Gems & Gemology

VOLUME XXIV

WINTER 1988

The quarterly journal of the Gemological Institute of America

WINTER 1988
Volume 24 Number 4

Gems & Gemology

TABLE OF CONTENTS

ABOUT THE COVER: Fine rubellite is among the most sought-after of colored stones. These intense rubellites (ring 13.8 ct; necklace 18.5 ct) are from the Queen Mine, San Diego County, CA. In recent years, irradiation has been used to try to reproduce such hues in lighter colored tourmalines. The irradiation of tourmaline, blue topaz, and many other gem materials is the subject of the article by Charles Ashbaugh in this issue. Jewelry designed by Jeanne Larson; courtesy of The Collector, La Jolla and Fallbrook, CA.

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

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

ISSN 0016-626X

Gems & Gemology

EDITORIAL STAFF

Editor-in-Chief
Richard T. Liddicoat

Associate Editors
Peter C. Keller
D. Vincent Manson
John Sinkankas

Technical Editor
Carol M. Stockton

Editorial Assistant
Nancy K. Hays

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

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

Editor, Gem Trade Lab Notes
C. W. Fryer

Editor, Gemological Abstracts
Dona M. Dirlam

Editor, Book Reviews
Elise B. Misiorowski

Contributing Editor, John I. Koivula

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

PRODUCTION STAFF

Jennifer Brosious
Linda Manion
Susan Kingsbury
Julie Matz
Patricia Mayer
Robin Teraoka
Ruth Patchick
Peter Johnston

SUBSCRIPTIONS

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

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

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

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

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

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

MANUSCRIPT SUBMISSIONS

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

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

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

THE RADIOACTIVITY ISSUE

In the early 1980s, *Gems & Gemology* published two articles on radioactivity in gemstones: "Irradiated Topaz and Radioactivity," by R. Crowningshield (Winter 1981) and "Radioactive Irradiated Spodumene," by G. Rossman and Y. Qiu (Summer 1982). Both were primarily concerned with stones that had been irradiated in nuclear reactors in Brazil and released while they were still highly radioactive. In recent years, gemstone irradiation has become more prevalent and widespread, with a number of facilities active in the U.S. as well as in Brazil, Europe, and Southeast Asia. According to the American Gem Trade Association, 30 million carats of blue topaz are now being irradiated annually worldwide, 40% of these in the U.S. alone.

The issue of irradiation and radioactivity, however, is very complex. The issue of whether some radioactive gemstones pose any health problems is in some respects even more complex, because gems are worn outside the body, usually in contact with relatively small areas of the skin, and for greatly varying periods of time. The article by Charles Ashbaugh attempts to explain, in basic terms, the variables involved in these issues. This article represents Mr. Ashbaugh's personal opinion regarding current regulation of irradiated gemstones in the United States, and not necessarily GIA's. However, we do applaud the Nuclear Regulatory Commission's recent efforts to license this area and hope that these efforts will conclude with fair licensing procedures and the establishment of reasonable radiation levels given the potential health hazards involved.

This issue also contains the eighth annual *Gems & Gemology* Most Valuable Article ballot. I urge you to review the four 1988 issues and vote for the articles that you found most useful to your activities and interests. Not only does your vote help us reward the hundreds of hours invested by many authors to provide these contributions, but it also tells us what types of articles you, our readers, most want to read. Please, take this opportunity and *vote.* We look forward to hearing from you.

Richard T. Liddicoat
Editor-in-Chief

GEMSTONE IRRADIATION AND RADIOACTIVITY

By Charles E. Ashbaugh III

With the increasing use of radiation to color enhance gemstones, the issue of radioactivity has become a source of concern for gemologists worldwide. This article examines the basic characteristics of radiation and radioactivity, the sources of radiation in the earth and in the laboratory, the radiation treatment of gemstones in particular, and the detection and measurement of radiation. Also included is a discussion of potential health hazards and current government regulations regarding gemstone radioactivity.

> "Nothing in life needs to be feared. It only needs to be understood."—Marie Curie, discoverer of radium and the recipient of two Nobel prizes.

Exposure to radiation, either from natural or man-made sources, will enhance the color and beauty of many different gemstones. The use of man-made sources of radiation to treat gem materials was experimented with soon after radiation was discovered, almost 100 years ago. In recent years, gemstone irradiation has become a common practice, as evidenced by the literally millions of carats of irradiated blue topaz, and increasing amounts of dark pink tourmaline, yellow beryl, red zircon, and colored diamonds, encountered in the marketplace (figure 1).

Accurate information on gemstone treatments, however, is difficult to obtain. Individuals involved in commercial gemstone irradiation are reluctant to reveal details of their treatment processes, which they consider to be proprietary information. Also, the general subject of radiation itself is rather technical and complicated. At the same time, government policy on the handling and distribution of radioactive irradiated gems to the general public is still being slowly and very cautiously formulated. Finally, only relatively recently have some irradiated gemstones been examined in detail to understand better the changes produced by such treatments. This article reviews the nature of radiation and its various sources, both natural and man-made, as well as the laboratory irradiation of gemstones. Also covered are the issues of radioactivity, its detection and measurement, and current pertinent government guidelines. While there is no question that some gemstones continue to be radioactive after treatment (and, in some cases, after simply being taken from the ground), only in very rare instances would these gems pose any health hazard.

ABOUT THE AUTHOR

Mr. Ashbaugh is a lecturer and facilities supervisor for the Nuclear Energy Laboratory at the University of California, Los Angeles (UCLA), and president of Nuclear Theory & Technologies, a consulting company.

Acknowledgments: The author wishes to thank the following for their assistance and critical evaluation of this article: Dr. Kurt Nassau of AT&T Bell Labs; Dr. Karl Bernstein of Trintec; Dr. Junaid Razvi and Dr. William Whittemore of General Atomics; Dr. Robert Block of the Rensselaer Polytechnic Institute; Anthony Zane and other colleagues at UCLA; George Drake of CN&L Investment Corp.; Charles Key; and especially Dr. Emmanuel Fritsch and Dr. James Shigley of GIA. Ruth Patchick was invaluable for typing the many drafts.

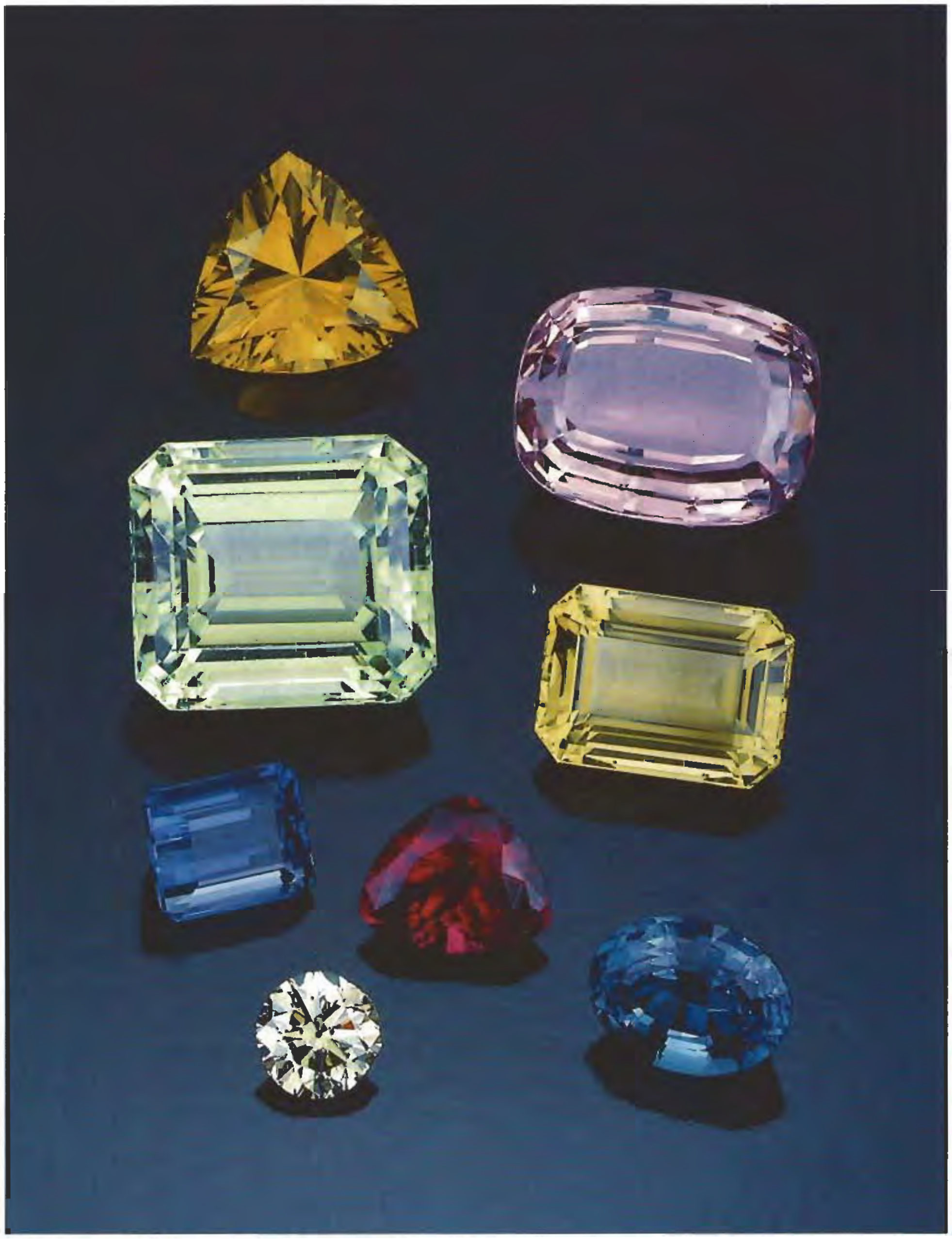


Figure 1. A variety of gems are now being irradiated for color enhancement. Illustrated here are (clockwise from top right) irradiated kunzite, citrine, blue topaz, rubellite, diamond, Maxixe beryl, green spodumene, and yellow beryl. The largest stone, the green spodumene, is 48.68 ct. Stones courtesy of George Drake and the GIA collection. Photo © Tino Hammid.

NATURE OF RADIATION

Radiation can be simply defined as energy emitted in the form of particles or electromagnetic waves. It is given off by a variety of sources. For example, an ordinary light bulb, a fire, and a disintegrating radioactive atom all give off energy as some form of radiation. However, only a particular type or class of radiation, known as ionizing radiation, has enough energy to disrupt and dislodge electrons and sometimes atoms within a gem crystal. As the ionizing radiation passes through, it imparts this energy to the crystal, thereby creating color centers (see Nassau, 1983; Fritsch and Rossman, 1988.)

During the decay of radioactive atoms or nuclides, one or more of four basic types of ionizing radiation are released:

Alpha particles: High-speed helium atoms without any electrons.

Beta particles: High-speed electrons.

Gamma rays: High-energy photons of electromagnetic radiation identical to X-rays. (X-rays originate from electrons and are nor-

UNITS OF MEASUREMENT

Becquerel (Bq): Radioactive content of a material equal to one nuclear disintegration or transformation per second.

Curie (Ci): Radioactive content of a material (originally defined as the amount of radioactivity in one gram of radium-226) equal to 37 billion Bq.

1 nanocurie (nCi) = 1 billionth of a curie = 37 Bq; 1 Bq = 0.027 nCi

Roentgen (R): Unit of exposure that defines the ability of radiation to ionize air (i.e., remove electrons from atoms and molecules). It is the quantity of X-ray or gamma-ray radiation able to produce 2.580 × 10^{-4} coulombs of charge in one kilogram of dry air (1 coulomb = 6.24 × 10^{18} [billion-billion] electrons worth of charge). 1 microroentgen (μr) = 1 millionth of a roentgen.

Rad (Radiation Absorbed Dose): Unit of absorbed dose. The quantity of radiation able to deposit 100 ergs of energy into a gram of any material. This unit is independent of the type and energy of the radiation. (An erg is a unit of energy equivalent to a force of one dyne [force able to accelerate a one gram object 1 cm per second per second] moving 1 cm.)

1 Mrad = 1 million rads
SI unit: Gray (Gy); 1 Gy = 100 rad

Rem (Roentgen Equivalent Man): Unit of biological radiation dose equivalent that places on a common scale the biological damage produced by ionizating radiation. A rem equals a rad multiplied by a quality factor that varies between 1 and 20 depending on the type and energy of the radiation.

1 mrem = 1 thousandth of a rem
SI unit: Sievert (Sv); 1 Sv = 100 rem

A simple analogy may help to explain these terms. Imagine going to the beach on a sunny day. Becquerels or curies would represent the total photon or light output of the sun, roentgens would relate to the amount of ultraviolet sunlight at the beach, rads would correspond to the energy absorbed by the sunbather's skin, and rems would be a measure of the amount of tan (or sunburn) produced. For beta and gamma radiation, the roentgen, rad, and rem are relatively equivalent radiation exposure and dosage units.

mally lower in energy, while gamma rays originate from the nucleus and are generally higher in energy.)

Neutrons: Neutral subatomic particles that are rarely found outside the nucleus of an atom and have a weight about the same as that of a simple hydrogen atom.

A *nuclide* is a type of atom that is defined by the number of protons and neutrons in the nucleus. There are roughly 1,400 different nuclides known to date. Radiation energy is described in units of electron volts (eV), which is the energy or energy equivalent of a subatomic particle that has been accelerated through an electric potential of one volt: 1 KeV = 1 thousand eV, 1 MeV = 1 million eV. Several terms are used to quantify radioactivity and radiation effects—*becquerel, curie, roentgen, rad,* and *rem* (see box). Because SI units (International System of Units) are also used in the literature, although not in this article, these equivalents are provided as well.

With respect to the possible health hazards of radioactive gemstones, we have to be concerned only with gamma radiation. Alpha radiation is essentially nonpenetrating and can be stopped by a piece of paper, while neutron radiation is virtually nonexistent outside neutron-producing devices. Beta particles are mostly absorbed within the gemstone itself, and what does exit the gemstone is weak and produces only a shallow, relatively harmless skin dose. Generally, only gamma radiation has the potential to affect those who wear or otherwise come into contact with a radioactive gem.

RADIATION IN NATURE

We exist in a "sea" of natural background radiation. This radiation originates from the decay of radioactive elements such as uranium, thorium, and the nuclide potassium-40 that are naturally present in the earth's crust; from cosmic radiation; from radon gas in our homes; and so on. Natural radioactivity is exhibited by more than 50 naturally occurring radioactive nuclides (Villforth and Shultz, 1970). Consequently, low levels of radiation are always found in the air, water, and ground. However, only terrestrial background radiation is relevant to the coloration of natural gemstones.

Terrestrial Background Radiation. Uranium-238 (U-238), thorium-232 (Th-232), and potassium-40

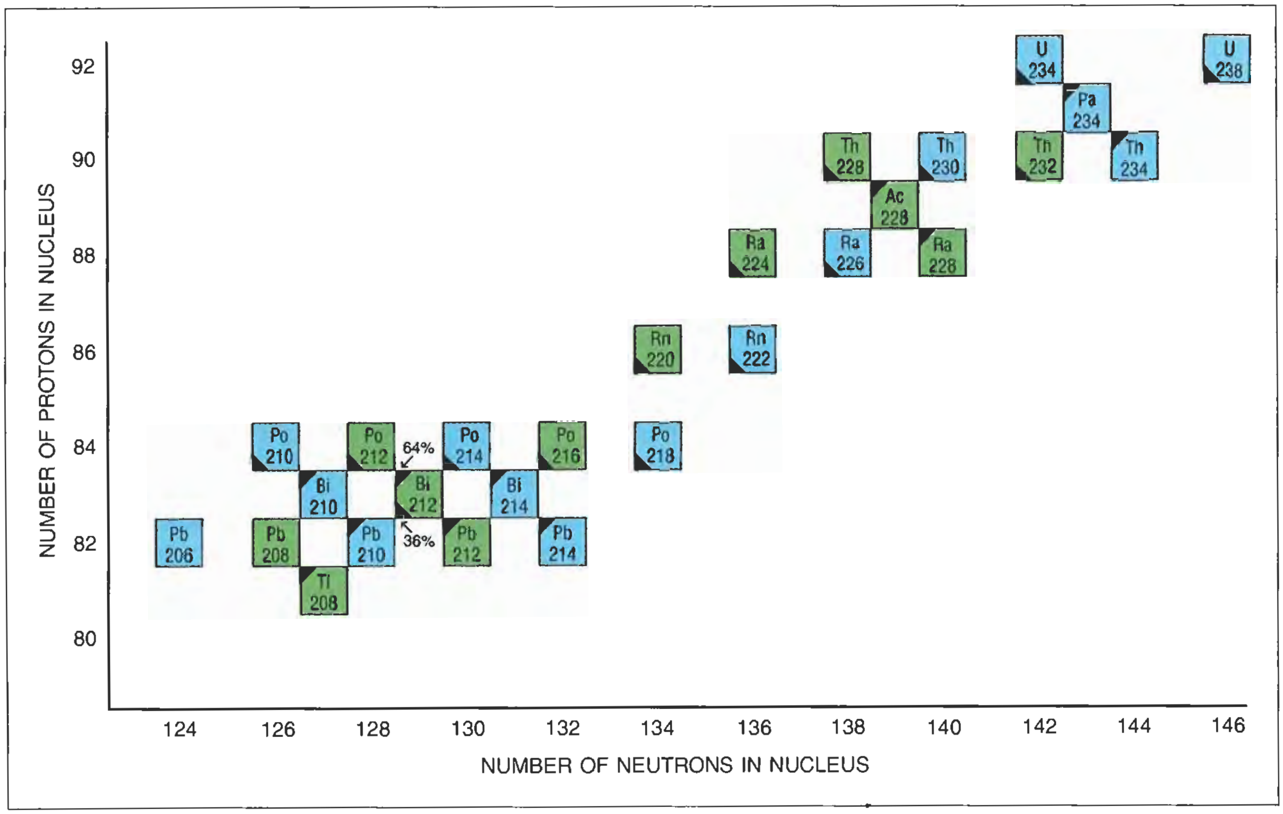


Figure 2. The decay chains of uranium-238 and thorium-232 show the major alpha and beta decays (as indicated by the black corner arrows) from parent to stable lead. Gamma emission is relatively weak for all nuclides except Pb-214, Bi-214, Ac-228, and Tl-208.

(K-40) are the three major radioactive nuclides found in the earth's crust. Ever since their origin inside exploding stars (long before their incorporation into primordial earth), these nuclides have undergone continuous radioactive decay or spontaneous disintegrations. In doing so, they constantly give off alpha, beta, and gamma radiation. Any radioactive atom or nuclide decays by the emission of radioactive particles or rays in a specific sequence of steps. At each step, a particular new type of atom or nuclide is formed until one is created that is not radioactive and does not decay any further. The length of time for one-half of a group of atoms of a particular type to decay into another type is called the half-life. Each nuclide has a specific half-life which can vary from much less than a second to as long as billions of years.

Over 99% of natural uranium is composed of the nuclide U-238, while nearly 100% of natural thorium is Th-232. These nuclides are referred to as "parents"; they decay by the emission of alpha particles which lead to a sequence of a dozen or so radioactive decay products called "daughters." These two radioactive decay sequences release many alpha, beta, and gamma rays before U-238 and Th-232 arrive at their respective nonradioactive daughter isotopes of lead (figure 2). For example, U-238 decays by alpha emission to Th-234, then Th-234 decays by beta emission to protactinium-234 (Pa-234), and so on.

