc.
Ruth May
Dodie McGraw
John F. Meacham
Yianni Melas
Marcus McCallum
Elise B. Misiorowski
Morgan's Jewelers
Merril Moses
Tom Moses
Ivan Mrazek
Eugene Mueller
Santi Musco
Nancy B. & Co.
Kusum S. Naotunne
Ed Nazelrod
John Ng
On Tai Jade & Travel
Barry F. Owen
Bette Page
Pala International
Anthony Parsons
D. J. "Doug" Parsons
Jon Phillips
Jean-Paul Poirot
Precision Cutting Co.
Maury Quam
Lorrie Dee Rascoe
Eli Ribicoff
Shinobu Sano
Hyman Savinar
Michael Schachter
Jeanne Scher
Gary S. Schmidt
Harold Seburn — In memoriam
Sherris Cottier Shank
Mark Smith
Dan Sofia
Stuller Settings
Margherita Superchi
Superior Diamond Corp./Temi B.
Edward R. Swoboda
Betty Terhune
Herb Walters
John J. Wellinghoff
Jeffery and Mary Wildman
Milan Zezulka
Anatoli Zolotarev

GEM WEALTH OF TANZANIA

By Dona M. Dirlam, Elise B. Misiorowski, Rosemary Tozer,
Karen B. Stark, and Allen M. Bassett

The East African nation of Tanzania has great gem wealth. First known by Westerners for its diamonds, Tanzania emerged in the 1960s as a producer of a great variety of other gems such as tanzanite, ruby, fancy-colored sapphire, garnet, and tourmaline; to date, more than 50 gem species and varieties have been produced. As the 1990s begin, De Beers has reinstated diamond exploration in Tanzania, new gem materials such as transparent green zoisite have appeared on the market, and there is increasing interest in Tanzania's lesser-known gems such as scapolite, spinel, and zircon. This overview describes the main gems and gem resources of Tanzania, and reviews their history, geology, mining, and economic development.

ABOUT THE AUTHORS

Ms. Dirlam is senior librarian, and Ms. Misiorowski, Ms. Tozer, and Ms. Stark are research librarians, at the Liddicoat Gemological Library and Information Center of the Gemological Institute of America, Santa Monica, California. Dr. Bassett is chief geologist/gemologist of Tan-Minerals Mining Co., Ltd., AICC, Box 8301, Arusha, Tanzania.

Acknowledgments: The authors are grateful for the valuable contributions by Dr. N. Barot, Edward Boehm, Campbell Bridges, Jo Ellen Cole, Patricia Gray, Dr. A. J. A. (Bram) Janse, Jonte Berlon, Holly Kane, Dr. P. Keller, Cheryl Kremkow, Dr. H. Krupp, Dr. A. Levinson, Dr. E. Malisa, Roland Naftule, Ruth Patchick, Dr. J. Saul, Rogers Sezinga, Abe Suleman, TOFCO, Tsavo Madini, and Alli S. Zullu.

Gems & Gemology, *Vol. 28, No. 2, pp. 80–102.*

The United Republic of Tanzania, the largest of the East African countries, is composed of mainland Tanzania and the island of Zanzibar. It is regarded by many as the birthplace of the earliest ancestors of *Homo sapiens*. To the gem industry, however, Tanzania is one of the most promising frontiers, with 50 gem species and varieties identified, to date, from more than 200 occurrences.

"Modern" mining started in the gold fields of Tanzania in the late 1890s (Ngunangwa, 1982), but modern diamond mining did not start until 1925, and nearly all mining of colored stones has taken place since 1950. Even so, only a few of the gem materials identified have been exploited to any significant extent: diamond, ruby, sapphire, purplish blue zoisite (tanzanite; figure 1), and green grossular (tsavorite) and other garnets. Relatively minor amounts of tourmaline, emerald, aquamarine, alexandrite, amethyst, scapolite, spinel, and other gem materials have also been mined (see figure 2). Recently, the Tanzanian government and the world's mining industry have begun to reinvestigate the potential for large-scale gem production, spurred by changing political, technological, and economic factors both in Tanzania and worldwide. For example, a consortium headed by the World Bank has approved a loan package of $1.8 billion for renovation of the nation's infrastructure ("Tanzania's latent opportunities," 1992). Tanzania seems poised on the edge of fully developing its rich gem resources.

This article will first briefly review the history, geology, and mining of Tanzania. We will then examine each of the major gem materials and their occurrences.

HISTORY

Hominid habitation in this part of East Africa has been documented back to about 6 million years (members of the Leakey family were the first to establish the anthropological importance of Olduvai Gorge). The ancient Greeks knew of Tanzania, which they called Azania. The Bantu people, who

Figure 1. Tanzania is perhaps best known for the transparent purplish blue variety of zoisite, tanzanite, which was discovered in the 1960s and named by Tiffany & Co. in honor of its country of origin. The tanzanite in this pendant weighs 96.42 ct; the earrings weigh a total of 24.29 ct. Jewelry courtesy of Tiffany & Co.

currently make up the majority of Tanzania's population of 26 million, apparently arrived in the region in the 1st century A.D. (Vidal-Naquet, 1987). Because of its strategic location, Tanzania has been a major trading center since the 9th century. About this time, the coastal regions were settled by Moslems from Arabia, Persia (now Iran), and elsewhere, who worked with the Swahili, a people of the eastern division of the Bantu. Together, they established trading centers such as Malindi, Mombasa, and Kilwa. The last, in southern Tanzania, controlled one of the ancient gold routes into the interior and later became the trading center for ivory, rock crystal (quartz), and slaves, as well as gold (Horton, 1987).

Portugal established control over the area in the early 1500s, but it was displaced by Great Britain in the 1600s. Then, in the 19th century, Germany gained control of the mainland, through treaties signed with inland chiefs, and established the German East Africa protectorate; following World War I, this became Tanganyika, under British mandate. Tanganyika gained independence from Great Britain in 1961 and three years later united with Zanzibar, a British protectorate since 1890, to form the United Republic of Tanzania. (Throughout this article we use the term *Tanzania* even though the country may have been known by another name at the time of the specific event being discussed. For example, when diamonds

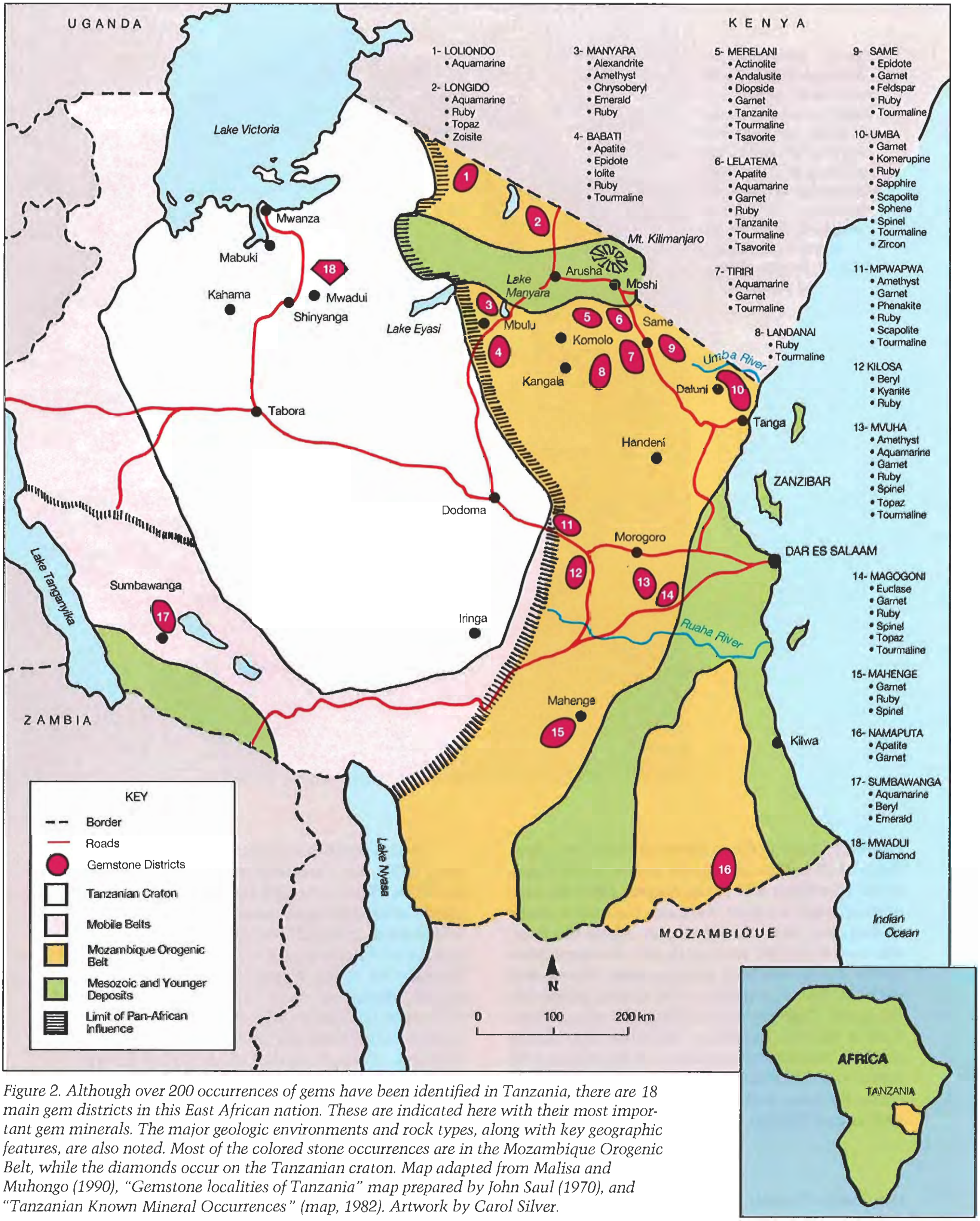


Figure 2. Although over 200 occurrences of gems have been identified in Tanzania, there are 18 main gem districts in this East African nation. These are indicated here with their most important gem minerals. The major geologic environments and rock types, along with key geographic features, are also noted. Most of the colored stone occurrences are in the Mozambique Orogenic Belt, while the diamonds occur on the Tanzanian craton. Map adapted from Malisa and Muhongo (1990), "Gemstone localities of Tanzania" map prepared by John Saul (1970), and "Tanzanian Known Mineral Occurrences" (map, 1982). Artwork by Carol Silver.

were first found, the country was known as German East Africa. Also, for the purposes of this discussion, *Tanzania* will refer exclusively to the mainland portion of the nation.)

Until the late 1960s, gem mining in Tanzania was done primarily by individuals and private companies. In 1971, however, the government nationalized the first mines and established Tanzania Gemstone Industries (TGI), under the National Development Corp., to oversee them (Rwezaura, 1990). In 1972, the government created the State Mining Corp. (STAMICO), with TGI as its subsidiary. Because overall gem production was so poor during this period, in 1976 STAMICO began geologic as well as mining studies in an effort to improve the situation.

During most of the 1970s and into the 1980s, the government required that all mining be controlled by the state. All gem rough had to be bought through STAMICO and sold on the open market. Although foreign companies were discouraged from engaging in mining activity for many years, selective foreign investment has been allowed since the early 1980s. In 1985, the newly enacted Economic Recovery Program established provisions favorable to foreign investment (Notholt, 1990). Today, the government is issuing gemstone prospecting, mining, and "master dealer" licenses under which private individuals may prospect, mine, trade, and export gem minerals ("ICA presents ...," 1991), as well as offering important economic incentives.

REGIONAL GEOLOGY

East Africa has been the subject of formal geologic mapping and exploration projects since the late 1800s. Several major geologic environments have been identified: an Archean craton, orogenic mobile belts, coastal marine sedimentary deposits, rift valleys of various ages, recent (Tertiary) volcanism, and various types of surface deposits. Several of these environments contain gem occurrences.

The main geologic divisions in Tanzania (again, see figure 2) are: on the west, the Tanzanian craton, which is of Archean age (2,500–3,000 My [million years]); and, on the east, the Mozambique Orogenic Belt (1,200–450 My). A craton is an ancient, stable part of a continent that is composed of igneous and metamorphic rocks (see, e.g., Janse, 1992; Kirkley et al., 1991). The Tanzanian craton is surrounded by Middle-to-Late Proterozoic (1,600–800 My) mobile belts, which are long, narrow crustal regions subjected to geologic forces that resulted in processes such as folding and mountain building. These belts include the Ubendian to the southwest, the Karagwe-Ankolean to the northwest, and the Usagaran to the east.

The Usagaran is the Tanzanian portion of the much larger Mozambique Orogenic Belt (orogenic belts are those that were mobile during their formative stages), which extends under most of East Africa. It is about 250 km wide and runs for about 5,000 km from Madagascar and Mozambique in the south to Ethiopia and Sudan in the north. The rocks in this belt have undergone extensive metamorphism, plutonism, folding, and faulting. This belt has a complex history of several cycles of tectonism (major crustal movements) and at least three stages of regional and contact metamorphism, starting in the Late Proterozoic (1,200 My). These include high-grade metamorphic events that produced several granulite complexes (sets of metamorphic mineral assemblages resulting from high pressures and high temperatures, 650°–800°C). The latest thermal events were caused by the Pan-African Orogeny (800–450 My). East of the Mozambique Belt lies the coastal plain of Tanzania, which is underlain by Mesozoic (225–65 My) and more recent sediments.

The formation of granulites in association with major tectonic events is particularly important, because a wide range of minerals were subjected to heat, pressure, and hot fluids. During such geologic processes, not only are new minerals formed, but chromophores such as chromium and vanadium may also be remobilized from their original mineral hosts. Under favorable conditions, this results in the formation of gem crystals of unusual colors and phenomena, such as "chrome" tourmalines and change-of-color garnets and sapphires (figure 3). Malisa and Muhongo (1990) outlined 17 major occurrences of granulite-type rocks and identified the eastern granulite complexes in the Mozambique Belt as having the greatest potential for gem materials (again, see figure 2).

MINING

Exploration and Techniques. Until recently, most exploration in Tanzania was based on prospecting using visual observation. In fact, major deposits have been found by local herdsmen familiar with gems (Key and Ochieng, 1991a). Traditionally, mining has been carried out with minimal mechanization. Most of the miners are itinerant laborers who work sporadically, depending on the climatic and political conditions. For example, mining is generally hampered

Figure 3. Tanzania is particularly noted for its production of unusual gem materials, like these color-change garnets seen here in incandescent (left) and fluorescent (right) illumination. The stones range from 3.89 to 1.57 ct. Photo © GIA and Tino Hammid.

from December to May, the wettest months of the year. Furthermore, miners sometimes leave one mining area for another that has just opened up or expanded, resulting in the temporary abandonment of the first mine.

The only consistently large-scale gem-mining operation in Tanzania has been at the Mwadui (Williamson) diamond mine. For a time in the 1960s, there were also large-scale operations at the Umba River deposits, but mechanization declined with the onset of nationalization. Although there are some operations that use heavy equipment, most gem mining in Tanzania today is small scale. The deposits mined may be either primary in the host rock or secondary (which includes both alluvial along rivers, or eluvial in the weathered zones above and/or adjacent to the primary deposits). Details relating to the type of mining associated with a particular deposit are provided below in the discussions of specific gem materials.

Small-scale mining in Tanzania—whether by private individuals, mining organizations, or private companies—is labor intensive. For example, in alluvial deposits along rivers such as the Umba and the Lukande, miners shovel gem-bearing gravels onto screens and wash them in nearby stream waters (figure 4). In primary deposits like the emerald occurrence at Lake Manyara, low-energy explosives are used to break up the rock and then the material is sorted by hand. Only recently have backhoes and mechanized shaker tables again been brought into some of the more accessible mining areas. Today, modern equipment is found at the Mwadui diamond mine, in some corundum-mining areas (figure 5), and in portions of the Merelani Hills tanzanite area.

It is appropriate to mention here how difficult it can be to ascertain the actual source for most gems. In East Africa, in particular, many gems mined in Tanzania are carried across the border into neighboring Kenya and especially to its cosmopolitan cities Nairobi and Mombasa. Consequently, gems from this area are commonly described simply as coming from East Africa rather than specifically from Tanzania. Even when specific sources are given by the seller, one cannot always depend on the accuracy of the information. An improvement in the reporting of localities is evident in the recent literature (see, e.g., Malisa and Muhongo, 1990; Key and Ochieng, 1991a). Still, we have taken this factor into consideration when evaluating information about specific gem materials.

Environmental and Health Concerns. The problems that face resource-rich but economically poor Tan-

Figure 4. Much of the mining in Tanzania is alluvial, often secondary deposits along streambeds. Here, miners use rudimentary shovels and screens to locate corundum and other gems in the gravels of the Umba River. Photo © Fred Ward.

zania are staggering. The temptation is to meet the nation's economic needs by accelerating the exploitation of its mineral resources, including gemstones.

The long-term environmental impact could be severe. The reported use of water cannons to mine gems in some of the Umba River alluvial deposits, a technique outlawed 100 years ago in the U.S. because of the damage it caused, is one example (F. Ward, pers. comm., 1991). At the African Mining Congress held in June 1991, concerns were raised about the inappropriate use of cyanide to process gold at deposits in Tanzania.

Perhaps the greatest challenge is the health of the populace. Just as a cholera epidemic stopped all mining in northern Tanzania in 1978 and again in 1987, so the spread of AIDS is predicted by some to have a major impact on the miners as well as on the population as a whole. It is predicted that, by the end of 1992, there will be 5,000 new cases of the HIV virus each day in East Africa. Tanzania is receiving both financial and educational assistance from international agencies such as the World Health Organization and the World Bank, as well as from regional groups such as the Southern African Development Coordinating Council (SADCC; Jourdan, 1991). Today, warnings against *ukime* (the Swahili word for AIDS) are already common at the gold fields. Unfortunately, the problem is compounded by the itinerant nature of the mining population (Bills et al., 1991). Such issues will need to be addressed as part of Tanzania's long-term planning for economic growth in general and for the exploitation of its gem resources in particular.

DIAMOND

Background. Although prospecting over the years has identified more than 300 kimberlites, of which 44 are diamondiferous, few have proved to be econom-

Figure 5. This mechanized washing plant serves a ruby mine located about one hour south of Mahenge that is operated by Simba International Investments Ltd. Using the diesel motor of a truck, the miner washes the gem-bearing gravels before they are sent to the jigs for final separation of the rubies. Photo © Fred Ward.

Figure 6. The Mwadui diamond mine, in northern Tanzania, is currently the largest, most sophisticated mining operation in Tanzania. The kimberlite pipe at Mwadui is about four times the size of the Premier mine. Photo courtesy of the Central Selling Organisation.

ically feasible ("Tanzania's latent opportunities," 1992). At present, the only active diamond mine is the Mwadui, also known as the Williamson mine, in northern Tanzania (figure 6). Although diamonds were found at Mabuki as early as 1910, mining did not begin there until after 1925 (B. Janse, pers. comm., 1992). Mabuki and two other small mines, at Kisumbe and Nzega, were operated by the Tanganyika Diamond and Gold Development Company until mining was halted in 1938. One of their geologists, Dr. John T. Williamson, continued to search independently in the area. In 1940, on the verge of bankruptcy, he discovered at Mwadui what would prove to be the world's largest (in surface area) kimberlite pipe: 146 hectares, about four times the size of South Africa's Premier mine (Gobba, 1991). Dr. Williamson subsequently developed the mine, now called the Mwadui, into one of the richest in Africa. It is unusual for a primary deposit, in that about half of the diamonds mined there are of gem quality (Balfour, 1987).

After Williamson died in 1958, De Beers and the national government jointly purchased the mine from his heirs. Although the mine was officially nationalized in the 1960s, ownership actually passed to a Bermuda-based holding company, Willcroft, a subsidiary of De Beers in which Tanzania took a 50% share. Reports in the literature suggest that the mine is nearly played out: Whereas 924,000 ct of diamond were produced from 3.3 million tons of ore in 1966, the same amount of ore produced only 265,600 ct in 1984 ("Background analysis—Tanzania . . .," 1986).

Two kimberlites found in the Kahama area west of Mwadui were mined briefly during the late 1960s, but they are not currently being worked (Janse, 1991).

Geology. The Tanzanian diamond deposits have certain characteristics that make them unique. The most notable feature is that they occur in kimberlite crater deposits or in closely associated weathered gravels, as well as in the kimberlite pipe itself. Elsewhere in the world, kimberlite crater deposits (by definition, on the surface) normally have been removed by erosion. For example, kimberlites that occur on Precambrian shields (outcropping Archean cratons) have usually been eroded down to their roots and, thus, crop out in the form of small dikes or irregular-shaped pipes. However, the Mwadui kimberlite outcrop is a large (1600 × 1100 m) ellipsoidal crater that is as much as 360 m deep. The diamond deposits are associated with shaley sediments deposited in a crater lake, with breccias derived from a mixture of kimberlite and disintegrated gneiss bedrock, and with gravels derived from these two components and from the overlying calcrete. Because the kimberlite intrusions in Tanzania are relatively young (45–55 My, as compared to 90–120 My for most of the South African pipes), they have not been subjected to the extensive erosion experienced by their older counterparts. Consequently, secondary deposits are minimal.

Although Tanzania is literally peppered with kimberlites, many of them are barren of diamonds. Of those 44 that are diamondiferous, only a few are economically viable and these are all found in a belt on the craton (B. Janse, pers. comm., 1992).

Description of the Material. In addition to its high percentage of gem-quality near-colorless diamonds, the Mwadui mine is also known for producing pink (figure 7) and green diamonds. In 1954, for example, the Mwadui mine produced 105 ct of bright pink diamonds for every 100 tons of ore mined ("Background analysis . . .," 1986). The only reported properties for Tanzanian diamonds (from Mwadui) are consistent with those reported for diamonds from other localities (Tsai et al., 1979).

Current Production and Future Potential. Tanzania has produced 18 million carats of diamonds since the end of World War I. More than 90% of these came from the Mwadui pipe ("Tanzania's latent opportunities," 1992), with most of the remainder coming from the adjacent Alamasi mine. After reaching a peak of 926,758 ct in 1967, production at the Mwadui mine has declined to between 150,000 and 200,000 ct annually in recent years (Wilson, 1971; Notholt, 1990). The Mwadui deposit has yielded several diamonds over 100 ct; the largest piece of rough on record weighed 256 ct. Williamson presented the largest recorded Tanzanian pink diamond—54 ct in the rough—as a wedding present to then-Princess Elizabeth of Great Britain in 1947. The gem was subsequently cut to yield a 23.68-ct internally flawless round brilliant, now known as the Williamson Pink (Balfour, 1987).

In January 1992, the Tanzanian Ministry of Water, Energy, and Minerals signed a diamond-prospecting agreement with De Beers Centenary AG's subsidiary Willcroft Co. and Tanex, a locally incorporated subsidiary of Willcroft ("Tanzania signs major diamond deal," 1992). Using modern geophysical methods like remote sensing, they are scanning an area over 23,000 km^2 in northern Tanzania, south of Lake Victoria and west of Mwadui. The newly developed method of nickel thermometry, which measures the nickel content of the garnet and chromite indicator minerals found in heavy mineral concentrates from kimberlites, provides a relatively inexpensive and fast test to distinguish between barren and potentially diamondiferous kimberlites (Griffin et al., 1991). Given the number of diamondiferous deposits already known, Tanzania holds the promise for other economically significant diamond mines.

CORUNDUM

Ruby. *Background.* Rubies and pink sapphires are found in the northern, northeastern, and central eastern areas of Tanzania: Longido, Umba River Valley, and Morogoro (figure 8), respectively (again, see figure 2). Ruby was first discovered in the early 1900s near Longido Mountain, close to the border with Kenya. Following World War I, the German officer credited with making the original discovery founded the Tanganyika Corundum Corp. and began mining at the locality now known as the Longido (also the Mdarara) mine. Longido was operated sporadically until 1971, when it was taken over by the Tanzanian government and subsequently closed. Reopened in 1988, it is now operated by the Longido Gemstone Mining Company—a joint venture between Tofco, a Swiss company, and Tanzania Gemstone Industries. The mine shaft is 3 m in diameter and 100 m deep. Explosives and pneumatic drills are used to penetrate the host rock, which is then brought to the surface using rail wagons (C. Garcea, pers. comm., 1992).

Figure 7. Tanzania is known for its production of pink diamonds as well as near-colorless and green stones. This 2.90-ct diamond is known as the De Young Pink. Courtesy of the Smithsonian Institution, Washington, DC; photo © Tino Hammid.

Figure 8. Since the 1970s, the Morogoro area has become an important source of ruby and pink sapphire. These ruby cabochons (the largest weighs 8.88 ct) were cut from Morogoro-area rubies. Courtesy of Pala International, Fallbrook, CA; photo © Harold & Erica Van Pelt.

Ruby was discovered in the Umba River Valley in the 1950s. Umba Ventures, owned by George Papaeliopoulos ("Papas"), mined ruby and sapphire in an area of 2,350 acres from 1961 until it was nationalized in 1972 (Rwezaura, 1990). The government controlled the mines until 1982, when Gupta Exploration and Mining Co. was granted mining rights. In 1989, the Asia Precious Stones and Equipment Co. of Thailand obtained a license to mine in the area. This company formed a joint venture between Thai and Tanzanian groups—the Africa-Asia Precious Stones and Mining Co. (AAPS)—which eventually acquired exclusive mining rights to Umba ("Thai joint venture...," 1989).

The Morogoro area began producing rubies in the 1970s. Although Morogoro is actually a large province that includes the town of the same name, to this day rubies from any part of this region are referred to as "Morogoro" ruby. In recent years, many new mines have been opened, including the Matombo, Kitonga, Epanko, Ruaha, Lukande, Mayote, and Kitwaro (Hänni and Schmetzer, 1991; N. Barot, pers. comm., 1992). As discussed by Hänni and Schmetzer, there are often significant differences from one Morogoro mine to the next in the properties of the rubies found there. They speculate that the "Burma type" rubies and pink sapphires found mixed in parcels of spinel reportedly from Morogoro actually came from the Matombo mine (figure 9). The Marazi deposit in Morogoro has also produced some unusually fine transparent rubies (figure 10).

South of the Usambare Mountains and north of Morogoro, the area near Handeni produces significant quantities of deep red to purplish red tabular hexagonal ruby crystals that are usually of cabochon grade (N. Barot, pers. comm., 1992). In addition, small amounts of ruby have been found with emerald and alexandrite in the Manyara escarpment to the west (Henn and Bank, 1991). This latter region is discussed in greater detail in the emerald section.

Geology. Pohl and Horkel (1980) identified four types of primary ruby-bearing deposits in East Africa: (1) desilicated pegmatites (i.e., that have been depleted of silica as a result of the breakdown of silicates through reaction with magma) in ultramafic bodies (igneous rocks high in iron-magnesium minerals); (2) desilication zones at the contacts of the ultramafic and metasedimentary country rocks; (3) metamorphosed aluminous sediments (not economically important); and (4) marbles associated with red spinel. Key and Ochieng (1991a) maintain that only those ruby deposits that form in association with chrome-bearing ultramafics have economic potential.

One of the coauthors (A.B.) draws on his experience as former manager of the Longido mine to provide the following information about the geology of the northern localities. The Longido mine is in a "reef" of "anyolite," a rock composed of opaque green zoisite with dark green to black amphibole that occurs with opaque to transparent ruby. This "reef," about one-half to one meter thick and approximately 500–600 m long, lies within a weathered peridotite that was intruded into a sequence of high-grade metamorphic rocks including marble (the second of the four types of primary ruby deposits listed above). The ruby is recovered as hexagonal crystals and irregular masses embedded in the green zoisite and/or black amphibolite.

Smaller deposits of ruby in anyolite are found nearby, as well as at Lossogonoi and Naberera, 60–70

Figure 9. Rubies (here, the two large crystals) have been found mixed with spinels in parcels from the Morogoro area. These pseudo-octahedral ruby crystals are ringed by seven smaller spinel octahedrons, all from Morogoro. Photo by Shane McClure.

km southeast of Arusha. In the past, ruby rough mined in the area around Landanai and Lossogonoi produced facet-grade stones in the one-carat range (N. Barot, pers. comm., 1992), but this deposit is no longer active.

One of the first geologists to report on the gem corundums of the Umba Valley, Solesbury (1967), maintained that both rubies and sapphires found in this area originally formed in pegmatites cutting a serpentinite (the first of the four types of primary ruby deposits listed above). The serpentinite (actually a "pipe"; C. Bridges, pers. comm., 1992) occupies the core of a fold in the Usagaran granulite rocks.

In the Morogoro area, rubies are found as alluvial deposits or as lenses in calc-silicate rocks within the marbles (the fourth type of primary ruby deposit mentioned) of the Usagaran granulite type rocks (Msolo, 1992).

Description of the Material. For the most part, the gemological properties of the various Tanzanian rubies are consistent with those of rubies from various other localities (Bank, 1970; Zwaan, 1974; Schmetzer, 1986). However, differences in chemistry, crystal morphology, and internal features have been reported, even for rubies that are believed to come from the same area (e.g., Morogoro; Hänni and Schmetzer, 1991).

Recent geochemical studies help explain the hues of rubies from the various Tanzanian deposits as compared to rubies from other localities. Although the chromium content of Morogoro and Umba rubies is relatively low in comparison to those from Myanmar (Burma), the amount of iron is similar to that in Burmese rubies and is considerably less than that identified in other Southeast Asian stones. Typical Morogoro-area rubies have the least iron, Longido has more, while Umba River specimens have the most (Hughes, 1990; Hänni and Schmetzer, 1991; Key and Ochieng, 1991b). Some of the Tanzanian rubies are heat treated in Thailand in an attempt to improve color and clarity. To date, such treatment has had mixed results (K. Schmetzer, pers. comm., 1992).

Figure 10. Spectacular rubies, like this 1-gram crystal and 0.87-ct pear shape, are being produced at the increasingly important Marazi deposit in Morogoro. Stones courtesy of Dr. Horst Krupp and Pala International; photo © GIA and Tino Hammid.

Figure 11. In the valley of the Umba River, mechanized mining is now used to recover corundum and associated gems from the rich gem gravels. Photo © Fred Ward.

Current Production and Future Potential. Mining at Longido produces, at best, about one ton of ruby per month; only about 1% of this is cabochon grade and an even smaller fraction is facetable, with the remainder suitable for carving. Faceted transparent stones seldom exceed one carat. Reserves at Longido appear to be sufficient to maintain production at this level for several years.

In the 1960s and 1970s, miners at Umba occasionally found pieces of rough that yielded cut rubies as large as 20 ct (R. Naftule, pers. comm., 1992). Although official reports indicate that there is now virtually no production from the Umba River region, mining of both primary deposits and alluvial gravels continues, and is now done with the help of bulldozers and backhoes (figure 11). This level of activity, and the extent of gem trading in nearby villages and towns, suggests that economic quantities of gem-quality ruby and sapphire are being recovered, and such mining will undoubtedly continue in the future (Ward, 1991).

Currently, hundreds of miners are operating at the various localities in the Morogoro area (Msolo, 1992). Dr. N. Barot (pers. comm., 1992) estimates that the total production from these deposits is approximately 200 kg per month of gem ruby—mostly cabochon and carving grade.

Figure 12. These are only a few of the many colors of sapphire mined from the Umba Valley. The average sapphire is approximately 3 ct. Courtesy of Gems of Africa, Los Angeles, CA; photo by Robert Weldon.

Sapphire. *Background.* The Umba River Valley has yielded sapphires in virtually every color as well as change of color. To date, this is the only region that produces gem-quality sapphires, although there are reports of other sapphire occurrences in the vicinity and pink sapphires have been identified with rubies in the Morogoro area, as noted above. Sapphires were first discovered in the 1950s, in alluvial gravels of the Gerevi Hills north of the Umba River (Solesbury,

Figure 13. The Umba Valley is also noted for its production of color-change sapphires. This 8.74-ct sapphire is blue in day or fluorescent light and purple in incandescent light. Courtesy of S. L. Dillon; photo © Tino Hammid.

1967). As mentioned above, Umba Ventures was formed in 1961; they worked the nearby primary deposit as well as the alluvial deposits (Sarofim, 1970). As with the other gem deposits, mining was halted for much of the 1970s and early 1980s, but activity resumed in 1986.

Geology. At Umba, the sapphires—like the rubies—formed in association with pegmatite veins that cut a serpentinite body in the Umba River Valley metasediments (Solesbury, 1967). Today, the miners are working secondary deposits almost exclusively. The main mine now extends to 100 m below the surface, with tunnels radiating from the primary shaft on the gem-bearing levels (N. Barot, pers. comm., 1992; again, see figure 9).

Description of the Material. For the most part, the gemological properties reported for Tanzanian sapphires overlap those of sapphires from other localities (Webster, 1961b; Bank, 1970; Zwaan, 1974; Schmetzer, 1986). They are most notable for their great range of colors: colorless, violet, purple, blue, green, orange, yellow, yellow-orange, red-orange, pink, parti-colored, and change of color (figure 12). The parti-colored sapphire crystals tend to be pale in the center and have a deeper hue around the edges (Pough, 1971; Bridges, 1982). Many of the Umba sapphires exhibit change of color such as greenish to grayish blue in day- or fluorescent light and deep purple to purplish red in incandescent light (figure 13). This unique range of colors is caused by variations in the proportions of the chromophores chromium, iron, manganese, nickel, titanium, and vanadium (Zwaan, 1974; Schmetzer, 1978).

Alluvial sapphire rough is usually found as rounded pebbles that produce stones of one carat or less. However, faceted stones as large as 40 ct and cabochons up to 90 ct have been cut from pieces of rough weighing hundreds of grams (R. Naftule, pers. comm., 1992).

Some members of the trade label Umba's orange sapphire "African padparadscha" (figure 14), although the trade name *padparadscha* is usually restricted to the delicate pinkish orange Sri Lankan sapphire. In the past, orange sapphires did not meet the generally accepted criteria for "padparadscha" (Crowningshield, 1983; Henn and Bank, 1992). However, East African sapphires with the more classic hues of padparadscha were seen at both the 1991 and 1992 Tucson shows.

Some of the pale sapphires are being heat treated in Thailand. Although all of the stones will be affected, the resulting color is often not commercially desirable (K. Schmetzer, pers. comm., 1992). The GIA Research Department heat treated three orange-pink sapphires from the Umba River region in a strongly reducing atmosphere, at 1700°C, for 18–21 hours.

Figure 14. The orange sapphires from Umba are distinctive for their saturation. Here, the orange rough is 3.80 ct and the cut stone is 1.04 ct. Courtesy of Don Clary; photo by Robert Weldon.

Figure 15. The Umba Valley sapphires reportedly do not respond to heat treatment as well as sapphires from some other localities. These three sapphires from the Umba Valley were cut and the left half of each heat treated to provide some idea of the extent of the change produced. Stones and experiment courtesy of the GIA Research Department; photo © GIA and Tino Hammid.

These stones showed little change of hue (figure 15), but the fading of yellow and production of violet color was interesting. Recently, it has also been reported that some of the material is being "quench crackled" and dyed to simulate ruby (Schmetzer and Hänni, 1992).

Current Production and Future Potential. As with rubies from this area, officially there is no current production of sapphires in the Umba River valley. Again, however, the extent of mining activity and local gem trading indicates that the area is still producing facet-grade sapphires in all colors (Ward, 1991). R. Naftule reports that a single pocket found at Umba in 1990 contained 10 kg of rough red-orange to orange sapphire that yielded stones as large as a carat (pers. comm., 1992).

ZOISITE (TANZANITE)

Background. Zoisite belongs to the epidote group of minerals. Its most famous gem variety is purplish blue tanzanite (again, see figure 1). However, Tanzania also produces the opaque green variety anyolite

Figure 16. The earliest variety of zoisite seen in the gem industry was the opaque green material that commonly occurs with ruby. It is a superb carving material, as illustrated by this ruby field mouse sitting on a green zoisite leaf. The carving—actually made from a single piece of ruby in zoisite—measures 45.13 mm high by 62.64 mm wide by 55.72 mm deep. Carving by Gerd Dreher, courtesy of Silverhorn, Santa Barbara, CA; photo © GIA and Tino Hammid.

Figure 17. Most of the opaque green zoisite is mined at Longido. Here a miner works a pillar of green zoisite underground at Longido. Photo courtesy of Carlos Garcea.

(Gübelin, 1969), as well as limited quantities of transparent zoisite in a number of hues (including green, yellow, pink, and violet; Barot and Boehm, 1992).

Before the discovery of tanzanite, the most notable zoisite in Tanzania was anyolite, which occurs with ruby. This unique combination makes a dramatic carving material (figure 16). It is mined underground at Longido (figure 17).

The gem community's appreciation of this species changed dramatically when transparent blue zoisite was discovered in the 1960s. It was first identified in 1962 by George Kruchiuk, who had received several samples that were purported to be blue sapphire; Manuel D'Souza is credited with discovering the location of the deposits while prospecting for ruby in the Merelani Hills (again, see figure 2) in the Lelatema district (Bank, 1968; Hurlbut, 1969; Webster, 1983). Tanzanite was first marketed in the United States in 1968 by Tiffany & Co. ("Tiffany discloses . . .," 1968), which named the gem in honor of its country of origin.

Private prospectors and local miners worked the Merelani Hills deposits until nationalization was started in 1971. The supply of tanzanite was sporadic until 1988, when the government temporarily opened the area and 20,000 miners descended on it. Working day and night, they dug hundreds of pits and recovered many thousands of carats of tanzanite. In late 1990, however, the government sought to establish greater control over the number of miners and the flood of tanzanite into the world market. Ultimately, the Tanzanian army was deployed to remove the miners and patrol the locality (Federman, 1991).

The government has since divided the tanzanite area into four sections, or blocks, and awarded mining contracts for each block to a different joint venture (see A. Suleman's report in Koivula and Kammerling, 1991c). Today, all are being mined and are beginning to be mechanized. The government also marked out several small blocks southwest and northeast of blocks A and D, respectively, and has already invited offers from Tanzanian firms and individuals.

Figure 18. Tanzanite is known for its distinct pleochroism, but this is one of the most spectacular examples ever recorded. Shown here are the colors seen along the three axes of this superb crystal, called the "Sleeping Beauty of Tanzania," which weighs 176 grams and measures 55 mm high × 43 mm wide × 28 mm thick. Note especially the deep red seen down the c-axis, which is usually brown. Courtesy of the John Barlow Collection; photo © Harold & Erica Van Pelt.

Geology. Tanzanite is found in both primary and secondary deposits. Malisa (1987) describes the primary tanzanite deposits as occupying the crest of the large Lelatema fold, which is composed of metamorphic rocks (e.g., dolomite marbles, graphitic gneisses, and schists) and is separated from the surrounding plateau by large faults. Hydrothermal solutions injected into local faults and fissures reacted with the bedrock to begin the tanzanite mineralization. The gneisses at Merelani were folded during the many stages of movement that followed. As a result, tanzanite—sometimes associated with green grossular garnet—is most commonly found in cavities in the metamorphic rocks or at the contact with quartz veins in the hinges of folds that can be tens of meters wide.

Description of the Material. One of the most notable features of tanzanite is its strong pleochroism, which is usually grayish blue, purple, and brown, green, or yellow. Red replaces brown in some crystals (figure 18; see also A. Bassett, as reported in Koivula and Kammerling, 1991b). Most of the gem-quality tanzanite recovered appears brown face-up when cut. The color in approximately 95% of the purplish blue tanzanites on the market today has been produced by heating the crystals to approximately 600°-650°C, which results in a change in the valence state of the vanadium (V^{3+} to V^{4+}; Anderson, 1968; R. Naftule, pers. comm., 1992) and converts the brown (or yellow or green) pleochroic color to blue. The extensive mining in recent years has produced unusually large quantities of tanzanite as well as extremely large crystals, some well over 100 grams.

Small quantities of transparent zoisite crystals are also found in other colors: greenish blue, green, yellow, and pink, as well as violet to reddish purple, colorless, change of color, and bicolored (Barot and Boehm, 1992; R. Kane and R. Naftule, pers. comm., 1992; figure 19). The most significant recent development has been the commercial production of transparent green zoisite (Barot and Boehm, 1992). Found at Block B, gem-quality pieces as large as 19 grams have been recovered from this primary deposit. The color ranges from a dark petroleum-like green to yellowish ("olive") to bluish green to green to a greenish blue. The "purity" of the green depends on the amount of chromium relative to vanadium present in the stone: "Pure" green stones show more chromium than vanadium; yellowish or bluish green stones show a higher vanadium content (Schmetzer and Bank, 1979; Barot and Boehm, 1992).

Current Production and Future Potential. Although there are more fine, large tanzanites on the market today than ever before, we do not know if the level of production achieved before the block system was established will be maintained. Even so, it appears that there is still a large stockpile of tanzanite among the independent miners: Many used the money they originally received for their tanzanite to purchase *more* tanzanite. "While termites will eat paper money, they are no threat to the gems," which can be safely stored for future sales (H. Krupp, pers. comm., 1992).

GARNET

A number of unusual garnets have been found in Tanzania: pyrope-spessartine (malaya), pyrope-almandine (rhodolite), green grossular (tsavorite), pyrope, and change of color. In fact, changes recommended in the gemological classification of species of the garnet group are largely the result of the availability of these

Figure 19. Transparent zoisite actually occurs in a wide range of colors. These zoisites are all from the Merelani area; the yellow gem weighs 9.36 ct, the blue tanzanite at the upper right weighs 7.14 ct, and the green zoisite at the lower left weighs 2.54 ct. Courtesy of Pala International, Fallbrook, CA; photo © Harold & Erica Van Pelt.

new garnets (see Stockton and Manson, 1985, for an in-depth discussion of this new classification). The hues represented by Tanzanian garnets include green, purplish red, orange, and various pastel shades (figure 20)—the result of variations in iron, manganese, chromium, and vanadium content. The most economically important garnets from Tanzania—malaya, tsavorite, rhodolite, and change of color—are discussed individually below.

Malaya (Malaia). This red-orange to yellow-orange garnet (figure 21) is found in alluvial deposits along the Umba River and in several plains that stretch from the Tanzanian border with Kenya north to the Mgama Ridge in the Taita Hills (Curtis, 1980). Malaya garnet was discovered in the mid-1960s by miners extracting rhodolite for George Papas in the Umba River Valley (R. Naftule, pers. comm., 1992). First thought to be spessartines, in the early 1980s they became known by the Swahili name *malaya* (which translates as "out of the family," or "outcast"), because their properties did not place them into traditional garnet categories.

Not only has *malaya* (malaia) garnet been known by two different spellings, but it is also known as *pyralspite* (Winchell, 1937) after its mixture of *py*rope, *al*mandine, and *sp*essartine (although its almandine content is generally low) and as "umbalite" because of its discovery in the Umba Valley (Jobbins et al., 1978; Schmetzer and Bank, 1981; Stockton and Manson, 1985).

Malaya garnet is a member of the garnet solid-solution series pyrope-spessartine, with significant amounts of almandine and grossular; the Umba Valley malaya garnets show a broad variation in chemistry (Schmetzer and Bank, 1981; Stockton and Manson, 1982). After cutting, malaya garnets often exhibit red scintillation flashes, possibly the result of traces of vanadium and/or chromium, that enliven their appearance.

Tsavorite. This transparent green grossular garnet has been found in the hills southeast of the village of Komolo (figure 22), in the Lelatema Mountains (Bank et al., 1970), and in the Merelani Hills (Kane et al., 1990) of Tanzania, as well as in Kenya. Tsavorite

Figure 20. As with many of the other gem materials found in Tanzania, garnets occur in various hues. These garnets range from 0.85 ct to 1.14 ct. Courtesy of Mayer & Watt, Beverly Hills, CA; photo © GIA and Tino Hammid.

and tanzanite are often found together, but not both in commercial quantities in the same deposit (Kane et al., 1990).

Like tanzanite, tsavorite was also named by Tiffany & Co. The name *tsavorite,* which first appeared in September 1974, was derived from the garnet's occurrence near the Tsavo National Game Park in Kenya. Geologist Campbell Bridges had pegged the first claims of this gemstone in Tanzania, at the Komolo occurrence, for the Costas Lycos family. It was tsavorite from Komolo that Bridges first showed Tiffany & Co. President Henry Platt (C. Bridges, pers. comm., 1992). Shortly thereafter, lighter green grossulars were found in the Lelatema Mountains (Muije et al., 1979). Since 1987, small amounts of large gem-quality tsavorite crystals, of exceptional form, have been recovered from pockets at the Karo tanzanite pit in the Merelani Hills (Kane et al., 1990).

Tsavorite occurs in graphitic gneisses (Bridges, 1974; Key and Hill, 1989). Although the material found in the Merelani Hills is well crystallized, tsavorite usually occurs as "potato shaped" nodules in pockets in replacement zones within the graphitic gneiss, immediately beneath an impervious limestone band (Bridges, 1987; Malisa and Muhongo, 1990). The unique color of these Tanzanian garnets was first attributed to chromium (Bank et al., 1970) and later to vanadium as well (Schmetzer, 1978).

Rhodolite. A member of the pyrope-almandine series, rhodolite comes from many localities in Tanzania, most notably (since 1964) from Umba. Rhodolite has been found in hues ranging from dark red to purplish red (figure 23) to reddish purple. Currently, purplish red rhodolite is also being recovered from Komolo and from a locality near the town of Same, which is on the road between Moshi and Tanga. A relatively new find of rhodolite from Kangala is described as "raspberry" in color, ranges from 5 to 10 ct, and in rare instances exhibits asterism.

Rounded "pebbles" of darker tone up to 50 grams (although commonly 1–3 grams) are produced from the area called Tiriri, in northeast Tanzania. Most of these stones have fine to heavy "silk" and can produce four- to six-ray stars (Koivula and Kammerling, 1989). Although there is currently little production, the area has been active for 15 years. Rhodolite garnets are also found in nearby Nyorinyori and Nyamberera, and—*in situ*—at Handeni. The Handeni material is a very fine, light reddish purple and is usually free of any "silk." (N. Barot, pers. comm., 1992).

The rhodolite garnets in Tanzania occur widely in Precambrian metamorphic rocks. Although most of the Umba production has been from alluvial deposits in the Umba River area (Malisa and Muhongo, 1990), Umba Ventures mined the primary deposits there in the mid- to late 1960s (R. Naftule, pers. comm., 1992).

Change-of-Color Garnets. Crowningshield (1970) first identified this unusual type of garnet (see, e.g., figure 3) when a waterworn pebble was submitted to the GIA Gem Trade Laboratory for identification. The pebble was blue-green in day or fluorescent light and purple-red in incandescent light. Further investigations have established that this material is a special type of pyrope-spessartine (Stockton and Manson, 1982, 1985; Manson and Stockton, 1984; Koivula and Kammerling, 1988).

Figure 21. Among the most unusual garnets found in Tanzania are these malaya garnets, which were first recovered from alluvial deposits along the Umba River. The rough piece in the upper center is typical of the material found in Tanzania. The round mixed cut stone on the left weighs 22.99 ct. Courtesy of Pala International, Fallbrook, CA; photo © Harold & Erica Van Pelt.

The only confirmed locality for change-of-color garnets in Tanzania is in the alluvial deposits at Umba, where they are usually found during the sorting process that follows recovery of other gem materials from this area. Color changes from red to orange, orange to pink, pink to purple, and orange to yellow have also been seen (see, e.g., figure 3).

Current Production and Future Potential. At present, there is a continuous and significant production of garnets from most of the numerous localities in Tanzania. However, at a recent, much-publicized gem auction in Arusha, only 31 grams of tsavorite were offered for sale. Currently, garnets are found in the fol-

Figure 22. Although commonly associated with Kenya, the green grossular garnet now known as tsavorite garnet was actually discovered in Tanzania. This 11.35-ct tsavorite garnet is from the Komolo deposits. Courtesy of Pala International; photo © Harold & Erica Van Pelt.

Figure 23. Spectacular rhodolites, like this 14.25-ct stone, have been found at a number of deposits in Tanzania. Courtesy of Mayer & Watt, Beverly Hills, CA; photo © GIA and Tino Hammid.

Figure 24. Tanzania is noted for the superb "chrome" tourmalines found there. This approximately 2.5 × 4 cm rough crystal and the accompanying 5.10-ct faceted "chrome" tourmaline are from Landanai. Courtesy of Pala International, Fallbrook, CA; photo © Harold & Erica Van Pelt.

lowing relative abundances (from most to least): rhodolite, malaya, tsavorite, change of color.

TOURMALINE

Background. A number of species of the tourmaline group—elbaite, uvite, and dravite—are found scattered throughout northern and eastern Tanzania (Webster, 1961a; Zwaan, 1974; Herschede, 1986; Dietrich, 1985). However, there is little organized mining of tourmaline in Tanzania. Most of the material produced to date is the result of two small operations in Landanai, as well as those tourmalines found as byproducts of alluvial mining for ruby, sapphire, and garnet at Umba. Tourmaline of a magnificent bluish green color occurs near Daluni.

Geology. In Tanzania, tourmaline is typically found in either crystalline limestone or in pegmatites associated with limestone and/or ultramafics (Bridges, 1982). Elbaite is found primarily in pegmatites, whereas dravite and uvite occur in various types of metamorphic rocks.

Description of the Material. The most notable Tanzanian tourmaline is the bright green variety of dravite called "chrome" tourmaline in the trade (Schmetzer and Bank, 1979; figure 24). Other colors and phenomenal varieties include yellow, ranging from "golden" to orange; change of color (dark green in day or fluorescent light, and red in incandescent light); cat's-eye; and, on rare occasions, bicolored—green and yellow—stones (figure 25).

The term *"chrome"* tourmaline has been used in the trade because chromium was originally thought to be the cause of color, as well as to distinguish these stones from the less "pure" green tourmalines typical of Brazil and other localities. H. Bassett reported this occurrence in the geologic literature in 1956, and subsequently identified vanadium as the cause of color. Bank (1982) found very little chromium present in the stones he examined at that time, although some green tourmalines from Tanzania tested since then have had higher contents of chromium than vanadium (Bank and Henn, 1988).

Current Production and Future Potential. Production of tourmaline reached a peak in the 1960s, when several hundred kilograms were recovered. Although most of the stones were under one carat, approximately 20% of the rough yielded 1- to 10-ct stones (R. Naftule, pers. comm., 1992). By the early 1980s, only 2,400 grams of rough were recovered annually, which yielded about 2,400 ct of faceted stones (Herschede, 1986). Since then, production has been sporadic. Today, although thousands of carats of low-grade tourmaline are recovered in Tanzania, only a small quantity of new facet-grade material enters the market each year.

EMERALD

Background. The primary emerald deposit in Tanzania is about 3 km west of Lake Manyara and south of Maji Moto Hot Springs. Themelis (1989) reports that emerald is also being recovered near Sumbawanga, in southwest Tanzania (again, see figure 2).

The first emerald crystals were found in eluvial gravels by a local farmer and identified by H. P. Kristen in 1969. Kristen, a prospector, discovered the primary deposit at Lake Manyara the following year and immediately started mining the area. He worked for Galai Mining Company, owned then by George Papas, who subsequently established 25 claims around Lake Manyara (Rwezaura, 1990). During the period 1970–1973, before the mining operation was nationalized, Kristen recovered 231,877 grams of emerald, with some crystals as large as 150 grams (Gübelin,

Figure 25. Tourmalines have also been found to occur in various deposits in Tanzania, and in some attractive and even unusual colors like those illustrated here. The orange tourmaline weighs 9.49 ct; the "chrome" tourmaline is 2.39 ct, and the rare bicolor weighs 1.82 ct. Courtesy of Overland Gems, Los Angeles, CA; photo © GIA and Tino Hammid.

1974). Today, small-scale mining continues and, at present, the mine is leased by Tofco.

Mining at Sumbawanga has progressed rapidly since the discovery of emeralds there in early 1988; the main shaft is more than 13 m deep, with at least 18 tunnels radiating from it. Although the heavily included crystals average 20–30 ct, specimens up to 100 ct have been recovered (Themelis, 1989).

Geology. The Lake Manyara emeralds are found in biotite schists interspersed with pegmatite and quartz segregations (Bridges, 1982). Several gems in addition to emerald are known to occur in the Lake Manyara vicinity. These include: apatite, garnet, spinel, ruby, sapphire, yellow chrysoberyl, and alexandrite (Gübelin, 1974). Eight areas have been identified on the Ufipa plateau as having potential for green beryl (Rwezaura, 1990). The Sumbawanga emerald deposit also occurs in a biotite schist. In both mining areas, blasting and backhoes are required to break up the host rock and remove it for processing.

Description of the Material. The properties of the Lake Manyara and Sumbawanga emeralds are, for the most part, consistent with those of emeralds from other biotite schist localities, especially those from the Ural Mountains. In both cases, the crystals are usually heavily included or, more accurately, fractured. Some of the material from Lake Manyara is facetable (figure 26); virtually all of the Sumbawanga material (being of a "milky" nature) is suitable only for carving or cutting into cabochons (Themelis, 1989).

OTHER GEMS IN TANZANIA

Most gemologists are unaware of the vast majority of Tanzania's gems. In addition to those discussed above, the list of gem materials that have been found in Tanzania includes actinolite, alexandrite, almandine,

Figure 26. Emeralds like this 1.90-ct. pear shape have been mined from the Lake Manyara region of Tanzania for many years. Photo © GIA and Tino Hammid.

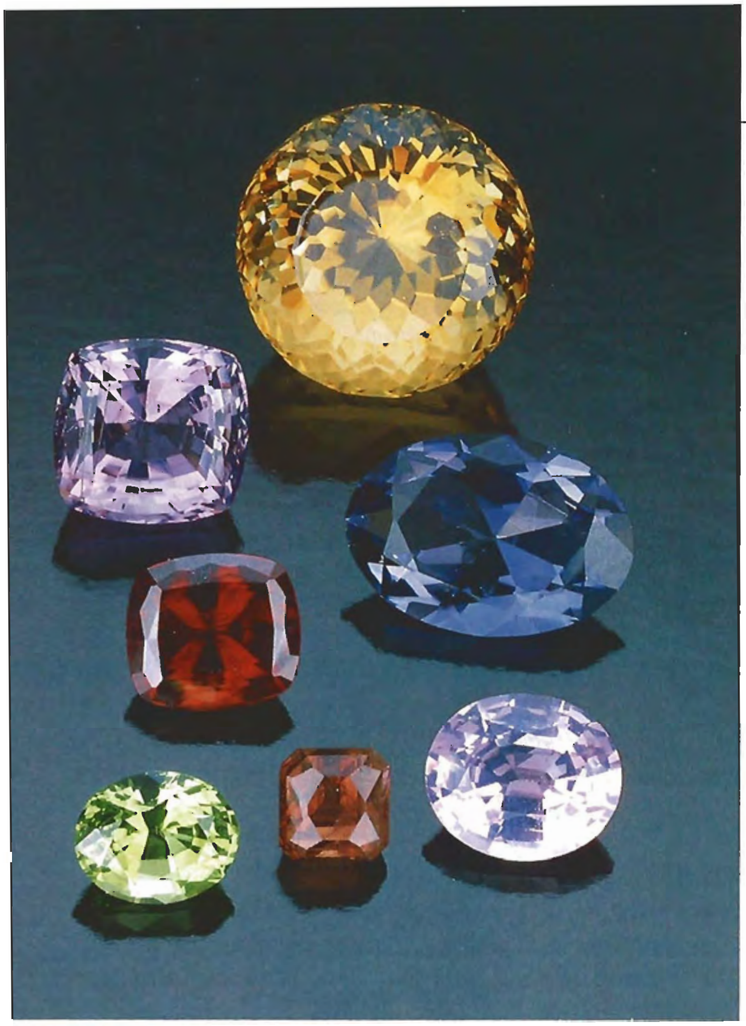


Figure 27. Tanzania is especially rich in its variety of gems. Shown here are a 12.62-ct golden scapolite, a 3.63-ct purple scapolite, a 3.48-ct iolite, a 1.80-ct zircon, a 2.15-ct spinel, a 1.29-ct alexandrite chrysoberyl, and a 1.39-ct peridot. Photo © GIA and Tino Hammid.

amblygonite, amethyst, andalusite, apatite, aquamarine, bronzite, cat's-eye chrysoberyl, chrysoprase, cryptocrystalline quartz, diopside, enstatite, epidote, euclase, feldspar (moonstone), fluorite, hypersthene, idocrase, iolite, kornerupine, kyanite, malachite, pearls, peridot, phenakite, prase opal, rock crystal quartz, rhodonite, scapolite, sillimanite, sinhalite, sphene, spinel, topaz, turquoise, and zircon (see, e.g., figure 27). The following briefly describes the occurrences of some of these other gemstones in Tanzania.

Alexandrite. The change-of-color variety of chrysoberyl, alexandrite, occurs in association with the emerald deposits at Lake Manyara. They are found in what Dr. E. Gübelin has described as "actinolite schists" of metamorphic origin.

Lake Manyara alexandrites exhibit a distinct change of color from bluish green in day or fluorescent light to purplish red in incandescent light. Densely packed actinolite fibers produce chatoyancy in some of the material. Unlike other natural alexandrites, which are inert to ultraviolet radiation, Lake Manyara alexandrites fluoresce a strong to medium dull red to long-wave U.V., and may fluoresce a weak yellow to short-wave U.V. (Gübelin, 1976).

Amethyst. Purple quartz appears in the early geologic literature of Tanzania. It is one of the more abundant gemstones, with over 12 occurrences recorded. It has been found within an area from just southeast of Lake Victoria in the northwest part of the country to Korogwe in the northeast to Morogoro just west of Dar es Salaam.