Potassium-40 comprises about one-hundredth of one percent of natural potassium (which is much more abundant in nature than uranium and thorium). This nuclide decays by the emission of a beta particle followed, 10% of the time, by a high-energy gamma ray. The result is the stable, nonradioactive daughter calcium-40.

Naturally Radioactive Gems. Uranium, thorium, and potassium occur in many minerals and gemstones (Fleischer, 1986). When uranium and thorium are present, enough time has usually elapsed since the material crystallized that radioactive equilibrium has been established between parents and daughters. For example, if a gemstone contains 1 nCi/gm of U-238, it also contains 1 nCi/gm of each of its 13 radioactive daughters. For both uranium and thorium, though, only a couple of the daughters produce the bulk of the energetic beta and gamma radiation.

Potassium is found in many gem materials, including feldspars such as orthoclase and labradorite. Since the nuclide K-40 has such a long half-life and makes up such a small percentage of the natural element potassium, gemstones containing potassium rarely contain more than about 0.1 nCi/gm of K-40. (Pure potassium contains only 0.855 nCi/gm of radioactivity.)

TABLE 1. Naturally radioactive gem materials.[a]

Gemstone	Nuclide	Concentration[b] (nCi/gm)
Zircon[c]	U-238	
red, yellow, blue		0.03 to 0.3
green		0.5 to 2.1
Ekanite[d]	Th-232/U-238	26/6.5
Euxenite	U-238	29
Fergusonite	U-238/Th-232	40/3
Thorianite	Th-232/U-238	87/19

[a] *Measured by the author.*

[b] *The legal release limit for manufactured items containing uranium is 0.168 nCi/gm and thorium, 0.055 nCi/gm. Because the radioactivity is naturally occurring, such gemstones are not subject to any form of regulation.*

[c] *Sometimes includes trace amounts of Th-232 and daughters. Similar values were reported by Müllenmeister (1986).*

[d] *Similar values were reported by Perrault and Szymanski (1982); see also Fryer et al. (1986).*

Although U-238, Th-232, and K-40 generally occur as minor trace elements, they may be present in rather high concentrations. Table 1 lists various naturally radioactive gem materials in increasing order of radioactivity; most exceed the legal U.S. release limits for manufactured items containing uranium (0.168 nCi/gm) and thorium (0.055 nCi/gm). Although the emerald-cut thorianite is primarily a rare collector's item, it does illustrate just how radioactive natural gemstones can be (in this case, more than 1,500 times the stated legal limit for manufactured goods containing uranium). GIA has examined gemstones of similar radioactive content in the recent past (Editorial Forum, 1987). The author measured all of the zircons in figure 3 and found them to be radioactive.

Figure 3. Many gemstones are naturally radioactive. In fact, radioactivity was measured in all of the zircons illustrated here (the largest is 4.77 ct). Photo © Tino Hammid.

Naturally Irradiated Gemstones. Terrestrial background radiation in the host rocks of a gem deposit can alter the color of the gem material if the radiation dose is high enough and the ambient temperature low enough. That is, the gem material must be in close proximity to a sufficient amount of radioactive nuclides for a long enough time and at a temperature that will not anneal or bleach out the radiation-induced color.

For example, tourmalines from gem pegmatites become pink or red from exposure to high-energy (1.46 MeV) gamma rays from K-40 over periods of millions of years (Reinitz and Rossman, 1988). The natural blue color of some topaz is thought to be produced by natural irradiation, as is the deep blue color of Maxixe beryl and some fluorites (Rossman, 1981). Surface coloration of yellow and yellow-green diamonds has also been attributed to natural radioactivity (Dugdale, 1953). The presence of radiation from uranium produces the color centers responsible for red in zircons (Fielding, 1970). The color of blue-green amazonite is also radiation induced (Hofmeister and Rossman, 1985). In addition, radioactive solutions in gem deposits can produce color, as in smoky quartz (Koivula, 1986). Although this list is not exhaustive, it does show the magnitude of gemstone coloration by natural radiation. As research progresses, more gemstones may prove to owe their color and beauty to natural terrestrial background radiation.

GEMSTONE IRRADIATION IN THE LABORATORY

It was not long after natural "radioactivity" was discovered by A. Henri Becquerel in 1896, and the term coined by Marie Curie in 1898, that gemstones began to be treated with radiation. Published reports of diamond coloration by radium treatment appeared as early as 1909 (Crookes, 1909). Today, a wide variety of gems are color enhanced by laboratory irradiation (table 2), including many fancy-color diamonds (figures 4 and 5).

Radiation produced in the laboratory is often more efficient in the coloration of gem materials than natural terrestrial background radiation. The higher radiation energy and doses obtainable can produce more desirable coloration, and the temperature conditions can be controlled so that the induced colors are not annealed during the process. Currently, three major types of laboratory radiation sources are used to irradiate gemstones: cobalt-60 facilities, which produce gamma radiation; linear accelerators, which generate high-energy electrons; and nuclear reactors, which produce high-energy neutrons.

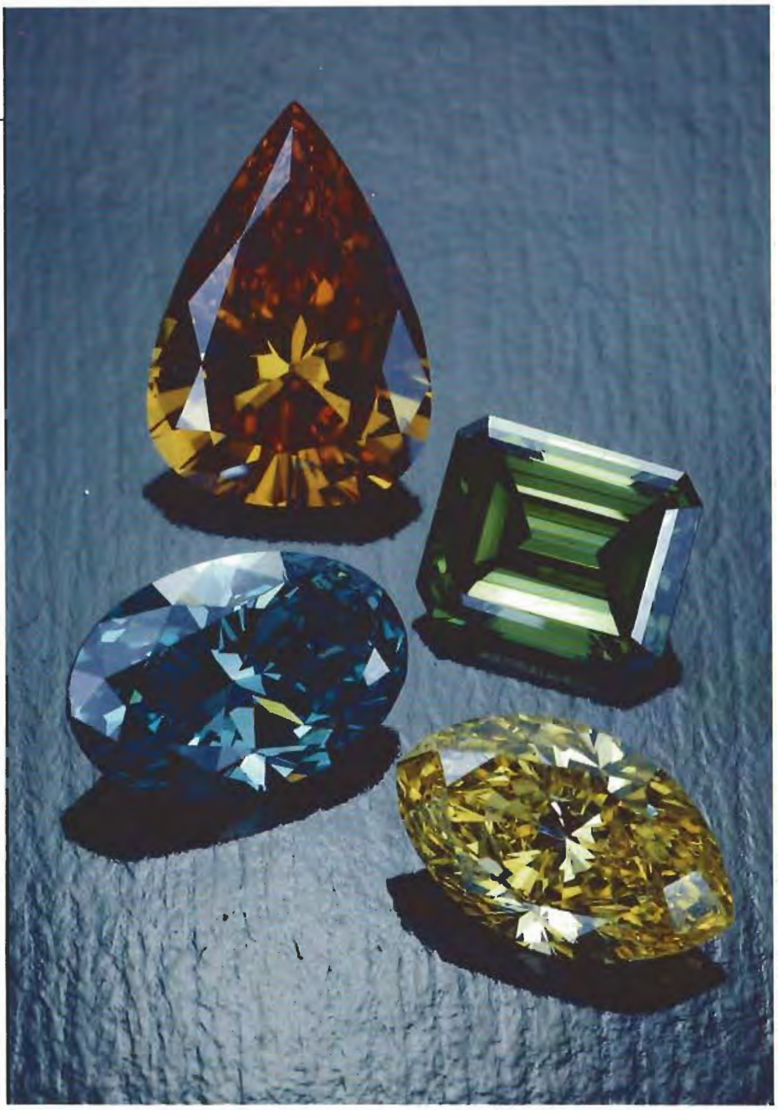


Figure 4. Diamonds were the first gemstones to be irradiated. Today, irradiation produces a variety of fancy colors in diamond, of which these are only a few. Stones courtesy of Theodore and Irwin Moed; photo © Tino Hammid.

TABLE 2. Effects of irradiation treatment on various gem materials.[a]

Material	Starting color	Ending color
Beryl	Colorless Blue	Yellow Green
Maxixe-type	Pale or colorless	Blue
Corundum	Colorless Pink	Yellow Padparadscha
Diamond	Colorless or pale to yellow and brown	Green or blue (with heating, turns yellow, orange, brown, pink, red)
Fluorite	Colorless	Various colors
Pearl	Light colors	Gray, brown, "blue," "black"
Quartz	Colorless to yellow or pale green	Brown, amethyst, "smoky," rose
Scapolite[b]	Colorless, "straw," pink, or light blue	Blue, lavender, amethyst, red
Spodumene	Colorless to pink	Orange, yellow, green, pink[c]
Topaz	Yellow, orange	Intensify colors
	Colorless, pale blue	Brown, blue (may require heat to turn blue), green
Tourmaline	Colorless to pale colors	Yellow, brown, pink, red, bicolor green-red
	Blue	Purple
Zircon	Colorless	Brown to red

[a] *Adapted from Nassau (1984).*
[b] *Charles Key, pers. comm., 1988.*
[c] *George Drake, pers. comm., 1988.*

Gamma-Ray Facilities. A typical gamma-ray facility (figure 6) is essentially a heavily shielded concrete room that contains up to several million curies of cobalt-60 (Co-60). The radioactive material is first encapsulated and then sealed inside hundreds of small stainless steel rods called pencils, which are grouped together to form modules (Wallace Hall, pers. comm., 1988). During irradia-

Figure 5. Irradiated diamonds are increasingly seen in fine jewelry. An example is the fancy-color irradiated pear-shaped diamond in this attractive geometric necklace that was recently sold at auction. Photo by Tino Hammid; courtesy of Christie's New York.

tions, the cobalt sources are raised up out of the shielding water to expose the subject material to the gamma rays.

During radioactive decay, Co-60 releases a beta particle and two gamma rays, with energies of 1.17 and 1.33 MeV respectively, in quick succession. The beta particles from the Co-60 do not contribute to the radiation dose since they are completely absorbed within the pencils. This type of facility can achieve gamma-ray dose rates as high as several Mrads per hour.

Many types of gemstones are currently irradiated with gamma rays to produce or improve their color. Colorless quartz is irradiated to produce smoky quartz. Iron-containing quartz is irradiated to produce amethyst and then heat treated to produce citrine (Rossman, 1981). Light pink tourmalines are irradiated to a couple hundred Mrads (Camargo and Isotani, 1988) to produce dark pink to red stones (figure 7). Gamma irradiation is also used to increase the color saturation of red zircons (Mike Gray, pers. comm., 1987). Near-colorless topaz is irradiated to several hundred Mrads and higher to produce a light blue color, called "Cobalt Blue" in the trade, and to even higher doses for a steely gray-blue color. Gamma irradiation is sometimes also used to screen out unwanted material such as beryl or quartz, or to prescreen topaz for subsequent treatments, since material that turns light blue under these conditions is likely to become much darker blue with additional radiation exposure from high-energy electrons.

Linear Accelerators. A linear accelerator, or "linac" (figure 8), is an electron "gun" that fires a pulsed beam of electrons at energies of 10 to 15 MeV and at a current of several hundred microamperes, producing dose rates to gemstones up to and exceeding several hundred Mrads per hour. At these dose rates, the gem materials must be water cooled to prevent elevated temperatures and ther-

Figure 6. This view down into a gamma-ray facility shows the many modules positioned on two racks held by steel cables that have been lowered into the storage pool. During irradiations, the racks are raised up out of the shielding water. Photo courtesy of Radiation Sterilizers, Tustin, CA, and Pirih Productions, Pasadena, CA.

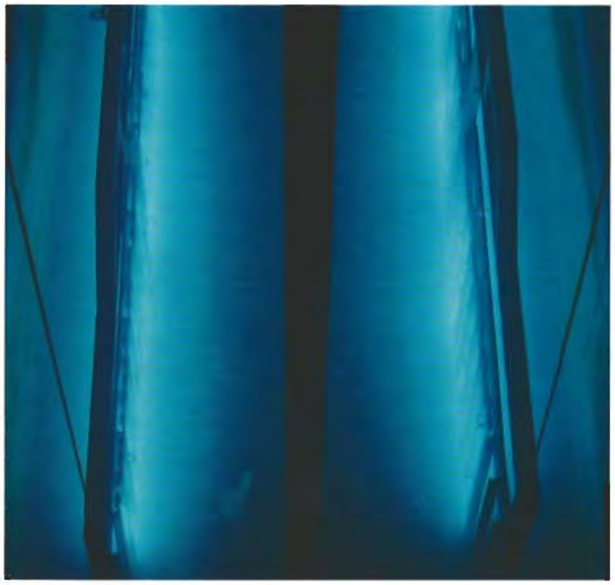


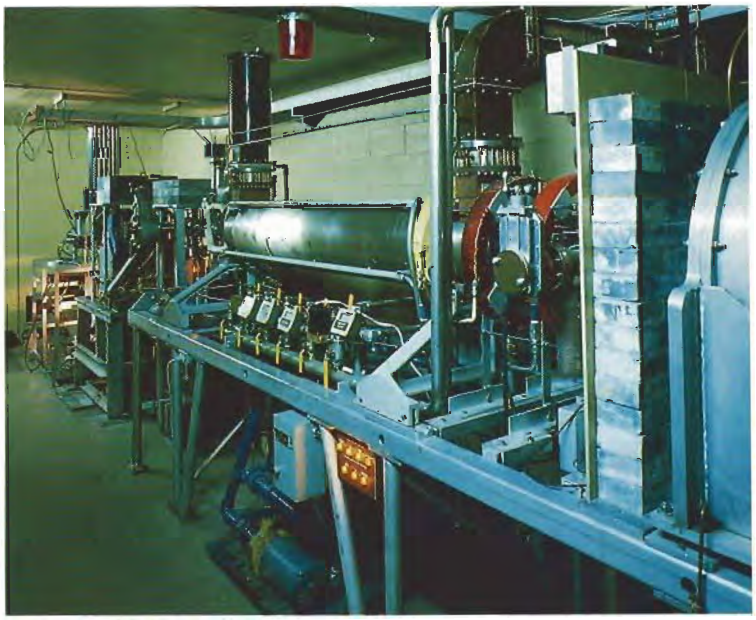
Figure 7. Today, pale colored tourmalines similar to those on the left are commonly irradiated with gamma rays to produce darker stones, like the irradiated tourmalines on the right (the largest is 5.91 ct). Stones courtesy of George Drake and the GIA collection; photo © Tino Hammid.

mal shock. High temperatures will anneal or destroy the color centers in the gem materials, while thermal shock will crack or shatter them. For instance, topaz receiving a typical dose rate of 250 to 500 Mrads per hour will increase in temperature at the rate of 50°C to 100°C per minute if it is not properly cooled.

Some linacs produce electron beams with maximum energies up to about 3 MeV, values on the order of the maximum energies of beta particles from radioactivity. Such facilities are useful only for irradiating small gemstones because the electron beam will not completely penetrate and provide an even radiation dose throughout stones over a few carats in size. If the electron beam stops within the gemstone, a large negative static charge can build up which can cause the stone to fracture or even shatter. By contrast, beam energies above 15 MeV are not generally used for gem materials because such high energies can induce radioactivity within the material.

Normally, gem materials that are irradiated in gamma-ray facilities, such as topaz, tourmaline, zircon, and diamond, can also be irradiated in linacs. Linacs are usually preferred for gemstones that require relatively high doses of radiation. Yellow beryl and blue topaz, for example, generally require irradiation doses from 1,000 to 10,000 Mrads (George Drake, pers. comm., 1988). Also, treatment in a linac will often produce much deeper colors, undoubtedly because higher-energy electrons deposit their energy inside the stones; with gamma rays, lower-energy electrons are produced as these rays travel through or are absorbed

Figure 8. Literally millions of carats of gemstones have been irradiated in linear accelerators (linacs) such as this one. Photo courtesy of IRT, San Diego, CA.



into the material. Currently, topaz is the most frequently irradiated gemstone; the linac-irradiated material becomes an attractive "Sky Blue" after subsequent heat treatment of the greenish or brownish product.

Nuclear Reactors. Nuclear research reactors found at universities and other research centers produce high-energy neutrons along with associated gamma rays. A typical research reactor consists of a large metal or concrete reactor vessel that contains a matrix of uranium fuel rods or plates, control rods for power control, water for cooling and neutron energy tailoring, and ports where materials can be placed for irradiation (figure 9).

Figure 9. This photo was taken looking down into the pool of a TRIGA nuclear research reactor. The bluish glow seen here and in the gamma-ray facility in figure 6 is called Cherenkov radiation. It is produced by gamma rays interacting with the electrons of the water molecules and causing them to very briefly travel faster than light does in water. The electrons must slow down, and consequently lose energy by emitting photons of light. Photo courtesy of General Atomics, San Diego, CA.

Since all gem materials become radioactive when bombarded by neutrons, residual radiation is a serious problem for reactor-irradiated gemstones (but not for gems properly selected and irradiated by the other two methods described above).

Currently, near-colorless topaz is the gemstone most often irradiated in a reactor. Therefore, the following discussion will focus on the reactor irradiation of topaz (called "London Blue" in the trade), although the comments apply equally well to other gems, such as spodumenes (Rossman and Qiu, 1982) and diamonds (Dugdale, 1953).

Theoretically, a few weeks after neutron irradiation in a reactor facility, chemically pure topaz would not be radioactive because the neutron-activated major constituents of topaz (fluorine, aluminum, oxygen, and silicon) have half-lives of only seconds to hours. Topaz from various localities, however, is likely to contain different concentrations of trace-element impurities such as tantalum, scandium, and manganese. Isotopes of these elements (Ta-182, Sc-46, and Mn-54) are the longer-lived radioactive nuclides found in reactor-treated topaz (Crowningshield, 1981).

High-energy (fast) neutrons produce the important color centers in topaz as well as most of the crystalline damage; low-energy (known as thermal, or slow) neutrons produce most of the radioactive nuclides. Therefore, to reduce the amount of neutron-induced radioactivity, gem treaters try to maximize the fast-neutron, and minimize the slow-neutron, components irradiating their material. They can accomplish this by placing the topaz in containers covered with materials such as cadmium or boron compounds that very easily absorb slow neutrons. They can also surround the containers holding the topaz with uranium converter plates; only the fast neutrons will get through the plate to the topaz, while the slower neutrons will be absorbed by the uranium in the plate, causing fissions that produce more high-energy neutrons to irradiate the topaz. In addition, since cooling water for topaz slows neutrons down to lower energies, the treaters try to use either as little water as possible, or a gas such as nitrogen for cooling. Because there are important differences in the designs of various nuclear reactors, and because of the variability in impurities among topaz from different localities, reactor irradiation can yield a variety of results in both induced color and induced radioactivity.

A relatively recent development in topaz enhancement is to combine treatment processes to produce a "brighter" blue color. The topaz is irradiated first in a nuclear reactor and then in a linac, after which it is heat treated (Fournier, 1988). The product is referred to in the trade by names such as "American," "Electra," "California," "Swiss," or "Super Blue" topaz. Figure 10 illustrates three types of irradiated blue topaz. Heat treating is applied to gamma-ray and electron-beam treated topaz to remove the undesirable and less stable brown and green colors. Heat treatment is generally not required for neutron-treated topaz except to remove the tell-tale inky or steely component and produce a lighter shade of blue (Schmetzer, 1987). For a further explanation of topaz treatments, see Nassau (1985).