Scapolite. The major locality for golden yellow and purple scapolite is in the Mpwapwa region near Dodoma. Many kilograms of yellow crystals, usually 2–5 cm long, have appeared on the market in recent years. Yellow cat's-eye scapolite has also been found at Mpwapwa. In addition, some yellow scapolite is recovered at Umba (Solesbury, 1967; Zwaan, 1971). Considerable research has been done on the gemological properties and chemical composition of this complex gem mineral (Graziani et al., 1983).

Spinel. Fine spinels have been discovered with rubies in the Morogoro region, particularly at the Matombo mine (Hänni and Schmetzer, 1991). Spinels in a variety of unusual colors were shown at the 1992 Tucson Gem and Mineral shows. They were reported as coming from the Umba Valley (Koivula and Kammerling, 1991a).

Zircon. Tanzanian zircon in a variety of colors has appeared at the Tucson Gem and Mineral shows since the late 1980s (Koivula and Kammerling, 1990). Keller (in press) names Mavumbi and Handeni, in the Tanga province, as localities. Zircon is also found in the Umba area. Experiments by one of the authors (AB) revealed that dark purple zircon, on heating, turns bright yellow.

CONCLUSION

The complex geologic environment of East Africa has resulted in an unparalleled diversity of gem materials in an equally diverse range of colors, dramatically illustrated by the gem riches of Tanzania. Production of diamonds, rubies, sapphires, tanzanites, and garnets is already significant and promises to increase.

There is considerable potential for other gem materials such as tourmaline, emerald, aquamarine, alexandrite, amethyst, peridot, scapolite, spinel, and zircon. Perhaps a virtually unknown stone, such as vanadium diopside, will emerge from Tanzania as a major gem material, as tanzanite and tsavorite have done.

Tanzania's ultimate success as a gem-producing nation, however, depends as much on international cooperation and economic support as it does on its gem resources. Now that the Tanzanian government is actively promoting its gem resources to the international community, the promise may become fulfilled. Under the auspices of the Ministry of Water, Energy, and Minerals, on May 26 and 27, 1992, the Tanzanian Miners' and Dealers' Association (TAMIDA) held its first gem auction since the early 1980s. More than 60 miners and dealers, including buyers from more than a dozen countries worldwide, participated in the sale at Arusha of more than a ton of ruby, sapphire, tsavorite, tanzanite, rhodolite, and other gem materials (C. Bridges and A. Suleman, pers. comms., 1992). A second auction is scheduled for October 1992, apparently signaling that Tanzania will continue its open-door policy in the future—a promising sign for the international gemological community.

REFERENCES

Anderson B. W. (1968) Three items of interest to gemmologists. *Journal of Gemmology*, Vol. 11, No. 1, pp. 1–3.

Background analysis-Tanzania: A small diamond producer with little prospects (1986). *Diamond Intelligence Briefs*, Vol. 2, No. 34, p. 211.

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

Bank H. (1968) Tansanit—Neue Varietatsbezeichnung fur strontiumhältigen trichroitischen Zoisit. *Gold & Silber-Uhren + Schmuck*, No. 11, p. 66.

Bank H. (1970) Hochlichtbrechender Orangefarbiger Korund aus Tansania. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 19, No. 1, pp. 1–3.

Bank H. (1982) Tourmalines from East Africa. *Gold & Silber-Uhren + Schmuck*, No. 3, pp. 140–141.

Bank H., Berdesinski W., Ottemann J. (1970) Durchsichtiger smaragtgrüner Grossular aus Tansania. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 19, No. 1, pp. 4–7.

Bank H., Henn U. (1988) Changierende chromhaltige Turmaline von Ostafrika. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 36, No. 3–4, pp. 161–163.

Barot N.R., Boehm E. (1992) Gem-quality green zoisite. *Gems & Gemology*, Vol. 28, No. 1, pp. 4–15.

Bassett H. (1956) A geological reconnaissance into the Umba Steppe region of Tanga Province, Tanganyika and a visit to Mrima Hill in Kenya, 1953. *Geological Survey of Tanganyika, Report No. HB/2*, Government Printing Office, Dar es Salaam, Tanganyika.

Bills J.H., Martineau M.P., Park J.G. (1991) Artisanal mining in the Lake Victoria Goldfields, Tanzania. In *African Mining '91*, Elsevier Scientific, London, pp. 291–296.

Bridges C.R. (1974) Green grossularite garnets ("tsavorites") in East Africa. *Gems & Gemology*, Vol. 14, No. 10, pp. 290–295.

Bridges C.R. (1982) Gemstones of East Africa. In D. M. Eash, Ed., *International Gemological Symposium Proceedings*, Gemological Institute of America, Santa Monica, CA, pp. 263–275.

Bridges C.R. (1987) Tsavorite. *Jewelers' Quarterly*, Annual Color Pages, pp. 49–51.

Crowningshield G.R. (1970) A rare alexandrite garnet from Tanzania. *Gems & Gemology*, Vol. 13, No. 6, pp. 174–177.

Crowningshield G.R. (1983) Padparadscha: What's in a name? *Gems & Gemology*, Vol. 19, No. 1, pp. 30–36.

Curtis C.M. (1980) "Malaya," lady of the evening. *Lapidary Journal*, Vol. 33, No. 11, pp. 2348–2349.

Dietrich R.V. (1985) *The Tourmaline Group*. Van Nostrand Reinhold, New York.

Federman D. (1991) Gem profile: Tanzanite, mainstream bound. *Modern Jeweler*, Vol. 90, No. 6, pp. 37–38.

Gobba J.M. (1991) The geology and mineralogy of some kimberlites in the Mwadui area. In *Fifth International Kimberlite Conference, Araxa, June 1991, Extended Abstracts*, CPRM—Special Publication 2/91, Brasilia, Brazil, pp. 116–118.

Graziani G., Gübelin E., Lucchesi S. (1983) Observations on some scapolites of central Tanzania. Further investigations. *Journal of Gemmology*, Vol. 18, No. 5, pp. 379–381.

Griffin W.L., Ryan C.G., O'Reilly S.Y., Nixon P.H., Win T.T. (1991) Trace elements in garnets from Tanzanian kimberlites: Relation to diamond content and tectonic setting. In *Fifth International Kimberlite Conference, Araxa, June 1991, Extended Abstracts*, CPRM-Special Publication 2/91, Brasilia, Brazil, pp. 145–147.

Gübelin E.J. (1969) Anyolite clarification. *Australian Gemmologist*, Vol. 10, No. 5, pp. 28–29.

Gübelin E.J. (1974) The emerald deposit at Lake Manyara, Tanzania. *Lapidary Journal*, Vol. 28, No. 2, pp. 338–360.

Gübelin E.J. (1976) Alexandrite from Lake Manyara, Tanzania. *Gems & Gemology*, Vol. 15, No. 7, pp. 203–209.

Hänni H.A., Schmetzer K. (1991) New rubies from the Morogoro area, Tanzania. *Gems & Gemology*, Vol. 27, No. 3, pp. 156–167.

Henn U., Bank H. (1991) Rubies of facet-cutting quality from Tanzania. *Goldschmiede und Uhrmacher Zeitung*, Vol. 89, No. 6, p. 116.

Henn U., Bank H. (1992) On the distinction between yellow corundum/"padparadschas"/rubies. Part I. *Goldschmiede und Uhrmacher Zeitung*, Vol. 90, No. 3, p. 226.

Herschede M.P. (1986) Chrome tourmaline from East Africa. *Jewelers' Quarterly*, First Quarter, pp. 6, 7, 30.

Horton M. (1987) The Swahili corridor. *Scientific American*, Vol. 257, No. 3, pp. 86–93.

Hughes R.W. (1990) *Corundum*. Butterworth-Heinemann, London.

Hurlbut C.S. (1969) Gem zoisite from Tanzania. *American Mineralogist*, Vol. 54, No. 5/6, pp. 702–709.

ICA presents 1991 world mining report (1991). *Colored Stone*, Vol. 4, No. 4, pp. 19–23.

Janse A.J.A. (1991) Is Cliffords Rule still valid? Affirmative examples from around the world. *Fifth International Kimberlite Conference, Araxa, June 1991, Extended Abstracts*, CPRM—Special Publication 2/91, Brasilia, Brazil, pp. 196–198.

Janse A.J.A. (1992) Diamond sources in Africa. In A. S. Keller, Ed. *Proceedings of the International Gemological Symposium*

1991, Gemological Institute of America, Santa Monica, CA, p. 55.

Jobbins E.A., Saul J.M., Statham P.M., Young B.R. (1978) Studies of a gem garnet suite from the Umba River, Tanzania. *Journal of Gemmology*, Vol. 16, No. 3, pp. 161–171.

Jourdan P. (1991) Regional strategies for the minerals industries of the States of the SADCC. In *African Mining '91*, Elsevier Scientific, London, pp. 347–353.

Kane R.E., Kampf A.R., Krupp H. (1990) Well-formed tsavorite gem crystals from Tanzania. *Gems & Gemology*, Vol. 26, No. 2, pp. 142–148.

Keller P. (in press) *Gems of East Africa*, Geoscience Press, Phoenix, AZ.

Key R.M., Hill P.G. (1989) Further evidence for the controls on the growth of vanadium grossular garnets in Kenya. *Journal of Gemmology*, Vol. 21, No. 7, pp. 412–422.

Key R.M., Ochieng J.O. (1991a) Ruby and garnet gemstone deposits in S.E. Kenya: Their genesis and recommendations for exploration. In *African Mining '91*, Elsevier Scientific, London, pp. 212–127.

Key R.M., Ochieng J.O. (1991b) The growth of rubies in southeast Kenya. *Journal of Gemmology*, Vol. 22, No. 8, pp. 484–496.

Kirkley M.B., Gurney J.J., Levinson A.A. (1991) Age, origin, and emplacement of diamonds: Scientific advances of the last decade. *Gems & Gemology*, Vol. 27, No. 1, pp. 2–25.

Koivula J.I., Kammerling R.C. (1988) Gem news: Change-of-color garnets. *Gems & Gemology*, Vol. 24, No. 3, pp. 176–177.

Koivula J.I., Kammerling R.C. (1989) Gem news: Star rhodolite garnet. *Gems & Gemology*, Vol. 25, No. 1, pp. 48–49.

Koivula J.I., Kammerling R.C. (1990) Gem news: Tanzanian zircon. *Gems & Gemology*, Vol. 26, No. 1, pp. 103–104.

Koivula J.I., Kammerling R.C. (1991a) Gem news: Tanzanian spinel. *Gems & Gemology*, Vol. 27, No. 3, p. 183.

Koivula J.I., Kammerling R.C. (1991b) Gem news: Unusual red zoisite. *Gems & Gemology*, Vol. 27, No. 3, pp. 185–186.

Koivula J.I., Kammerling R.C. (1991c) Gem news: Update on Tanzanian mining. *Gems & Gemology*, Vol. 27, No. 4, p. 262.

Malisa E. (1987) Geology of the tanzanite gemstone deposits in the Lelatema area, northest Tanzania (Ph.D. Thesis). *Annales Academiae Scientiarum Fennicae 111, Geologica Geographica*, Vol. 146, pp. 1–160.

Malisa E., Muhongo S. (1990) Tectonic setting of gemstone mineralization in Proterozoic metamorphic terrane of the Mozambique belt in Tanzania. *Precambrian Research* (III), Vol. 46, No. 1-2, pp. 167–176.

Manson D.V., Stockton C.M. (1984) Pyrope-spessartine garnets with unusual color behavior. *Gems & Gemology*, Vol. 20, No. 4, pp. 200–207.

Msolo A.P.B. (1992) Ruby mining in the Morogoro region. *SMI (Small Mining International) Bulletin*, No. 4, p. 7.

Muije P., Muije C.S., Muije L.E. (1979) Colorless and green grossularite from Tanzania, *Gems & Gemology*, Vol. 16, No. 6, pp. 162–173.

Ngunangwa F.E. (1982) Potential of small-scale mining in Tanzania. In J.M. Neilson, Ed., *The Geosciences in International Development, AGID Report No. 8: Strategies for Small-Scale Mining and Mineral Industries*, Association of Geoscientists for International Development, Bangkok, pp. 55–61.

Notholt A. (1990) Tanzania: Mineral development. *Mining Annual Review*, pp. 124–125.

Pohl W., Horkel A. (1980) Notes on the geology and mineral resources of the Mtito Andei-Taita area (Southern Kenya). *Mitteilungen der Osterreichichen Geologischen Gesellschaft*, Vol. 73, pp. 135–152.

Pough F.H. (1971) Meet Tanzania's fancy sapphires. *Jewelers' Circular-Keystone*, Vol. 142 , No. 1, pp. 84–100.

Rwezaura M. (1990) Known gemstone deposits in Tanzania. Unpublished manuscript, 27 pp.

Sarofim E. (1970) Gem rich Tanzania. *Lapidary Journal*, Vol. 24, No. 3, pp. 434–441.

Saul J.M. (1970) Gemstone localities of Tanzania (map). Rockland International Corp., Nairobi, Kenya.

Schmetzer K. (1978) Vanadium III als Farbtrager bei natürlichen Silikaten und Oxiden—ein Beitrag zur Kristallchemie des Vanadiums. Ph.D. Dissertation, Heidelberg, Germany.

Schmetzer K. (1986) *Natürliche und synthetische Rubine-Eigenschaaften und Bestimmung*. Schweizerbartsche, Stuttgart, Germany.

Schmetzer K., Bank H. (1979) Bluish-green zoisite from Merelani, Tanzania. *Journal of Gemmology*, Vol. 16, No. 8, pp. 512–513.

Schmetzer K., Bank H. (1981) Garnets from Umba Valley, Tanzania—members of the solid solution series pyrope-spessartine. *Neues Jahrbuch für Mineralogie Monatshefte*, No. 8, pp. 349–354.

Schmetzer K., Hänni H.A. (1992) Dyed natural corundum as a ruby imitation. *Gems & Gemology*, Vol. 28, No. 2, pp. 112–115.

Solesbury F.W. (1967) Gem corundum pegmatites in NE Tanganyika. *Economic Geology*, Vol. 62, No. 7, pp. 983–991.

Stockton C.M., Manson D.V. (1982) Gem garnets: The orange to red-orange color range. In D. M. Eash, Ed., *International Gemological Symposium Proceedings*, Gemological Institute of America, Santa Monica, CA, pp. 237–242.

Stockton C.M., Manson D.V. (1985) A proposed new classification for gem-quality garnets. *Gems & Gemology*, Vol. 21, No. 4, pp. 205–218.

Tanzania known mineral occurrences (map, 1982). Ministry of Mines, Dar es Salaam, Tanzania.

Tanzania signs major diamond deal (1992). *Diamond Intelligence Briefs*, Vol. 7, No. 143, p. 857.

Tanzania's latent opportunities (1992). *Mining Journal*, Vol. 318, No. 8164, pp. 186–187.

Thai joint venture gets Umba exclusive (1989). *Colored Stone*, Vol. 2, No. 4, p. 25.

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

Tiffany discloses finding what may be a new gem (1968). *Wall Street Journal*, October 14, p. 4.

Tsai H.M., Meyer H.O.A., Moreau J., Milledge H.J. (1979) Mineral inclusions in diamond: Premier, Jagersfontein and Finsch kimberlites, South Africa, and Williamson Mine, Tanzania. In F. R. Boyd and H. O. A. Meyer, Eds., *Kimberlites, Diatremes, and Diamonds: Their Geology, Petrology, and Geochemistry. Proceedings of the Second International Kimberlite Conference, Vol. 1*, American Geophysical Union, Washington, DC, pp. 16–26.

Vidal-Naquet P. (1987) *The Harper Atlas of World History*. Harper & Row, New York.

Ward F. (1991) Rubies and sapphires. *National Geographic*, Vol. 180, No. 4, pp. 100–125.

Webster R. (1961a) Tanganyika tourmalines. *The Gemmologist*, Vol. 30, No. 356, pp. 41–45.

Webster R. 1961b) Corundum in Tanganyika. *Gems & Gemology*, Vol. 10, No. 7, pp. 202–205.

Webster R. (1983) *Gems: Their Sources, Descriptions and Identification*, 4th ed. Rev. by B. W. Anderson, Butterworth and Co., London.

Wilson A.N., Ed. (1971) Tanzania: Thirty years in production. *International Diamond Annual*, Vol. 1, p. 71.

Winchell A.N. (1937) *Elements of Optical Mineralogy*, Part I, 5th ed. John Wiley & Sons, New York.

Zwaan P.C. (1971) Yellow scapolite: Another gem mineral from Umba, Tanzania. *Journal of Gemmology*, Vol. 12, No. 7, pp. 304–309.

Zwaan P.C. (1974) Garnet, corundum and other gem minerals from Umba, Tanzania. *Scripta Geologica*, Vol. 20, pp. 1–41.

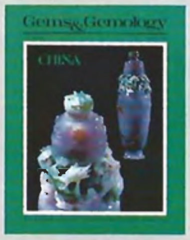
Back Issues of GEMS & GEMOLOGY

Limited quantities of these issues are still available.

Spring 1985

Summer 1985

Spring 1986



Summer 1986

Fall 1986

Winter 1986

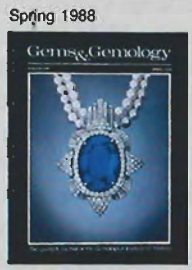
Spring 1987

Summer 1987

Fall 1987

Winter 1987

Spring 1988



Summer 1988

Fall 1988

Winter 1988

Spring 1989

Summer 1989

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

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

Fall 1986
A Simple Procedure to Separate Natural from Synthetic Amethyst on the Basis of Twinning
Pink Topaz from Pakistan
Carbon Dioxide Fluid Inclusions as Proof of Natural-Color Corundum
Specific Gravity—Origins and Development of the Hydrostatic Method
Colombage-Ara Scheelite

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

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

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

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

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

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

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

Fall 1988
An Economic Review of Diamonds
The Sapphires of Penglai, Hainan Island, China
Iridescent Orthoamphibole from Wyoming
Detection of Treatment in Two Green Diamonds

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

Spring 1989
The Sinkankas Library
The Gujar Killi Emerald Deposit
Beryl Gem Nodules from the Bananal Mine
"Opalite:" Plastic Imitation Opal

Summer 1989
Filled Diamonds
Synthetic Diamond Thin Films
Grading the Hope Diamond
Diamonds with Color-Zoned Pavilions

Fall 1989
Polynesian Black Pearls
The Capoeirana Emerald Deposit
Brazil-Twinned Synthetic Quartz and the Potential for Synthetic Amethyst Twinned on the Brazil Law
Thermal Alteration of Inclusions in Rutilated Topaz
Chicken-Blood Stone from China

Winter 1989
Emerald and Gold Treasures of the Atocha
Zircon from the Harts Range, Australia
Blue Pectolite
Reflectance Infrared Spectroscopy in Gemology
Mildly Radioactive Rhinestones and Synthetic Spinel and-Glass Triplets

Spring 1990
Gem Localities of the 1980s
Gemstone Enhancement and Its Detection
Synthetic Gem Materials of the 1980s
New Technologies: Their Impact in Gemology
Jewelry of the 1980s

Summer 1990
Blue Diffusion-Treated Sapphires
Jadeite of Guatemala
Tsavorite Gem Crystals from Tanzania
Diamond Grit-Impregnated Tweezers

Fall 1990
Majorica Imitation Pearls
Tourmalines from Paraíba, Brazil
Hydrothermally Grown Synthetic Aquamarines
Diamonds in Trinity County, California

Winter 1990
The Dresden Green Diamond
Identification of Kashmir Sapphires
A Suite of Black Diamond Jewelry
Emeraldolite

Spring 1991
Age, Origin, and Emplacement of Diamonds
Emeralds of Panjshir Valley, Afghanistan

Summer 1991
Fracture Filling of Emeralds: Opticon and "Oils"
Emeralds from the Ural Mountains, USSR
Treated Andamooka Matrix Opal

Fall 1991
Rubies and Fancy Sapphires from Vietnam
New Rubies from Morogoro, Tanzania
Bohemian Garnet—Today

Winter 1991
Marine Mining of Diamonds off Southern Africa
Sunstone Labradorite from the Ponderosa Mine, Oregon
Nontraditional Gemstone Cutting
Nontransparent "CZ" from Russia

Spring 1992
Gem-Quality Green Zoisite
Kilbourne Hole Peridot
Opal from Querétaro, Mexico: Fluid Inclusion Study
Natural-Color Nonconductive Gray-to-Blue Diamonds
Peridot as an Interplanetary Gemstone

Complete your back issues of Gems & Gemology NOW!

Single Issues:*	**$ 8.00** ea. U.S. **$ 11.50** ea. Elsewhere
Complete Volumes:* 1986, 1987, 1989, 1991	**$ 28.50** ea. vol. U.S. **$ 38.50** ea. vol. Elsewhere
Three-year set**	**$ 75.00** U.S. **$100.00** Elsewhere

*10% discount for GIA Alumni Association members
**Please indicate which volume years

ORDER NOW!

TO ORDER: Call: toll free **(800) 421-7250, ext. 201 or (310) 829-2991, ext. 201**
OR WRITE: GIA, 1660 Stewart Street, Santa Monica, CA 90404, Attn: G&G Subscriptions

GAMMA-RAY SPECTROSCOPY TO MEASURE RADIOACTIVITY IN GEMSTONES

By Charles E. Ashbaugh III

Over the last several years, the trade has seen a number of radioactive gemstones. While a Geiger counter may show the existence of radioactivity, determination of the actual type of radionuclide and the quantity present requires a more sophisticated technique, gamma-ray spectroscopy. This article reports on the use of this technique to measure the radionuclides in two radioactive gemstones, a yellowish green diamond and a large dark blue topaz.

Numerous radioactive gem materials have appeared in the jewelry trade over the past decade (figure 1). Among these are topaz (Crowningshield, 1981), spodumene (Rossman and Qiu, 1982), rhinestones and glass triplets (Nassau and Lewand, 1989), and diamonds as well as zircons and ekanites (Ashbaugh, 1988). As an aftereffect of certain radiation processes used for color enhancement, radioactivity can sometimes help identify the treatment process used on a particular gemstone. Both natural and induced radioactivity can also be used to determine trace-element content, from which the identity and possibly the origin of a gem may be determined. In addition, the radioactivity allowed in commerce varies from country to country, with United States regulations being the most restrictive: Quantification of the radioactive elements (radionuclides) in a gem or a parcel of gems can reveal if the material can be legally sold or traded.

The Geiger counter is the most common instrument used to detect radioactivity. However, it only indicates whether a gem or an article of jewelry is radioactive; it cannot determine the type or amount of radionuclides causing the radioactivity.

Today, gamma-ray spectroscopy is used in many fields to determine the kinds and quantities of radioactive nuclides induced in various materials. It is now being used more often in gemology to perform research on gemstones and to test them for radioactivity. This includes gemstones like zircons, which contain the natural radioactive elements uranium and thorium (Murakami et al., 1991), as well as neutron-irradiated topaz, which contains radionuclides such as tantalum-182 and scandium-46 (Cozar, 1989) that have been produced by irradiation in a nuclear reactor. The analytical process is the same whether the radioactivity is natural or laboratory induced.

Gamma-ray spectroscopy is a viable analytical tool because each radioactive nuclide has a unique radiation signature that separates it from all other radionuclides. The radiation (gamma rays) emitted, and the energy or energy distribution of that radiation, identifies each nuclide or isotope present (Browne et

ABOUT THE AUTHOR

Mr. Ashbaugh is a nuclear engineer in charge of radiation testing at the GIA Gem Trade Laboratory, Inc., Santa Monica, California.

Acknowledgments: The author thanks Dr. James E. Shigley of the GIA Research Department for his assistance with the many drafts of this article, and Sharon Patty for typing them. Thanks also go to Colin Sanderson of the Environmental Measurements Laboratory, New York, for writing the computer program ATEN; to Mat Satuloff of GIA for the computer program DECAY; and to Maha Smith of GIA for the computer-screen photographs.

Gems & Gemology, *Vol. 28, No. 2, pp. 104–111.*

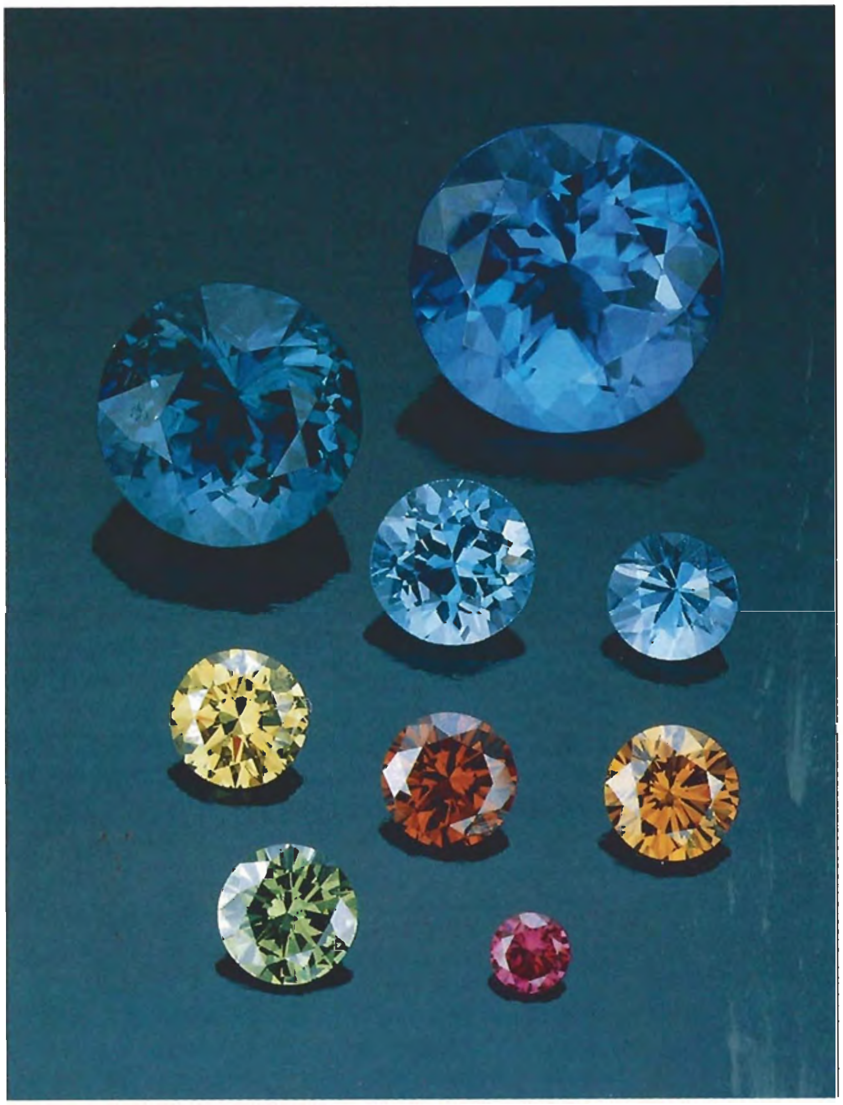


Figure 1. An important issue in gemology today is the presence of radioactivity in gem materials, especially that induced during color enhancement. Radioactivity is most commonly seen in irradiated blue topaz and colored diamonds. The four topazes at the top (0.52–7.87 ct) and the five diamonds at the bottom (0.10 [reddish purple stone] to 0.52 [yellow] ct) in this suite are known to be irradiated. The four topazes are still very slightly radioactive. Photo © GIA and Tino Hammid.

al., 1986). With a high-purity (intrinsic) germanium (HPGe) spectroscopy system, just about any gamma-ray-emitting radioactive nuclide can be readily identified and quantified.

This article details the equipment and the analytical method of gamma-ray spectroscopy by illustrating its use to determine the type and quantity of residual radioactive nuclides present in two laboratory-irradiated gemstones—a yellowish green diamond and a large dark blue topaz. In these two cases, the analysis also revealed the treatment processes used and the approximate dates on which the radionuclide concentrations in the gemstones will have decayed to U.S. legal release limits.

DESCRIPTION OF THE SAMPLES

The first gemstone selected for radiation analysis was a 2.60-ct yellowish green type Ia diamond (figure 2). It had been purchased for the GIA reference collection (collection no. 14052) in 1983 as a radium-treated diamond. Several features supported the origin of its color as radiation treatment. Specifically, when the diamond was viewed with magnification in diffused white light, three pavilion facets showed small areas of mottled green or uneven color distribution. In addition, U.V.-visible spectrophotometry revealed a weak but characteristic GR1 (General Radiation) line that is typical of natural and laboratory-irradiated green diamonds (Kane et al., 1990). When the diamond was placed in front of the pancake probe of a Victoreen Model 290 survey meter (Geiger counter) and observed for at least a minute, the readings registered slightly above the average background level of 45 counts per minute in the West Coast Gem Trade Laboratory. Its radioactivity was barely detectable.

The second gem chosen was a large, 140.5-ct,

Figure 2. Gamma-ray spectroscopy determined that this 2.60-ct yellowish green diamond, believed to have been radium treated when purchased in 1983, was actually color enhanced by americium-241. GIA Gemstone Reference Collection no. 14052; photo © GIA and Tino Hammid.

dark "London blue" topaz (figure 3) originally from Sri Lanka. The topaz was selected because of its size and the fact that it had been irradiated relatively recently (June 1990) in a nuclear reactor and had a gamma-ray spectrum typical of most neutron-irradiated topaz. To achieve the "London blue" color, this stone had been irradiated in a water-cooled channel several centimeters outside the core of the University of Virginia's 2-megawatt thermal nuclear research reactor. Its radioactivity was very evident at the time of initial examination (summer of 1991), when it gave a reading of about 1,200 counts per minute on the Victoreen Geiger counter. This topaz was released by the University of Virginia to GIA via a radioactive material license transfer.

INSTRUMENTATION

The gamma-ray spectroscopy system at GIA includes a computer, associated electronics, a lead shield that contains a detector, and a liquid-nitrogen storage tank (figure 4). The heart of the system is the detector, which is made from a very-high-purity germanium (HPGe) crystal that is mounted inside an evacuated magnesium container (Debertin and Helmer, 1988). The germanium crystal is cooled to nearly 77°K (–196°C, or –321°F) by the liquid nitrogen. To minimize the background radiation reaching the detector, the crystal is completely surrounded by a graded "virgin" (radionuclide-free) lead shield at least 4 in. (10 cm) thick. The shield is lined with cadmium and copper to prevent unwanted lower-energy gamma rays produced in the lead from reaching the detector.

Gamma rays from the radioactive nuclides in the gemstone are emitted randomly in all directions. Thus, when the stone is placed in position above the detector (figure 5), most of the gamma rays travel into the lead shield; only a small fraction enters the detector directly, and only some of these are completely absorbed and used in the analysis. However, when gamma rays are absorbed into the germanium crystal, they generate minute electrical pulses. These pulses are then amplified, digitized, sorted by energy level, added, converted into spectrum peaks, and ultimately sent to the computer screen for visual analysis by the spectroscopist (NCRP, 1985).

Figure 3. This unusually large, 140.5-ct, "London blue" topaz was neutron irradiated in June 1990. More than a year later, in August 1991, it still showed some radioactivity. Stone courtesy of Danny Duke, Gem Marketing International; photo by Shane F. McClure.

To calculate the radionuclide content of a gemstone, the analyst must determine the detector efficiency at all gamma-ray energies of interest. The number of gamma rays completely absorbed by the germanium crystal detector depends on the energy of the gamma rays; the size, density, and dimensions of the gemstone being analyzed; and the distance of the gemstone from the detector (as determined by the spectroscopist based on a number of variables).

Special radioactive calibration sources were made for GIA by Analytics, Inc., of Atlanta, Georgia, from a resin with a specific gravity of 1.15. These sources were constructed to simulate the size and shape of various gemstones, because the closer the stone to be analyzed approaches the size, shape, and counting geometry (position above the detector) of the calibration source, the closer the calculated results are to the true values. Figure 6 is the efficiency curve for the round-brilliant radioactive simulant closest in size to the yellowish green diamond. For the diamond, the system was calibrated with the simulant table-down, its center of mass 0.25 cm above the detector. For the topaz, the detector was calibrated with another, larger simulant also table-down, but with its center of mass 3 cm above the detector.

PREPARATION OF THE SAMPLES

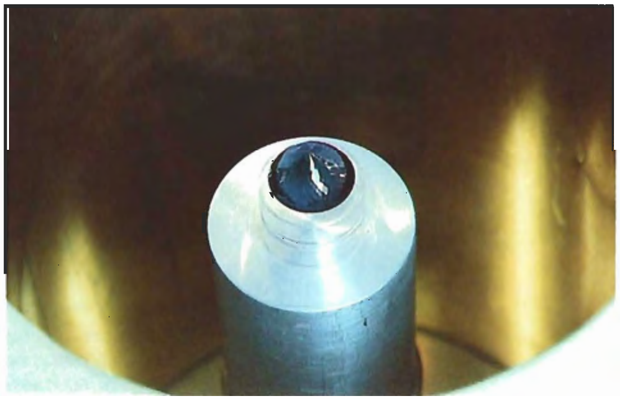
Any radioactive counting analysis begins with eliminating all removable radioactive surface contamination. Therefore, the surface of each gemstone was thoroughly wiped with a damp piece of absorbent filter paper that was subsequently checked for radioactivity in a shielded Geiger tube assembly. The paper registered background only, which showed that the two gems were free of any removable contamination. As a further precaution, the gems were washed in a standard radioactive decontamination soap solution. Prior to analysis, each was weighed on an electronic balance.

METHODOLOGY

For the analysis, each stone was placed inside the one-ton lead shield in the same position as the simulants to which the system had been calibrated. Counting times for the diamond (10,000 seconds, or about two-and-three-quarter hours) and the topaz (2,000 seconds, or about one half hour) were established on the basis of the gem's distance above the detector and the gross radiation readings from the Geiger counter.

Figure 4. The high-purity (intrinsic) germanium (HPGe) gamma-ray spectroscopy system at the GIA radiation testing facility includes, from left to right: a computer, associated electronics, a 2,000-lb. graded lead shield (which houses the germanium crystal detector), and a liquid-nitrogen storage tank. Gamma rays from the sample stone are absorbed by the germanium crystal, which then produces minute electrical pulses that are amplified and sent to a computer for analysis. This system was manufactured by EG&G Ortec. Photo by Maha Smith.

Figure 5. The high-purity germanium crystal detector is housed in an evacuated magnesium container that is enclosed in a lead shield lined with cadmium and copper. The sample stone (here, the large blue topaz) has been placed with its center of mass 3 cm above the detector. Photo by Maha Smith.



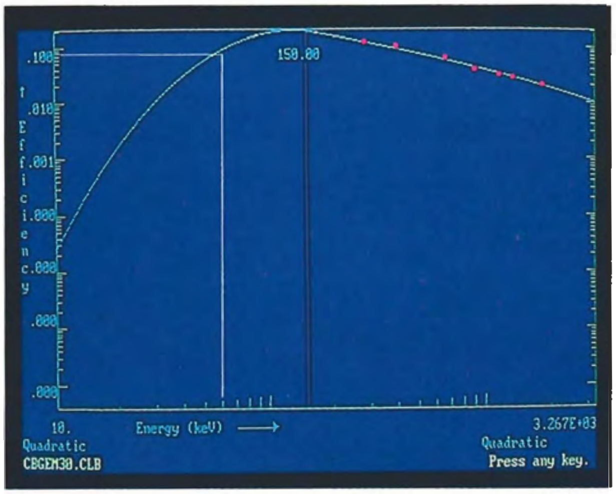


Figure 6. To quantify the radionuclides in a sample, the spectroscopist must first establish the efficiency of the detector with respect to the size of the sample and its distance from the germanium crystal. For this purpose, a radioactive gem simulant is used. Shown here is the calibration curve used for the yellowish green diamond, with the simulant's center of mass 0.25 cm above the detector. For example, at 59.5 keV, the detector efficiency is 0.082.

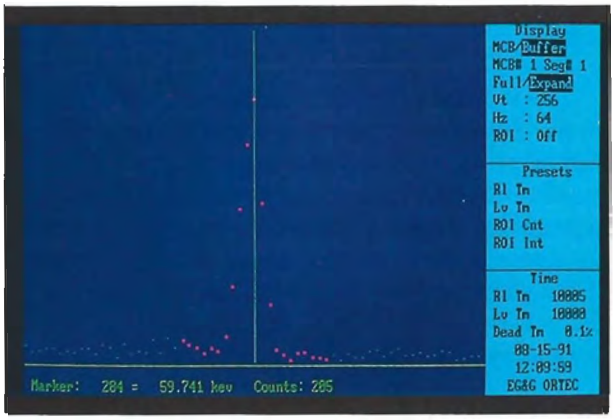

```
Display
MCB/Buffer
MCB# 1 Seg# 1
Full/Expand
Vt  : 256
Hz  : 64
ROI : Off
Presets
Rl Tm
Lv Tm
ROI Cnt
ROI Int
Time
Rl Tm    10005
Lv Tm    10000
Dead Tm   0.1%
08-15-91
12:09:59
EG&G ORTEC
Marker:  284 =  59.741 kev   Counts: 285
```

Figure 7. Here, the computer screen shows an expanded display of the relevant portion of the diamond's gamma-ray spectrum. The peak's energy (59.5 keV) and the absence of other peaks identifies the radionuclide as Am-241. Note, on the right, the live count time (Lv Tm) and, at the bottom, the number of net counts under the peak.

RESULTS

Table 1 lists the radionuclides found in the diamond and in the topaz, provides some of the data needed to calculate the amount of radioactivity, and gives the determined release dates. For a complete calculation on the diamond, see box A.

Diamond. Gamma rays emitted from the diamond generated a flat, featureless spectrum on the computer screen, except for a peak at 59.5 keV* (figure 7), which indicates the presence of gamma rays of that energy. The presence of the 59.5-keV peak and the absence of other peaks between 32 keV and 3,200 keV identifies the radionuclide in the diamond as americium-241 (Am-241). This radionuclide is produced in nuclear reactors by bombarding uranium-238 and subsequent plutonium nuclides with neutrons (Benedict et al., 1981). Its presence indicates that the diamond was packed in Am-241 oxide powder (not radium salts as previously believed). The surface color of the diamond is due to the creation of the GR1 color center by alpha-particle (high-speed helium

TABLE 1. Radionuclide data for the 2.60-ct diamond and the 140.5-ct topaz.[a]

Nuclide	Half-life	Gamma-ray energy (keV)[b]	Gamma-yield fraction[b]	Activity August 1991 (nCi/g)	NRC limit[c] (nCi/g)	Release date
Diamond						
Am-241	432.7 y	59.5	0.357	0.125	0.0009	June 30, 5071
Topaz						
Ta-182	114.4 d	1121.3	0.347	2.858	0.4	August 15, 1992
		1189.1	0.165			
		1221.4	0.273			
		1231.0	0.116			
Sc-46	83.8 d	889.3	1.0	0.858	0.4	
		1120.5	1.0			
Mn-54	312.2 d	834.8	1.0	0.238	1.0	

[a] *Am = americium, Sc = scandium, Ta = tantalum, Mn = manganese; y = years, d = days.*

[b] *Each number represents a specific gamma-ray peak in the spectrum.*

[c] *United States Nuclear Regulatory Commission, Rules and Regulations, Title 10, Chapter 1 (August 30, 1991), Part 30.70, Schedule A; (May 31, 1991) Part 20, Appendix B.*

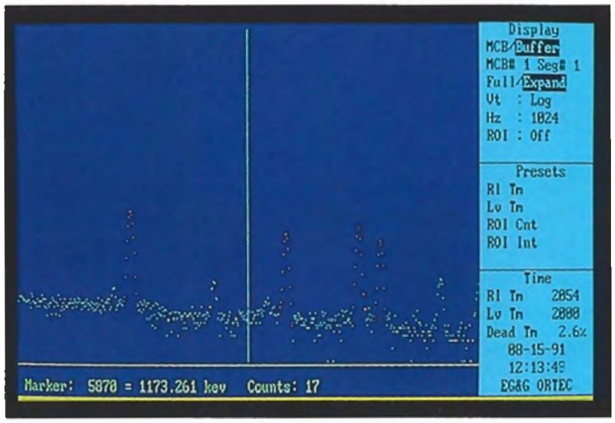
nuclei) radiation from the powder; the residual Am-241 radionuclides responsible for the radioactivity result from inadvertent contamination during the enhancement process.

We have known for many years that diamonds have been treated with radiation, including that from radium salts (Dugdale, 1960). Color enhancement of diamonds with americium was introduced relatively recently (Haynes, 1971). Like radium salts, Am-241 is no longer available commercially for this purpose. From the patent (Haynes, 1971), we do know that the americium treatment process involved placing the stones in Am-241 oxide powder for one to two weeks and then soaking and washing them in three different baths of concentrated nitric acid before scrubbing them with water and detergent. The diamonds were then placed in a furnace to lighten the green color or alter it to a strong yellow.

Topaz. The 140.5-ct topaz revealed a much more complex gamma-ray spectrum (see, e.g., figure 8). Although the full spectrum included dozens of gamma-ray energy peaks, only a few were needed for the analysis. The positions of the peaks confirmed that this topaz was irradiated in a nuclear reactor. The topaz was found to contain tantalum-182 (Ta-182), scandium-46 (Sc-46), and manganese-54 (Mn-54), in decreasing order of activity. Nuclear interactions with trace elements already present in the topaz produced these radionuclides. Ta-182 and Sc-46 are created by neutron absorption reactions from the natural stable isotopes of those elements; Mn-54 is mostly produced by the absorption of a neutron into iron-54 (Fe-54, one of the stable isotopes of iron) and the immediate release of a proton (McLane et al., 1988).

DISCUSSION

The information provided by gamma-ray spectroscopy not only revealed the treatment process (Am-241 oxide) and the amount of radionuclides present (0.125 nCi/g) in the diamond, but it also supplied the data necessary to determine the legal release date for this stone—approximately June 30, 5071. A similar computation on the 140.5-ct topaz on August 15, 1991, revealed 2.858 nCi/g Ta-182, 0.858 nCi/g Sc-46, and 0.238 nCi/g Mn-54. The gamma-ray attenuation (self-shielding) for the topaz was determined by the computer program ATEN as between 5% and 6% for the gamma-ray energies used. The release date calculated by GIA's computer program DECAY (1991)—wherein the radionuclide concentration "sum of the ratios" (i.e., the sum of the concentrations divided by the release-limit concentrations for each radionuclide) is equal to or less than 1.0—is approximately August 25, 1992 (again, see table 1).



```
Display
MCB/Buffer
MCB# 1 Seg# 1
Full/Expand
Vt  : Log
Hz  : 1024
ROI : Off
Presets
RI Tn
Lv Tn
ROI Cnt
ROI Int
Time
RI Tn     2854
Lv Tn     2880
Dead Tn   2.6%
 08-15-91
 12:13:49
EG&G ORTEC
Marker:  5878 = 1173.261 kev   Counts: 17
```

Figure 8. The large blue topaz revealed dozens of gamma-ray peaks. Here, the screen shows an expanded view of four of the largest tantalum-182 peaks (highlighted in red) used in the analysis; the 1121.3 keV peak is on the left side, and the 1231.0 keV peak is on the right. This view represents about 6% of the entire gamma-ray spectrum.

It is also possible with gamma-ray spectroscopy to distinguish some laboratory-irradiated gemstones, namely those irradiated by neutrons and sometimes those irradiated by very high-energy electrons, from those that have not been irradiated. However, this can be done only when the gem has some residual radioactivity. For example, neutrons from a nuclear reactor and those created by photoneutron reactions in a high-energy linac (linear electron accelerator) will produce readily identifiable radionuclides in irradiated gemstones. In addition, reactor-irradiated diamonds usually reveal the telltale gamma-ray signatures of cobalt-60, which has a 5.27-year half-life, and europium-152, which has a 13.5-year half-life. It would take decades for time to conceal that these stones had been irradiated (Reinitz and Ashbaugh, 1992). However, some irradiation techniques, such as lower-energy linacs and gamma-ray irradiation, do not generate any radioactive signatures in gemstones.

**The abbreviation keV stands for "kiloelectron volts" (a thousand electron volts), which quantifies and places the energy of all radiation on a common scale. For instance, green light is electromagnetic radiation made up of photons of 2.4 eV (electron volts; Nassau, 1983). Gamma rays (also made up of photons) from radionuclides are simply thousands to millions of times more energetic than visible-light photons.*

BOX A: QUANTITATIVE ANALYSIS OF RADIOACTIVITY IN THE DIAMOND

The actual quantity of radioactivity—that is, the amount of each radionuclide present in a gemstone on a per-gram basis—is calculated as follows: For each spectral peak, the activity in nanocuries (nCi) per gram for the radionuclide responsible for producing that peak is:

Equation 1

$$A = \frac{n}{37t\gamma\epsilon ms}$$

Where:

A = nanocuries of radioactivity per gram: 1 nCi = 37 becquerels (disintegrations per second).

n = number of counts (area under the spectral peak).

37 = conversion factor (converts counts per second into nanocuries).

t = time (duration of the live count in seconds).

γ = gamma yield (fraction of gamma rays released at that particular energy level per radioactive disintegration).

ϵ = efficiency (fraction of gamma rays at the specified energy that are completely absorbed into the germanium crystal).

m = gemstone mass in grams.

s = self-shielding correction factor (compensates for the density difference between the gemstone and the calibration source).

Thus, to compute the amount of radioactivity in the diamond, take equation 1 using the live count time in seconds (10,000) and the number of counts under the Am-241 peak (678) from figure 7, the gamma yield for the Am-241 peak from table 1 (0.357), the detector efficiency at 59.5 keV from figure 6 (0.082), the weight of the stone in grams (0.52), and the self-shielding correction factor (0.96) from the computer program ATEN:

$$A = \frac{678}{(37)(10{,}000)(0.357)(0.082)(0.52)(0.96)} = 0.125$$

Therefore, the activity of Americium-241 in this diamond is calculated to be 0.125 nanocuries per gram (nCi/g).

To compute the release date of the diamond, radioactive decay must be considered, which is represented by the following:

Equation 2

$$A = A_o e^{-\lambda t}$$

Where:

A = NRC release limit activity at time t.

A_o = current activity (activity at time $t = 0$).

e = 2.71828...(the base of natural logarithms).

λ = decay constant = $\frac{\ln 2}{T_{1/2}}$ (where ln2 is the natural logarithm of 2 [0.6931...] and $T_{1/2}$ is the half-life).

t = time for the activity to reach A.

Therefore, take the NRC release-limit activity concentration for Am-241 (0.0009) given in table 1, the known amount of Am-241 in this stone (0.125), and the half-life for Am-241 (432.7), again as shown in table 1, and insert into equation 2:

$$0.0009 = 0.125e^{\frac{-(0.6931)(t)}{432.7}}$$

Divide both sides of the equation by 0.125, take logarithms, rearrange terms, and solve for t to get:

$$t = \frac{432.7}{0.6931}\ln\left(\frac{0.125}{0.0009}\right)$$

Therefore, t = 3,079.87 years.

Since the analysis was performed in mid-August 1991 (1991.63 AD), the release date is:

1991.63 + 3079.87 = 5071.50 AD
or
June 30, 5071

How good are the activity values and release dates calculated by gamma-ray spectroscopy? Error analysis is complex (Knoll, 1989). First, because all of the numbers used in equations 1 and 2 are to some extent approximations, the calculated activity values may be in error. In addition, errors are multiplicative, there are small errors in the efficiency curve, and so on. Therefore, because of the comparatively low levels of radioactivity seen in gemstones, the values obtained in gamma-ray spectroscopy have a possible margin of error of 5%–10%.

CONCLUSION

Two gemstones, a 2.60-ct yellowish green diamond and a 140.5-ct dark blue topaz, were analyzed by GIA's gemstone radiation testing facility using gamma-ray spectroscopy. With this technique and associated calculations, the diamond was shown to have been treated with an Am-241 oxide compound and to contain enough residual radioactivity that, according to current U.S. government regulations, it could not be released to the general public until the fifty-first century. This is due to the extremely low release concentration limits for Am-241 and its relatively long half-life of almost 500 years. Similarly, the topaz was shown to have been irradiated in a nuclear reactor and to contain the types and amounts of radionuclides typically found in reactor-irradiated topaz. It was found to be releasable, after radioactive decay, by late summer of 1992, a little more than two years after irradiation.

REFERENCES

Ashbaugh C. (1988) Gemstone irradiation and radioactivity. *Gems & Gemology*, Vol. 24, No. 4, pp. 196–213.

Benedict M., Pigford T., Levi H. (1981) *Nuclear Chemical Engineering*, 2nd ed., McGraw-Hill Book Co., New York.

Browne E., Firestone R., Shirley V. (1986) *Table of Radioactive Isotopes*. John Wiley & Sons, New York.

Cozar J. (1989) Determinación de rasgos de tratamiento, en topacios azules irradiados, por espectroscopia gamma de alta resolución. *Boletin del Instituto Gemológico Español*, No. 31, September, pp. 8–18.

Crowningshield R. (1981) Irradiated topaz and radioactivity. *Gems & Gemology*, Vol. 17, No. 4, pp. 215–217.

Debertin K., Helmer R. (1988) *Gamma and X-ray Spectrometry with Semiconductor Detectors*. Elsevier Science Publishers B.V., Netherlands.

Dugdale R. (1960) Process for coloring diamonds. United States Patent No. 2,945,793, issued July 19, 1960.

Haynes J. (1971) Method of modification of the color of gems. United States Patent No. 3,616,357, issued October 26, 1971.

Kane R., McClure S., Menzhausen J. (1990) The legendary Dresden green diamond. *Gems & Gemology*, Vol. 26, No. 4, pp. 248–266.

Knoll G. (1989) *Radiation Detection and Measurement*, 2nd ed. John Wiley & Sons, New York.

McLane V., Dunford C., Rose P. (1988) *Neutron Cross Sections, Volume 2, Neutron Cross Section Curves*, National Nuclear Data Center, Brookhaven National Laboratory. Academic Press, San Diego, CA.

Murakami T., Chakoumakos B., Ewing R., Lumpkin G., Weber W. (1991), Alpha-decay event damage in zircon. *American Mineralogist*, Vol. 76, No. 9–10, pp. 1510–1532.

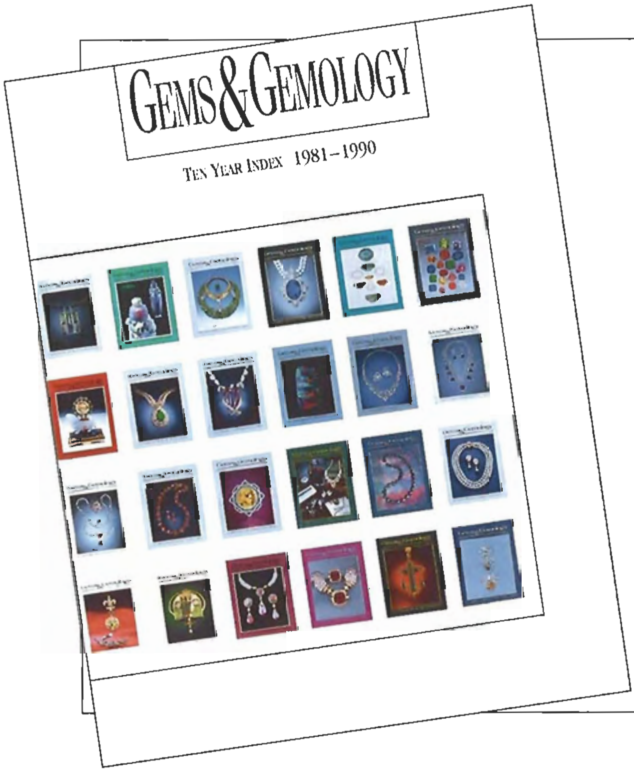
Nassau K. (1983) *The Physics and Chemistry of Color, the Fifteen Causes of Color.* John Wiley & Sons, New York.

Nassau K., Lewand E. (1989) Mildly radioactive rhinestones and synthetic spinel-and-glass triplets. *Gems & Gemology*, Vol. 25, No. 4, pp. 232–235.

NCRP (1985) *A Handbook of Radioactivity Measurements Procedures*, 2nd ed. NCRP Report No. 58, National Council on Radiation Protection and Measurements, Bethesda, Md.

Reinitz I., Ashbaugh C. (1992) Gem Trade Lab Notes: Treated "black" diamond. *Gems & Gemology*, Vol. 28, No. 2, pp. 124–125.

Rossman G.R., Qiu Y. (1982) Radioactive irradiated spodumene. *Gems & Gemology*, Vol. 18, No. 2, pp. 87–89.



DYED NATURAL CORUNDUM AS A RUBY IMITATION

By K. Schmetzer, H. A. Hänni, E. P. Jegge, and F.-J. Schupp

The gemological properties of a new ruby imitation, produced by dyeing natural colorless to pale-colored corundum, are described. Microscopic and spectroscopic examination revealed a number of diagnostic features: fluorescence of the dye-containing fissures but not the surrounding corundum, red deposits on the fracture planes, and the absence of a 694-nm (chromium) doublet in the spectrum.

Various treatments are known for natural ruby and sapphire. These include irradiation, heat treatment, diffusion treatment, synthetic ruby and sapphire overgrowths, and the filling with glass or organic substances (oil, paraffin, resin, epoxy, etc.) of surface-reaching cavities and fissures.* Such treatments have been described extensively in the literature, for example: Gübelin, 1961; Crowningshield, 1979; Nassau, 1981; Koivula, 1983; Scarratt and Harding, 1984; Kane, 1984; Schmetzer, 1986, 1988; Hänni, 1988; and Kammerling et al., 1990.

Most of the corundum treatments reported to date are performed to improve the visual appearance and/or stability of the natural stones. Occasionally, Verneuil flame-fusion synthetic corundum is subject to "quench crackling" (heating then rapid cooling by immersion in a liquid) and subsequent flux treatment to mask its synthetic origin by producing artificial fingerprint-like inclusions (Koivula, 1983; Kane, 1985; Schmetzer, 1986).

ABOUT THE AUTHORS

Dr. Schmetzer is a research scientist residing in Petershausen, Germany. Dr. Hänni is director of the Swiss Gemmological Institute (SSEF), Zürich, and associate professor of gemology at Basel University, Switzerland. Mr. Jegge is staff gemologist at SSEF. Mr. Schupp is a gemstone dealer who resides in Pforzheim, Germany.

Gems & Gemology, Vol. 28, No. 2, pp. 112-115.

Recently, the authors encountered a new corundum treatment, whereby fractures are induced in natural colorless to pale-colored sapphire and then dyed to produce a purplish red imitation of ruby. The red staining of fissures induced in quartz by quench crackling has been used for centuries to imitate ruby (see, e.g., Fryer et al., 1981; Nassau, 1984), but to our knowledge this is the first report of such a treatment being used on corundum.

BACKGROUND

In late 1991 (see International Colored Stone Association [ICA] Alert No. 50, December 1991), four strands of flattened spherical beads (figure 1) were submitted to the SSEF laboratory in Zürich for testing. The beads had reportedly been manufactured in India; the largest were 15 mm in diameter (approximately 10 ct).

Some beads exhibited large areas that were colorless to pale yellow (again, see figure 1). We subsequently determined, using the techniques discussed below, that they had been dyed.

According to CIBJO rules for treatments of natural corundum, all such treatments of natural stones, with the exception of a simple heat treatment (performed without any addition of chemicals and/or color-causing trace elements), must be disclosed to the consumer. All of the above-mentioned treatments for corundum are identified on official identification reports issued by GIA's Gem Trade Laboratory. In contrast to CIBJO rules, this also includes disclosure of heat treatment of rubies and sapphires.

It appears that the process was later improved, because six faceted samples subsequently submitted to one of the authors (see, e.g., figure 2) displayed no colorless areas when examined with the unaided eye. According to information from the supplier, these faceted ruby imitations were purchased in India as heat-treated Indian rubies. The sizes of these six stones ranged from about 5 to 8 ct, and the diaphaneity ranged from semitransparent to translucent. Because of their purplish red color, the samples closely resembled some Indian rubies. Again, as described below, standard gemological testing readily revealed that they had been dyed.

GEMOLOGICAL AND SPECTROSCOPIC CHARACTERISTICS OF THE DYED CORUNDUM

On preliminary examination, the beads and faceted stones appeared to lack any remarkable features: Both the refractive index and specific gravity values were normal for corundum. Surprisingly, the fluorescent doublet at 694 nm did not show up when the hand spectroscope was used. When exposed to long-wave ultraviolet radiation, the stones lacked the red fluorescence typical of rubies from many localities, but the fractures fluoresced an intense yellow-orange. Also unlike most rubies, the stones were inert to short-wave U.V. radiation. We subsequently determined that these features appear to be characteristic for this imitation.

Figure 1. Virtually all of these "flattened" red beads, which were reportedly manufactured in India, contained large, distinct, colorless areas. The beads shown here are approximately 10 mm in diameter. Photo by H. A. Hänni.

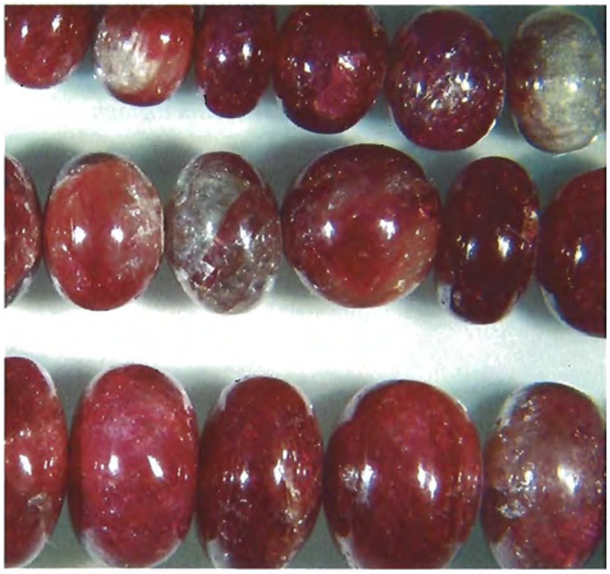


Figure 2. These faceted stones were found to have been treated by a method similar to that used to color the corundum beads shown in figure 1. However, no colorless areas could be seen in these stones with the unaided eye. Photo © GIA and Tino Hammid.