Figure 10. Far more topaz than any other gem material is being irradiated in laboratory facilities. The American Gem Trade Association (Willett, 1987) has estimated that 6,000 kg (30 million carats) of topaz are irradiated annually, 40% of this total in the U.S. Each of the stones shown here was treated by a different method (from lightest to darkest): linac-treated "Sky Blue," combination reactor- and linac-treated "California Blue," and reactor-treated "London Blue." Photo © Tino Hammid.

INDUCED RESIDUAL RADIOACTIVITY IN LABORATORY-IRRADIATED GEMSTONES

Atoms become radioactive whenever there is an excess of energy in their nuclei, brought on by a nuclear reaction or by the disruption of the proper ratio of protons to neutrons. They shed this energy by undergoing some type of radioactive decay or radiation emission. A nuclear reaction between the nucleus of an atom and a subatomic particle or photon can provide that excess energy. Radioactivity is induced by two out of the three treatment processes discussed, linac and nuclear reactor, although the latter poses the potentially most serious problem.

Linac Induced. High-energy electrons produce X-rays, called *bremsstrahlung* or braking radiation, as they lose energy going through a material. Some of these X-ray photons will have enough energy to enter the nucleus of an atom and make it radioactive. This is called photoactivation. A subatomic particle such as a neutron can be released in this nuclear reaction (called a photoneutron reaction) and proceed to enter another gemstone nuclide and make it radioactive. For instance, an X-ray photon can interact with a sodium-23 nuclide and transform it into sodium-22. The free neutron released during this nuclear reaction can go on to make another nuclide radioactive, transforming, for example, cesium-133 into cesium-134.

Photoneutron reactions are produced only above a certain energy and thus are called threshold reactions. They generally occur with photons of energies of from 7 to 18 MeV. As a general rule, the lower in atomic weight the atom is, the higher the photon energy needed to cause the reaction, the fewer the number of neutrons released, and the shorter the half-life of the new radioactive atom (De Voe, 1969). For most gem materials, if the electron-beam energy is kept below 12 MeV, the half-lives of the induced radioactive nuclides are short enough that the radioactivity decays to background levels within a few weeks and only an insignificant number of neutrons are produced.

Gemstones containing the elements beryllium (such as beryls), lithium (such as spodumene and some tourmalines), and uranium and thorium (such as zircons) produce neutrons during linac irradiation; all of these elements have low energy thresholds for photoneutron reactions. The lowest, for beryllium, is only 1.67 MeV (Berman, 1974).

For example, the author has measured sodium-22 and cesium-134 in linac-treated beryls, and manganese-54 in linac-treated tourmalines, which testify to the photoneutron and neutron-absorbing reactions that have taken place. As for topaz irradiated properly in a linac, the most significant radionuclide produced is believed to be germanium-69, the result of a photoneutron reaction with the stable nuclide germanium-70. Since this nuclide has a half-life of 39 hours, the gemstones are not released for many half-lives (a few weeks) to allow the activity to die out (Robert Block, pers. comm., 1988).

Reactor Induced. Nuclear reactors produce copious amounts of neutrons which vary in energy from a hundredth of an eV to over 10 MeV. Unlike most other nuclear reactions with the nuclei of atoms, neutron absorption occurs at all energies but becomes much easier at thermal neutron energies. A neutron is not affected by the positive and negative charges of atoms, as are alpha, beta, and gamma radiation. Therefore, a neutron can enter a nucleus relatively easily, depending on the type of nuclide, and alter the neutron-to-proton ratio. The nuclide then has too many neutrons in its nucleus, and thus undergoes beta decay to correct this imbalance; that is, a neutron turns into a proton and a beta particle is released from the nucleus, normally along with a gamma ray. Consequently, much larger amounts of induced radioactivity (i.e., beta- and gamma-emitting nuclides) are generated per Mrad during irradiation in a reactor.

DETECTION AND MEASUREMENT OF RADIATION

As radiation travels through a material, it loses its energy to the surrounding atoms by ionization, where atoms and molecules lose one or more electrons, and by electron excitation, where electrons are raised to higher energy levels. These processes can lead to other effects such as altering the electrical resistance of a material, producing minute flashes of light, causing slight temperature increases, and so on.

To detect or measure radiation, one takes advantage of one of these effects and either amplifies it or uses it as a gauge or reference. There are many kinds of instruments and methods used to detect and measure radiation. Three types of instruments—the Geiger counter, the sodium iodide scintillation crystal, and the lithium-drifted germanium detector—are particularly useful for measuring radioactive gem materials. For further information on these and other radiation detection instruments, see Knoll (1979).

Geiger Counter. This is perhaps the most commonly recognized and widely used radiation detection instrument (figure 11). Geiger counters are inexpensive, ruggedly built, easy to operate, and work relatively well for measuring low levels of beta radiation and somewhat higher levels of gamma radiation. A G-M (Geiger-Müller) tube, the detector part of a Geiger counter, is a hollow gas-filled metal tube with a charged wire running down its center. As radiation passes through the tube, it causes ionizations in the gas. Because of the high voltage within the tube, each single ionization gives rise to millions of additional ionizations, producing an electrical pulse that is then converted to an audible "click."

The response of a Geiger counter depends on the type and the energy of the radiation. Essentially, a single beta particle has anywhere from less than 1% to as much as a 20% chance of being

Figure 11. The most common, and least expensive, radiation detector is a Geiger counter such as this Victoreen Model 290 Survey Meter with a Model 489 pancake probe. Photo courtesy of Victoreen, Inc., Cleveland, OH.

TABLE 3. Level of radioactivity detectable in various gemstones with a Geiger counter.[a]

Gemstone	Weight (ct)	Radio-nuclides present[b]	Activity[b] (nCi)	Direct readings[c] (cpm)	nCi of detectable radioactivity[d]
Green zircon	2.15	U-238[e]	0.75	≃ 300	0.12
Green zircon	3.71	U-238[e]	0.5	≃ 200	0.13
Ekanite	3.86	U-238[e] Th-232[e] Total	5 20 25	≃ 5500	0.18
Blue topaz (neutron irradiated)	4.62	Sc-46	0.75	≃ 75	0.86
Blue topaz (neutron irradiated)	4.72	Ta-182	2.0	≃ 110	1.1

[a] *Victoreen Model 290 Survey Meter with a pancake probe Model 489-110B (see figure 11). Data generated by Dr. Emmanuel Fritsch of GIA, November 17, 1988. This instrument is able to detect alpha particles above 3.5 MeV, beta particles above 35 KeV, and gamma rays above 6 KeV.*
[b] *As measured with NaI and Ge(Li) systems.*
[c] *Average of visible readings—background is approximately 40 counts per minute (cpm).*
[d] *Nanocuries of radioactivity needed to cause direct readings to be twice background (i.e., 80 cpm).*
[e] *U-238 and Th-232 include daughters.*

counted, because nuclides emit beta particles over a broad energy spectrum and only the highest ones have any likelihood of arriving inside the G-M tube to be registered. A gamma ray has less than a 0.1% to 2% chance of being counted, because a gamma ray must interact within a critical layer in the wall (cathode) of the G-M tube to be registered. In general, then, a Geiger counter is less than 5% efficient in quantifying radioactivity. However, as shown in table 3, the Geiger counter does indicate whether radioactivity is present within a certain range. Note also that the response per nCi depends on the type of nuclide being measured and the size of the stone. For example, stones of a few carats would have to contain at least 0.1 to 0.2 nCi of uranium and thorium, or about 1 nCi of typical mixed by-product nuclides, to double the count rate above that of the background and therefore be measurable with any confidence within a short period of time (e.g., half a minute). Smaller stones with similar amounts of radioactivity should be more easily measured.

NaI Scintillation Crystal. A more refined and sensitive method to measure radiation is through the use of a scintillation crystal such as sodium iodide—thallium doped to 0.1%, NaI(Tl), set within a low-background lead shield. When a gamma-ray enters this crystal, it loses its energy by causing electrons to be moved out of their normal sites in the structure of the NaI(Tl) crystal. These electrons then move very quickly to lower-energy levels at the thallium activator sites, producing tiny pulses of visible fluorescent light (photons) that combine to form one single large light pulse, the intensity of which is proportional to the energy of the absorbed gamma ray. Each type of radioactive atom releases gamma rays at specific energies. When a scintillation crystal is coupled to a photomultiplier tube, which in turn is connected to an analog-to-digital converter and the output manipulated by a computer, it is possible to determine the type and amounts of radioactive nuclides present in a material (again, see table 3). Note, however, that this system is considerably more expensive than a good Geiger counter and requires technical expertise to operate and interpret the data.

Lithium-Drifted Germanium Detector. The best method for measuring a large number of different gamma rays at a single time is with a semiconductor detector. The most popular is the lithium-drifted (doped) germanium detector, Ge(Li), which produces electron-hole pairs when gamma rays are absorbed into it. The motion of these pairs in an applied electrical field generates the basic electrical signal that is fed into a multichannel analyzer (Knoll, 1979). The Ge(Li) most clearly distinguishes between different gamma energy peaks for different radioactive nuclides, but it is less sensitive, requires constant liquid nitrogen cooling, and is much more expensive than the NaI system. Both systems use the same type of multichannel an-

Figure 12. The ND 65B Multi Channel Analyzer (MCA) shown here is a pulse-height analyzer that converts electrical signals from either a NaI or a Ge(Li) detector into useful information such as the type and quantity of radioactive nuclides present in a gemstone. Courtesy of Nuclear Data, Inc., Schaumburg, IL.

alyzer (figure 12). Figure 13 compares the energy spectra for two nuclides generated by the NaI and the Ge(Li) systems. The areas under the peaks or curves on the screen are proportional to the concentrations of the radioactive nuclides.

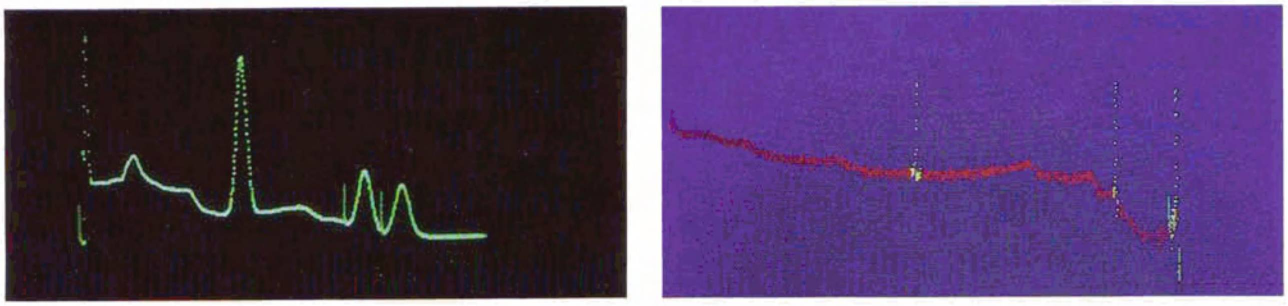
SOME CONSIDERATIONS REGARDING HEALTH HAZARDS

What are the safe limits of radiation and how hazardous are radioactive gems? The answer is highly controversial. Some maintain that any and all radiation is harmful, others feel that low levels are harmless since people live in a sea of background radiation, and still others regard even relatively high levels of radiation as safe.

Figure 14 gives the current estimate of the contributions of background radiation that an average American receives per year (Sinclair, 1987). The total average whole-body dose equivalent is about 360 mrem per year, or 1 mrem per day. In other parts of the world, it may reach as high as 3,000 mrem per year (Eisenbud, 1987). Whole-body dose equivalent can be illustrated as follows: From radon we receive 2,400 mrem per year to the lung tissue; this is the equivalent of about 200 mrem to the entire body. To place these numbers in perspective, those who work in the U.S. radiation industry are allowed by government regulations to receive up to 5,000 mrem to their entire body, 30,000 mrem to the skin of the whole body, and up to a total of 75,000 mrem per year to their hands, forearms, feet, and ankles (U.S. Code of Federal Regulations, Title 10, Part 20, Section 20.101 – 10 CFR 20). These dose levels are considered acceptable (safe) for workers. The 75,000 mrem is comparable to wearing radioactive rings, watches, or bracelets that produce dose rates to these relatively small areas that are more than 8.5 mrem per hour, 24 hours per day, 365 days per year. For comparison, dental X-rays can give doses from 100 mrem to as high as 1,500 mrem.

Table 4 quantifies the variables involved in determining the potential health hazard of a gem material. The half-life and the decay mode of a radioactive nuclide in a gemstone determine its relative radiation hazard. The total gamma-ray energy (γ KeV) emitted per radioactive decay can help quantify the relative gamma-ray dose that a person will receive from a radioactive gemstone. Because radiation doses to humans are very difficult to compute and vary with depth of penetration into tissue, they can be more closely approximated

Figure 13. These two displays illustrate the gamma-ray spectra of cesium-137 (0.662 MeV) and cobalt-60 (1.17 MeV and 1.33 MeV) as shown using a NaI scintillation crystal with an ND 6 multichannel analyzer (left) and a Ge(Li) detector with an ND 76 multi-channel analyzer (right). Photos courtesy of Nuclear Data, Inc., Schaumburg, IL.



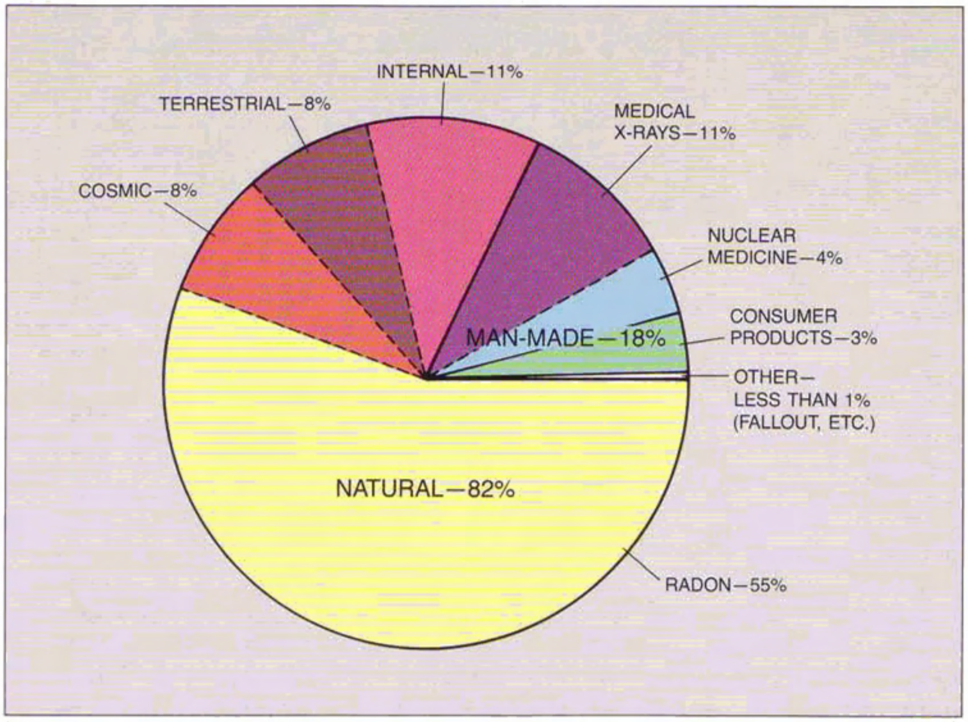


Figure 14. This illustration shows the percentage contribution of various radiation sources to the background radiation whole-body dose equivalent that an average American receives in a year (360 mrem/yr). Adapted from Sinclair, 1987.

by the specific gamma-ray constant (SGRC). This gives the gamma-ray exposure rate in air in microroentgens (μr) per hour, 1 cm from a 1-nCi-point (very small) source.

Consider a series of gemstones, each of which contains a different radioactive nuclide yet produces the same gamma-ray exposure. If we use the data in table 4, and divide each SGRC for uranium-238 and daughters by the SGRC for each nuclide, we get a term for each nuclide called the inverse relative exposure rate index, IRERI. This value is equal to the number of nCi of a nuclide that produces the same exposure rate as one nCi of U-238. Therefore, a gemstone that contains 3 nCi/gm of zinc-65 (Zn-65) or antimony-125 (Sb-125) produces the same exposure rate per hour as a similar gemstone containing 1 nCi/gm of U-238. The relative exposure rate is simply the inverse of the IRERI; that is, for example, Zn-65 and Sb-125- are one-third as radiant as U-238.

When time, half-lives, and the resultant decreases in radioactivity are taken into consideration, the indices will become even more varied. Assuming that the average lifetime or ownership of a typical piece of jewelry is 10 years, the original concentration of each nuclide that would give the same radioactive exposure as 1 nCi of U-238 would be the inverse relative exposure index, IREI. For example, for scandium-46 or tantalum-182, the most prevalent radionuclides in reactor-treated blue topaz, the concentration would be about 25 nCi/gm. In other words, two stones of the same size, a green zircon containing 1.0 nCi/gm of uranium-238 and a blue topaz containing about 25 nCi/gm of either scandium or tantalum, would give roughly the same total radiation exposure over a 10-year period.

Release limits are concentration limits of radioactive nuclides contained in material made radioactive by man that are allowed to be released to the general public. The concentrations are deemed safe and are based on political issues as well as scientific data. The values for various nuclides are found in U.S. Code of Federal Regulations Title 10, Part 30 (10 CFR 30), Section 30.70, Schedule (Table) A. For example, for scandium-46 or tantalum-182, the limit is 0.4 nCi/gm. If a gemstone contains more than one type of nuclide, the sum of the ratios (the concentration divided by the release limit concentration for each isotope) must be less than or equal to 1.

Accordingly, we can see that with respect to long-lived natural radioactive nuclides and shorter-lived man-made radionuclides, the energy and type of decay, as well as the SGRC and half-lives, must be taken into account to arrive at a proper perspective when considering radiation exposures, doses, and release limits for radioactive gemstones.