A common test for dye is to rub a cotton swab dipped in acetone across the surface of a suspect sample to see if any color comes off on the swab. We tried this on some of our samples, but observed no dye on the swab. Nor did we detect any evidence that the fractures had been sealed at the surface to prevent detection by the cotton swab test or to keep the dye from being removed.

Examination of both the beads and the faceted stones with the microscope revealed identical and diagnostic properties. In all samples examined, the red color was deposited only in irregular fracture planes. Unstained areas between fractures were seen mainly at the girdle region. They were easily observed when the stones were immersed in liquid, even if it was only water (figure 3). Because the stained fractures were so densely distributed, they were more difficult to see in the thicker areas (figure 4).

The stones also contained various natural inclusions. Dense sets of parallel twin lamellae were observed in one or two directions. Particles of what appeared to be boehmite were confined to the intersection lines of the latter lamellae. Small, doubly refractive mineral inclusions, probably zircon or apatite (or both), were common (figure 5). These inclusion characteristics strongly resemble those of corundum from the Umba Valley of Tanzania (Schmetzer, 1986; Hänni, 1987).

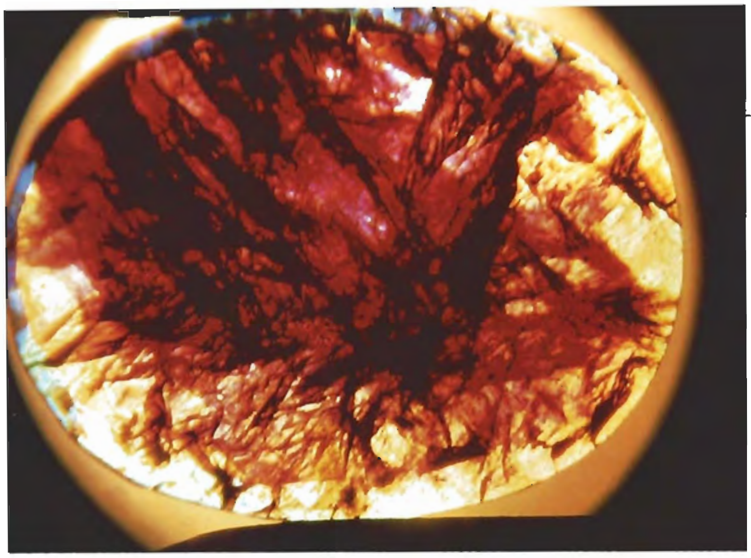


Figure 3. With low magnification and immersion in water, colorless areas were readily apparent along the girdle of this faceted ruby imitation. Photomicrograph by H. A. Hänni; magnified 20×.

The absorption spectrum of the new ruby imitation, recorded on a Pye-Unicam SP8-100 U.V.–visible spectrophotometer, revealed additional diagnostic features. Specifically, the stones we studied lacked the chromium lines in the red area of the spectrum that are characteristic of ruby and responsible for its typical red fluorescence (figure 6). Yet these ruby imitations did show strong Fe^{3+} absorption bands in the blue-green (450 nm) and ultraviolet (374, 388 nm) regions of the spectrum, which are consistent with spectral features observed in yellow sapphires and other Fe^{3+}-containing corundum from the Umba Valley. Even with a hand spectroscope, the 450-nm line due to Fe^{3+} was evident; again there was no chromium absorption. This evidence also strongly suggests that the stones probably came from the Umba region.

Figure 4. Virtually no colorless to pale-colored areas are visible in the thicker portions of the dyed stones examined, although the uneven color distribution along irregular fracture planes is readily apparent. Photomicrograph, taken with the stones immersed in water, by H. A. Hänni; magnified 40×.

Energy dispersive X-ray fluorescence analysis, performed on a Phillips 9500, confirmed the presence of iron in the samples and revealed no other color-causing trace elements.

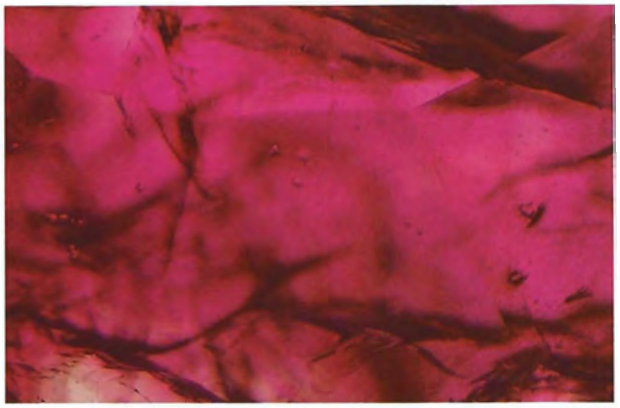
The dominant absorption band in the spectrum of these ruby imitations has a maximum at about 560 nm, with a shoulder at about 530 nm. These two absorption maxima are close to the position of the major chromium absorption band (at about 550 nm) typically found in the visible spectrum of ruby (again, see figure 6). The similarities in the main peak position of ruby and the artificial dye are responsible for the convincing color of the imitation.

DISCUSSION

The results of microscopic examination indicate that colorless to pale-colored natural corundum was treated to produce a purplish red ruby imitation. Comparison of the microscopic properties of the dyed ruby imitation with those of natural rubies and sapphires from various sources revealed that the greatest overlap of characteristics occurred with corundum from the Umba Valley, Tanzania (see, e.g., Schmetzer, 1986; Hänni, 1987).

Large quantities of colorless and pale-colored sapphires have been mined at Umba. Such hues are not in demand for jewelry purposes, and research has shown that these stones cannot be transformed into blue or brilliant yellow by simple heat treatment. It appears that a dyeing process has been chosen to improve the marketability of pink, pale green, brown,

Figure 5. Rounded crystals of what appear to be zircon, some showing stress fractures, were seen in the dyed corundum examined. Photomicrograph by H. A. Hänni; magnified 60×.



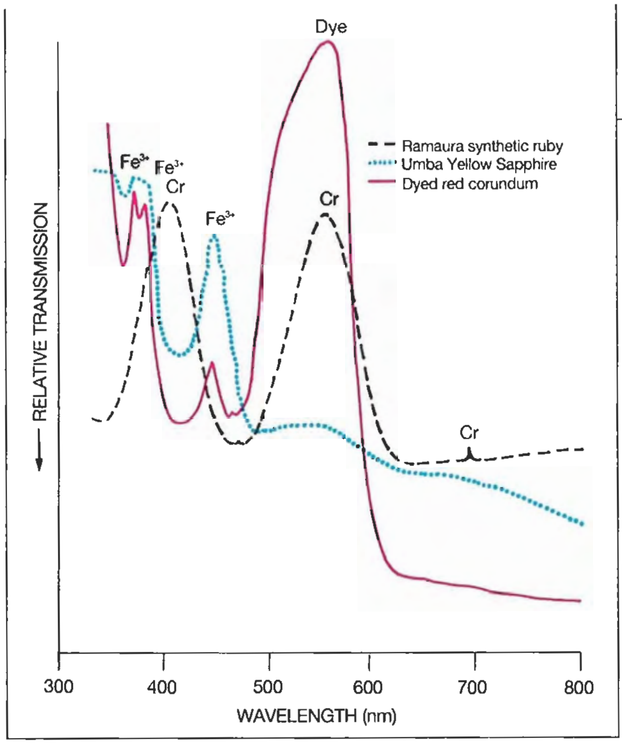


Figure 6. Dominant iron (Fe^{3+}) bands were evident in the absorpton spectra of both the dyed ruby imitation and the Umba yellow sapphire. The spectrum of the ruby imitation also shows a maximum at 560 nm, undoubtedly due to the presence of dye, that mimics the absorption typical of ruby (represented here by a Ramaura synthetic ruby).

or any other color type that would be too pale for commercial usage.

At present, we do not know the exact process used. However, it is probably a method similar to the quench crackling of quartz. The corundum, like quartz, would first be heated, quenched, and then immersed in a red dye that would be gradually absorbed into the fractures caused by the stress of rapid cooling. In the stones examined here, the absorption maximum of the dye corresponds to that of ruby, which explains the convincing color of the imitation. However, the strong Fe^{3+} absorption bands are characteristic of the Fe^{3+}-containing corundum presumably used as the starting material.

It is likely that this process will also be used to produce blue sapphire imitations from the same rough material. Gemologists and jewelers alike should beware of the possible entry of such material into the market.

CONCLUSION

Natural colorless and pale-colored corundum, probably from Tanzania, was subjected to an artificial staining process, most likely by heating and subsequent quenching in red dye. Although this ruby imitation showed natural inclusions and produced no evidence of dye when wiped with an acetone-soaked swab, the fact that it had been treated was readily recognized by the irregular color distribution. In addition, when sample stones were examined with immersion at low magnification, films of red stain were seen to occur only in the fracture planes; larger, unstained areas between the fractures appeared colorless or pale colored. Since the original corundum does not contain chromium, the stones also lack the characteristic red fluorescence of ruby and the related Cr lines usually visible with a spectroscope. A yellow fluorescence confined to stained fracture planes may provide the first clue to correctly identifying this ruby imitation.

REFERENCES

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

Fryer C.W., Crowningshield R., Hurwit K.N., Kane R.E. (1981) Dyed "crackled" quartz. *Gems & Gemology*, Vol. 17, No. 4, pp. 229–230.

Gübelin E.J. (1961) More light on beryls and rubies with synthetic overgrowth. *Gems & Gemology*, Vol. 10, No. 4, pp. 105–113.

Hänni H.A. (1987) On corundums from Umba Valley, Tanzania. *Journal of Gemmology*, Vol. 20, No. 5, pp. 278–284.

Hänni H.A. (1988) An oil well in your garden? *Swiss Watch & Jewelry Journal*, No. 3, pp. 461–464.

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

Kane R.E. (1984) Natural rubies with glass-filled cavities. *Gems & Gemology*, Vol. 20, No. 4, pp. 187–199.

Kane R.E. (1985) A preliminary report on the new Lechleitner synthetic ruby and synthetic blue sapphire. *Gems & Gemology*, Vol. 21, No. 1, pp. 35–39.

Koivula J.I. (1983) Induced fingerprints. *Gems & Gemology*, Vol. 19, No. 4, pp. 220–227.

Nassau K. (1981) Heat treating ruby and sapphire: Technical aspects. *Gems & Gemology*, Vol. 17, No. 3, pp. 121–131.

Nassau K. (1984) The early history of gemstone treatments. *Gems & Gemology*, Vol. 20, No. 1, pp. 22–33.

Scarratt K., Harding R.R. (1984) Glass infilling of cavities in natural ruby. *Journal of Gemmology*, Vol. 19, No. 4, pp. 293–297.

Schmetzer K. (1986) *Natürliche und synthetische Rubine—Eigenschaften und Bestimmung*. Schweizerbart, Stuttgart, Germany.

Schmetzer K. (1988) Lechleitner synthetic rubies with natural seed and synthetic overgrowth. *Journal of Gemmology*, Vol. 21, No. 2, pp. 95–101.

AN UPDATE ON SUMITOMO GEM-QUALITY SYNTHETIC DIAMONDS

By James E. Shigley, Emmanuel Fritsch, Ilene Reinitz, and Mike Moon

Examination of two large (5.06 and 5.09 ct) tabular pieces of Sumitomo synthetic diamond revealed that they were cut from single crystals of predominantly cubic {100} and octahedral {111} morphologies, respectively. These two crystal forms exhibit different patterns of color zoning, internal graining, anomalous birefringence ("strain"), and luminescence. Such differences suggest that both crystal morphology and size can greatly affect the properties observed in a synthetic diamond.

Since GIA first reported on the gemological properties of Sumitomo yellow synthetic diamonds (Shigley et al., 1986), continued developments in high-pressure synthesis techniques have led to the production of larger and better-quality diamond crystals by several companies and research organizations. At present, the high-technology applications that have spurred these improvements consume essentially all single-crystal synthetic diamonds manufactured at Sumitomo Electric Industries. However, the availability of larger crystals, and the fact that there is now a steady commercial production of gem-quality synthetic diamonds, increase the potential impact this material could have on the gem industry.

In 1990, one of us (JES) visited the Sumitomo research facilities in Itami, Japan, and met with the scientists responsible for Sumitomo's production of single-crystal synthetic diamonds. During this visit, Sumitomo loaned GIA two large (5.06 and 5.09 ct) tabular pieces of synthetic diamond (figure 1), which they reported as having been prepared from 9-ct single crystals, the largest size they had produced thus far. These two pieces, although much larger than the Sumitomo synthetic diamonds we had previously studied, were grown using the same high-temperature/high-pressure flux process (see Shigley et al., 1986, 1987). During our meeting, the Sumitomo representatives stated their continuing company policy of selling only tabular, finished pieces of yellow synthetic diamond and only for industrial applications, not for use in jewelry. The two 5-ct samples they loaned us represent the kind of material they are now beginning to manufacture on a limited basis for high-technology applications such as heat sinks and other electronic components.

Gemological examination of these two samples revealed several features we believe to be characteristic of synthetic diamonds and that can help distinguish them from natural gem diamonds. More importantly, however, this study demonstrates how larger synthetic diamonds have many of the same general

ABOUT THE AUTHORS

Dr. Shigley is director of research; Dr. Fritsch is manager of research; Dr. Reinitz is a research scientist, and Mr. Moon is a research associate at the Gemological Institute of America, Santa Monica and New York.

Acknowledgments: We thank Mr. Shuji Yazu, of the Sumitomo Itami Research Laboratories, for the loan of these two samples. We also thank G. Robert Crowningshield and David Hargett, of the East Coast GIA Gem Trade Laboratory, for assisting in the gemological examination of these two synthetic diamonds. Dr. Anthony Kampf, of the Los Angeles County Museum of Natural History, helped document the morphology of the two crystals.

Gems & Gemology, *Vol. 28, No. 2, pp.116–122*

gemological properties (e.g., ultraviolet luminescence behavior, presence of color zoning) as smaller ones, but the visual patterns of these properties might be significantly different.

INSTRUMENTATION AND METHODS

Our examination was conducted using standard gemological testing equipment as well as other laboratory instrumentation. The former included a binocular gemological microscope, a long-wave (366 nm) and short-wave (254 nm) ultraviolet lamp unit, a Beck prism spectroscope, and a DISCAN digital-scanning diffraction-grating spectroscope. A Pye-Unicam Model 8800 spectrophotometer was used to record visible spectra at liquid-nitrogen temperatures over the range 250–850 nm. A Nicolet Model 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 Model ELM-2B luminoscope. Measurements of interfacial angles on the two samples, to document crystal morphology, were made with a Huber optical goniometer. Qualitative chemical analysis was carried out using a Tracor X-Ray energy-dispersive X-ray fluorescence (EDXRF) system.

DESCRIPTION OF THE SAMPLES

Sample 1 weighs 5.06 ct and measures 11.37 × 11.12 × 2.40 mm. This tabular piece has two large polished surfaces; at right angles to these surfaces, portions of the original, unpolished crystal faces occur around the narrow sides (figure 2). The square shape and the arrangement of the remaining crystal faces suggest that this sample was prepared from a predominantly cube-shaped crystal. The four narrow sides are cube {100} faces (as are the orientations of the two polished surfaces). At the corners there are smaller octahedral {111}, dodecahedral {110}, and trapezohedral ({113}, {115}) faces, all of varying arrangement and relative size (see Rooney, 1992). When examined with reflected light, the original crystal surfaces are smooth to slightly rough. Occasionally, small areas display a subtle dendritic pattern that is an imprint of the solidified flux metal in which the crystals grew (see Shigley et al., 1986; Frank et al., 1990).

The overall color of this sample is brownish yellow. It contains eye-visible areas of brown graining parallel to the cube {100} faces, a central brownish yellow area free of graining, and narrow, very light yellow-to-colorless-to-blue zones beneath the corners

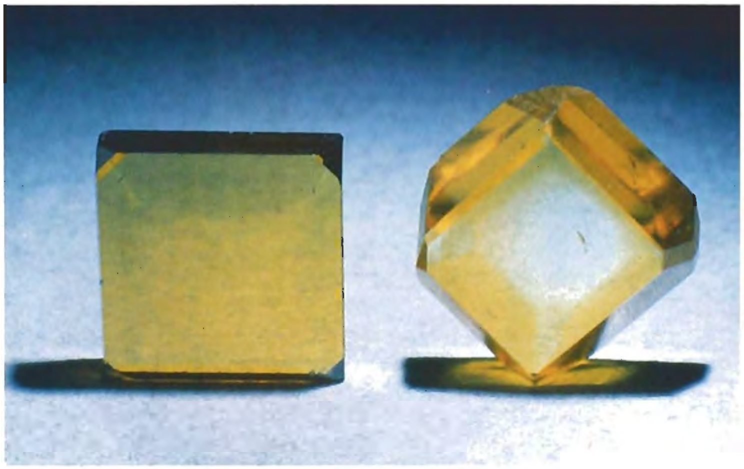
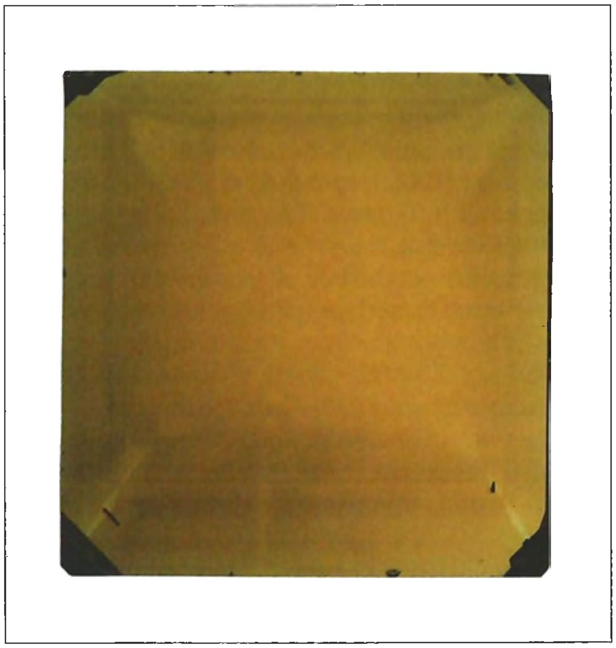


Figure 1. These two polished, tabular samples of Sumitomo synthetic diamond were reportedly prepared from approximately 9-ct crystals. In the text, they are referred to as Sample 1 (5.06 ct, left) and Sample 2 (5.09 ct, right). Photo by Robert Weldon.

Figure 2. Sample 1 exhibits the morphology of a cube-shaped crystal and is predominantly brownish yellow. It contains areas of brown planar graining, as well as zones of darker and lighter brownish yellow and even very small near-colorless zones. Note the two tiny, dark metallic inclusions near the two corners. Photomicrograph by John I. Koivula.



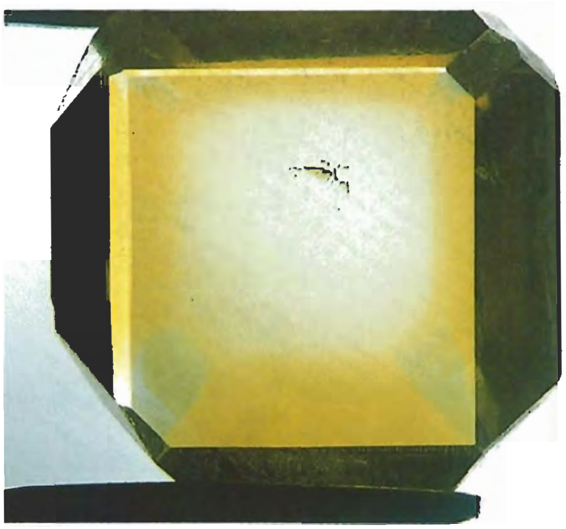


Figure 3. Sample 2 was cut from an octahedral crystal. It displays prominent color zoning, with yellow areas near the outer edges, a colorless area at the center, and narrow blue areas under each of the four corners. These color variations are due to differences in impurity content between the various internal growth sectors in the crystal. In the upper center of the crystal is a small group of metal flux inclusions. Photomicrograph by John I. Koivula.

of the sample (again, see figure 2). Two rounded, elongate, metallic-appearing inclusions (between 0.2 and 0.5 mm long) are also visible 1–2 mm below the surface near the corners of the sample.

Sample 2 weighs 5.09 ct and measures 12.10 × 11.89 × 2.88 mm. It is also tabular with two polished surfaces (figure 3). Along the four narrow sides, which are oriented at a 45° angle to the polished surfaces, there are larger, unpolished octahedral {111} faces and smaller cube {100}, trapezohedral ({113}, {115}), and dodecahedral {110} faces. The morphology of these faces suggests that this sample was prepared from a predominantly octahedron-shaped crystal. Since the most common crystal morphology for synthetic diamonds is a cuboctahedron, the dominant {100} and {111} forms of these two crystals are unusual (for a further discussion, see Frank et al., 1990).

The two polished surfaces on Sample 2 are, like Sample 1, parallel to cube faces. When the rough crystal faces of this sample were examined with a gemological microscope, they appeared to be smooth to slightly undulating. In reflected light, however, the faces did show some distinctive surface markings—a faint dendritic pattern on cube, trapezohedral, and octahedral faces, and parallel striations on dodecahedral faces. Again, these surface markings are imprints of the solidified flux metal (Frank et al., 1990), and they differ in appearance from the growth markings typically seen on natural diamond crystals.

The most remarkable feature of Sample 2, however, is its striking color zoning (again, see figure 3). There is also a small group of rounded or elongate, crystallographically oriented inclusions with a metallic appearance in the central area.

INTERNAL GROWTH SECTORS

In GIA's original description of yellow gem-quality Sumitomo synthetic diamonds (Shigley et al., 1986), we noted the conspicuous zoning of certain gemological features such as color, reaction to short-wave U.V. radiation, and graining. Rapid crystal growth in the laboratory favors the formation of large cubic {100} (and, to a lesser extent, dodecahedral {110} and trapezohedral {113}, {115}) growth sectors (Woods and Lang, 1975; Burns et al., 1990; Frank et al., 1990). These sectors are not present in natural diamond crystals, which grow only along octahedral {111} planes (i.e., crystal faces). A segregation of impurities (such as nitrogen) during crystallization within and between different growth sectors in synthetic diamond can cause a visible zonation of features such as color and ultraviolet luminescence (Burns et al., 1990; Frank et al., 1990).

Each of the two large Sumitomo samples we examined showed the same internal growth sectors, but these sectors create very different geometric patterns in each diamond because of the differences in sector development and impurity content between sectors. In Sample 1, we observed brown graining within the {100} sectors in planes parallel to the six cube crystal faces (again, see figure 2). Graining in yellow synthetic diamonds is believed to be due to index-of-refraction variations caused by changing nitrogen content (Burns et al., 1990; Frank et al., 1990). The narrow zones under the small faces at the corners lack graining, and point toward the dodecahedral {110} faces. Because of their small size, these narrow {110} sectors may not be easy to observe once the diamond is faceted. Frank et al. (1990, p. 356) provided a photograph of the internal growth-sector arrangement in a De Beers synthetic diamond that is nearly identical to the sector pattern observed in this sample.

In Sample 2, the pattern of internal growth sectors is revealed by color zoning, with only very subtle graining visible between sectors. The narrow dodecahedral {110} sectors are blue, while the larger octahedral {111} sectors near the edges are yellow. The central section, which contains less nitrogen (as evidenced by its infrared spectrum; see below), is colorless. The near-absence of graining in Sample 2 can be explained by the lack of large cube {100} growth sectors, like those seen in Sample 1, where such graining is best developed (see Shigley et al., 1987).

As these two samples illustrate, the appearance of internal growth sectors can manifest itself in very different ways (zoning of color *or* graining) depending on the synthetic diamond crystal and its particular growth conditions (see also Burns et al., 1990).

ULTRAVIOLET LUMINESCENCE

Both samples are inert to long-wave U.V. radiation, but fluoresce weak orangy yellow to short-wave U.V. In contrast, natural type Ia diamonds are either inert or fluoresce blue, yellow, or sometimes green to both long- and short-wave U.V. (Liddicoat, 1987, p. 83). There is also some variation in luminescence among natural yellow type Ib diamonds. Our observations on 45 natural-color diamonds of this type revealed that 4 pure Ib and 11 mixed (Ib + IaA) type were inert to long-wave U.V. but luminesced weak to moderate orange to short-wave U.V., while the others were inert or reacted to both long- and short-wave U.V. Therefore, the U.V. luminescence of some natural type Ib diamonds can appear similar to that of these two synthetic samples. Nonetheless, all synthetic diamonds we have tested to date are inert to long-wave and fluoresce to short-wave U.V. Therefore, we continue to believe that this luminescence behavior (but not necessarily the luminescence color) is a good starting point to check for a synthetic diamond.

The short-wave U.V. luminescence pattern in Sample 1 is uneven and duplicates the arrangement of growth sectors: It is weak orangy yellow in the cube sectors and inert in the other sectors.

In Sample 2, the colorless center is inert to short-wave U.V., while the yellow outer areas fluoresce weak yellow in planes that parallel the octahedral crystal faces. Under the corners, a stronger yellow luminescence appears to be banded parallel to the dodecahedral faces. The fluorescent areas (especially those beneath the corner faces) phosphoresce a weak yellowish white that lasts 10–15 seconds. The uneven distribution of ultraviolet luminescence within a stone provides one more way to reveal the presence of both octahedral and cubic internal growth sectors that is typical of the synthetic diamonds we have examined to date.

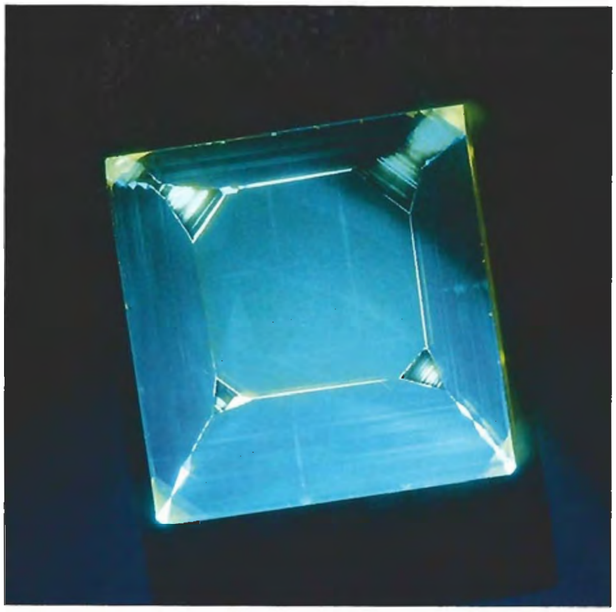


Figure 4. The cathodoluminescence of Sample 1 exhibits a chalky yellow in narrow octahedral growth sectors at the four corners and blue in the large cube sectors around the edges. In both sectors, zoning parallel to the respective crystal faces can be seen. Toward the center, a square, box-like region is also outlined by the bright luminescence. Photo by Maha Smith.

The uneven luminescence patterns are seen more clearly with cathodoluminescence (luminescence to a beam of electrons). As shown in figure 4, the "chalky" yellow cathodoluminescence in Sample 1 is readily visible at the corners, beneath the octahedral and dodecahedral faces. There is also a weak blue luminescence in the larger cube sectors that appears to be banded parallel to the cube faces. Four thin, bright, luminescent bands form a "box" at the center of the crystal. These appear to represent the transition between two growth sectors.

In contrast, the cathodoluminescence of Sample 2 shows the different pattern of the same internal growth sectors. As illustrated in figure 5, the octahedral sectors luminesce yellow, while the smaller cube and other sectors luminesce a weak blue.

Cathodoluminescence may reveal the differing patterns of internal growth sectors in natural and synthetic diamonds (Shigley et al., 1987) more clearly than ultraviolet luminescence. In the future, this method may become a standard technique to distinguish natural from synthetic gem diamonds (Ponahlo, 1992).