U.S. Code of Federal Regulations Title 10, Part 40 (10 CFR 40) states that any person is exempt from license requirements for materials manufac-

TABLE 4. Radioactive nuclide data for radioactive gemstones.[a]

Nuclide	Half-life[b]	γ KeV[c]	Γ SGRC[d]	IRERI[e]	IREI[f]	Release limit[g] (nCi/gm)
				(nCi nuclide/nCi U-238)		
Chromium-51	28 d	33	0.16	51.6	4710	20.0
Cerium-141	32.5 d	77	0.35	23.6	1840	0.09
Niobium-95	35 d	764	4.2	1.96	142	1.00
Iron-59	44.5 d	1188	6.4	1.29	73.3	0.60
Antimony-124	60 d	1852	9.8	0.842	35.4	0.20
Zirconium-95	64 d	733	4.1	2.01	79.6	0.60
Strontium-85	65 d	518	3.0	2.75	107	1.00
Cobalt-58	71 d	977	5.5	1.50	53.6	1.00
Iridium-192	74 d	813	4.8	1.72	58.9	0.40
Scandium-46	84 d	2009	10.9	0.757	22.9	0.40
Tantalum-182	115 d	1301	6.8	1.21	26.7	0.40
Tin-113	115 d	280	1.7	4.85	107	0.90
Zinc-65	244 d	585	2.7	3.06	31.7	1.00
Manganese-54	312 d	836	4.7	1.76	14.2	1.00
Cesium-134	2.06 a	1555	8.7	0.948	3.30	0.09
Sodium-22	2.60 a	2187	12.0	0.688	1.97	0.40[k]
Antimony-125	2.73 a	443	2.7	3.06	8.42	1.00
Cobalt-60	5.27 a	2504	13.2	0.625	1.12	0.50
Barium-133	10.54 a	404	2.4	3.44	4.69	—[l]
Europium-152	13.33 a	1162	5.8	1.42	1.82	0.60
Potassium-40	1.28 Ga	157	0.78[i]	10.6	10.6	n/a
Uranium-238 plus daughters	4.47 Ga	1796[h]	~8.25[j]	1.00	1.00	n/a
Thorium-232 plus daughters	14.06 Ga	2470[h]	~5.1[j]	1.62	1.62	n/a

[a] *This list is not all-inclusive; it covers the major man-made nuclides encountered in irradiated gemstones with half-lives between a month to a dozen years. Shorter-lived nuclides die out quickly and longer-lived nuclides are too difficult to produce in sufficient quantity to be a problem. The nuclides are those identified in gemstones by the author, by J. Razvi and W. Whittemore of General Atomics (pers. comm., 1988), and by D. Alger of the University of Missouri (pers. comm., 1988). The data were taken, and calculations made, from Brown et al. (1986), Kocher (1981), Johns (1983), and Jaeger (1968). The three major natural radioactive nuclides (K-40, U-238, and Th-232) are also included.*

[b] *Half-life: The time it takes for the activity (nCi) of a nuclide type to decay to one-half its original value. d = days, a = years, Ga = billion years.*

[c] *γ KeV: The total energy (in KeV) of the gamma rays emitted per radioactive decay (Bq). X-rays are not included.*

[d] *SGRC: Specific Gamma-Ray Constant. This is the exposure rate in air (roentgens per hour) from the gamma rays emitted by a millicurie point source of radioactive nuclides at a distance of one centimeter. Author converted R to μr and mCi to nCi.*

$$\Gamma = \frac{\mu r - cm^2}{hr - nCi}$$

Example: Exposure rate in air from a 2 nCi point source of Ta-182 at a distance of 0.5 cm

$$\mu r/hr = 2\ nCi \times 6.8/\ (0.5\ cm)^2 = \underline{54.4}\ \mu r/hr \text{ or } \sim 0.05\ mr/hr$$

[e] *IRERI: Inverse Relative Exposure Rate Index. This is the number of nCi of a particular nuclide needed to give the same gamma-ray exposure rate in air as one nCi of U-238 plus daughters.*

[f] *IREI: Inverse Relative Exposure Index. This is the original number of nCi of a particular nuclide required to give the same gamma-ray exposure in air over a 10-year period as one nCi of U-238 plus daughters.*

[g] *Current release limits for reactor-irradiated faceted blue topaz as listed in Schedule A of 10 CFR 30. For nuclides that are not listed and that have a half-life of less than three years, the limit is 0.001 nCi/gm.*

[h] *Energy computed by assuming all daughters in equilibrium with parent nuclide.*

[i] *Computed by the author using Johns (1983).*

[j] *Includes radium-226 and radium-228 and their respective daughters only—not the parents U-238 and Th-232 (Jaeger et al., 1968).*

[k] *Limit changed in 1988 from 0.001 to 0.4 for faceted blue topaz only, by license request from General Atomics.*

[l] *Not listed in 10 CFR 30 and has a half-life greater than three years.*

tured that contain less than 1/20 of 1% of uranium and thorium source material. For instance, eyeglass lenses cannot be sold unless they contain less than these amounts (Moghissi, 1978). This translates into 0.168 nCi/gm of U-238 and 0.055 nCi/gm of Th-232. From the IREI in table 4, one can calculate that the exposure from a gemstone containing about 4.5 nCi/gm of Sc-46 or Ta-182 would produce about the same gamma-ray exposure or dose over a 10-year period as a gemstone containing source uranium at exempt (0.168 nCi/gm) concentrations. As another comparison, the average human contains about 200 nCi of K-40 and eats and drinks about 140 nCi of uranium per year (Eisenbud, 1987). Therefore, with respect to the small quantities of radioactivity found in gemstones and the resultant radiation doses people may receive, 2 nCi of any radioactive nuclide per gram of material can be judged to be harmless and safe, and a very small fraction of background radiation.

U.S. REGULATION OF IRRADIATED MATERIAL

All irradiation facilities in the United States are controlled by one or more of several regulatory agencies: the U.S. Nuclear Regulatory Commission, the U.S. Department of Energy, and the health and safety agencies of the various states. The Atomic Energy Act of 1946 established control over nuclear energy by the federal government. Further legislation in 1954 provided for the civilian licensing of nuclear power plants, allowed civilian access to nonmilitary uses of atomic energy, and gave the Atomic Energy Commission (AEC) the responsibility for protecting public health, safety, and property in matters concerning radiation.

A 1959 amendment to the Atomic Energy Act of 1954 transferred some of the federal licensing authority and responsibility to certain qualified states called agreement states. Currently, there are 29 agreement states, each with its own radiation control programs. New York and California were among the first states in this group, while Illinois was the most recent to join.

In 1974, the AEC was separated by legislation into two groups, with the regulatory side being renamed the Nuclear Regulatory Commission (NRC). The other side eventually became the Department of Energy.

If a gem is made radioactive during irradiation treatment in a nuclear reactor facility anywhere in the United States, the NRC has total jurisdiction over its handling and release to the general public. The NRC also has control over reactor-irradiated radioactive gem materials entering or leaving this country. If the material is made radioactive in a linac or some other device not regulated by the NRC, then the state has jurisdiction.

On March 16, 1965, the AEC issued its first and only policy statement concerning the use of either radioactive source materials (uranium and thorium) or by-product materials (those rendered radioactive by exposure to radiation in a reactor) in products intended for use by the general public without the imposition of regulatory controls. This policy statement set forth criteria for exempting, on a case-by-case basis, the possession and use of approved items from licensing requirements. Approved possession and use by the general public would depend both on the associated radiation doses people could receive and on the apparent usefulness of the products. In particular, the AEC at that time considered that "the use of radioactive material in toys, novelties, and adornments [gemstones] was of marginal benefit" ("Products intended . . .," 1965).

On June 25, 1986, the NRC issued a letter to all non-power reactors (NRC, 1986) that states in part that "the distribution of irradiated materials, even with low levels of induced radioactivity, to unlicensed persons is prohibited unless the distributor of such materials has a specific license . . . , which permits such distribution. The staff [NRC] considers gems to be adornments and has not granted licenses for the distribution of irradiated gems. If you directly distribute the irradiated products to unlicensed persons, you must obtain a license to reflect this activity." Thus, the distribution of reactor-treated gemstones to the general public was prohibited. For the next two years, however, enforcement was uneven and no distribution licenses were issued.

On February 23, 1988, after much debate (Stello, 1987a and b), the NRC announced that "applications will now be considered for interim licenses authorizing the distribution of neutron-irradiated gems, particularly topaz, to unlicensed persons" (Miraglia and Cunningham, 1988). In March 1988, the NRC stated that this applies only to cut, finished gems and that the "NRC staff plans to control distribution of irradiated gemstones at the source, and thus envisions two principal groups of applicants for distribution licenses: domestic reactor facilities and initial importers" (Michael Lamastra, letter to author, March 3, 1988).

These interim guidelines appear to place an undue burden on domestic irradiation operations, since few reactor facilities are willing to assume the many responsibilities that certification entails. A licensed importer can certify stones irradiated outside the U.S. for distribution in this country, but cannot certify domestically irradiated material. The importer still must contract with a U.S.–

licensed reactor facility to determine radiation concentrations for release to the general public. The NRC goal here is to "limit the impact of licensing requirements on the jewelry industry. If domestic reactors and importers obtain licenses, then no one else in the jewelry distribution chain need obtain a license" (M. Lamastra, letter to the author, October 31, 1988). The net result, however, is that more constraints are placed on gems irradiated domestically than those irradiated outside the U.S.

An additional problem or inequity is that the exempt concentrations for the various nuclides in 10 CFR 30 (again, see table 4) are based on *"ingestion"* or *"inhalation"* (Stello, 1987b), and have not been adjusted for solid, nonsoluble materials (such as gemstones) that remain outside the body. The author has tried to find legal definitions of "radioactive" material and the only state or federal regulation found so far was 49 CFR 173.403 (X), issued by the Department of Transportation: "'Radioactive material' means any material having a specific activity greater than 0.002 microcuries per gram" (2 nCi/gm). At this time, the U.S. federal release limits for the great majority of the nuclides are 1 nCi/gm or less (again, see table 4), but the NRC prefers 0.4 nCi/gm (J. Razvi and W. Whittemore, pers. comm., 1988).

Most other countries—e.g., West Germany, Italy, Japan, Taiwan, and Hong Kong—regard 2 nCi/gm as releasable (Scott Kohn, pers. comm., 1987). Canada temporarily set the releasable value at 1 nCi/gm while waiting for the U.S. NRC to make a final determination; Great Britain uses 2.7 nCi/gm (see Ilari, 1985, for further information on international recommendations in this area).

It is the author's opinion that two nanocuries of induced radioactivity per gram of irradiated gemstones would be a fair and safe limit for distribution to the general public, considering natural background radiation doses we receive during our lives, the amount of radioactivity contained in natural gemstones and other consumer products, and other data presented in this article.

CONCLUSION

Gemstone irradiation and radioactivity are very complex issues. This article has summarized the various components of these issues in an effort to clarify the nature of gemstone radioactivity and the potential health hazards involved. Current U.S. regulations appear to be unrealistic.

REFERENCES

Berman B., Comp. (1974) *Atlas of Photoneutron Cross Sections Obtained with Monoenergetic Photons*, 2nd ed. Lawrence Livermore Laboratory URRL-75694 [CONF-740806-1].

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

Camargo M.B. de, Isotani S. (1988) Optical absorption spectroscopy of natural and irradiated pink tourmaline. *American Mineralogist*, Vol. 73, pp. 172–180.

Crookes W. (1909) *Diamonds*. Harper and Brothers, London.

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

De Voe J. (1969) Modern trends in activation analysis. National Bureau of Standards Special Publication 312, Vol. 11, June, pp. 721–725.

Dugdale R.A. (1953) The colouring of diamonds by neutron and electron bombardment. *British Journal of Applied Physics*, Vol. 4, No. 4, pp. 334–337.

Editorial Forum (1987) Want to buy a hot diamond? *Gems & Gemology*, Vol. 23, No. 2, p. 11.

Eisenbud M. (1987) *Environmental Radioactivity—from Natural, Industrial, and Military Sources*, 3rd ed. Academic Press, Orlando, FL.

Fielding P. (1970) The distribution of uranium, rare earths, and color centers in a crystal of natural zircon. *American Mineralogist*, Vol. 55, pp. 428–440.

Fleischer M. (1986) *Glossary of Mineral Species*, 5th ed. Mineralogical Record, Inc., Tucson, AZ.

Fournier R. (1988) Process for irradiating topaz and the product resulting therefrom. United States patent no. 4,749,869, filed May 14, 1986, issued June 7, 1988.

Fritsch E., Rossman G. (1988) An update on color in gems. Part 2: Colors involving multiple atoms and color centers. *Gems & Gemology*, Vol. 24, No. 1, pp. 8–14.

Fryer C.W., Crowningshield R., Hurwit K.H., Kane R.E. (1986) Gem Trade Lab Notes—Ekanite, a markedly radioactive metamict gemstone. *Gems & Gemology*, Vol. 22, No. 1, pp. 47–48.

Hofmeister A., Rossman G. (1985) A spectroscopic study of irradiation coloring of amazonite: Structurally hydrous, Pb-bearing feldspar. *American Mineralogist*, Vol. 70, pp. 794–804.

Ilari O. (1985) *A Guide for Controlling Consumer Products Containing Radioactive Substances*. OECD*—Nuclear Energy Agency, Paris, France. [*OECD = Organization for Economic Co-Operation and Development]

Jaeger R., Ed.-in-Chief (1968) *Engineering Compendium on Radiation Shielding. Volume 1: Shielding Fundamentals and Methods*. Springer-Verlag, Berlin.

Johns H., Cunningham J. (1983) *The Physics of Radiology*, 4th ed. Charles C. Thomas, Springfield, IL.

Knoll G.F. (1979) *Radiation Detection and Measurement*. John Wiley & Sons, New York.

Kocher D. (1981) *Radioactive Decay Data Tables*. Technical Information Center, U.S. Department of Energy.

Koivula J. (1986) Solution coloration of smoky quartz. *Journal of Gemmology*, Vol. 20, No. 4, pp. 208–209.

Miraglia F., Cunningham R. (1988) Distribution of gems irradiated in research reactors. Nuclear Regulatory Commission Generic Letter 88–04 to all non-power reactor licensees, February 23, 1988.

Moghissi A., Paras P., Carter M., Barker R. (1978) *Radioactivity in Consumer Products.* U.S. Nuclear Regulatory Commission, NUREG/CP-0001.

Müllenmeister H.J., Schwaben M. (1986) Untersuchung radioaktiver Edelsteine und Mineralien. *Zeitschrift der Deutschen Gemmologischen Gesellschaft,* Vol. 35, No. 1/2, pp. 59–63.

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

Nassau K. (1984) *Gemstone Enhancement.* Butterworths, New York.

Nassau K. (1985) Altering the color of topaz. *Gems & Gemology,* Vol. 21, No. 1, pp. 26–34.

Nuclear Regulatory Commission (1986) Distribution of products irradiated in research reactors. Nuclear Regulatory Commission Generic Letter 86–11, June 25, 1986.

Perrault G., Szymanski J. (1982) Steacyite, a new name, and a reevaluation of the nomenclature of "ekanite"-group minerals. *Canadian Mineralogist,* Vol. 20, pp. 59–63.

Products intended for use by general public (consumer products) (1965). In *Guidelines of the Atomic Energy Commission,* No. 30FR3Y62, March 16, 1965.

Reinitz I., Rossman G. (1988) Role of natural radiation in tourmaline coloration. *American Mineralogist,* Vol. 73, pp. 822–825.

Rossman G. (1981) Color in gems: The new technologies. *Gems & Gemology,* Vol. 17, No. 2, pp. 60–71.

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

Schmetzer K. (1987) Colour and irradiation-induced defects of topaz treated with high-energy electrons. *Journal of Gemmology,* Vol. 20, No. 6, pp. 362–368.

Sinclair W.K. (1987) Ionizing radiation exposure of the population of the United States—recommendations of the National Council on Radiation Protection. NCRP Report #93, September 1, 1987.

Stello V. (1987a) *Distribution of Radioactive Gems Irradiated in Reactors to Unlicensed Persons.* U.S. Nuclear Regulatory Commission, SECY-87–186, July 28, 1987.

Stello V. (1987b) *Distribution of Radioactive Gems Irradiated in Reactors to Unlicensed Persons (Follow-up to SECY-87-186).* U.S. Nuclear Regulatory Commission, SECY-87-186A, October 5, 1987.

Villforth J., Shultz G. (1970) *Health Handbook.* U.S. Department of Health, Education, and Welfare, January, 1970.

Willett P., Zajicek R. (1987) AGTA letter to region III. Nuclear Regulatory Commission, August 18, 1987.

MAKE YOUR OPINION COUNT

VOTE FOR THE *GEMS & GEMOLOGY* MOST VALUABLE ARTICLE AWARD

This is your chance to tell us how you feel about the 1988 volume year of *Gems & Gemology.* Your vote gives our authors the recognition and encouragement they deserve, and helps us ensure that the journal continues to reflect the needs and interests of you, our valued subscriber.

Your ballot is located on the insert card inside this issue. Please choose three articles from 1988 and mark them in order of numerical preference: (1) first, (2) second, (3) third. **Be sure to mark only three articles for the entire year.** Additional comments concerning the journal are welcome in the space provided.

Just mark your ballot, detach it, and drop it in the mail (postage is prepaid if mailed in the U.S.). Ballots must be postmarked by March 13, 1989, to be included in the final tally.

The winning articles will be announced in the Spring 1989 issue of *Gems & Gemology.* Cash awards of $500, $300, and $100, respectively, will be given to the authors of the articles that place first, second, and third in the balloting.

VOTE TODAY!

AMETHYST MINING IN BRAZIL

By David Stanley Epstein

Brazil is currently the leader in overall production of amethyst. This article describes the author's visits to three of Brazil's most important mining areas: Marabá, Pau d'Arco, and Rio Grande do Sul. Each represents a different geologic environment and, therefore, a variety of mining methods are used. In Marabá and Rio Grande do Sul, much of the amethyst is heat treated to become citrine.

ABOUT THE AUTHOR

Mr. Epstein is a gem sculptor and president of Precious Resources Ltda., Rua Dr. João Antonio, 287, Teófilo Otoni, Minas Gerais, Brazil.

Acknowledgments: The author thanks the Brazilian D.N.P.M. (National Department of Mineral Products) and its department heads in Pará and Rio Grande do Sul for assistance in obtaining information on and access to the amethyst mining areas. He also thanks geologist R. A. Correa Mártires for his help, patience, and exposure to personal risk. Assistance was also provided by Dr. E. Fritsch, J. C. Schmit, T. A. Collyer, A. A. Muller, H. M. Santos, A. Bortoluzzi, S. Klein, V. R. Sudback, O. B. Ferreira, B. F. Filho, S. H. S. de Matos, B. F. de Alcontara, J. Miranda, O. Miranda, M. do Carmo-Barreto, J. C. Miolo, K. Elawar, H. Elawar, and Bernd Munsteiner. Special thanks to Dr. J. E. Shigley, without whose constant support this work would not have been possible.

Because of its ready availability, modest cost, and attractive color, amethyst is currently one of the most popular colored gemstones (figure 1). Fine amethyst historically came from Russia's Ural Mountains and from the Idar-Oberstein area of West Germany, although both deposits are now largely exhausted. Today, economic quantities occur in Zambia, Mexico, and Uruguay, with lesser deposits in Australia, Sri Lanka, India, Madagascar, Southwest Africa, and the United States (Webster, 1983). The major source, however, is Brazil. Hundreds of tons of various grades of amethyst are produced there annually (419 tons in 1985), of which a small but important percentage is of cutting quality.

Amethyst was discovered in Brazil early in the 19th century, by settlers from Idar-Oberstein (V. R. Sudback, pers. comm., 1987; Gonçalves, 1949); to date, mining claims have been filed in at least eight of Brazil's 27 states and territories. This article describes current mining of gem amethyst in three of the most important producing areas—Marabá (which currently is producing the most amethyst in Brazil), Pau d'Arco (which produces some of the finest material), and Rio Grande do Sul (which has the longest sustained production). These localities also provide good examples of the occurrence of amethyst in three different geologic settings: as large veins in quartzite, as a constituent of sedimentary alluvium, and as geodes in basalt.

This report is based primarily on the author's own observations made during a fall 1987 visit to these three areas, which involved travel of over 12,000 km, plus information obtained from numerous discussions with local miners, amethyst dealers, and government geologists. For each area, information is included on location and access, occurrence of the amethyst, history of the deposit, mining methods, production levels, and quality grades of the amethyst recovered (see table 1). Because almost all

Figure 1. This faceted 9-ct amethyst and the Rio Grande do Sul crystal cluster are representative of some of the fine material that has come from Brazil. Jewelry courtesy of Silverhorn, Santa Barbara, CA; photo © Tino Hammid.

citrine on the market today is produced by heat treating amethyst, the treatment procedures practiced at Marabá and Rio Grande do Sul are briefly described as well. Research done by Cassedanne (1988 a and b) indicates that there are no significant differences in the gemology of amethyst from different areas of Brazil; general properties are summarized in the accompanying box.

MARABÁ

Approximately 450 km south of Belém, the capital of the northern state of Pará, lies the municipality and town of Marabá (figure 2). Although the most productive occurrence of faceting grade amethyst being mined in Brazil today is that of Alto Bonito, all of the material from this general region is commonly referred to by the name Marabá.

Marabá is easily reached from Belém by regularly scheduled airline. The hour-long flight is almost entirely over dense, tropical rainforest that is interrupted occasionally by small, grassy clearings and meandering rivers. From Marabá, one must take an air taxi southwest to the ranch (*fazenda*) on which the mine is located. A difficult

GEMOLOGICAL DESCRIPTION OF AMETHYST

Gemology

Amethyst is the purple to violet variety of crystalline quartz and is colored by an $O^{2-} \rightarrow Fe^{4+}$ charge-transfer process (Cox, 1977; Fritsch and Rossman, 1988). Aside from color, its properties are those of all crystalline quartz, regardless of locality: uniaxial positive with refractive indices of o = 1.544 and e = 1.553 ±0.001, and birefringence of 0.009. Since gem-quality specimens are essentially flawless, the specific gravity of 2.66 ± 0.01 can be regarded as almost constant, although mineral specimens and uncut crystals used in jewelry may be sufficiently included to expand the range of density. The most reliable and distinctive property, however, is the "bull's-eye" optic figure that is unique to quartz. With crossed Polaroids and a condensing lens, a uniaxial figure with an open center where the black cross fails to meet can usually be seen.

Separation of Natural from Synthetic Amethyst

None of these properties, however, will distinguish natural from synthetic amethyst. In addition, the absence of inclusions in the vast majority of faceted amethysts negates the potential diagnostic value of this characteristic. It was recently determined, however, that Brazil law twinning could be used to make the separation (Lind et al., 1983; Schmetzer, 1985, 1986). The author has found that this twinning can be observed in more than 50% of natural amethyst simply with a diffused light source such as a light table. In more difficult cases, placing a single polarizing filter between the light source and the amethyst will usually make the twinning visible. Finally, observation with the stone between crossed Polaroids, possibly even with immersion, should resolve the most stubborn cases. Details of this technique are covered in Crowningshield et al., 1986. Brazil law twinning has not been observed in any synthetic amethyst studied to date.

The presence of Brazil law twinning in natural amethyst separates the natural stone from its synthetic counterpart. Photomicrograph by John I. Koivula; magnified 20×.

TABLE 1. Geologic and descriptive comparison of amethyst from Marabá, Pau d'Arco, and Rio Grande do Sul, Brazil.

Mining area	Occurrence	Condition and size of crystals	Color[a]	Treatment	Production
Marabá	Fracture fillings in quartzite	Generally good condition; some free-standing, some interlocked; individual crystals up to 15 kg in weight, 50 cm long	Maximum tone of 7 in best 19+-ct stones, tone 8 in 50+-ct stones	To citrine: buried in sand and heated by woodfire	Approximately 9.6 tons of gem-quality material produced in 1986
Pau d'Arco	Alluvial deposits	Partially eroded; from 300 grams to 40 kg	Maximum tone of 10 in 1-ct stones	To lighten color, heated in test tube; never turns to citrine	Approximately 7 tons of all qualities produced annually in 1985 and 1986
Rio Grande do Sul	Geodes inside basalt	Pyramidal crystals; up to 10 cm long	Maximum tone of 7 in 10-ct stones	To citrine: heated in oven	Approximately 19 tons of gem-quality amethyst and heat-treated citrine shipped legally through Rio Grande do Sul in 1986

[a] *Based on tone scale used by author in the field (see figure 5).*

Figure 2. Brazil is now the most important source of amethyst in the world. This map shows the location of the Alto Bonito (Marabá) and Pau d'Arco amethyst deposits in the state of Pará, and the Iraí and Santa Maria workings in the state of Rio Grande do Sul. Artwork by Peter Johnston.

one-hour drive by truck (a "taxi" service provided by the landowner) leads to the hillier region of Serra dos Carajás, where the amethyst is mined. The approximate geographic coordinates of the Alto Bonito amethyst deposit are 5°15′ S and 50°30′ W. Travel is advisable during the drier months, June to November, when temperatures range from 18° to 40°C (64° to 104°F).

Occurrence. Alto Bonito lies within the broad Carajás mineral province (Collyer and Mártires, 1986), which also includes the famous Serra Pelada gold deposit. The amethyst occurs in a series of sedimentary and extrusive volcanic rocks of lower Proterozoic age (approximately 1.7 to 2 billion years old). Specifically, it is distributed irregularly in veins and cavities in highly fractured and folded

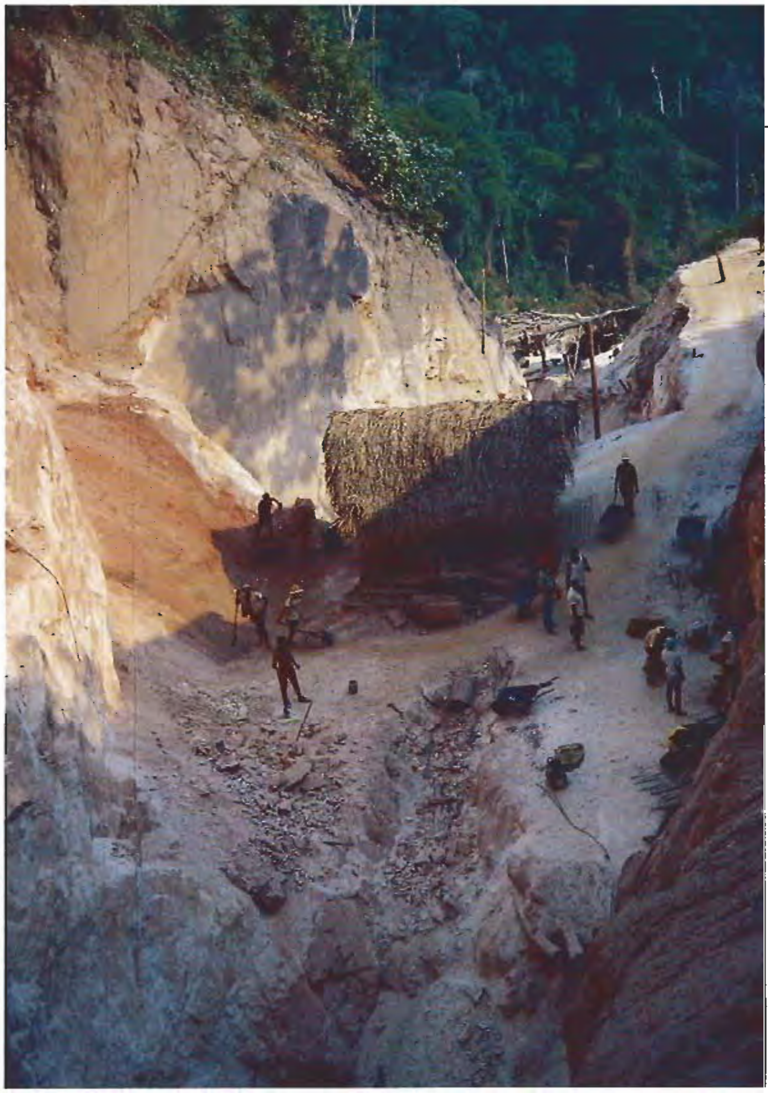


Figure 3. Both white quartzite and reddish quartzite are evident in this photo of an amethyst-mining operation at Alto Bonito, near Marabá, in the state of Pará.

layers of quartzite, a tough, siliceous, metamorphosed sedimentary rock. Two kinds of quartzite, which differ primarily in color, can be recognized in the field (figure 3). One is white or light colored, and the other is more reddish due to staining by hematite and other iron oxides. Collyer and Mártires (1986) report that amethyst occurs with greater frequency in the reddish quartzite.

The veins may reach a meter in thickness and vary greatly in length. The cavities are oval or elongate and may reach a diameter of several meters. In both the veins and cavities, the amethyst occurs as tightly packed crystals that range up to half a meter long.

History. In mid-1981, workers for the family of Pedro Miranda found fragments of amethyst crystals scattered on the ground at Alto Bonito. Because the fragments were of poor quality, and no one in the area had any knowledge of amethyst, this find remained unexploited for over a year until a prospector from Bahia, Manuel Xavier, saw the material and recognized its cutting potential. Xavier began the first amethyst diggings in the Marabá area.

These early workings were simple pits that reached a depth of only 2 to 3 m and were soon exhausted. Subsequently, José Miranda Cruz, the eldest of six Miranda sons, initiated a more organized exploration and recovery of amethyst. He built houses for the miners, and later a general store, school, and other facilities to sustain a community of several hundred persons. He also initiated the use of mechanized equipment so that the workings could be extended underground. At Alto Bonito there are currently 22 *barrancos* (shafts or tunnels) spread over an area of approximately 500 m^2. Each has numerous owners and partnerships, who pay 10% of the value of the recovered amethyst to the landowners for the opportunity to mine.

Mining Methods. The majority of the mining is done with picks, shovels, buckets, jackhammers, and occasionally small amounts of dynamite. Vertical shafts and horizontal tunnels are excavated to follow the veins of amethyst, and are reinforced with timbering taken from the surrounding forest. Electricity for lighting and ventilation systems are added as needed and as money is available. During my visit I was able to explore a number of these workings and experience some of the trauma and excitement of the amethyst miner firsthand.

To reach the first level of the Paulinho *barranco,* I was lowered by rope 20 m into almost total darkness. I then walked about 5 m along a tunnel to another opening, where two miners lowered me another 30 m. The lack of oxygen made breathing difficult, and the danger of the fragile walls collapsing was everpresent. At the bottom of this shaft were a few simple picks and a lantern. The tunnel followed a vein of amethyst that had been quite broad and of good color at the top, but here was very narrow and pale. The miners had been rewarded for their efforts at these depths, however, by the discovery of some richly colored amethyst in cavities—up to 1 m in diameter—embedded in the walls of the workings.

The next *barranco* I visited, known as the

Figure 5. In the field, the author uses an informal tone scale to grade amethyst. This photo represents tone values 2 (extremely pale pink) through 9 (deep purple) on the author's scale (tone value 0 would be colorless and tone value 10, black). On this scale, the amethyst must be a tone value of 4 or higher to be considered cutting quality. Stones courtesy of Samuel Goldowsky, Bob Bryan, and Simon Watt; photo © Tino Hammid.

Figure 6. In general, the amethyst from Marabá is less saturated than that from Pau d'Arco and Rio Grande do Sul. These fantasy cuts were fashioned by the author from Marabá amethyst. The largest stone is 28 ct. Photo © Tino Hammid.

make the amethyst from this area of great commercial importance. These include the uniformity of color (or regularity of color banding in banded material), the clarity and classic shape of the crystals, the unusually large size of unflawed sections, and the large production.

PAU D'ARCO

This area, which produces some of the best amethyst available today, is about 250 km south of Marabá, on the western bank of the Araguaia River (again, see figure 2). The approximate coordinates are 7°32′ S and 49°23′ W. It can be reached from Marabá by taking a rough paved road southeast and then a barge across the Araguaia River to the town of Xambioá. From here, one continues south-southeast through the city of Araguaina and then southwest by a new paved road for 100 km, and by dirt road for 65 km, to the town of Pau d'Arco. The actual mining village, Villa Esperança, is approximately 6 km south of Pau d'Arco on the west side of the river. This final leg of the journey requires recrossing the Araguaia River by a 7–9 passenger motorized rowboat at Pau D'Arco. Public transportation is available from Marabá, but is very primitive. A journey that might take eight hours by car could take 21 hours by public transport.

Villa Esperança, which has approximately 250 inhabitants, is situated at an elevation of about 200 m above sea level. As with Marabá, it is best to visit during the dry season, June to November. Malaria is common in this area.

Figure 4. Veins of amethyst line the walls of this tunnel at Alto Bonito. Because the air is so thin, the miners operate in groups of three, with one man working while the other two rest.

Penhão, was about 200 m deep. It had been constructed into six different levels, each connected by vertical shafts. The descent into this system of workings seemed endless, until suddenly the shaft opened up into a large cavern, about 25 × 20 × 25 m. As in many of the tunnels, sections of large amethyst cavities and veins could be seen in the walls and ceiling of this natural cavern (figure 4). At this depth the air contains very little oxygen, and the ventilation equipment in these rudimentary mining operations is inadequate. Consequently, the miners work in shifts, with one man digging while two others rest.

The last tunnel I entered was that of Ze Liete. After walking several meters, I realized that I was standing inside the remains of a giant amethyst cavity. Such cavities may contain single crystals up to 15 kg, although these large crystals rarely contain much cuttable material.

Production. Buyers purchase amethyst directly from the various tunnel owners and cobb it (i.e., remove unwanted material from the crystal) either on site or at some distant location to produce gem rough. Table 2 provides some rough estimates of the quality and quantity of amethyst produced monthly at Alto Bonito in 1985 (Collyer and Mártires, 1986). Accurate estimates of the amethyst reserves at Alto Bonito are not available, but I observed material in place in the underground workings that would require one year's mining effort to recover. To date, there has been no systematic exploration of the surrounding area for additional occurrences of amethyst.

Description of the Amethyst. It is convenient to describe the color of gem amethyst from Brazil in terms of a tone scale (similar to that taught in the GIA colored stone grading course) that ranges from 0 (colorless) to 10 (black). Figure 5 provides a general idea of the range represented by tones 2 to 9 on this scale; cutting-quality amethyst generally has a tone value of 4 or greater. Although table 1 indicates that 5% of the monthly production at Alto Bonito is represented by good-quality, faceting-grade material, only 1% to 2% of the total production consists of pieces of amethyst that would yield a tone 7 in cut stones 19 ct or larger. Smaller cut stones rarely attain the darker tone values.

On average, the amethyst from Marabá is less saturated than that from the other localities discussed here (figure 6). Other factors, however,

TABLE 2. Estimated monthly production of amethyst at Alto Bonito, Pará, in 1985.[a]

Type of amethyst	Average monthly production (kg)	% of total production
Good quality (facet grade)	300	5.00
Reasonable quality (facet grade)	500	8.33
Tailing (carving/tumbling grade)	3,800	63.33
Samples and collector pieces, druzes	1,400	23.33
TOTAL	6,000	100.00

[a] *Adapted from Collyer and Mártires, 1986.*

Occurrence. In contrast to the primary deposits at Marabá, amethyst occurs at Pau d'Arco only in secondary, alluvial deposits (figure 7; Cassedanne, 1986). The crystals are unusually large: 20 kg pieces are not uncommon and crystals as large as 40 kg have been found. According to geologists who have studied this area (B. F. Filho, O. B. Ferreira, and R. A. C. Mártires, pers. comm., 1987), it is likely that the amethyst was transported from the same mountain range in which the Marabá amethyst is found. Recently, other amethyst deposits have been noted in this range (Cassedanne, 1988 a and b).

History. According to local miners, amethyst was first discovered at Pau d'Arco during a boar hunt sometime in 1979. In their efforts to capture a boar that had escaped into a narrow burrow, the hunters started digging to widen the opening. The boar ransomed its life when the hunters were diverted by a large crystal of fine amethyst. The quality of the crystal was confirmed at Xambioá, itself a source of fine amethyst at that time, and miners began the rush to Pau d'Arco.

The first year or so of mining activity produced only a few of these large amethyst crystals. Then production picked up, until it reached its peak between 1982 and 1984 (B. P. de Alcontara, pers. comm., 1987). Throughout this period, most of the mining was by *garimpeiros*, independent miners, none of whom had registered their claims with the government. In December 1985, a company named Mineração Conceição Araguaia obtained the rights to explore the area and mine for amethyst. Local *garimpeiros* were furious, and violence followed. Eventually, an accord was reached whereby the local miners could continue to work on a portion of the property. The company brought in water cannons, heavy equipment, and professional geologists, but after much earth moving, the amount of

Figure 7. Mounds of gravel and other sediments mark the Pau d'Arco mining area, where loose crystals are found in secondary, alluvial deposits.

Figure 8. Picks and shovels are used at Pau d'Arco to remove the various layers of dirt and gravel that cover the amethyst-producing layer. The pits average 4 m wide × 7 m long, and usually reach 2–3 m deep.

good quality amethyst recovered could not support costs and the project was halted (O. B. Ferreira, pers. comm., 1987). Currently, amethyst mining has reverted to simpler methods and a smaller scale, where individual miners or groups of miners will work a particular area. Most of the residents of Villa Esperança are involved in amethyst mining.

Mining Methods. Amethyst is currently recovered at Pau d'Arco from pits and tunnels. The pits (figure 8) average 4×7 m and are only 2–3 m deep. Because the water table is so high, these pits may contain water much of the year. The pit miners recover the amethyst by digging downward with picks and shovels into the various layers of sediments until a productive one is reached, typically from 1 to 3 m below the surface. They then remove all of the rocks and sediments in this layer and subsequently wash them to reveal the amethyst.

In contrast, tunnels are excavated 3–5 m below the surface, where a thick, hard layer overlies the amethyst-bearing alluvium and provides support. The author saw no evidence of electrical generators during his visit; the tunnel miners work only by candlelight. They dig the material out with picks and shovels, hoist it to the surface, and then wash and sort it.

Each group of miners has its own prospect pit or tunnel. Often several pits or tunnels are clustered in a single productive area called a *mansion*. The amethyst workings at Pau d'Arco currently cover an area that is approximately 1.5 km^2.

Production. Amethyst production at Pau d'Arco was relatively constant at about 7,000 kg per year in 1985 and 1986 (S. H. S. de Matos, pers. comm., 1987). There are no estimates available of potential reserves. All amethyst is sold as rough, not cobbed; production usually is brought into the village daily and sold to buyers from Minas Gerais. Except for a very small quantity that is sent to Japan, most of the amethyst is faceted in the Minas Gerais gem centers of Governador Valadares or Teófilo Otoni. It is difficult to estimate the percentage of amethyst recovered that is suitable for cutting. However, most of the stones that are faceted are less than 2 ct when finished, although larger stones—over 50 ct—have been cut.

The best amethyst from Pau d'Arco rivals the finest African amethyst in intensity and saturation (figure 9). However, the color in the rough may be quite unevenly distributed, and requires care in orientation by even an experienced cutter. Color zones of bluish and reddish purple can often be seen in the rough, even in the same piece, in a pattern that is quite different from the distinct spots or bands of color in African or other Brazilian amethyst. The tone of the Pau d'Arco amethyst can be so dark that even 1-ct stones may appear black.