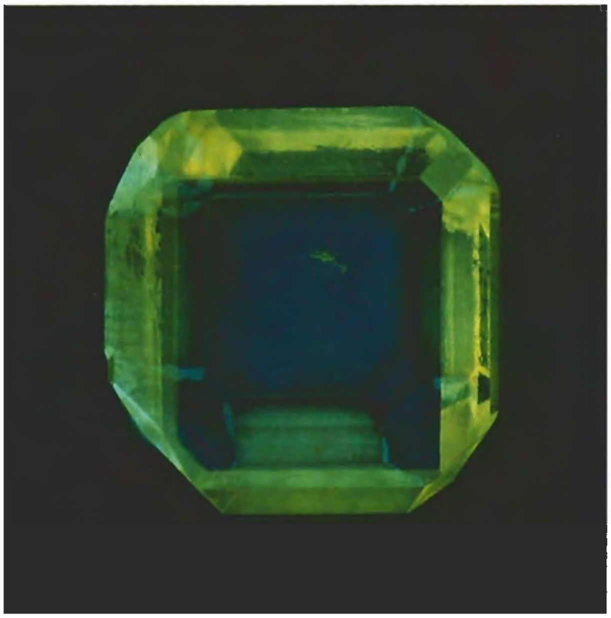


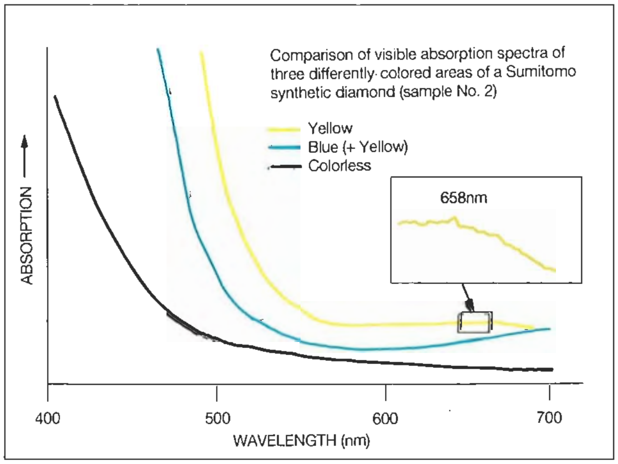
Figure 5. Cathodoluminescence of Sample 2 revealed more intense luminescence in the octahedral sectors (especially the one on the right side of the crystal), with a chalky yellow color that is banded. At the smaller sectors near the corners, and near the center, the sample luminesced a weak blue. Photo by Maha Smith.

SPECTROSCOPY

All of the yellow synthetic diamonds studied previously were type Ib. Thus, they lacked the sharp absorption bands (the well-known "Cape" lines) present in the visible spectra of almost all type Ia natural yellow diamonds. In general, the visible spectra of Sample 2 exhibited the expected features for a type Ib diamond (with increasing absorption toward the violet). However, the areas of differing color in this sample also displayed differences in their spectra (figure 6). The yellow and colorless areas both showed gradually increasing absorption toward the violet (but less so for the latter), while the blue areas (with some yellow component because they were so small and thus included the surrounding yellow areas) showed a gradually increasing but much weaker absorption toward the red. In addition, a very weak, narrow band at 658 nm was observed in the visible spectrum recorded for the yellow areas of this sample. Collins and Spear (1982) attributed this sharp band (referred to as the zero-phonon line of the 1.883 eV system) to the presence of nickel incorporated into the diamond from the flux metal during crystallization. The visible spectrum of Sample 1 was the same as that of the yellow areas in Sample 2 and did not show any sharp bands.

The infrared spectra for Sample 1 confirmed that this crystal is a type Ib diamond throughout, but revealed a higher nitrogen concentration in the areas of brown graining. However, the infrared spectra recorded for Sample 2 indicate that the various colored areas each represent a different diamond type (figure 7). The center colorless area is type IIa, the yellow outer areas are type Ib (because of the series of features between 900 and 1600 cm^{-1}), and the blue areas are type IIb (because of the series of features between 2200 and 3000 cm^{-1}), with some amount of intermixed type Ib for the reasons explained above. We previously noted weak type-IIb features in the infrared spectra of the type-Ib greenish yellow De Beers synthetic diamonds (Shigley et al., 1987). The infrared

Figure 6. Visible absorption spectra were recorded for the three areas of different color in Sample 2. The yellow areas show sharply increasing absorption below 500 nm, while the colorless area shows a more gradual increase in absorption, at a region below about 450 nm. Because the blue zone is so narrow, it was impossible to record the spectrum of just the blue area without also recording a contribution from the surrounding yellow areas; however, this spectrum also exhibits gradually increasing absorption toward the red end of the spectrum (plus the absorption below 500 nm due to the yellow areas). The very weak sharp band at 658 nm noted in the spectrum recorded from the yellow area is shown here as an enlarged insert (this band cannot be seen with a hand spectroscope). Spectra were recorded at liquid-nitrogen temperature.



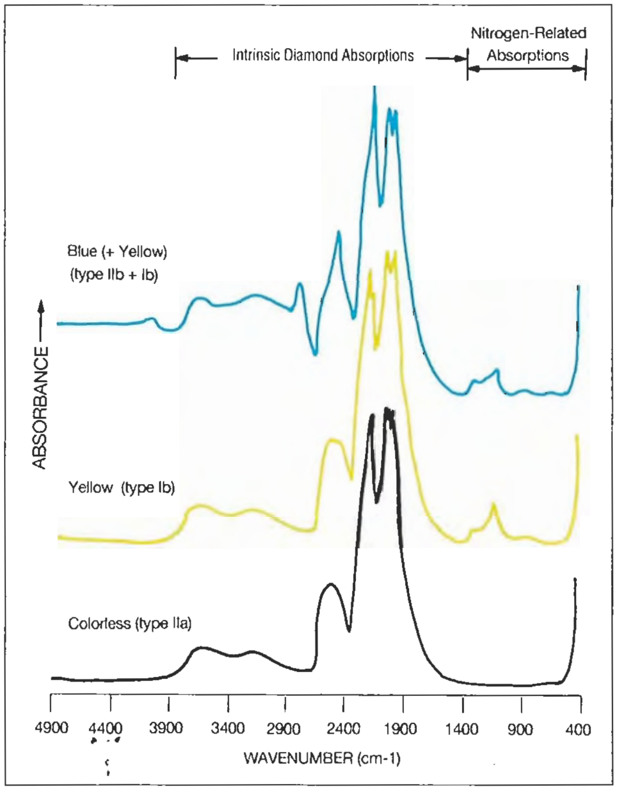


Figure 7. This diagram shows a comparison of the mid-infrared spectra for various color areas of Sample 2. From the top, the spectrum that includes the blue area indicates that it is type IIb with some type-Ib components; the spectrum through the yellow area indicates it is pure type Ib, and the spectrum through the colorless area indicates it is type IIa. Because of the uniform thickness (path length) of the sample, these spectra are scaled correctly one to another relative to their intensity (vertical axis).

spectra in figure 7 again illustrate the very distinctive character of some synthetic diamond crystals. While natural diamonds can be of mixed type (see Fritsch and Scarratt, 1992), we know of no natural diamonds that are a mixed type Ib + IIa + IIb, as is the case for Sample 2.

MICROSCOPY

When viewed between the crossed polarizing filters of the microscope, the two samples display rather weak first-order (black or gray) anomalous birefringence colors ("strain") in a cross-shaped pattern. In Sample 1, black zones extend outward from the center and perpendicular to the four cube faces (figure 8). Near the center of the sample, these zones intersect as a black box-shaped area, the sides of which are oriented parallel to the octahedral faces. Within this box, the birefringence appears to be cross-hatched, and corresponds to the "cluster-type" of mottled birefringence described by Kanda et al. (1990). Around the edges, there is a weak "crystal-type" birefringence pattern parallel to the cube faces (Kanda et al., 1990). The birefringence pattern in Sample 2 is much less regular but, again, appears to form a rough cross that is oriented with respect to the arrangement of growth sectors and external morphology. In general, these birefringence patterns correspond to what has been reported previously in synthetic diamonds (Shigley et al., 1986, 1987; Frank et al., 1990). According to our observations, they differ significantly from those seen in natural diamond crystals, where the planes showing anomalous birefringence are often parallel to the octahedral crystal faces, and the strain is generally more intense.

As mentioned earlier, both samples contain a few rounded, elongate, crystallographically oriented, metallic-looking flux inclusions similar to those seen previously in other synthetic diamonds (figure 9).

Figure 8. This anomalous birefringence ("strain") pattern was seen in Sample 1 with a gemological microscope equipped with crossed polarizing filters. Photomicrograph by John I. Koivula.

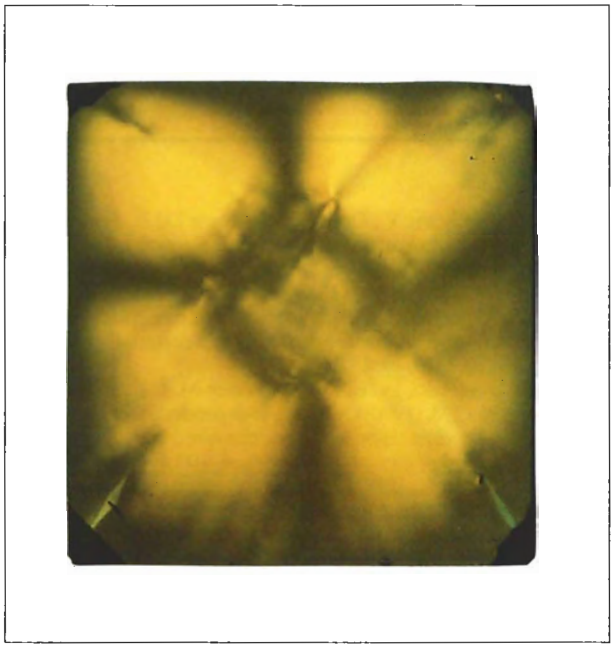


Figure 9. In Sample 1, a narrow, near-colorless-to-blue {110} zone points toward a corner of the sample. Brown graining runs parallel to two sides of the crystal that are cube faces. The elongated flux inclusion appears to be oriented parallel to one of the crystal faces. Photomicrograph by John I. Koivula; magnified 75 ×.

Qualitative chemical analysis of the inclusions in Sample 2 revealed them to be an iron-nickel alloy (with Fe>Ni). Metallic inclusions like these have not been reported in natural diamonds and, when present, are proof that the diamond is synthetic.

DISCUSSION AND CONCLUSION

The two large, 5-ct, samples of Sumitomo synthetic diamond that we examined exhibit different kinds of growth zoning. This zoning is revealed by patterns of color distribution, luminescence to short-wave U.V. radiation, cathodoluminescence, and internal graining. This combination of features is characteristic of synthetic diamonds grown by the high-pressure flux method, and can help distinguish synthetic from natural gem diamonds of similar size, color, and clarity.

The striking color zoning, luminescence, anomalous birefringence ("strain"), and graining patterns in the two samples illustrate the varied development of internal growth sectors and the uneven distribution of impurities in a synthetic diamond. This uneven distribution of impurities between growth sectors can also lead to the presence of more than one diamond type within a single crystal (as in the case of Sample 2, which contains type Ib, IIa, and IIb diamond) that has never been reported in a natural diamond.

Sample 2 is particularly interesting because it contains a central area that is colorless and outer areas that are yellow. If one attempted to facet a large cut stone from such a crystal, it could show a pattern of gemological features (such as color) that is distinctive of a synthetic diamond, as we have reported previously. However, if one were to facet a smaller stone from just one internal growth sector, this stone might lack the distinctive zonation. Future production of large synthetic diamond crystals with even larger, colorless or colored growth sectors may lead to the possibility of stones cut from just one sector. Such faceted synthetic diamonds might be difficult to identify gemologically, even by advanced techniques such as infrared spectroscopy or cathodoluminescence, when they lack the zonation currently used as the primary indication of their synthetic origin.

REFERENCES

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.

Collins A.T., Spear P.M. (1982) Optically active nickel in synthetic diamond. *Journal of Physics, Section D (Applied Physics)*, Vol. 15, pp. L183–L187.

Frank F.C., Lang A.R., Evans D.J.F., Rooney M.-L.T., Spear P.M., Welbourn C.M. (1990) Orientation-dependent nitrogen incorporation on vicinals on synthetic diamond cube growth surfaces. *Journal of Crystal Growth*, Vol. 100, pp. 354–376.

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

Kanda H., Ohsawa T., Yamaoka S. (1990) Differences in morphology and impurity content of synthetic diamonds grown from molten nickel. *Journal of Crystal Growth*, Vol. 99, pp. 1183–1187.

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

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) The gemological properties of the De Beers gem-quality synthetic diamonds. *Gems & Gemology*, Vol. 23, No. 4, pp. 187–206.

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
Gem Trade Laboratory, East Coast
Robert Crowningshield • David Hargett •
Thomas Moses

Gem Trade Laboratory, West Coast
Karin Hurwit • Robert E. Kane

DIAMOND

Heat-Damaged Filled Diamond

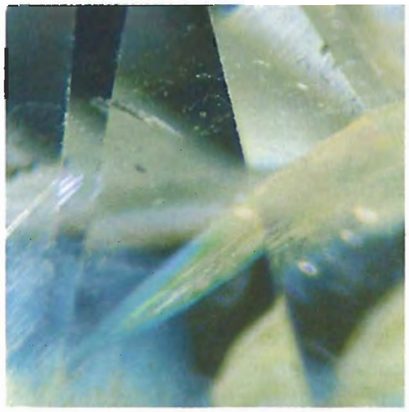
When GIA first began to study fracture-filled diamonds, we discovered that heat from a jeweler's torch during jewelry repair could damage the filling substance and make a fracture more visible (see, e.g., "The Characteristics and Identification of Filled Diamonds," *Gems & Gemology*, Summer 1989, p. 80). Because in most cases diamond jewelry can be repaired without removing the diamonds, we knew it was just a matter of time before we would begin to hear from unsuspecting jewelers who had unwittingly damaged filled diamonds by exposing them to the heat of the torch.

Therefore, we were not surprised when a jeweler recently submitted to the East Coast laboratory a 3.02-ct diamond mounted in a ring that was being repaired. Fractures that previously had been invisible could now be seen with the unaided eye and had a strong yellow cast (figure 1).

When we examined the stone, we saw that it still exhibited the "flash effect" (figure 2) characteristic of filled diamonds (again, see the Summer 1989 issue of *Gems & Gemology*, p. 72; also, the Gem News section of the Spring 1990 *Gems & Gemology*, p. 105). In general, a filled fracture will reveal an orange-to-blue or purple-to-green "flash" when examined in a direction nearly parallel to the fracture. Because our research has shown that the filling material used contains some lead, which is relatively opaque to X-rays, we took an X-radiograph of the stone to confirm that it had been filled. As we had suspected, the filled fractures did indeed appear "lighter" on the X-ray film (figure 3).

Figure 1. The filling in this 3.02-ct diamond was damaged by the heat from a jeweler's torch.

Figure 2. A faint orange-to-blue flash effect can still be seen in the damaged fracture-filled diamond shown in figure 1. Magnified 32×.



Such heat damage reinforces the need for jewelers to identify the presence of fracture filling in diamonds before they perform any jewelry repair that requires heat. If the diamonds are filled, they MUST be removed from their mountings to prevent heat damage.
DH

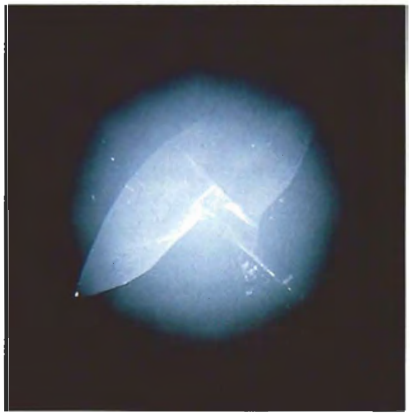


Figure 3. An X-radiograph of the diamond in figure 1 provides further proof of fracture filling, as the filling material is opaque to X-rays.

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

Gems & Gemology, Vol. 28, No. 2, pp. 123–128

Large Chameleon-Type Diamond

The color and appearance of the 22.28-ct heart-shaped brilliant-cut diamond (figure 4) recently submitted to the East Coast lab suggested that the stone might be a chameleon-type diamond. A strong greenish yellow fluorescence to long-wave ultraviolet radiation (figure 5) and a persistent yellow phosphorescence, combined with absorption bands at 415 and 425 nm, identified the stone as diamond and proved the natural origin of its color (see, e.g., Fritsch et al., "Optical properties of diamonds with an unusually high iron content," *New Diamond Science and Technology, 1991*). Furthermore; gentle heating with an alcohol lamp prompted a color change from fancy grayish yellow to nearly pure yellow with similar intensity.

Although we have encountered chameleon diamonds with more dramatic color changes (see, e.g., this section of the Winter 1982 *Gems & Gemology*, p. 228), this stone was nearly three times larger than any previous chameleon diamond tested in the East Coast lab. *TM*

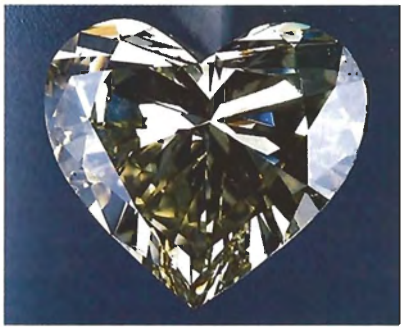


Figure 4. At 22.28 ct, this heart shape is by far the largest chameleon-type diamond ever tested at the East Coast lab.

Figure 5. The strong fluorescence to long-wave U.V. radiation (and persistent phosphorescence) of the stone in figure 4 is typical of chameleon-type diamonds.

Treated "Black" Diamond

The East Coast lab recently received a pear-shaped diamond, which appeared to be black, for an identification and origin-of-color report. The stone measured 15.20 × 10.00 × 6.30 mm (computed to be approximately 5.75 ct) and was set in a yellow- and white-metal pendant-style locket with numerous near-colorless round brilliants (figure 6). The visual characteristics and the high thermal conductivity, as measured with a GIA GEM Instruments Duotester, confirmed that the stone was diamond. The stone appeared to be opaque throughout, and microscopic examination showed a well-polished surface. Most natural-color black diamonds polish poorly because the black appearance is caused by the presence of numerous minute graphite inclusions (Kammerling et al., *Gems & Gemology*, Winter 1990, pp. 282–287).

Closer examination with a GIA GEM FiberLite with pinpoint attachments revealed that the stone was actually very dark green, a color we have never seen in nature and we know results from radiation treatment in a nuclear reactor. Stones treated in this manner can exhibit residual radioactivity. Indeed, scanning of this diamond with a hand-held Geiger counter did reveal residual radioactivity.

For a more precise measurement of the radioactivity, the pendant was forwarded to our new radiation-testing facility in the West Coast lab. The piece was placed over a high-purity germanium gamma-ray detector (see the article by C. Ashbaugh in this issue) and counted for an hour. Analysis of the gamma-ray spectrum showed measurable quantities of three radionuclides that were produced during treatment in the nuclear reactor: 3.75 nCi/g (nanocuries per gram) of europium-152 (Eu-152), 0.5 nCi/g of europium-154 (Eu-154), and 0.3 nCi/g of cobalt-60 (Co-60). Our data (the ratio of Eu-152 to Eu-154) indicate that this stone was treated relatively recently, that is, within the past few years.

Figure 6. The "black" diamond in this pendant proved to be a radioactive laboratory-irradiated dark green diamond. It was computed to be approximately 5.75 ct.

The United States Nuclear Regulatory Commission (NRC) has set legal limits for the sale or distribution of gem materials in the U.S. that contain reactor-produced radionuclides. For these three isotopes, the limits are 0.6, 0.6, and 0.5 nCi/g, respectively. At the time we measured this diamond, the total radioactivity of the stone was more than seven times these limits combined (computed as the sum of the ratios). However, this value is still only about twice the ambient radiation found in the environment (background level) for most of the United States, so, in compliance with the laws of the United States and the regulations of the NRC, the item was returned to the client with full disclosure.

Radioactivity decreases with time. The decay rate of each radionuclide is described by its half-life, which is the time it takes for the amount of the radionuclide present (and, therefore, the amount of radioactivity) to decrease by half. Thus, after two half-lives there will be one-fourth of the original radioactivity present, after three there will be one-eighth, and so on. The half-life of Eu-152 is 13.5 years, that of Eu-154 is 8.6 years, and that of Co-60 is 5.3 years. Using these decay rates, we calculated that this diamond would reach the NRC release limits in about 36.6 years.

Ilene Reinitz and Chuck Ashbaugh

Editor's Note: GIA recently received licenses from the United States Nuclear Regulatory Commission (NRC) and the State of California to possess, test, and distribute radioactive material in conjunction with a new Radiation Testing Service being offered at the West Coast facility of the GIA Gem Trade Laboratory.

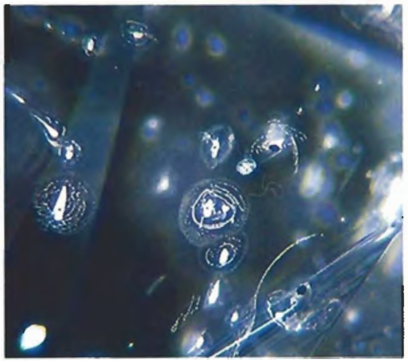
EMERALD Imitation: YAG

Green YAG (yttrium aluminum garnet) is sometimes used as an emerald imitation. Although it is usually relatively easy to identify, a local dealer, suspicious about a reportedly Colombian emerald he had been offered, was confused by inclusions that he thought resembled the "*jardin*" seen in natural emeralds. To be on the safe side, he sent the 5.56-ct oval mixed cut to the East Coast lab for identification.

The GTL examination revealed that the stone had a refractive index over the limits of the refractometer (emerald typically ranges from 1.57 to 1.58), was singly refractive (emerald is doubly refractive and uniaxial), and had a high specific gravity, 4.55 (compared to about 2.72 for emerald). Finally, examination with the microscope at high magnification revealed that the inclusions that the dealer thought were "*jardin*" were actually a myriad of gas bubbles intermixed with a white flux-like material of unknown composition (figure 7).

Figure 7. High magnification (126×) revealed that what was believed to be "jardin" in an emerald is actually a combination of bubbles and flux in a green YAG.

Figure 8. Inclusions in this near-colorless YAG are similar to those shown in the YAG in figure 7. Magnified 27×.



All of the properties obtained were typical of YAG. On checking the GTL reference collection, we found a 3.95-ct near-colorless round-brilliant-cut YAG with similar inclusions (figure 8).

DH

GLASS Imitations of Various Gems

From time to time, GTL almost simultaneously receives items from different sources that turn out to be the same material. Lately, we in the East Coast lab have seen several different types of glass imitations. The following describes three such identifications.

The samples shown in figure 9 resemble some of the many thousands of "crystals" that have been used in jewelry and sold in the crystal-healing market with claims that they will cure almost anything. However, closer examination showed stretched gas bubbles which, together with the specific gravity of 2.52 and R.I. of 1.52 (singly refractive), proved they were glass.

Another item was a turn-of-the-century ring that some dealers believed was set with a piece of fine Persian turquoise (figure 10). Identification of this material as glass was not easy, since we could not take a good refractive index because the surface was pitted. Higher magnification revealed that these "pits" were actually vitreous conchoidal fractures, which would indicate glass or at least eliminate turquoise as a possibility. With the aid of a strong fiber-optic light source, we observed

Figure 9. These two glass imitations (note the stretched gas bubbles in the larger one) were sold as "healing crystals." The larger piece measures 34.16 × 10.10 × 9.27 mm.

Figure 10. Some dealers thought that the 9 × 6 mm glass cabochon in this ring was fine Persian turquoise.

translucent internal flow lines; these, together with the vitreous luster on the conchoidal surface fractures, proved that the material was glass.

The third example illustrates a situation that is of concern to many dealers. A number of stones in what looks like, and was thought to be, a parcel of amethyst or synthetic amethyst (figure 11) turned out to be glass. Not only are they a good color match, but they have a refractive index of about 1.55, which overlaps the R.I. range for amethyst (1.544–1.553). So, taking a hasty single refractive index, without checking for birefringence, could well lead to the wrong conclusion.

One good "quick" test on a parcel of such stones is to expose them to short-wave U.V. radiation. As illustrated in figure 12, the glass fluoresces a chalky blue, while the amethyst (whether synthetic or natural) is inert. Note that this "quick" test should only be used as an indicator that something is amiss, not as an identification.

Nicholas DelRe

Figure 11. Note the fine color match of the natural amethysts and glass imitations in this parcel. The R.I. s are also closely matched, at 1.55.

Figure 12. In this parcel, the glass imitations fluoresce chalky blue—while the amethysts are inert—to short-wave U.V. radiation.

PEARLS

Black, from Baja California

As we reported in the Spring 1991 issue of *Gems & Gemology* (p. 42), the Gulf of California appears once again to have become a major source of natural black pearls. Even before this earlier report, the editors were shown some shells of the pearl-producing oyster *Pinctada mazatlanica*, measuring approximately 13 × 14 cm, that had been fished off the east coast of Baja California. One shell showed a light brown 3/4 blister pearl that was approximately 11.5 mm in diameter.

At the 1991 Tucson Gem & Mineral Show, we were shown a beautiful purplish brown button pearl (figure 13), approximately 15 mm in diameter and 10 mm deep, that had recently been found off La Paz, Baja California. Subsequent X-ray examination in our West Coast lab confirmed that the pearl was indeed natural. The pearl also fluoresced a strong red to long-wave U.V. radiation, a characteristic of natural-color black pearls from the La Paz area.

KH

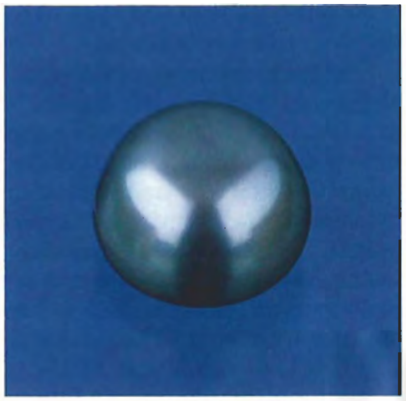


Figure 13. This natural-color natural black pearl (15 mm in diameter × 10 mm deep) was recently found off the coast of Baja California.

Treated Black Mabes

Shortly after our note on treated white assembled blister pearls (mabes) appeared in the Fall 1991 issue of *Gems & Gemology* (p. 177), the West Coast laboratory examined yet another type of enhanced assembled blister pearl. This assemblage had the usual white mother-of-pearl base, but the top was a dark purplish brown nacre that showed very high luster and orient. Figure 14

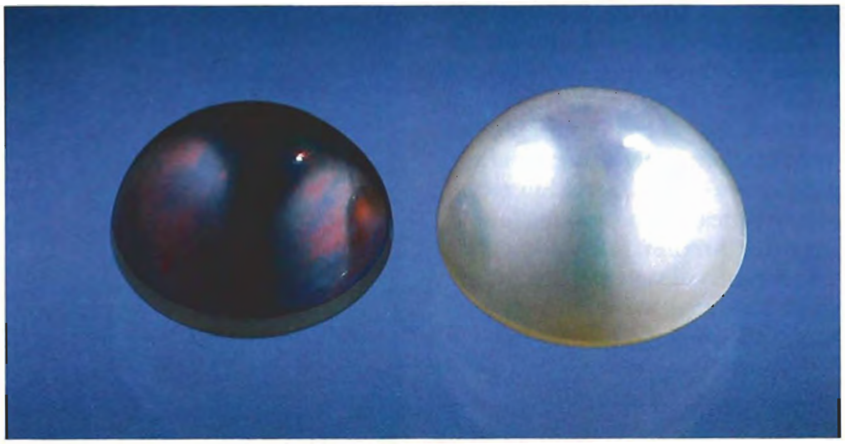


Figure 14. The color of the 13-mm black mabe assembled blister pearl on the left was produced by dye. It is shown here with a white mabe.

shows one of these "black" mabes (here, approximately 13 mm in diameter) next to a typical white mabe.

Closer examination of the black mabe assembled blister pearl revealed a slightly uneven color distribution in the nacre layer; with strong overhead illumination and high magnification, irregular darker brown areas became visible (figure 15). This splotchy color appearance suggested enhancement. A cotton swab soaked in 2% dilute nitric acid solution was stained when gently rubbed over the surface—proving that the nacre top had been dyed. In addition, this mabe pearl fluoresced a dull reddish orange to long-wave U.V. radiation, unlike the brownish red to red fluorescence usually seen in natural-color black pearls. We have since seen a number of such treated black mabes—reportedly manufactured in Japan—in the laboratory.

The GIA Research Department analyzed the nacre layer by energy dispersive X-ray fluorescence (EDXRF) to determine the chemical component that could have been used to treat this type of assembled blister pearl. In addition to silver, small amounts of bromine were detected. *KH*

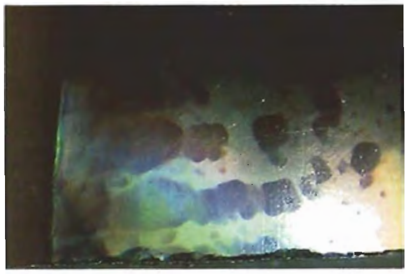


Figure 15. Irregular areas of color suggested that this black mabe assembled blister pearl had been dyed. Magnified 5×.

"Geneva [Synthetic] RUBY"

The Fall 1991 issue of *Gems & Gemology* (p. 178) has a photo of a pendant containing diamonds and early synthetic rubies with a sprinkling of natural rubies. Because of the rudimentary equipment used in their manufacture (as early as 1884), the first synthetic ruby boules produced were under considerable strain. Consequently, attempts to cut sizable stones usually met with failure. The small stones in the pendant described earlier were consistent in size with most of those we had seen thus far at GTL.

Recently, however, the East Coast laboratory had the pleasure of identifying relatively large examples of these early synthetics, which were commonly called "Geneva Rubies" in the trade. These synthetic rubies were mounted in a yellow- and white-gold ring, with rose-cut diamonds (figure 16), that appears to be in the "turn of the century" style. The center stone measured approximately 7.00 × 6.00 × 3.00 mm. The weight-estimation formula suggests that the stone weighs more than 1 ct. In figure 17, the tightly curved growth lines and black impurities characteristic of these early synthetics are readily apparent. We have rarely seen this material in stones this large, and to find nine—all without strain cracks—in one piece is unexpected. *GRC*

SAPPHIRE, Durability of Heat-Treated Stones

The East Coast lab received a 3-ct sapphire, set in a modern ring, for a damage report. The client had complained about the worn facet junctions (see figure 18), which resembled those commonly seen on heat-treated zircons, and wondered about the cause. Since all damage reports include an identification report, we first determined that this stone was diffusion treated—a fact that came as a complete surprise to

Figure 16. This beautiful period ring contains nine "Geneva rubies" (early flame-fusion synthetics). The center stone is over 1 ct; none of the stones shows strain cracks.

Figure 17. Sharply curved striae and dark inclusions, seen here at 19×, prove that the synthetic rubies shown in figure 16 are of early manufacture.

our client. Unfortunately, because the color is confined to a thin surface layer, the client probably could not even repolish the stone to eliminate the abraded facet junctions.

A possible explanation for the worn facet junctions was given to us more than 10 years ago, by sapphire dealers in Australia who reported that heat treatment could make the stones brittle. Such stones would suffer more than usual "paper wear" unless each one was wrapped separately. However, one informant reported, once the parcels of wrapped stones were sent to Bangkok for marketing, they were unwrapped and mixed with other stones.

If the durability of a sapphire is indeed impaired after successful heat treatment, the question arises as to how much more it would be impaired if the sapphire were to undergo repeated exposures to high heat, as is commonly the case for those stones that do not respond to heat treatment (because they lack the necessary iron and titanium) and are submitted to diffusion treatment only after several unsuccessful attempts at heating. In addition, the "deep" diffusion treatment to which many thousands of sapphires have been subjected in recent years reportedly requires multiple heatings (for further information on diffusion-treated sapphires, see the article by Kane et al. in the Summer 1990 *Gems & Gemology*, pp. 115–133).

GRC

Figure 18. The abraded facet junctions on this approximately 3-ct diffusion-treated sapphire probably could not be repolished without removing part of the shallow color layer.

Identifying Curved Striae in Yellow SYNTHETIC SAPPHIRE

Curved striae are usually difficult, if not impossible, to see in yellow or orange flame-fusion synthetic sapphires. They are more difficult to see in stones with a pale body color than in the darker synthetic rubies and blue sapphires.

If it is suspected that a yellow or orange stone is a flame-fusion synthetic, it is often helpful to use a filter of complementary color when looking for curved striae. With orange to yellow sapphires, a blue plastic or glass filter placed between the stone and the microscope light source may make the curved striae easier to see (see, e.g., the article by R. Hughes in *Journal of Gemmology*, Vol. 21, No. 1, 1988, pp. 23–25; also, *Gems & Gemology*, Winter 1990, p. 299).

East Coast lab staff were, therefore, surprised when the curved striae in a yellow flame-fusion synthetic sapphire they had been asked to identify were readily visible under normal observation even without magnification (figure 19)!

DH

Figure 19. Curved striae are easily visible without magnification in this 15.50 x 10.75 x 6.15 mm flame-fusion synthetic yellow sapphire.

PHOTO CREDITS

Figures 1, 2, 4, 5, 7-12, and 16-19 were supplied by Nicholas DelRe. The photos used in figures 6 and 13 were taken by Shane McClure. The X-radiograph in figure 3 was taken by Bob Crowningshield. Figure 14 is © GIA and Tino Hammid. Figure 15 is by John I. Koivula.

GEM NEWS

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

DIAMONDS

Claim-staking rush in Canada. One of the biggest claim-staking rushes ever seen in Canada was triggered in late 1991 by the discovery of 81 small diamonds in a 59-kg kimberlite sample from the Lac de Gras area, about 350 km northeast of Yellowknife in the Northwest Territories. As of April 1992, an estimated 3.6 million hectares had been staked with at least 16 companies involved, including De Beers's Canadian exploration subsidiary, Monopros Ltd. Before the Lac de Gras discovery, diamond prospecting in Canada had focused on central Saskatchewan, where drilling in 1989 identified a number of kimberlites. Since then, 160 diamonds larger than 2 mm in diameter have been recovered from 15 kimberlites, but the projected yield is still too low for commercial mining. The Northwest Territories discovery, however, appears much more promising. The kimberlite from which the 81 diamonds were recovered is believed to have a surface area of about 20 hectares, which compares in size to some South African pipes. The discovery was made after more than 10 years of exploration, during which diamond indicator minerals were traced systematically in heavily glaciated terrain. (*Mining Journal*, April 10, 1992, p. 255)

International Diamond Technical Symposium in Israel. In October 1991, some 500 of the world's leading diamond manufacturers gathered in Tel Aviv to share ideas and information on advances in manufacturing technology. Cosponsored by the Central Selling Organisation and the Israel Diamond Institute, this meeting provided attendees from 23 countries an opportunity to better comprehend the truly global character of the diamond market and the unique contributions of each diamond-cutting center.

Presentations by industry experts covered a range of topics: market forces, cutting technology (sawing, bruting, polishing), laser technology, environmental concerns, safety, new cutting styles, and employee training. Dr. James E. Shigley of GIA Research gave a presentation on the gemological aspects of identifying natural, enhanced, and synthetic gem diamonds.

In addition to these presentations, 28 companies exhibited the latest diamond-cutting equipment. The first technical evaluation of automatic diamond-cutting equipment featured systems from developers in six countries. These new systems are variously composed of automatic bruting machines, computerized centering instruments, and girdle-polishing machines, as well as additional equipment, all of which may be used separately or combined for full automation.

Uri Schwartz, chairman of the Technical Israel Committee of the Israel Diamond Institute, addressed the problems of converting from manual to automated diamond processing. He advised diamantaires to consider two fundamentals: (1) the "production basket"—the variety of stones processed by the factory, and (2) the "critical mass"—the minimum quantity of machinery required on the basis of machine capacity and the types of stones to be processed.

Prospecting reveals kimberlite pipes in Ukraine. Two diamondiferous kimberlite pipes have been discovered in the Donetsk region of the Ukraine. The successful search, made by specialists from the Azov prospecting expedition, was prompted by a recent find in the Arkhangelsk region in northern Russia. This earlier discovery led the prospectors to believe that additional pipes might be found in this more southern region of the former Soviet Union. (*Diamond Intelligence Briefs*, February 20, 1992, p. 861)

Small industrials in Uzbekistan. Industrial-quality diamonds, reportedly up to 2 mm in diameter, have been discovered near Tashkent in the Tyan Shan mountains of Uzbekistan. Diamondiferous kimberlites have also been found in the same area. (*Mining Journal*, April 24, 1992, p. 296)

De Beers and the Republic of Sakha sign sales agreement. De Beers Centenary AG recently signed a sales agreement with the Republic of Sakha (formerly Yakutia). According to De Beers, Sakha will now market its rough gem-quality diamonds exclusively through De Beers's Central Selling Organisation (CSO).

The agreement followed a December 1991 decree by Russian President Boris Yeltsin that gave Sakha the right to retain 10% of its rough gem diamond production for independent sale. In the past, all of Sakha's production was sold to the central diamond authorities in Moscow (formerly Glavalmazzoloto, now Rossalmazzoloto), which marketed Russia's rough gem-quality diamonds through the CSO. The Russian diamond authorities will continue to handle

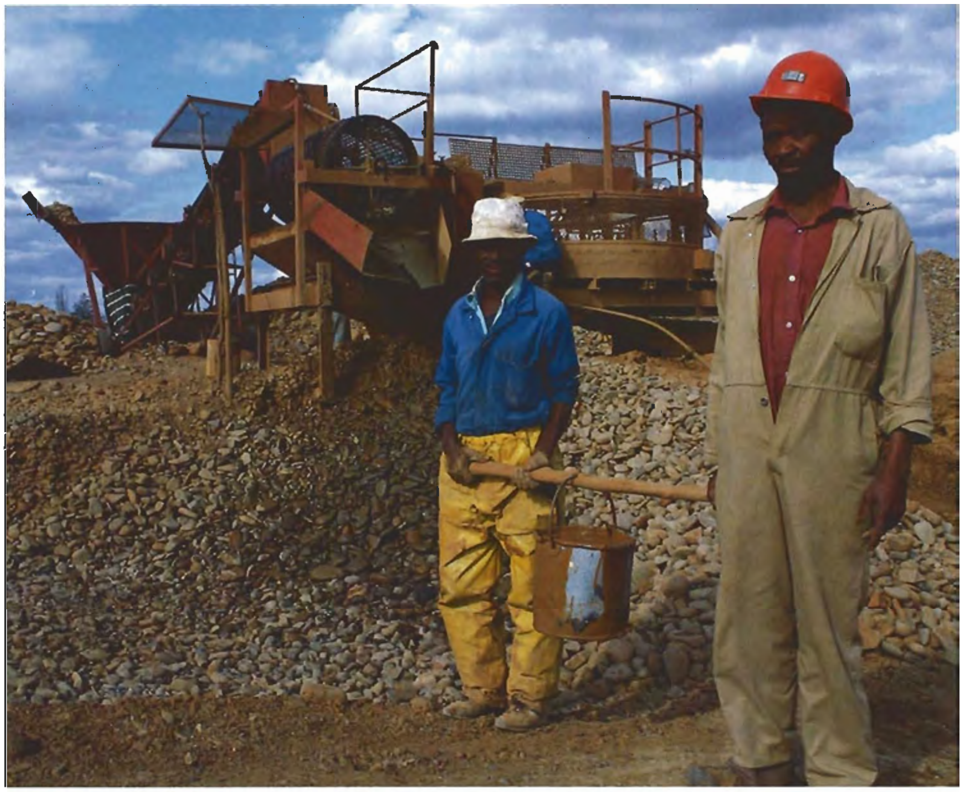


Figure 1. At this small diamond mine in South Africa, the concentrate is carried by bucket from the original recovery plant to a nearby sorting shed. Photo by Robert E. Kane.

Sakha's rough diamond production and will sort the diamonds in Moscow on Sakha's behalf.

In July 1990, De Beers Centenary and Rossalmazzoloto signed a five-year exclusive sales contract for Russia's rough-gem diamond production. The agreement between Sakha and De Beers Centenary will run concurrently with this contract.

With such important mines as Udachnaya, Mir, and Jubilee, Sakha (now an autonomous republic within the Russian Federation) is responsible for 99.8% of the Federation's total diamond production. This makes Sakha one of the world's largest producers of gem-quality diamonds.

Visit to a small diamond-mining operation in South Africa. While on a trip to South Africa in late 1991, Robert E. Kane of the GIA Gem Trade Laboratory visited the Longlands area, approximately 50 km west of Kimberley. The first alluvial diamond deposits in South Africa were discovered here in 1869, along the Vaal River. There are still many small independent mining operations in the area, with both miners and buyers licensed by the government.

Mr. Kane visited the mine owned and operated by Danie Van Wyk, who has 18 years of experience in the Longlands area. At the time of the visit, Mr. Van Wyk had been working his present site for two years. The operation is rather sophisticated for a small-scale mine, employing heavy equipment and a portable recovery plant operated by three employees.

Recovery begins with a front-end loader that picks up the diamond-bearing gravels and carries them a short distance to the recovery plant, where they are dumped into a vibrating hopper that feeds a conveyor belt. Large rocks are removed by hand, while smaller rocks are sorted by a rotating cylindrical sizing screen. The remaining gravels are then fed into a rotating pan to which water is added, and the less-dense material is siphoned off the top. The heavier material collects in the bottom of the pan, where a drain is then opened to fill buckets with the muddy concentrate.

The concentrate is carried in a bucket (figure 1) to a nearby sorting shed that contains three circular metal pans, each with a different size screen mesh (approximately 3, 7, and 12 mm), stacked vertically and separated by sheet-metal cones. This stack is placed in a large, water-filled metal drum, the gravel mixture poured into the top, and the assembled screens agitated. This separates the heavier material into three size categories and allows waste to collect at the bottom.

The pans are next gravitated separately to concentrate the heavier material (including, hopefully, diamonds) in the bottom center of the pan. Under Mr. Van Wyk's supervision, each pan is then overturned onto a sorting table and any diamonds are removed by hand. Mr. Van Wyk reported that he recovers only colorless to yellow diamonds at his operation and that he had found three good-size crystals—9, 12, and 16 ct—the previous week.

De Beers signs prospecting agreement with Tanzania. A diamond-prospecting and mining agreement has been signed by De Beers's subsidiary Wilcroft Co. Ltd. of Bermuda, Tanex Ltd. (a locally incorporated subsidiary of Wilcroft), and the Tanzanian Ministry of Water, Energy and Minerals. The agreement covers reconnaissance, prospecting, and mining operations in a 22,310-km area of the regions of Mwanza, Shinyanga, and Tabora.

Diamond exploration, including airborne geophysics, has indicated that there may be as many as 300 kimberlite pipes in Tanzania. Under the agreement, Tanex initially will receive a one-year reconnaissance license to identify targets for detailed exploration. (*Mining Magazine*, March 1992, p. 178)

Zaire produced fewer diamonds. Production at the MIBA mine in Zaire dropped from 9.5 million carats in 1990 to 6.8 million carats in 1991. A recent report indicates that January 1992 production was 240,000 ct, down significantly from the projected monthly average of 600,000 ct. The decrease has been attributed to problems that include transportation, supplies, and even obtaining food for employees. (*Diamond Intelligence Briefs*, March 31, 1992, p. 870)

Zaire tightens trade regulations. The Zaire government has ordered all foreign nationals out of its diamond-mining areas and tightened trading regulations in an effort to curb smuggling. A government announcement televised in late February stated that all licenses to purchase diamonds from small, private diggers had been cancelled and that new applications must be submitted. Each licensee may employ no more than 10 buyers, all of whom must be citizens of Zaire, although exemptions can be obtained for significant additional fees. Security measures include tightened surveillance in mining areas and stricter border security. (*Mining Journal*, March 20, 1992, p. 202)

COLORED STONES

Exotic "jewel" beetles. We have previously reported on the occasional use of colorful, iridescent beetle exoskeletons in jewelry (Gem Trade Lab Notes, Fall 1989, and Gem News, Summer 1991). Although somewhat brittle and therefore unsuitable for items such as rings, these unique organic "gems" can be used in brooches and pins, where damage is less likely to occur.

There are over 297,000 different species of *Coleoptera* (beetles) known, but we had previously encountered only brightly colored green beetles in jewelry. However, at a recent science career day held at Chapman College in Orange County, California, one of the Gem News editors viewed an exceptional insect collection, several cases of which were labeled "exotic jewel beetles." These beetles displayed iridescent colors of the entire visible-light spectrum (figure 2). According to the owner, Mr. Les Stockton of Stockton Enterprises, Santa Monica, California, the 107 different beetle species illustrated came from 27 countries, including most of the countries in Central and South America, as well as Madagascar, Malaysia, New Guinea, and Spain. The largest beetle (genus *Megaloxantha*, species *bicolor*), from the Philippines, is more than 3 in. (7.5 cm) long. Most of these "jewel" beetles have found use as personal adornments in the countries in which they are found.

Cat's-eye golden beryl. Elongated, tubular inclusions running parallel to the c-axis are fairly common in beryls, especially in the near-colorless to light-blue aquamarines from Brazil and Zimbabwe. When these inclusions are plentiful, a chatoyant stone may be fashioned from such material.

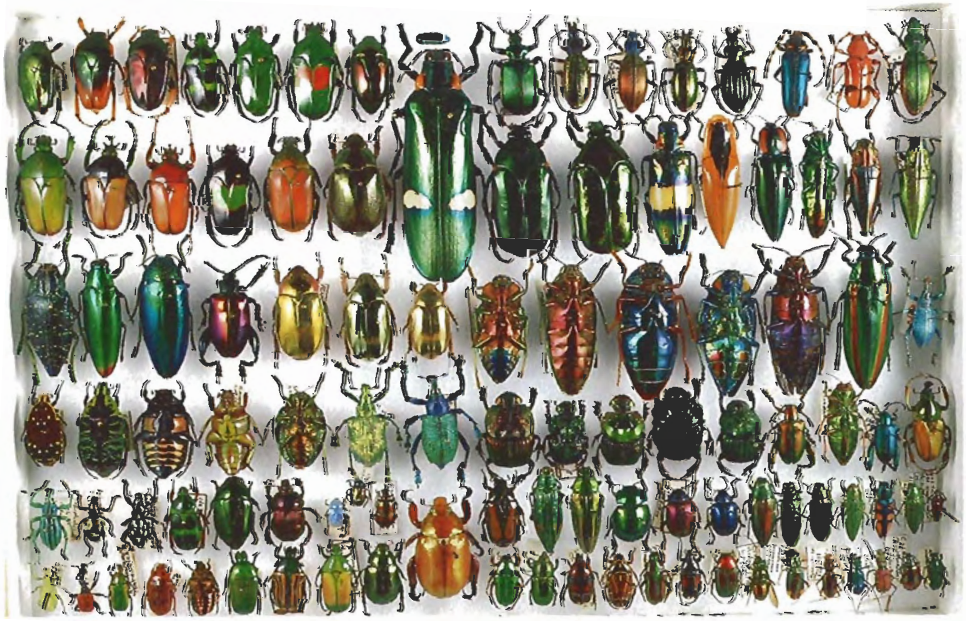


Figure 2. This collection of exotic "jewel" beetles represents 107 different species from 27 countries. The largest beetle shown here is more than 3 in. (7.5 cm) long. Photo by Maha Smith.

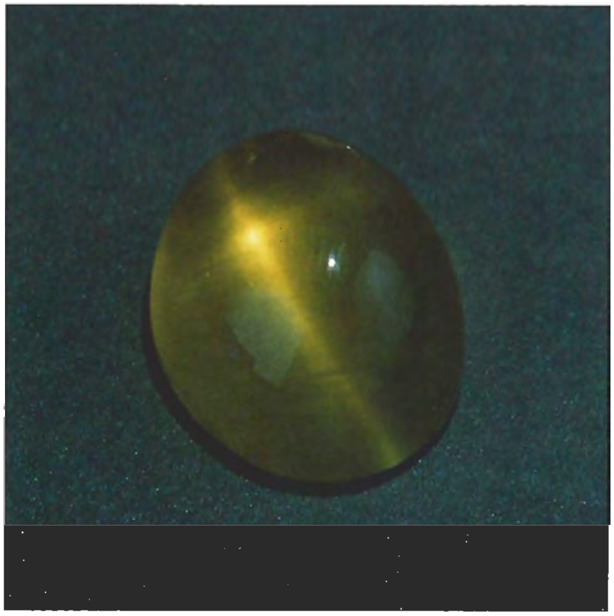


Figure 3. This 7.24-ct chatoyant "golden" beryl may owe its color to artificial irradiation. Photo by Maha Smith.

It is also known that a yellow, or "golden," color can be induced in beryl through irradiation. Although we have regularly seen faceted gems in this color, this year at one of the Tucson shows we came across a dealer with several hundred carats of cat's-eye beryl cabochons, some of which we suspect may owe their color to irradiation. Approximately half of the stones were light-blue aquamarines; the other half, like that pictured in figure 3, were a medium to medium-dark yellow.

Figure 4. The Sinai Peninsula of Egypt is the reported source of the almandine garnet beads (12.3–13.0 mm in diameter) in this necklace. Photo by Maha Smith.

Garnets from Egypt. While on a trip to Egypt in late 1991, one of the Gem News editors (RCK) saw some of the gem-set antiquities displayed in the Egyptian Museum Cairo. Among the gems in the Greco-Roman jewelry were some very dark brownish red stones that resembled almandine garnet. In one room of the museum, a chart listing the gem materials used by the ancient Egyptians included garnet, although neither species nor variety was given.

Later in the trip, at Luxor, the editor visited a gem dealer who displayed a necklace of dark brownish red beads represented as garnets recovered from the south-central area of the Sinai Peninsula, "two mountains over from Gebel Musa" (Mt. Sinai). According to the merchant, his father obtained garnets at the mine site several years before, but the exact location was no longer known. John D. Rouse, in his book, *Garnet*, cited Pliny's report of Egypt as an early source of "carbuncles," a gem name now thought to have referred to garnets. While Pliny mentioned the Thebes (not the Sinai) area as the source, Rouse speculated that this might have been a trading station rather than the mining area.

The necklace was acquired for gemological examination. The 36 off-round beads range in diameter from approximately 12.3 to 13.0 mm. In reflected light, they appear brown and almost opaque; when examined with transmitted light, however, they are brownish red and transparent (figure 4). Magnification revealed dark solid inclusions with irregular outlines and stained fractures.

Spot refractive indices of 13 beads revealed readings over the limit (1.80+) of the conventional refractometer. Examination with desk-model spectroscopes (both prism and diffraction-grating types) revealed absorption features like those associated with almandine and spessartine garnets. EDXRF analysis, carried out by GIA Research, confirmed the presence of iron and manganese. On the basis of these data, we identified the garnets as almandine-spessartine.

Large jadeite boulder. During a trip to Myanmar (formerly Burma) in March 1992, one of the editors (RCK) and GIA-GTL's Bob Kane saw what was described by local officials as the largest jadeite boulder ever recovered from the Mogaung area of upper Myanmar (figure 5). The boulder was discovered on July 19, 1982, at the Khy-Siu mine, Kan Mine township, Kachin State, and transported to Yangon (formerly Rangoon) one year later. The boulder is approximately 4 m long × 2 m wide × 2.25 m high, and has a circumference of 8.75 m. It weighs approximately 33 metric tons. This impressive specimen is displayed in front of the Myanmar Gems Enterprise headquarters at Yangon.

Gemstones from Laos. Myanmar and Thailand have long been known as important sources of colored stones; over the past few years, Vietnam has gained considerable recognition

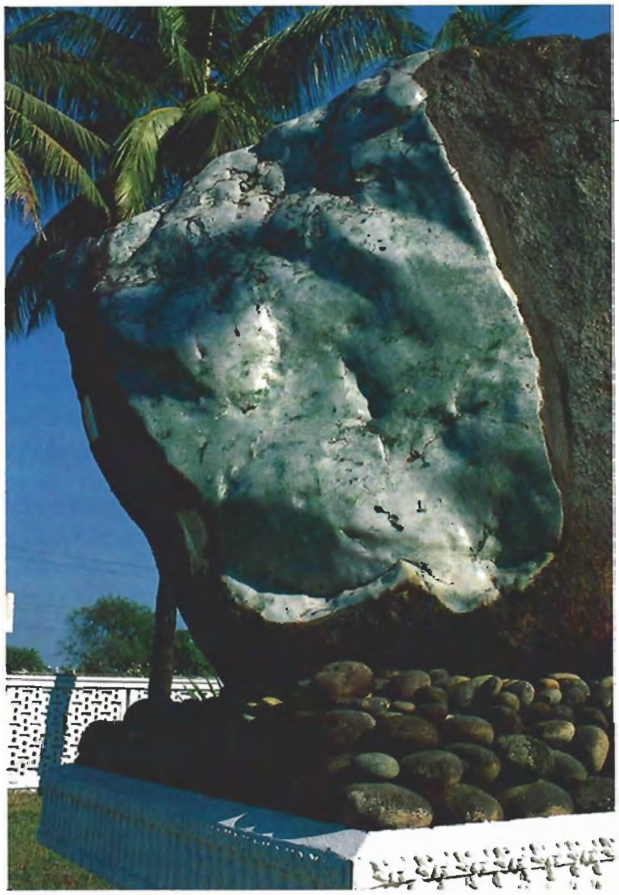


Figure 5. At approximately 33 metric tons, this is reportedly the largest jadeite boulder ever mined in Myanmar (Burma). Photo by Robert E. Kane.

for the fine-quality rubies and fancy sapphires found there. A recent mining summary report indicates that another southeast Asian nation—Laos—may also hold important gemstone potential.

According to *Mining Magazine*, both gem- and industrial-quality sapphires are currently being mined in Laos by a state mining enterprise, as well as by groups of individuals at Ban Houeixai in the country's northwest. There is speculation that additional potential exists on the Bolovens Plateau.

In addition, amethyst is presently mined from vugs and veins in rhyolites in Champasak Province. Zircon and topaz have been noted in this province as well, in alluvial deposits similar to those of the zircon-producing Kantharalak area of neighboring Thailand. Beryl has been identified in pegmatites running northwest along a strike from a known beryl-rich zone in northern Vietnam. (*Mining Magazine*, March 1992, p. 147)

Attractive meteorite jewelry. A report on an extraterrestrial form of olivine (peridot) recovered from pallasitic meteorites was published in the Spring 1992 issue of *Gems & Gemology*. This is not, however, the only "gem" material from a non-earthly source.

At the Tucson gem shows this past February, the editors came across a type of meteorite being set in jewelry (figure 6). According to Mark Castagnoli, president of Canadian Placer Gold Ltd. and the vendor of this material, this "Gibeon class" iron-nickel meteorite was recovered in Namibia. The fine octahedrite crystal structure, or "Widmanstatten" lines (a check-type intergrowth pattern) it displays, is characteristic of this particular material. Mr. Castagnoli informed us that the fashioned material, including the samples we examined, are usually etched with dilute nitric acid to expose the crystal structure.

Black mabe "pearls" and simulants (from nautilus shell). Mabe "pearls" are one of the more interesting assembled gem materials. First, blister pearls are cultured around hemispherical beads placed against the shell; they are then cut from the shell and the bead removed. A smaller spherical bead is inserted into the cavity along with a wax filler. Finally, a section of mother-of-pearl shell is added to form a slightly convex base. Perhaps the most unusual mabe assembled cultured blister pearls are the black mabes that are produced in the South Seas (figure 7).

At the February 1992 Tucson gem shows, we saw some assemblages made from iridescent shell that reminded us of mabe pearls (figure 8). One type, marketed as "Osmeña pearls" by Denis Brand of Gardena, California, was made from the curved innermost shell section of the chambered nautilus. The exposed, strongly iridescent layer of shell (the outermost white-and-brown layer has been polished away) has a delicate grayish blue body color. The larger shell portion is capped at the base with a very thin, flat section of shell, through which it could be seen that the

Figure 6. These 18-K gold cuff links are inlaid with "Gibeon class" iron-nickel meteorite from Namibia. Photo by Maha Smith.

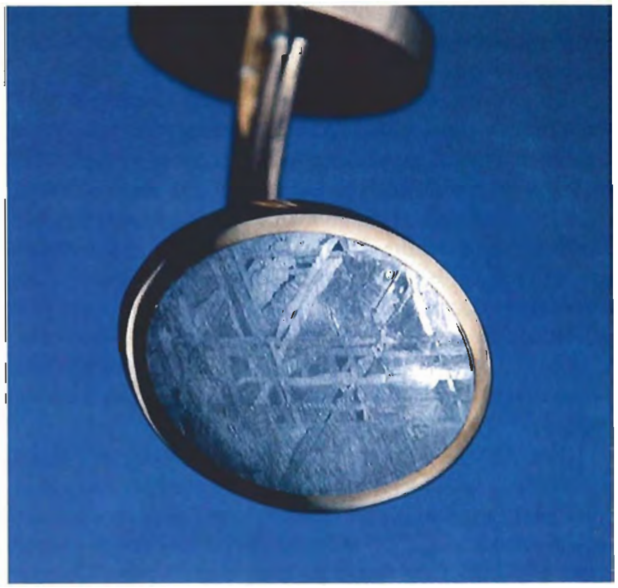


Figure 7. The fine black mabe assembled cultured blister pearls in these earrings measure approximately 14.6 × 12.8 mm; they are recent products of the Polynesian pearl culturing industry. Courtesy of Seung Hae Moon; photo by Maha Smith.

inner cavities were empty; that is, no wax or other filling material had been used. We saw similar assemblages, with creamy white body colors and strong iridescence, made from the curved turbo shell (again, the outer layer of shell had been polished away). "Osmenia pearls" were quite common several years ago; it is interesting to find them reappearing in the market.

Rare gemstones from Quebec. In October 1991, one of the editors (EF) visited the Mont St. Hilaire quarry near Montreal, Quebec. He was accompanied by Guy Langelier and Gilles Haineault, both of whom facet rare gems from this world-famous locality and provided information on the unusual gem species mined from Mont St. Hilaire.