Figure 9. Pau d'Arco produces some of the finest amethyst, in terms of hue and saturation, in the world. This 14-ct stone was cut by the author. Photo by Robert Weldon.

At its best color and when properly cut, the material has a velvety violet body color and projects red flashes from the pavilion facets. The smaller stones make fine calibrated goods.

RIO GRANDE DO SUL

Rio Grande do Sul, the southernmost state of Brazil, borders on Uruguay and Argentina. In fact, the Uruguayan amethyst deposits are continous with these of Rio Grande do Sul. Within the Paraná basin, in the northern part of the state, is the longest continuously producing amethyst-mining region in Brazil. Paved roads are available from Porto Alegre to the mining areas. Amethyst is found in numerous places in the state, but these many occurrences are of similar geologic setting. In the following descriptions details will be given on two typical occurrences: Santa Maria (160 km west of Porto Alegre) and Iraí (375 km northwest of Porto Alegre).

Geology and Occurrence. About 130 million years ago, this region experienced extensive volcanic activity, which produced massive lava flows that are horizontal for the most part but do follow the topography (A. A. Muller, pers. comm., 1987). In some of these flows, now hardened to a black, fine-grained basalt, amethyst is found. The most productive basalt layer, 2 to 5 m thick, is located at an elevation of 300 to 350 m above sea level.

Amethyst occurs as crystals in geodes in the basalt (figure 10). The geodes probably represent pockets of gas that was released from, and trapped in, the lava as it cooled. They are distributed randomly within the host rock, commonly in the shape of elongate, rounded tubes. Typically these geodes are less than 1 m in diameter, but geodes exceeding 3 m have been found.

Almost invariably, the geodes exhibit an outer "skin" of celadonite, a green, micaceous, iron-silicate mineral; inside this is a layer of colorless quartz or agate. Amethyst is found clustered in the center of some geodes in crystals up to 10 cm long; other geodes are filled entirely with agate.

Miners at Rio Grande do Sul also use the presence of celadonite as an indicator of amethyst. Since celadonite is an iron-rich mineral, and the amethyst color requires iron, one expects to see amethyst in iron-rich zones. Nodules of solid celadonite 2–8 mm in diameter often precede small, 0.5–1.5 cm, geodes of crystalline quartz with celadonite rims and reddish (presumably iron-rich) bands around the geode (figure 11). As the miners continue in the direction in which the quartz geodes occurred, the first indication of an amethyst geode is a rounded, green, celadonite-

Figure 10. In Rio Grande do Sul, the amethyst occurs in vugs or geodes within basalt. As evident here, sometimes the amethyst completely fills the cavity; other times it simply lines the inner surface.

Figure 11. At Rio Grande do Sul, small (2–8 mm in diameter) celadonite nodules often precede 0.5–1.5 cm geodes of crystalline quartz with celadonite rims. These small quartz geodes commonly lead miners to the larger, amethyst-filled geodes for which this locality is known. Photo by Robert Weldon.

coated nob of rock sticking out of the gray-black basalt. Those geodes that contain the thickest celadonite layers have been found to be richer in amethyst (A. A. Muller and H. M. Santos, pers. comm., 1987).

History. In about 1820, immigrants from the Hunsrück region near Idar-Oberstein, in what is now West Germany, arrived in Rio Grande do Sul and settled the area between the Taquari and Jacuí Rivers. When occurrences of amethyst and agate were found shortly thereafter, about 1825, these immigrants recognized the economic potential and began shipping the rough material to Idar-Oberstein (Gonçalves, 1949; V. R. Sudback and B. Munsteiner, pers. comm., 1987). Descendants of these early immigrants are the current landholders in this area of Rio Grande do Sul. Although some of the original landholdings were quite large, subdivision among family members over several generations has resulted in the current situation whereby most private parcels are less than 50 acres.

Figure 12. Before cutting-quality amethyst is sold on the open market, pale-colored or fractured sections are usually broken off with a small hammer in a procedure called "cobbing."

Although mine ownership in Rio Grande do Sul is similar to that in other areas of Brazil, there are some important differences. With the tacit approval of the government, small landowners usually retain the mineral rights without filing the necessary documents. Some families work the diggings themselves, and rent a bulldozer or jackhammer as necessary. More commonly, a landowner will arrange with a second party, often a gem merchant, to underwrite the costs of exploration and mining. The landowner usually receives 25% or more of the production profits, a higher percentage than in other parts of Brazil because the land is more valuable for cultivation. Often, the second party will buy out the original landowner to retain all of the profits.

Mining Methods. Amethyst mining in Rio Grande do Sul may be carried out with simple hand tools, or with heavy equipment and explosives. Open-pit mining is most common, although other methods are also used.

In 1969, a local miner at Iraí, Alberto Lemos de Moraes, decided to try recovering amethyst by underground mining of those portions of the massive basalt that were not broken by fractures and were still unweathered; here is where the greatest number of intact amethyst-lined cavities are encountered (A. Lemos de Moraes, pers. comm., 1987; again, see figure 10). Lemos de Moraes used explosives and power tools to remove the dense rock, eventually extending the tunnel to 60 m. Hand tools are used to chisel the amethyst geodes, intact if possible, out of the basalt. Because the basalt is so hard, removal of a large, intact amethyst geode may take as long as a week.

At some of the mines, the amethyst crystals are often sold before they are even removed from the ground. Once a geode is located, a small hole is punctured in the surface and a light is lowered into it. The potential buyer then attempts to assess the quality and value of the amethyst crystals, and a price is negotiated. The geode is then chiseled from the host rock in as intact a condition as possible, which gives the buyer the option of selling it as a mineral specimen or cobbing the individual crystals for cutting rough.

Cobbing of amethyst crystals to remove unwanted material is usually done off the mine site. The person doing the cobbing sits at a bench under a strong incandescent light, holds the crystal on a metal plate, and then strikes it with a small

Figure 13. Amethyst from Rio Grande do Sul is often of excellent color, though a bluish rather than reddish purple. Because the amethyst commonly occurs in vugs or geodes, it is also popular as mineral specimens. This radiated amethyst slab, with an agate center, is from Iraí. Photo © Harold & Erica Van Pelt.

hammer to break off fractured, poor-colored, or included sections (figure 12).

Production. In 1986, official government statistics indicate, 4,152 kg of cobbed amethyst, 14,752 kg of cobbed citrine (produced by heat treating amethyst), and 155,560 kg of mineral specimen material were exported from Rio Grande do Sul (A. A. Muller, pers. comm., 1987). Indeed, most of the amethyst specimens on the market today come from Rio Grande do Sul. The vast majority of the cobbed amethyst exported is shipped to Idar-Oberstein for cutting.

Faceted amethyst from this area can reach a tone 7 value (again, see figure 5) in stones of about 10 ct, and a tone 5 or 6 value in stones of 1–9 ct. Faceted amethysts from Rio Grande do Sul average 3–7 ct; that is, they are smaller than the average stones from Marabá but a bit larger than those from Pau d'Arco. The Rio Grande do Sul amethyst is often bluish rather than reddish (figure 13), which may distinguish it from amethyst found in other areas. The color rarely has any brownish tinge, but it can be slightly grayish.

Santa Maria. One of the most interesting mining areas within Rio Grande do Sul is near Santa Maria, the state capital. Located in the center of Rio Grande do Sul, Santa Maria is a well-ordered town of some 200,000 inhabitants that is easily accessible by various modes of transportation.

In the early 1930s, German gem dealers visited this region looking for amethyst. They were surprised to find crystals scattered on the ground in several places. After negotiating agreements with local landowners, they began to mine using picks and shovels. Recovery of amethyst in this area has continued up to the present day (S. Klein and J. C. Moto, pers. comm., 1987).

We visited the mine of Siegfried Klein, about 20 km outside of Santa Maria, which had been worked for amethyst intermittently since the

Figure 14. At Iraí in Rio Grande do Sul, a tractor is used to remove much of the hill in which the amethyst-bearing basalt layer is found, 30 m below the original surface.

arrival of the German merchants over 50 years ago. One pit that four miners had recently opened with simple picks had yielded thousands of loose crystal sections of amethyst geodes. In fact, during the first week that this deposit was in production, about 1,000 kg of amethyst were recovered, of which about 200 kg were specimen or cobbing quality; these 200 kg might yield 5 to 10 kg after being cobbed. It was an unusually large find for the first week's production.

Amethyst Mining at Iraí. The town of Iraí is situated in the extreme northern part of Rio Grande do Sul, near the border with the state of Santa Catarina. The topography consists of gently rolling hills and the climate is quite mild, making this one of the loveliest regions in southern Brazil.

Amethyst was first found here in the 1920s. Revolutionaries fleeing from the Brazilian army hid along the banks of the Rio Uruguai. While foraging, they came across occurrences of amethyst near the future site of the town of Iraí. At present, this area produces approximately 200 to 250 kg of cobbed amethyst and 700 to 800 kg of cobbed citrine (i.e., heat-treated amethyst) per month (V. R. Sudback and A. Bortoluzzi, pers. comm., 1987).

I visited the Bortoluzzi-Fischer mines on a small hill near the outskirts of Iraí. Mines in Rio Grande do Sul are often named in this fashion for both the mine owner and the landowner. Unlike the relatively simple mining observed at Iraí, here 20 miners use highly sophisticated open-pit methods to recover the amethyst from a layer of basalt that lies 30 m below the present surface (figure 14). These men had worked, with a bulldozer, for an entire year to remove the hundreds of tons of dirt that covered the productive layer. At the basalt level, jackhammers, some explosives, and hand tools were used to locate and remove the amethyst-lined geodes. Some of these geodes weighed up to 100 kg, but many of the crystals were very dark.

Most of the other mines in this area consist of underground tunnels that are excavated into the hillsides surrounding the town of Iraí, to reach the productive layer of basalt. The tunnels average about 2 m in height and may be up to 5 m wide. The miners use explosives and hand tools to dig through the hardened lava. The longest tunnel I observed was about 60 m.

CITRINE PRODUCED BY HEAT TREATING AMETHYST

Citrine rarely occurs naturally, although some has been reported in Brazil (Sauer, 1982; Webster, 1983). Essentially all the citrine on the market today is created by heat treating amethyst (Webster, 1983; figure 15), particularly because lighter colored amethyst frequently becomes a more desirable color as citrine. Several treatment methods are used. At Marabá, amethyst is embedded in sand in wheelbarrows and then heated over wood fires to turn the stones yellow (figure 16). Samples are extracted at various intervals to monitor the degree of change in color. In the course of my

Figure 15. Virtually all of the citrine sold in the gem market today is created by heat treating amethyst. This approximately 15 × 20 mm citrine is actually Marabá amethyst that has been heated. Photo © Tino Hammid.

Figure 16. The heat treatment of amethyst to produce citrine at Marabá is simple but dramatic. The amethyst crystals are buried in sand in wheelbarrows and then heated over a wood fire.

travels, I noted that the temperature for a complete color alteration could vary from as low as 235°C to as high as 550°C, depending on the origin of the amethyst. When choosing amethyst for heat treatment, miners look for the presence of one or more bands of color with a rusty appearance that seems to indicate a high iron content. If the stone is going to turn yellow, it will do so before reaching 550°C.

In Rio Grande do Sul, the stones are placed in airtight ovens, sometimes embedded in a firmly packed powder or sand, and heated at approximately 450°–550°C for 45 minutes to two hours. The oven is then allowed to cool to room temperature (several hours) before the stones are removed. Citrine produced by heating amethyst from this area is often given the misnomer Rio Grande do Sul "topaz," especially in Brazil. The darkest material may display a strong brownish red color and approach the color of some garnets. When heat treating amethyst from Rio Grande do Sul, the miners look for particular features (e.g., a grayish band) that they know from experience will produce the best citrine color. More than 15 tons of cobbed citrine was shipped from this state in 1986.

Miners at Iraí reported that finding natural citrine is a once-in-a-lifetime occurrence. Like the amethyst from Rio Grande do Sul, the citrine occurs in geodes; sometimes several citrine geodes may be found in a particular section of the basalt. The miners theorize that these sections have been "heated" in the earth. Government geologists reported a recent find of natural citrine in the neighboring state of Santa Catarina.

Simple heating experiments with Pau d'Arco amethyst revealed that heating this material only lightens the color and may remove it altogether. Changes in color due to treatment are directly related to the chemical and physical properties of the individual piece of rough (Nassau, 1984). Within the same mine, however, pieces of rough with similar visible characteristics will usually react the same to treatment.

CONCLUSION

Several other localities in Brazil also actively produce amethyst. These include the states of Rio de Janeiro, Minas Gerais, Pernambuco, Ceará, Piauí, and Goiás (Cassedanne, 1988b). A number of workings can be found in Bahia.

The three Brazilian localities discussed in this article are among the three most active amethyst mining operations in the world today. Most of the Brazilian amethyst currently seen in the market is from these occurrences, with literally thousands of kilograms of specimen and faceting-quality amethyst produced annually. Significant amounts of this material are also heat treated to produce citrine.

Although formal estimates of amethyst reserves in Brazil are not currently available, it appears that significant quantities will be available for many years to come.

REFERENCES

Cassedanne J. (1986) L'amethyste de Pau d'Arco. *Revue de Gemmologie a.f.g.*, No. 89, pp. 12–15.

Cassedanne J. (1988a) L'amethyste au Brésil. *Revue de Gemmologie a.f.g.*, No. 94, pp. 15–18.

Cassedanne J. (1988b) L'amethyste au Brésil. *Revue de Gemmologie a.f.g.*, No. 95, pp. 3–9.

Collyer T.A., Mártires A.C. (1986) O depósito de ametista do Alto Bonito, Município de Marabá, Pará. Departamento Nacional da Produção Mineral, Belém.

Cox R.T. (1977) Optical absorption of the d^4 ion Fe^{4+} in pleochroic amethyst quartz. *Journal of Physics*, Vol. C10, pp. 4631–4643.

Crowningshield R., Hurlbut C., Fryer C.W. (1986) A simple procedure to separate natural from synthetic amethyst on the basis of twinning. *Gems & Gemology*, Vol. 22, No. 3, pp. 130–139.

Fritsch E., Rossman G.R. (1988) An update on color in gems. Part 2: Colors involving multiple atoms and color centers. *Gems & Gemology*, Vol. 24, No. 1, pp. 3–15.

Gonçalves A.D. (1949) *As Pedras Preciosas na Economia Nacional*. Grafica Olimpica Editora, Rio de Janeiro, pp. 97–100.

Lind Th., Schmetzer K., Bank H. (1983) Untersuchungsmethoden zur Unterscheidung von natürlichen und synthetischen Amethysten. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 32, No. 2/3, pp. 126–137.

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

Sauer J.R. (1982) *Brazil: Paradise of Gemstones*. Jules Roger Sauer, Rio de Janeiro.

Schmetzer K. (1985) Ein verbesserter Probenhalter und seine Anwendung auf Probleme der Unterscheidung natürlicher und synthetischer Rubine sowie natürlicher und synthetischer Amethyste. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 34, No. 1/2, pp. 30–47.

Schmetzer K. (1986) An improved sample holder and its use in the distinction of natural and synthetic ruby as well as natural and synthetic amethyst. *Journal of Gemmology*, Vol. 20, No. 1, pp. 20–33.

Webster R. (1983) *Gems: Their Sources, Descriptions and Identification*, 4th ed. Butterworths, London.

NOTES
• AND •
NEW TECHNIQUES

OPALS FROM OPAL BUTTE, OREGON

By Kevin Lane Smith

Recent mining at Opal Butte in northeastern Oregon has produced a wide variety of large flawless opals. The most common gem-quality varieties are hyalite and rainbow opal, but the less common play-of-color varieties contra luz, hydrophane, and crystal opal are economically more important. Fire, blue, and dendritic opal are also found. The opal occurs in rhyolite geodes embedded in decomposed perlite. More than 100 kg of material was uncovered from November 1987 through November 1988. The opal varies greatly in stability, but the finest stable material makes excellent carvings, cabochons, and even faceted stones.

The northeastern Oregon deposit of precious opal at Opal Butte has been known to collectors since at least 1892 (Kunz, 1893), but because of the inconsistency with which opal was found and the highly variable stability of the gem material itself, it was not considered to have significant commercial potential. Recent exploratory work, however, has established that there is enough stable gem-quality opal (figure 1) to make commercial mining feasible. In November 1987, West Coast Gemstones began the first systematic mining of this deposit.

LOCATION AND ACCESS

The mine is located on privately owned land in Morrow County, 35 miles (56 km) south of the town of Heppner. It lies on the western slope of Opal Butte, at an elevation of 4700 ft (1400 m). Opal Butte is part of the Blue Mountain Range, which covers much of northeastern Oregon. Snowy winters make mining possible only from May through November. Summers are quite dry, however, and temperatures up to 90°F (32°C) are common in July and August.

GEOLOGY AND OCCURRENCE

The dominant geologic features of northeastern Oregon are the extensive and voluminous Columbia River basalt flows. Erosional dissection of a northeast-trending anticline in this area has exposed an underlying series of early Tertiary (60–65 million years old) rhyolitic volcanic flows (Walker, 1977). The rhyolite geodes (popularly known as "thunder eggs") in which opal is found occur in perlite, the glassy basal vitrophyre of the rhyolite.

ABOUT THE AUTHOR

Mr. Smith is a consulting geologist for West Coast Gemstones and a free-lance designer, goldsmith, and stone cutter residing in Seattle, Washington.

Acknowledgments: Special thanks to Dale Huett, of West Coast Gemstones, whose expert mining has made this opal available. Thanks to Jim O'Donnell, Dick Graham, and other fine people of the Kinzua Corporation for their help and cooperation in establishing a mine at Opal Butte. Special thanks also to Whitney Alexander for continuous support, to Linda Brown for support and for typing the manuscript, and to Curt Wilson for generous assistance in compiling the gemological data. Woody Palmer provided invaluable information and encouragement at the start of this project.

All of the stones illustrated in this article were cut or carved by the author, who also designed and manufactured the two pieces of jewelry shown. Photos that are not otherwise credited are by the author.

Figure 1. *This faceted 105-ct contra luz opal represents some of the finest play-of color material found at Opal Butte, in northeastern Oregon, during the 1987–1988 mining season. Unlike the "normal" play-of-color typically seen in Australian opal, contra luz play-of-color is visible only with transmitted light. Photo by Stan Thompson.*

Locally, the perlite, a dark green, silica-rich rock, has been altered to a pastel clay. Opal-bearing geodes are found exclusively in the clay zones. This suggests that the hydrothermal alteration of the perlite to clay minerals is related to the opal deposition (Staples, 1965). No reports have been found of any other opal deposits in this area.

The geodes may contain one or more of the following: agate stalactites, quartz crystals (rarely), banded agate, common opal, or various types of gem-quality opal. Approximately 70% of the geodes contain no opal, 20% contain common opal, and 10% contain some gem-quality opal; less than 1% contain opal with prominent play-of-color. The play-of-color opal most commonly occurs in a 0.5–2.5 cm layer near the top of a partially filled geode (figure 2). The occurrence of opal in Oregon most closely resembles that of Querétaro, Mexico (Koivula et al., 1983).

The fact that the geodes differ greatly in content suggests that the temperature and/or composition of the mineralizing solutions varied considerably over time (Renton, 1936; Staples, 1965). About half of the geodes are lined with botryoidal agate and/or agate stalactites. On top of this agate layer in some geodes are alternate horizontal layers of agate and common opal. There was at least one major episode of common-opal deposition which completely filled many geodes. Almost every other geode, however, contains a unique sequence of layering. Some geodes contain convergent layers that indicate a tilt in the original beds of up to 10° during the mineralization sequence.

The geodes also vary greatly in size, from a few centimeters to well over a meter in diameter. Most of the smaller geodes have little or no empty space, whereas the larger geodes have cavities comprising up to 75% of their total volume. There is little correlation between the size of a geode and its opal content. We have observed, however, that the smaller geodes may contain all gem-quality opal, whereas the giant geodes contain mostly common opal.

MINING

Mining is by open-pit excavation with a backhoe. To the best of the author's knowledge, the West Coast Gemstones operation represents the first use of mechanized mining at this locality. At the present time, only two people do the actual min-

Figure 2. *A layer of opal with some play-of-color is evident in this typical partially filled geode (10 in.—25 cm—in diameter) from Opal Butte.*

Figure 3. Two people currently mine at Opal Butte: One operates the backhoe, while the other retrieves the geodes that have been dug out. This is believed to be the first mechanized mining ever conducted at this locality.

ing: One person operates the backhoe while the other retrieves the geodes (figure 3). After a few dozen geodes have been accumulated, they are carefully split to determine if they contain any opal. Most of the geodes contain natural fractures and can be opened easily without damaging much of the opal inside. Because so few of the geodes actually contain opal, it would not be economically feasible to saw each one open.

From November 1987, when mechanized mining first began, through November 1988, the mine produced a total of 100 kg of gem-quality material. Of this, 10 kg show definite play-of-color. Play-of-color opal is so rare that sometimes the miners may go as long as two weeks without finding any. The word that characterizes this deposit most succinctly is *unpredictable.* For this reason, it is difficult to assess its future potential. However, mining is planned for at least the next five years.

STABILITY OF OREGON OPAL

The opals found at Opal Butte vary tremendously in stability. Some of the material can safely be left in the sun immediately after being mined; other pieces craze thoroughly within a few minutes of being exposed to dry air. Most of the geodes are layered, and some contain one or more layers that craze badly while the adjacent layers remain intact.

Crazing occurs when stress is created due to shrinkage from uneven loss of water. If a freshly dug water-saturated opal is exposed to dry air, the surface may begin to dry and shrink. We routinely test the stability of the opal by taking one of the many pieces that may be found in a single geode and placing it outside (the balance of the material is wrapped in wet paper towels and sealed in plastic buckets). If after several days the test piece has not crazed, the rest of the opal from that geode is unwrapped and left at room temperature and dryness. If these pieces do not craze after two months, they are deemed stable. Of the opals that were stable after two months, more than 95% remained uncracked a year later.

Crazing can be prevented in some opals by carefully controlled or extremely slow drying, to avoid a steep moisture gradient between the surface and the interior by promoting even shrinkage. For example, if the initial test piece from a geode does craze, the remaining material is usually allowed to dry out slowly, at room temperature, over the course of eight or more months. This slow curing stabilizes about half of the material that initially crazed readily. The author has developed another method whereby some of the unstable material is packed in wet sand in covered Pyrex containers. These containers are then placed in an oven at 200°F. After the sand dries out, approximately two days later, the stones are left in the dry heat an additional 12 hours to firmly establish the outcome. Approximately 25% of the material treated by this method emerges uncrazed.*

---

*Tests still underway indicate that approximately 20% of the opals that do not make it through the oven without cracking would have become stable if put through the much longer room-temperature curing process.

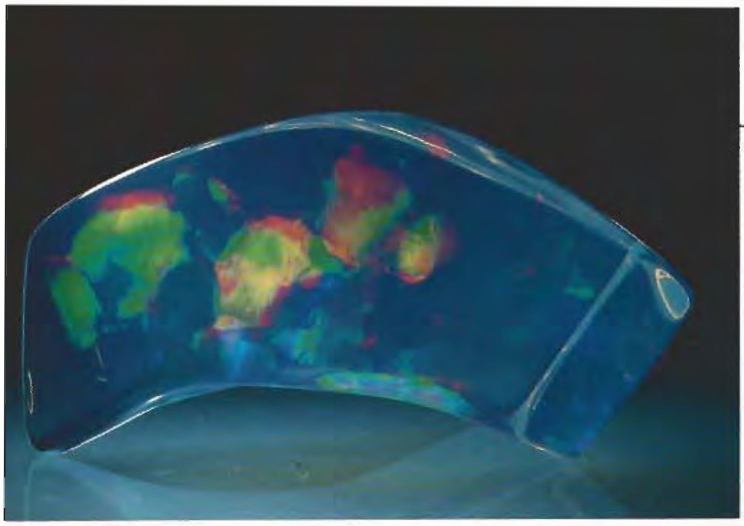


Figure 4. This 135-ct contra luz opal was found at Opal Butte in 1972. Note the large "harlequin" patches of color. Photo by Stan Thompson.

These methods will usually work as long as the opal is homogeneous in terms of water affinity. If some layer or zone in an opal holds water less tightly than another, however, differential shrinkage will cause cracking no matter how carefully it is cured. Even very stable opal may crack some if left on the matrix, because cracks may form near the interface between the opal (which may shrink some) and the rhyolite matrix (which will not shrink). Cracks near the opal/geode boundary generally do not propagate deeply into an otherwise solid opal, so matrix pieces can still be very attractive mineral specimens.

Considerable work remains to thoroughly evaluate the various techniques for stabilizing opal that at first appears to be unstable, but the assessment of the opal that is stable from the start appears to be very good. The author knows of three private collections with opals collected from this locality over 15 years ago that have remained stable. The flawless 135-ct contra luz opal in figure 4 was found in 1972.

It is not possible to predict with great certainty which opals will crack, and which will not, based on macroscopic appearance. However, some generalizations are made in the following description of the different types of opal found at Opal Butte.

VISUAL APPEARANCE AND GEMOLOGICAL PROPERTIES OF THE DIFFERENT OPAL TYPES

Several varieties of gem-quality opal have been recovered at Opal Butte. The rarest, those with distinct play-of-color, are referred to as contra luz, hydrophane, and crystal. The most common varieties are rainbow and hyalite, but fire and blue opal also occur, as well as a dendritic variety. Table 1 provides approximate figures on the relative abundance and stability of the various types of gem opal found at Opal Butte. Table 2 lists the refractive indices (flat facet readings) for the different types as well as their reaction to long- and short-wave U.V. radiation. In general, the opals vary in specific gravity from 1.3 for the lightest (dry) hydro-

TABLE 1. Approximate relative abundance and overall stability of the different types of gem-quality opal mined at Opal Butte from November 1987 to November 1988.

Type	Abundance[a] (%)	Stability[b] (%)
Contra luz	5	70
Crystal	2	60
Hydrophane	2	90
Contra luz/crystal	1	80
Rainbow	25	90
Hyalite	43	70
Fire	6	20
Blue	12	90
Dendritic	1	75

[a] *Percentage of the 100-kg of gem-quality opal mined during this period. The remaining 3% include hydrophane with no play-of-color.*

[b] *The percentage of the material of this type found that was stable when mined and has remained so over time.*

TABLE 2. Refractive index and reaction to ultraviolet radiation of the different types of Opal Butte opal.

		Reaction to U.V. radiation[a]	
Type	R.I.	Long-wave	Short-wave
Contra luz	1.44–1.45	Weak green	Very strong green
Crystal	1.45	Very weak green	Medium green
Hydrophane	1.43–1.45	Strong chalky bluish white	Very weak white
Contra luz and crystal play-of-color	1.44–1.45	Chalky white	Weak green
Rainbow	1.44	Weak green	Very strong green
Hyalite	1.45	Weak green	Very strong green
Fire	1.42–1.43	None	None to weak green
Blue	1.47	None	None to weak green

[a] *No phosphorescence was observed in any of the pieces tested.*

phane to 2.2 for the heaviest (wet) clear material. Similarly, they vary in hardness from 4 on the Mohs scale for the chalky hydrophane to 6 1/2 for the clear pieces. All show a conchoidal fracture, pearly to vitreous in luster. No reaction was visible with either the polariscope or the Chelsea color filter. The most distinctive properties of each type found at Opal Butte are described below.

Opal with Play-of-Color: Contra Luz, Crystal, and Hydrophane. About 10% of the gem-quality opal found at Opal Butte shows distinct play-of-color. Half of this material is similar in appearance to Mexican contra luz opal (Leechman, 1984). The play-of-color is only apparent in transmitted light and most commonly occurs in a pinfire pattern, but harlequin (again, see figure 4) and other types (see figure 1) are also observed. Most of the contra luz opal is clear or very nearly clear, but white, orange, and yellow opal with contra luz play-of-color is also found. About 70% of the contra luz opal is stable to spontaneous crazing.

Almost half of the opal with "normal" play-of-color (i.e., that which is apparent with reflected light, as with most Australian opal), is clear or almost clear, and is referred to as crystal opal (figure 5). Sixty percent of this material is stable. Some pieces show both contra luz and "normal" (crystal) play-of-color.

Figure 5. The finest piece found at Opal Butte in 1988 is this 315-ct crystal opal. Photo by Stan Thompson.

The remaining half of the opal with "normal" play-of-color is referred to as hydrophane; that is, it is exceptionally porous and does not hold water tightly. Hydrophane may be either clear or white when saturated with water, but the clear material turns white when dry (figure 6). Unlike the hydro-

Figure 6. This 145-ct hydrophane opal is clear when wet (here, having been soaked in glycerin), as evident on the left, and white when dry, as photographed on the right. Good play-of-color is seen in both conditions. The photo on the left is © Tino Hammid; the one on the right is by Robert Weldon.

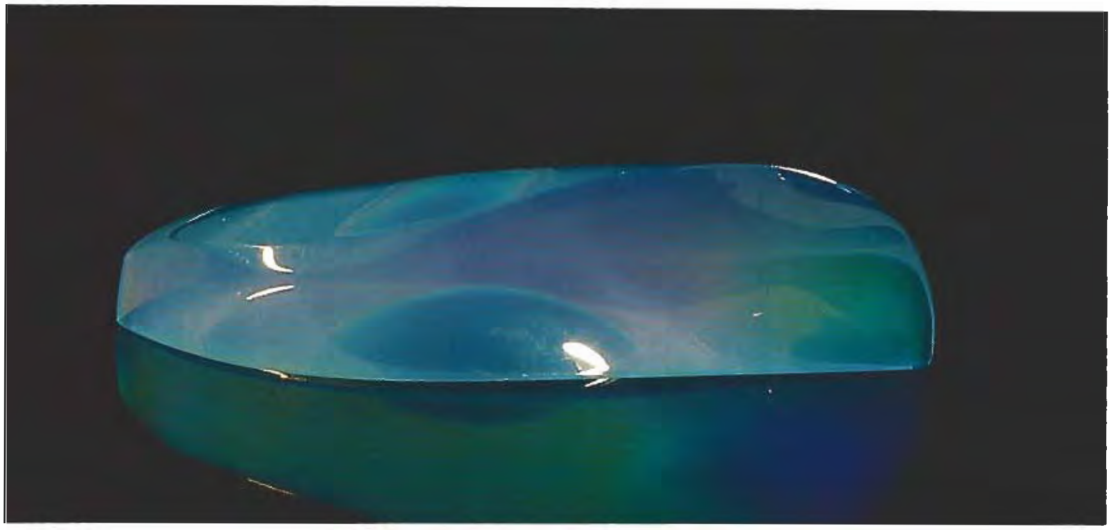


Figure 7. Rainbow opal represents 25% of the gem-quality opal mined at Opal Butte. This material glows soft hues as light passes through it. Note the different colors in the reflected image of the 62-ct rainbow opal carving as compared to the actual stone. Photo by Stan Thompson.

phane described in Bauer (1969), this material has good play-of-color both when clear and when white. The hydrophane that is white when wet is not only more porous and softer than the clear hydrophane, but it is also less likely to crack when it dries. Some of the clear hydrophane is unstable when wet but becomes stable when it dries out. Conversely, some white hydrophane may crack if suddenly immersed in water. Resorption of water occurs quite readily: A dry stone takes only a few hours to become completely saturated. You can distinguish most hydrophane from other opals by touching it with the tip of your tongue, which will stick to dry hydrophane.

Figure 8. Rainbow opal is particularly well suited to faceting, as evidenced by this 27-ct stone. Stone courtesy of Harold Johnston; photo by Robert Weldon.

The play-of-color in white hydrophane opal is usually stronger when the material is dry. Some of the clear hydrophane, however, has more brilliant play-of-color when it is wet. Thus far we have found no hydrophane at Opal Butte that has play-of-color when in water but none when dry. Over 90% of the hydrophane opal from this locality is stable.

Rainbow Opal. This material has a type of color play that makes the stone glow soft shades of the spectrum as light passes through it (figure 7). The colors change as the angle of illumination changes, with red light being bent more than blue light. Rainbow opal is about five times more plentiful than contra luz at Opal Butte, but the two types commonly are closely associated. In most geodes that contain contra luz opal, the contra luz overlies a layer of rainbow opal.

Rainbow opal has been the most consistently stable type of opal found at Opal Butte, and represents the largest flawless pieces (some more than 500 grams) found to date. Rainbow opal also lends itself well to faceting (figure 8).

Hyalite Opal. Hyalite is clear opal with no fire. This is the most abundant type of opal (other than common opal) found at Opal Butte. The best is a light ethereal blue that is well suited for faceting and carving (figure 9). When faceted, it reflects yellow light off the pavilion faces even though the body of the stone is light blue. Much of the hyalite opal contains zones or layers of orange. Several flawless pieces of blue hyalite weighing 300–500 grams were found in 1987 when mining began, but only one piece this size was uncovered in 1988. Most of the hyalite opal is stable.

Fire Opal. Orange and red opal similar to Mexican fire opal is also found at Opal Butte (figure 10). Unfortunately, most of the orange opal is unstable, crazing within minutes of exposure to air. The dark red material tends to be much more stable.

Blue Opal. A few geodes have been found to contain nearly opaque, dark blue opal. Although these geodes are rare, thus far they have been quite large. Most of this "blue" opal has a greenish tint, but some is pure blue. We found approximately 100 grams of this material that at first appeared to be opaque, but when backlit proved to be very translucent.

Dendritic Opal. Another rare feature in Oregon opal is the presence of manganese oxide dendrites. These dramatic inclusions may form as dense black spots or as delicately branching dendrites.

DISTRIBUTION AND CUTTING

Most of the high-grade play-of-color material from Opal Butte has been worked into finished jewelry or stone carvings by the author. Although some adjustments have to be made for the softness of the dry white hydrophane, the rest of the opal works very much like opal from other localities. High-dome cabochons are the most effective cut for

Figure 9. The best hyalite is light blue and makes excellent carvings and faceted stones. This 44-ct hyalite is mounted in a 14k gold pendant.

Figure 10. A small percentage of the gem-quality material found at Opal Butte strongly resembles Mexican fire opal. Although most of this material is not stable, this 113-ct dark reddish orange carving has proved to be.

displaying the contra luz play-of-color in jewelry (figure 11). Much of the material is suitable for doublets. Specimens on matrix as well as cutting-grade rough and cut stones are also marketed.

CONCLUSION

Although it does not occur in large quantities, the quality and diversity of Oregon opal gives it special gemological significance. Many interesting geologic and gemological questions concerning the physical properties and mode of occurrence of these opals remain to be addressed.

Figure 11. High-dome cabochons best reveal the play-of-color of contra luz opal in jewelry. This cabochon weighs 22 ct.

REFERENCES

Bauer M. (1969) *Precious Stones.* Tuttle Co., Rutland, VT.

Koivula J.I., Fryer C., Keller P.C. (1983) Opal from Querétaro, Mexico: Occurrence and inclusions. *Gems & Gemology,* Vol. 19, No. 2, pp. 87–96.

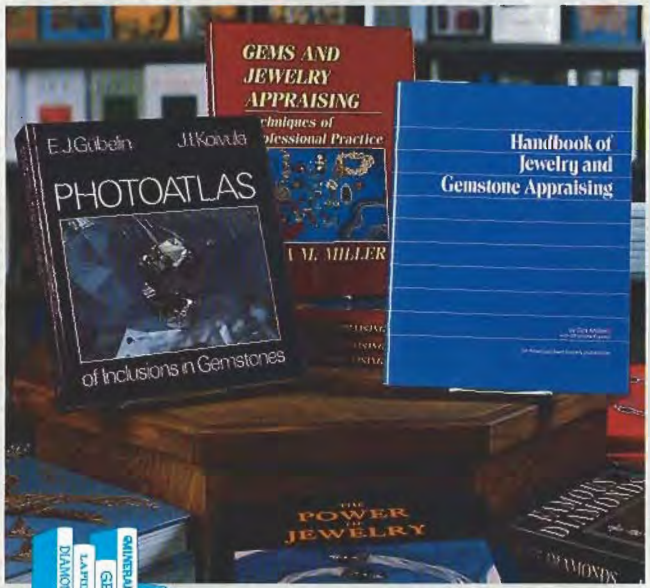
Kunz G.F. (1893) Precious stones. In D. T. Day, Ed., *Mineral Resources of the United States, Calendar Year 1892,* Government Printing Office, Washington, DC.

Leechman F. (1984) *The Opal Book.* Lansdowne Press, Sydney, Australia.

Renton J.L. (1936) Opal or agate filled "thunder eggs." *The Mineralogist,* Vol. 4, pp. 12, 46, 48, 50, 52.

Staples L.W. (1965) Origin and history of the thunder egg. *The Ore Bin,* Vol. 27, pp. 189–204.

Walker G.W. (1977) Geological Map of Oregon East of the 121st Meridian. United States Geological Survey, Department of the Interior.



A GEMOLOGICAL LOOK AT KYOCERA'S NEW SYNTHETIC STAR RUBY

By John I. Koivula and Robert C. Kammerling

Kyocera Corporation of Kyoto, Japan, is currently marketing under the trade name "Inamori" a macroscopically natural-appearing semitransparent asteriated synthetic ruby. With the exception of obvious internal characteristics and a relatively strong fluorescence to ultraviolet radiation, all of the gemological properties shown by this material are essentially the same as those encountered in natural star rubies. For the majority of gemologists without access to research-grade testing equipment, the internal characteristics of Kyocera's synthetic star ruby are the only universally reliable means of identifying this new product.

Since late 1986, Kyocera America Corporation's Inamori Gemstone Division has been marketing a number of new, high-quality synthetic materials under the trade name "Inamori." Until the introduction of this Inamori line, Kyocera was selling their synthetics only in a flawless grade under the trade name "Crescent Vert." According to Kyocera America's April 1, 1987, press release, "The new Inamori line will offer three grades [in some cases, two in others] with characteristic inclusions in response to customer demand for gemstones which more closely match the mined stone."

The two most interesting among these new offerings are the synthetic cat's-eye alexandrite (described in Kane, 1987, and Koivula et al., 1988), and the synthetic star ruby. Both are stated to be manufactured, "from a proprietary method," by their parent company, Kyocera Corporation, which is headquartered in Kyoto, Japan.