Brownish red villiaumite sometimes exhibits two or three tones within a single gem and was seen in sizes up to about 5 ct, with larger pieces generally being quite dark. This material is very difficult to fashion, as it is water-soluble.

Carletonite, a mineral with a very saturated "royal" blue color, is also difficult to facet. It is relatively soft (Mohs hardness 4), cleavable, and strongly pleochroic. This pleochroism makes it necessary to orient the optic axis perpendicular to the table facet for good face-up color, although such orientation generally results in rather low weight retention. The largest faceted carletonite seen by Mr. Haineault is 1.48 ct.

Hackmanite, a variety of sodalite, is probably one of the most sought-after gems from this locality. Normally near colorless to light yellow, it typically turns pink on exposure to U.V. radiation, then fades within a few minutes (see pages 112-113 of the Summer 1989 Gem News). There is some variability in this reaction, however: Some stones barely change color on U.V. exposure, while others turn a deep pink that remains for some time after exposure to daylight. Mr. Haineault reports that the largest faceted hackmanite he has seen to date is a light yellow 15.33-ct shield cut.

Colorless natrolite crystals vary from completely transparent to somewhat hazy. Some larger crystals might yield faceted stones as large as 10 or 15 ct, although most stones cut to date have been under 5 ct.

Also seen were sphalerite gems, including a 55.62-ct oval of yellowish green ("olive") color. Some smaller, paler faceted stones resemble some yellowish green diamonds.

Among the other transparent faceted collector gems seen were colorless catapleiites, orange serandites, slightly violet albites, and colorless pectolites, all in sizes up to about 1 ct. Facet-quality burbankite, shortite, and cryolite are also found at Mont St. Hilaire. Finally, Mr. Langelier showed a rare 1-ct faceted, colorless vesuvianite from the Jeffrey mine.

Tajikistan to develop gem resources. Tajikistan, a former Soviet republic and now an independent central Asian state, is showing interest in developing its significant natural resources. The government has taken steps to encourage foreign investment in a number of basic industries, including mining, and is seeking outside help to identify commercially viable deposits. For the first time in decades, exploration by foreign firms is possible.

Gems and ornamental stones are among the resources receiving particular attention. A quarry near Pendjikent, in the far west of the republic, has been producing blocks of white marble since 1991 and is expected to yield material comparable to that from Carrara, Italy. Pink spinel is also being mined, as the Pamir Mountains lie in Tajikistan.

Figure 8. These shell assemblages, consisting of nautilus shell (the two on the left) and turbo shell (the two on the right), are somewhat reminiscent of mabe "pearls." The largest measures 28.50 × 17.22 × 9.84 mm. Photo by Maha Smith.

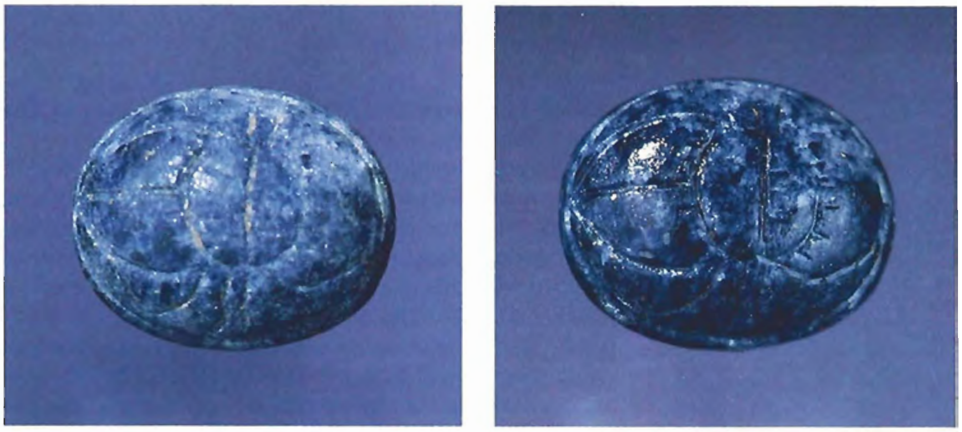


Figure 9. Application of a colorless, transparent acrylic spray to the otherwise dull surface of this 23.29-ct lapis lazuli cabochon (left, before treatment) caused a significant apparent improvement in its luster (right). Photos by Maha Smith.

Amethyst is being recovered near the city of Garm in the west-central region. Reportedly, significant mining of garnets has taken place, and ruby has been found that will soon reach world markets. Lapis lazuli, described as comparable to the finer grades from Afghanistan, has also been located in the Pamir Mountains, very close to the republic's border with Afghanistan. (*Mining Magazine*, January 1992, pp. 6-9)

ENHANCEMENTS

Acrylic coating of gem materials. It is well known that various surface coatings are used on gems to improve the apparent quality of their polish. Wax and paraffin are two substances reportedly used frequently, but plastic coatings have also been used on a number of gem materials (see, e.g., the entries on plastic-treated ammonite and enhanced Paua shell in Gem News, Spring 1991).

It was, therefore, with interest that the editors read a brief entry in a lapidary magazine in which the writer recommended two brands of aerosol sprays for enhancing the surface appearance of gems. One—a transparent, colorless acrylic spray—was subsequently purchased for experimentation.

One fashioned sample of lapis lazuli and one of jadeite (both with dull, worn surfaces) were chosen for the investigation. Each was given four separate light coatings with the acrylic spray, which resulted in significant improvement in apparent luster (figure 9).

When examined with magnification, the treated specimens appeared to have a somewhat unnatural, glassy appearance. Also noted was a slight concentration of the coating in surface irregularities, for example, in areas of undercutting and in carved recesses. The coating was easily scraped off the stones with a razor blade, and material so removed melted readily when tested with a thermal reaction tester. An acetone-dipped cotton swab rubbed across the base of one treated stone readily attacked and removed the coating, revealing the dull gemstone surface beneath.

Dyed massive beryl and quartz resembling ornamental gems. One of the editors (EF) was recently shown a new, enhanced gem product developed by Dominique Robert of Lausanne, Switzerland. The unnamed material consists of massive beryl with variable amounts of intergrown quartz; this composite is heat treated and then dyed purple to imitate such ornamental gem materials as charoite and sugilite. The heat treatment most likely increases porosity, which in turn permits deep penetration of the dye—to 0.5 mm or more, according to Mr. Robert. This was later confirmed when one of two rough specimens donated to GIA's permanent collection was fashioned into a cabochon (figure 10).

We subsequently learned that Mr. Robert was also producing this material in a "turquoise" blue and "coral" orangy red. All of the material is easy to identify from dye concentrations in fractures.

Figure 10. This cabochon (17.23 ct) and rough specimen (approximately 2.5 cm), which resemble charoite, consist of heat-treated and dyed massive intergrown beryl and quartz; the cabochon is primarily quartz while the unfashioned piece is predominantly beryl. White areas can be seen on the cabochon where the dyed surface layer was removed during fashioning. Photo by Robert Weldon.

Figure 11. This strand of beryl beads (6–7 mm in diameter) has been "color enhanced" by a combination of colored thread and dye concentrations in fractures and along the drill holes. Photo by Maha Smith.

Beryl beads with multiple color enhancements. Beads are commonly color enhanced in a number of ways. One of the simplest methods is to induce dye into fractures that were either pre-existing or intentionally induced by "quench crackling." Another technique is to coat the drill holes of pale beads with dye (e.g., a red dye for pink corundum beads so they will resemble ruby). Similarly, pale beads may be strung on a brightly colored thread.

This year at Tucson, the editors came across inexpensive strands of beads being sold as "aquamarine" that had their apparent color enhanced by both of the above methods (figure 11). Most obvious was the bright, slightly greenish blue thread on which the beads were strung. However, careful examination also revealed the presence of a greenish blue dye concentrated in surface-reaching fractures. We subsequently purchased a strand for investigation. Standard gemological testing on several beads confirmed that they were beryl. Examination of these beads with magnification revealed heavy concentrations of brightly colored dye lining the drill holes.

In an attempt to determine their true color, we soaked several beads for a few days in acetone, followed by a brief cleaning in an ultrasonic unit. After examination with magnification showed that most of the dye was removed from the fractures and drill holes, we restrung the beads on white thread. This revealed that, in addition to improving the apparent depth of color, the combination of dye and colored thread had helped to "homogenize" the color of the strand. The beads appeared much less well matched with the treatments removed, some beads being pale blue aquamarines while others were essentially colorless beryl (i.e., goshenite).

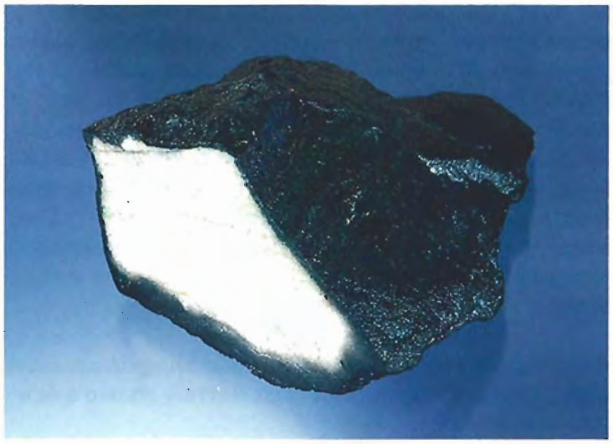
Treatable "concrete" opal. In the Fall 1990 Gem News, the editors reported on an opal material that apparently had been "sugar" treated and then coated with a plastic-like substance. This entry was subsequently expanded and published as an article in the February 1991 issue of *The Australian Gemmologist.*

As a follow-up, the editors were contacted by Paul B. Downing of Majestic Gems & Carvings, Tallahassee, Florida. Mr. Downing informed us that, over the past several years, a material has been found in quantity at Andamooka that is referred to locally as "concrete," or sandstone opal. This matrix opal differs from the traditional Andamooka matrix opal in that the newer material is much softer and more porous. Therefore, although "sugar" treated like the typical Andamooka material (see the excellent report on this method by Grahame Brown, in the Summer 1991 *Gems & Gemology*), it is then "toughened" with a plastic coating (figure 12). The product can be quite attractive, resembling the best Honduras matrix opal, with typical matrix patterns and the obvious black inclusions characteristic of sugar-treated material.

Silver-nitrate-treated matrix opal. A number of enhancements have been used on porous types of opal and opal-bearing rocks to produce a dark background for an otherwise weak play of color. In addition to the "sugar" treatment of Andamooka matrix opal mentioned above, there is also the "smoke treatment" of porous opal from Jalisco, Mexico, and the impregnation with black plastic of porous material from Brazil.

Recently, the editors learned of another treatment that produces a dark background for matrix opal, reminiscent of one used to produce black color in pearls. The "recipe" appeared in the August–December 1991 issue of *The Opal Express* and was provided by the Andria Bree Gem Co. of El Cajon, California. In this process, the stone is treated

Figure 12. This 1.20-ct specimen of "concrete" opal is a porous matrix-type of opal from Andamooka, Australia. The thin black layer represents a quick sugar-acid treatment carried out to determine how well the sample would respond. Specimen courtesy of Paul H. Downing; photo by Maha Smith.



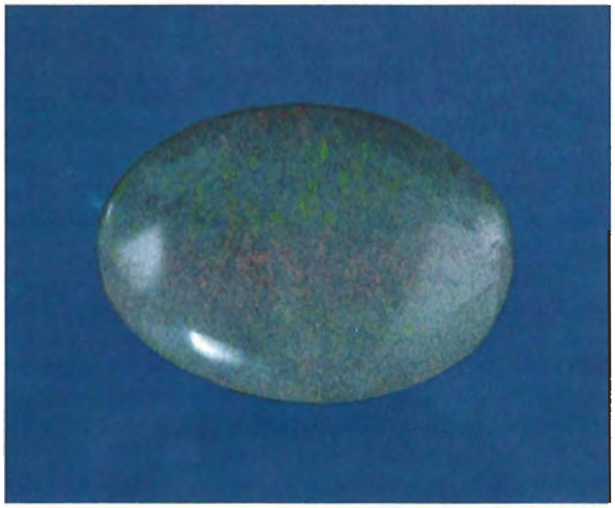


Figure 13. The dark background of this 5.00-ct matrix opal was produced by a silver-nitrate treatment. Photo by Maha Smith.

Figure 14. The 6.34-ct blue Egyptian turquoise cabochon on the right is untreated; the 9.04-ct green turquoise cabochon on the left, also from Egypt, was treated with mineral oil. Photo by Maha Smith.

after cutting but before final polishing. Following drying at low temperature, the matrix opal is gently heated in a silver-nitrate solution for several hours. The stone is then cleaned and heated in a solution of film developer, cleaned again, and given its final polish. An optional step—after the silver nitrate but before using the developer—is to place the stone in direct sunlight.

Tom and Phyllis Malicki of Benecia, California—opal enthusiasts who have first-hand experience with this treatment—provided the editors with a 5.00-ct oval cabochon of silver-nitrate-treated matrix opal (figure 13) and an untreated 9.53-ct specimen for comparison. The treated sample displays a medium-dark-gray background color that enhances the play of color. Magnification revealed dark, irregular specks reminiscent of sugar-treated material.

In an experiment conducted by the Gem News editors, an irregular piece of Andamooka matrix opal (provided by Paul Downing) was sawn in half; one section was retained as a control, while the other was treated in the silver-nitrate solution. The treatment produced a dark background color, as expected. Both treated and untreated sections were then examined using EDXRF, which revealed the presence of silver in the treated section and none in the untreated piece.

Modern-day turquoise oiling. The so-called "oiling" of emeralds is often justified by its supposedly ancient origins. Some in the international gem trade have even questioned the need to disclose the treatment on the same grounds of venerability.

In articles appearing in the July 1991 *Journal of Gemmology* and the October 1991 *Modern Jeweler*, however, Dr. Kurt Nassau reexamined the alleged antiquity of the treatment. He concluded that emerald oiling is probably less than 100 years old. Instead, it appears that the "oiling" mentioned in early texts involved the treatment of other gems to induce or improve a desired green color, for example, to turn blue turquoise green or improve the appearance of chalky malachite.

In Luxor, Egypt, in late 1991, one of the Gem News editors (RCK) learned of a modern-day turquoise treatment that appears to further justify Dr. Nassau's hypothesis. While looking through parcels of Egyptian turquoise at a Luxor gem shop, the editor was told that the predominantly blue material was preferred by many tourists, but that the local populace had a definite, long-standing preference for green material. The vendor then produced a plastic jar containing a viscous, colorless liquid and what appeared to be several hundred carats of turquoise cabochons.

The vendor described his turquoise treatment: First, mineral oil is boiled for approximately one hour and then allowed to return to room temperature. The turquoise to be treated—already fashioned—is placed in the "prepared" mineral oil and examined every day or so until the desired color change has occurred (normally one to two weeks). Finally, the stones are cleaned with denatured alcohol prior to sale. Figure 14 shows samples of Egyptian turquoise both before and after a one-week treatment.

SYNTHETICS AND SIMULANTS

Assembled imitation emerald crystal. The Summer 1989 Gem News column contained an entry on a clever imitation emerald crystal obtained in Brazil. The specimen was apparently produced by sawing in half a light-toned beryl crystal, coring out the two halves, filling the sections with a viscous green fluid, and reassembling them.

Recently, Thomas Chatham of Chatham Created Gems, San Francisco, California, loaned the editors the components of a similar imitation that had been disassembled. This particular simulant had been purchased in Bogotá, Colombia, by a Japanese buyer in 1991. The ruse was discovered when a cutter began to saw through the "crystal" near one of the terminations, causing a green fluid to leak from the stone.

This latest deceptive specimen consisted of a hollowed-out hexagonal prism that, even with the filling

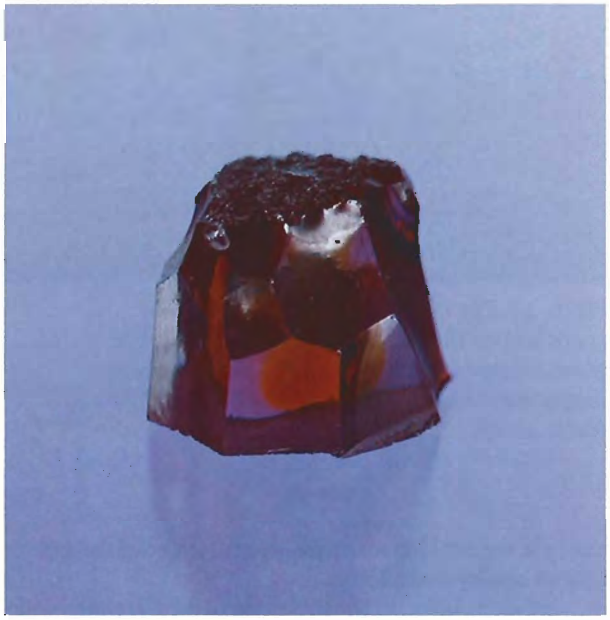


Figure 15. This 230.10-ct CZ displays interesting color zoning due to a combination of the dopants and growth conditions used. Photo by Maha Smith.

removed, appears medium-dark green. Examination under magnification, however, revealed the color to be due, at least partly, to a colored coating adhering to much of the internal cored surfaces; areas where the coating is absent appear nearly colorless. A second component of the assemblage is what appears to be a waterworn, elongated subhedral crystal, composed of (or coated with) a green substance. This component had been inserted in the hollowed-out cavity of the hexagonal prism. Although it could not be conclusively identified, its extremely low heft and very soft nature suggest a plastic.

The third component, the cap, is an assemblage of its own, consisting of a squat, soft, gray metal (lead?) plug covered with what appears to be a mixture of ground mineral matter in a polymer (?) groundmass that melted when the tip of a thermal reaction tester ("hot point") was applied gently.

Mr. Chatham informed us that this and other such deceptions are rumored to be produced in a "factory" in Bogotá. Among the other frauds reportedly produced there and seen by the editors are the glass imitation tourmaline crystal described below and two small hexagonal prisms with green surface coatings.

Update on nontransparent CZ. The Winter 1991 issue of *Gems & Gemology* included a report on nontransparent cubic zirconia from Russia. One gemological property not included in the report was refractive-index values, as conventional refractometers do not read above approximately 1.80.

Subsequently, the editors were contacted by Cornelius S. Hurlbut, Professor Emeritus of Mineralogy at Harvard University. Professor Hurlbut has been developing his own Brewster-angle refractometers and was interested in testing samples of the nontransparent CZs with his latest instrument. Samples used in the original study were therefore sent to him for testing.

Professor Hurlbut has since provided us with R.I. values for these Russian-produced materials: black, 2.140; pink, 2.160; and white, 2.165. Although readings on the latter two were taken on the slightly curved surfaces of cabochons, very consistent readings were obtained through approximately 50 tests on each type.

Bicolored CZ. As a further follow-up to the Winter 1991 *Gems & Gemology* report on nontransparent CZ from Russia, Joseph F. Wenckus, of the Ceres Corp., provided the editors with an interesting 230.10-ct CZ crystal section (figure 15) that has an orange core and a lavender periphery. According to Mr. Wenckus, the unusual bicolored effect is caused by the combination of dopants used—both cerium oxide (CeO_2) and neodymium oxide (Nd_2O_3)—and the conditions under which the crystal was grown—partially oxidizing. Reduced cerium oxide present in the core causes the orange color and masks the weaker color effect of the neodymium. Oxidized cerium oxide in the outer section of the crystal contributes no color, revealing the lavender hue caused by the neodymium dopant. It is possible that attractive color-zoned gems, reminiscent of amethyst-citrine ("ametrine"), could be cut from such a crystal.

Blue spinel from Vietnam as sapphire imitator. A number of incidents have been reported over the past year of synthetic rubies represented as natural rubies from Vietnam. A recent ICA Laboratory Alert, originating from the Hong Kong Gems Laboratory, reported that natural blue spinels from Vietnam have been represented as sapphires from that country. According to the report, the rough stones involved were quite large, in the range of 100–180 carats. Standard gemological testing carried out on one large specimen, first in the rough state and again after cutting, revealed properties consistent with those reported in the literature for spinel.

Glass imitation tourmaline crystal. Many simulants for Paraíba tourmaline—both rough and faceted—have been encountered in the gem trade (see, e.g., Gem News, Winter 1991). Recently, Thomas Chatham of Chatham Created Gems brought to the editors' attention another interesting tourmaline simulant. Purchased by a gem dealer in Bogotá, Colombia, the specimen weighs 49.81 ct and is a grayish blue color very similar to some indicolite tourmaline from Brazil (figure 16). In cross-section this "crystal" has the distinctive three-fold symmetry associated with tourmaline, and roughly parallel "striations" similar to those typical of tourmaline run the length of the specimen. Some of the more deeply recessed of the latter contained a reddish brown, earthy staining.

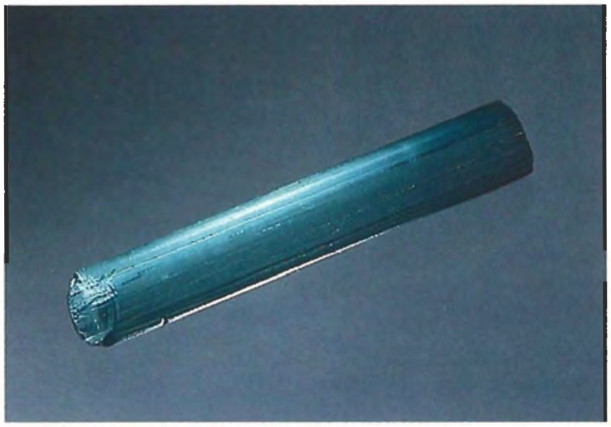


Figure 16. This 49.81-ct imitation of indicolite tourmaline was fabricated from glass. Specimen courtesy of Thomas Chatham. Photo by Maha Smith.

Although the long "crystal faces" have a dull luster that gives them a waterworn appearance, the two ends are vitreous, one consisting of a large conchoidal fracture. Through the latter it was possible with magnification to resolve a single spherical gas bubble. Other properties (spot R.I. 1.52, moderate heft, strong anomalous double refraction) were also consistent with those of glass.

More synthetics sold as natural rubies from Vietnam. In both the *Gems & Gemology* article on Vietnamese rubies (Fall 1991) and a subsequent Gem News entry (Winter 1991), we reported that flame-fusion synthetic rubies have been sold as natural stones in Vietnam.

Since then, other gem laboratories have reported a number of cases of similar deceptions in Vietnam and elsewhere. A March 27, 1992, update to the International Colored Gemstone Association's Laboratory Alert No. 22 contains a report from Dr. Grahame Brown of Allgem Services, Brisbane, Australia, on what outwardly resembled waterworn natural ruby crystals, but proved to be Verneuil synthetics.

In Dr. Brown's experience, as well as that of the Gem News editors and others, immersion can help reveal the curved growth associated with Verneuil synthetic rubies, especially when the exterior of a sample has been abraded to simulate the effects of alluvial transport. With this in mind, gemologists purchasing rough corundum should consider carrying an immersion cell, or other transparent container, to check for these diagnostic features.

Experimental synthetic sodalite from China. In late 1991, Professor Liu of the Institute of Geochemistry of the Academia Sinica in Guangzhou, China, donated to GIA a number of laboratory-grown materials produced in his country. These include synthetic quartzes (amethyst and citrine), flame-fusion synthetic corundums, synthetic cat's-eye alexandrite, synthetic spinel, green YAG, and various colors of CZ.

Perhaps the most interesting specimens, however, were three samples of synthetic sodalite that ranged in weight from 20.38 to 57.39 ct. Professor Liu reported that the samples, which were heavily included and twinned, were produced experimentally, with research ongoing to improve the quality. As grown, the synthetic sodalite is colorless; it is subsequently irradiated to produce an attractive blue color (figure 17).

Figure 17. This 20.38-ct synthetic sodalite crystal was produced in China. Photo by Robert Weldon.

INSTRUMENTATION

Low-cost quartz wedge simulator. Determining whether a gem is uniaxial or biaxial can help distinguish among anisotropic gems with similar refractive indices and birefringence, such as transparent yellow labradorite feldspar and golden beryl. This can be done by plotting refractometer readings or by resolving an interference optic figure between crossed polars. Occasionally, a gemologist will also need to determine whether a gem is positive or negative in optic sign—to separate, for example, quartz (uniaxial positive) from scapolite (uniaxial negative). This, too, is most commonly done by plotting readings from the refractometer, provided there is an appropriate facet to test.

Another method, more familiar to mineralogists than to gemologists, is to use a quartz wedge in conjunction with a polariscope and condensing lens. Unfortunately, quartz wedges are rather costly and difficult to obtain; in practice, few gemologists use them. Hanneman Gemological Instruments of Castro Valley, California, now offers a low-cost alternative. Called the Hanneman-Daly Wavelength Modifier & Quartz Wedge Simulator, this accessory is used in essentially the same manner as a quartz wedge. Those familiar with the quartz wedge should have little difficulty working with the Hanneman product.

LETTERS

GREEN ZOISITE, *NOT* GREEN TANZANITE

Once again I am pleased to congratulate you on the latest issue (Spring 1992) of *Gems & Gemology*, and on the excellent and highly informative articles it contains.

Of the two articles (the one on green zoisite, and the one on peridot by J. R. Fuhrbach) that particularly caught my interest, the one on Gem-Quality Green Zoisite by N. R. Barot and Edward W. Boehm attracted my special attention, not only because I know the deposit, which I visited on previous occasions, but also because I have always felt a particular attraction toward the variety of zoisite used in the gem trade, blue tanzanite. To the attentive reader it becomes easily apparent that the two authors were keen to be correct and accurate in every statement and that they endeavored to publish a paper reliable in every respect. They have certainly succeeded and are to be congratulated on their paper. It is a classical study in the true sense of the word.

Unfortunately, the authors were somewhat too lenient with regard to the nomenclature in that, despite the correct title, they referred to "green tanzanite" throughout the entire article. Tanzanite is the name exclusively given by Mr. Platt of Tiffany's to the blue variety of zoisite. Other color varieties of the zoisite species also have their individual variety names. Thus, opaque pink zoisite is called thulite and the green opaque variety is named anyolite, which together with hornblende forms the mother rock of the rubies found at Longido, Tanzania. To be gemologically, mineralogically, and scientifically correct, the new green transparent variety must either be called green zoisite or be given an entirely new variety name. It must be considered that transparent blue and green are not the only color varieties of the mineral species zoisite; since pink, purple, yellow, and mixed colors are also found. To give extra names to each color variety would make nomenclature extremely complicated. Consequently, it would be most feasible, practical and logical to use the species name *zoisite* with the color prefix. The already named varieties tanzanite for the transparent blue, thulite for the opaque pink, and anyolite for the opaque green zoisite may nevertheless be maintained.

To summarize, I wish to suggest that the new transparent green variety of zoisite be in the future called green zoisite, which is mineralogically and gemologically correct and helps to avoid any confusion.

E. GÜBELIN, Ph.D., G.G., F.G.A.
Lucerne, Switzerland

MORE ON ALCOHOL DAMAGE TO AMBER

The photograph of alcohol-damaged amber beads in the Gem Trade Lab Notes section of the Summer 1991 *Gems & Gemology* (p. 108) reminded me of an event that occurred five years ago when a group of local metalsmiths gathered in the jewelry lab at Ohio State University to prepare an exhibit. After polishing a silver ring set with amber beads, I used soap to remove the polishing compound and then followed with a drying rinse in denatured alcohol. A number of the beads were damaged, and it took hours of scraping, filing, and sanding to remove the hazed subsurface areas.

The late Ann Rudolph, who was watching this process, remarked that "all the literature" mentions that alcohol will damage amber and I should have known better. The next day, she delivered copies of three publications to support her claim. The *Physical Properties and Geological Occurrence of Amber* (Leaflet Number 3, Field Museum of Natural History, Department of Geology, Chicago, 1923) states that amber "is attacked but slowly by alcohol, ether, and similar solvents, a property by which it may be distinguished from most modern gums and some other fossil ones." In the appendix to her *Amber: The Golden Gem of the Ages* (Van Nostrand Reinhold, 1980, p. 289), Patty C. Rice warns: "do not allow amber to come in contact with perfume or hair spray." Finally, in her book *Amber* (Butterworths Gem Books, London, 1987, p. 176), Helen Fraquet advises that: "On a basic level, perfumes and hair sprays will damage the surface of amber jewellery over a period of time. The surface will become dull and opaque, and the items will need repolishing."

Thanks to Ann Rudolph, here is a start to literature references on alcohol's effect on amber.

WILLIAM A. WEIDINGER
Goldsmith, Jewelry Designer
Columbus, Ohio

ERRATUM

The name of the designer of the pendant and earrings published on page 29 of the Spring 1992 issue was misspelled. The correct name is Paula Crevoshay. Note also that the Mexican opals in these pieces were cut by George Crevoshay, while the rutilated quartz was carved by Michael Dyber.