To provide the gemological community with information on their new product, Kyocera loaned the Gemological Institute of America five sample cabochons of this new synthetic star ruby for study. The results of this detailed examination are reported below.

DESCRIPTION

The largest round and oval stones supplied by Kyocera (figure 1) are well-polished cabochons that weigh 1.99 and 1.60 ct, respectively. The remaining three samples weigh 0.92 ct (oval), 1.46 ct (oval), and 1.95 ct (round). All five of the cabochons are semitransparent with flat, semi-polished backs.

Figure 1. Shown here are the largest round (1.99 ct) and oval (1.60 ct) cabochons of Kyocera synthetic star ruby studied for this report. Note the near-transparency and slightly imperfect stars.

When viewed with an overhead incandescent light source, all of the stones display relatively sharp and intense, white, six-rayed stars. Unlike the perfect stars of the Union Carbide ("Linde") synthetic star rubies, the Kyocera stars show very convincing imperfections, such as slightly wavy or broken rays, which make them appear much more natural (again, see figure 1). Some of the cabochons also exhibit less than perfect surfaces with slight pitting evident. The body color of these synthetic

---

ABOUT THE AUTHORS

John I. Koivula is chief gemologist and Robert C. Kammerling is general manager of technical development at the Gemological Institute of America.

Acknowledgments: The authors are grateful to Mr. Ken Takada, former director of the jewelry division of Kyocera America, Inc., for supplying the Inamori star rubies. Thanks also to Mr. Dino DeGhionno at GIA for his assistance in obtaining the specimens. Mr. Chuck Fryer performed the X-ray diffraction, Ms. Carol M. Stockton provided the chemical analysis, and Dr. Emmanuel Fritsch supplied the infrared spectroscopy. All photographs and photomicrographs are by John I. Koivula.

TABLE 1. The gemological properties of the Kyocera synthetic star ruby.

Properties that overlap those of natural star rubies	
Color	Slightly purplish red
Visual appearance	Very convincing body color with slight imperfections to the asterism
Refractive index[a]	Spot readings of 1.76–1.77
Polariscope reaction	Uniaxial optic figures
Pleochroism	Strong orangy red and purplish red
Color filter reaction	Bright red
Specific gravity	4.00 ± 0.02 using Clerici's solution with indicator
Absorption spectrum	Identical to the spectrum shown by natural ruby
Key identifying properties	
Ultraviolet fluorescence[b]	
Long-wave	Very strong red
Short-wave	Strong to very strong red with a moderate to strong superficial chalky blue-white overtone
Inclusions[c]	Extremely fine white-appearing exsolution rutile. Numerous bluish white smoke-like swirls. Both round and distorted gas bubbles.

[a] In their promotional brochure, Kyocera reports a more accurate refractive index reading of 1.762–1.770 with a corresponding birefringence of 0.008. This had to be taken on a flat well-polished surface which was not available to the authors of this report.

[b] Testing done in total darkness (darkroom conditions). Useful if known fluorescence comparison stones are used.

[c] Observed using fiber-optic illumination and/or shadowing.

rubies is a very natural looking slightly purplish red that compliments their near-transparency.

From the back, because of their flat, semi-polished bases, these synthetic star rubies "look synthetic." This is a cutting style gemologists have come to associate with synthetic star corundum similar to that produced by the Linde division of Union Carbide. Should these backs be roughed and rounded, however, without magnification they would look very natural.

GEMOLOGICAL PROPERTIES

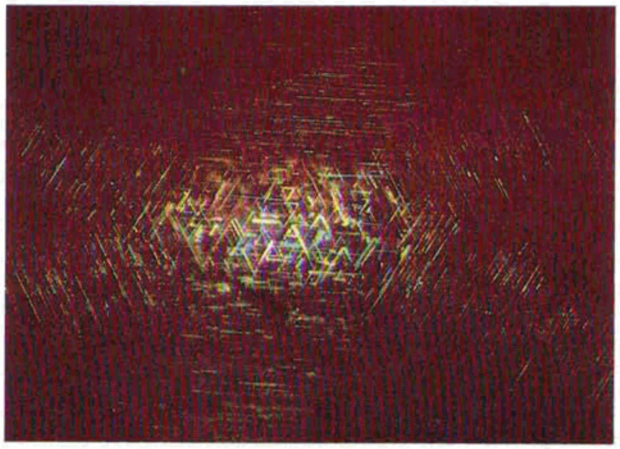
The gemological properties determined on these five samples agreed for the most part with those reported by Kyocera in their promotional literature. As indicated in table 1, with the exception of fluorescence and internal characteristics, the properties of the Inamori synthetic star ruby overlap those of their natural counterparts. The distinctive features are described below.

Reaction to Ultraviolet Radiation. When exposed to long-wave ultraviolet radiation, the Kyocera synthetic star rubies all fluoresced a very strong red. The short-wave reaction appeared to be slightly weaker with a variable (moderate to strong) superficial chalky blue-white overtone that was most obvious when the lamp was held very close to the stone and the room was in total darkness (darkroom conditions). No phosphorescence was observed in any of the stones. If rubies of known origin were used as indicators in fluorescence testing, perhaps this reaction would prove useful in providing evidence of synthesis.

Microscopy. When we examined the samples with a gemological microscope, the first thing we noticed was the fineness of the exsolution "rutile" needles (figure 2) when compared to the rutile

Figure 2. The exsolution needles that form the star in Kyocera synthetic ruby are extremely fine. Incident fiber-optic illumination; magnified 25×.

Figure 3. The star-causing exsolution rutile needles in this Burmese ruby are much coarser than those observed in the Inamori synthetic. Incident fiber-optic illumination; magnified 30×.



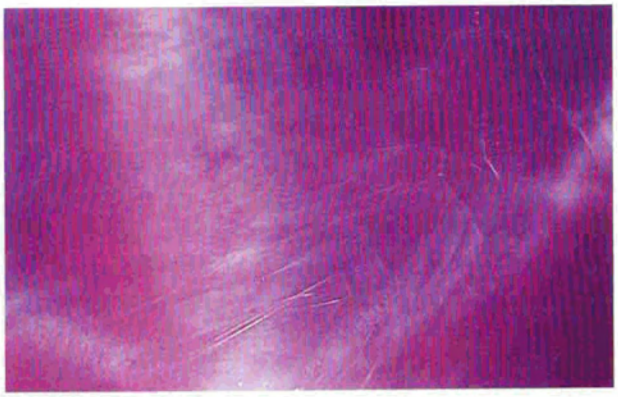


Figure 4. Present in all five specimens examined, these white smoke-like patterns, together with the fineness of the asterism-causing needles, provide proof of synthesis. Darkfield and oblique fiber-optic illumination; magnified 50×.

Figure 5. A crude hexagonal pattern seen through the apex of the 1.99-ct stone may be the trace remnant of a seed. Transmitted and oblique fiber-optic illumination; magnified 35×.

needles typically responsible for asterism in natural star rubies (figure 3).

When fiber-optic illumination was used, numerous smoke-like, bluish white, swirling wispy veils were seen running haphazardly between the star's rays (figure 4) throughout all five synthetic stones. These swirls are composed of white-appearing matter that is far too fine to be resolved with a standard gemological microscope.

Similar-appearing swirls have been observed in very poor quality Czochralski-pulled synthetic ruby and suggest that Kyocera's star rubies are crystallized from a high-temperature melt process, such as Czochralski pulling, rather than grown as euhedral crystals in a flux or hydrothermal environment. The absence of curved striae suggests that the flame-fusion process was not used. The 1.99-ct stone shows a crude hexagonal pattern through its apex that appears to be surrounded by swirls (figure 5) and may be the trace remnant of a seed.

Particularly distinctive of this synthetic is the presence of gas bubbles, both round and distorted. In shadowed transmitted light (figure 6) the swirls are observed as dark-edged wavy bands, while the gas bubbles, although small, stand out in relatively high relief.

We also noticed that one stone had a tiny chip with a pronounced conchoidal fracture. While this type of fracture can also be seen in natural rubies and sapphires, it is rare in natural stones because, when put under excessive stress, natural gems are more likely to separate along weak parting planes, leaving a flat break similar to a cleavage surface.

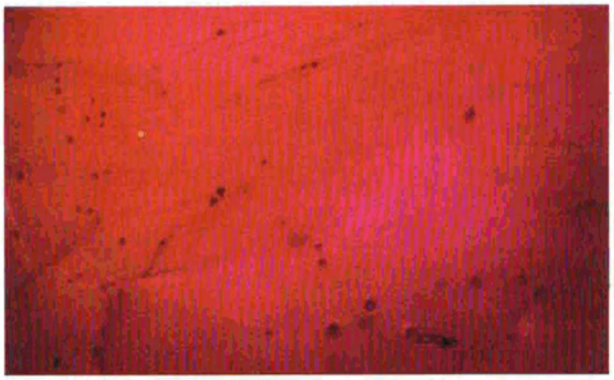
In general, the internal features in Kyocera's product in no way resemble the suite of characteristic inclusions recognized thus far in natural star corundums (Gübelin and Koivula, 1986). On the basis of their inclusions, these new synthetic star rubies are easy to distinguish from the natural.

INFRARED SPECTROSCOPY

Using a Nicolet 60SX Fourier-transform infrared spectrometer, Dr. Emmanuel Fritsch tested the mid-range infrared absorption characteristics of one of the synthetic star rubies (in a direction normal to the cabochon's base) to check for the possible presence of water within the structure. No structural water could be detected.

This lack of water adds support to the premise

Figure 6. In addition to the wavy patterns, small gas bubbles, both round and distorted, are sometimes observed. Shadowed transmitted light; magnified 50×.



that Kyocera's new synthetic star rubies are crystallized from a high-temperature melt using a process such as Czochralski pulling or Verneuil flame fusion.

QUALITATIVE CHEMICAL ANALYSIS

Ms. Carol Stockton examined one of the synthetic star rubies in GIA's Tracor Northern energy dispersive X-ray fluorescence unit to determine qualitatively what elements were present within the specimen's structure.

The cabochon was mounted, semi-polished base down, in a transparent Mylar-floored cup. The sample chamber was evacuated and the stone subjected to a tube voltage of 20 kV and a tube current of 0.10 mA for a 100-second measurement.

In addition to aluminum, traces of chromium (the color-producing chromophore) and titanium (the asteriating agent) were present, as expected. Very minor traces of calcium and iron were also detected and may be the result of a slight contamination in the feed chemicals. The fact that no gallium was found is a very strong indication of synthesis, since, in nature, aluminum-containing compounds such as corundum always contain traces of gallium. Oxygen, another major component in this chemical system, is not detectable with the Tracor unit.

X-RAY DIFFRACTION

To confirm the corundum identification, we asked Mr. Chuck Fryer to do an X-ray powder diffraction analysis on the sample material. A spindle of powder from one of the cabochons was prepared and mounted in a Debye-Scherrer powder camera. The resulting pattern matched the JCPDS standard for corundum, thus proving the identification.

CONCLUSION

This study of the new Inamori synthetic star ruby was based on an examination of only five polished cabochons. According to Kyocera's April 1, 1987, press release, the company is marketing only two grades of synthetic star ruby. These grades are designated "A" ("almost pure stones") and "B" ("very slightly flawed stones"). Both grades were represented in the samples studied by the authors.

Although very close, the key gemological properties, as listed by Kyocera in their brochure, are not in exact agreement with those obtained by the authors during testing. The properties listed in the brochure may reflect average values for a great number of stones.

With the exception of ultraviolet fluorescence and internal characteristics, all of the other gemological properties of these synthetic star rubies, such as specific gravity and refractive index, overlap with those shown by natural star rubies. Qualitative chemical analyses will also provide a positive identification, but the sophisticated equipment necessary is not readily available to the jeweler-gemologist. While ultraviolet fluorescence may provide a useful clue that the material is probably synthetic, the authors feel that this criterion alone is not sufficient to give a positive identification. Microscopy is the key to identifying Kyocera's new synthetic star rubies.

REFERENCES

Gübelin E.J., Koivula J.I. (1986) *Photoatlas of Inclusions in Gemstones.* ABC Edition, Zurich, Switzerland.

Kane R.E. (1987) Inamori synthetic cat's-eye alexandrite. *Gems & Gemology,* Vol. 23, No. 3, pp. 158–162.

Koivula J.I., Fritsch E., Fryer C. (1988) The gemmological characteristics of Inamori synthetic cat's-eye alexandrite chrysoberyl. *Journal of Gemmology,* Vol. 21, No. 4, pp. 232–236.

Gem Trade LAB NOTES

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

Imitation Dyed Black CHALCEDONY Beads

The West Coast laboratory received for identification a broken strand of black beads. Our client was curious as to why some of the beads had retained their high luster, while others had turned dull (figure 1). Spot refractive index readings of 1.54 on both the lustrous and the dull beads indicated that they might consist of the same material. Examination with overhead illumination showed the same small dull surface fractures, especially around the drill holes, in quite a few beads of both types. In strong transmitted light, however, the duller beads were semitranslucent with a brownish gray body color, while the lustrous beads remained opaque black. In the duller beads, transmitted light also revealed the parallel banding that is characteristic of the agate variety of chalcedony, as well as a very thin black layer that was missing in some areas. When tested with a cotton swab soaked with acetone, the black layer was easily removed.

Apparently these agate beads had been enhanced with a colored surface coating so that they closely resembled the dyed black chalcedony beads on the strand. Because this coating was susceptible to abrasion, some of these beads had lost their apparent luster and turned dull. As is to be expected with dyed black chalcedony, no dye could be removed from the lustrous beads. *KH*

Figure 1. Some of the beads in this 6-mm strand are dyed black chalcedony; the rest are brown agate that has been given a colored coating.

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

DIAMOND

Imitation Crystal

Separating cut and polished cubic zirconia from diamond is usually accomplished in a straightforward manner using standard tests. On occasion, the Gem Trade Laboratory examines cubic zirconia that is fashioned in the form of octahedral diamond crystals. Usually these imitations have an unnatural "sand blasted" appearance (see *Gems & Gemology*, Fall 1982, p. 169).

These clever cubic zirconia imitations (figure 2) were a puzzlement to one East Coast dealer. In fact, the dealer's cutter became alarmed at the rapid abrasion after he put one of the stones on the wheel. Careful fashioning of the material had produced "crystals" that appeared at first glance to have the morphology of diamond. They were excellent reproductions, especially with the "striations produced by laminar dissolutions of faces of an octahedron" (see Orlov, *Mineralogy of the Diamond*, John Wiley & Sons, New York, 1973, p. 91). However, standard gemological tests—including magnification, a specific gravity of approximately 5.85, and a typical fluorescence to long-wave ultraviolet radiation—proved that the two simulated crystals in figure 2 were actually cubic zirconia, a manufactured product. *DH*

With Radiation Stains

An approximately 0.75-ct round brilliant-cut diamond submitted to our West Coast laboratory for a quality grading report turned out to be one of the most unusual diamonds we have seen. This very pale, slightly yellowish green diamond showed numerous brown radiation stains in several prominent positions: one small one at the culet, two others at the girdle, almost exactly opposite each other, and the most remarkable ones

Figure 2. Cubic zirconia has been very cleverly fashioned to imitate rough diamond crystals. These two samples measure 10.21 × 7.88 × 7.38 mm and 8.50 × 7.30 × 6.96 mm, respectively, with a total weight of 15.19 ct. Magnified 10×.

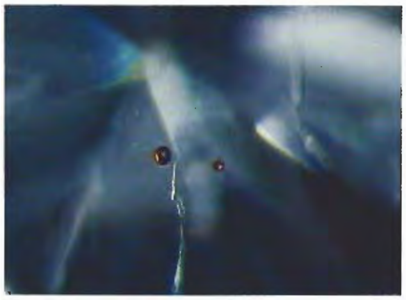


Figure 3. It is very unusual to encounter brown radiation stains on the table of a diamond. Note also the white void in the center of each stain. Magnified 50×.

Figure 4. Drag lines originating from the stains shown in figure 3 indicate that there probably were included crystals in these areas that were pulled out during cutting.

slightly off-center in the table (figure 3). The presence of stains in the table is what makes this stone so unusual.

At first glance, the two table stains resembled dark red garnet inclusions. When the stone was examined with higher magnification, however, both stains revealed cube-shaped white granular voids in their centers, with prominent drag lines originating from each (figure 4). When polarized light was used, strain halos, which usually accompany included crystals, became visible. These findings led us to conclude that the white voids had been crystals, possibly knots in the diamond, that were removed during the cutting process. The presence and cause of color of the stains remains a mystery.

Since radiation stains *per se* are an indication of irradiation, but not proof of whether the irradiation is natural or artificially induced, the origin of color of this diamond is currently undeterminable.

KH

Mysteriously Damaged

The Gem Trade Laboratory is frequently asked to determine if a flaw in a diamond is the result of recent damage to the stone. Usually, we examine fractures, chips, indented naturals, or similar questionable flaws. Occasionally, we are asked to report on a burned diamond. The burning of facets, which is usually caused by the use of a jeweler's torch on a dirty diamond or by excessive heat generated by the polishing wheel, will leave a very thin whitish area on the stone that is easily polished off with minimal weight loss. Damage resulting from exposure to a house fire is usually more severe.

The East Coast laboratory was recently asked to report on a 0.88-ct burned diamond. The 415-nm absorption line, medium blue fluorescence to long-wave ultraviolet radiation, and a positive reaction to the thermal reaction tester, all easily proved that this translucent white stone was diamond.

We have seen a large number of burned diamonds over the years, but never before had we seen anything quite like this. Although the heat damage permeated the entire stone, some of the original facets were still faintly visible. In addition, a circular indentation (figure 5) appeared to

Figure 5. There appears to be a "melted" indentation on the crown of this 0.88-ct burned diamond. Magnified 20×.

have been melted into the crown. Since diamond has only been observed to melt under very special and extremely difficult to achieve conditions, the real mystery is how to account for the depression in this stone. *DH*

Dyed GROSSULARITE

Among the dyed green gemstones frequently encountered as jadeite imitations are materials such as quartzite, chalcedony, serpentine, nephrite, and calcite. Off-color jadeite may also be dyed to improve its appearance. The green dye is easily identified with a spectroscope by the presence of a broad absorption band from approximately 630 nm to 670 nm. Green aniline dyes also usually produce a red color filter reaction.

Occasionally, we encounter the translucent naturally green (chrome-bearing) variety of grossularite garnet represented as jadeite. Recently, however, the East Coast laboratory was asked to identify a stone purchased as jadeite that proved to be dyed grossularite (figure 6). It showed the absorption band and color filter reaction characteristic of the usual dyed imitations. The refractive index of 1.72, the hydrostatic specific gravity of 3.70, and the orange X-ray fluorescence of the 6-ct oval cabochon proved that it was grossularite. *DH*

Figure 6. This unusual 11.25 × 16.28 mm grossularite cabochon was dyed to imitate jadeite.

Walrus IVORY

A GIA staff member brought to our West Coast laboratory a 3 1/2 inch (approximately 9 cm) high, slightly brownish yellow, artistically stained carving (figure 7). This carving, part of a complete chess set (figure 8), was supposedly made from mammoth ivory. We were asked to verify its identity.

Standard gemological testing methods readily identified the material as ivory. When we examined the piece closely, however, we noted that the basal surface showed the appearance of a cross-section of tusk and that the characteristic engine-turned effect present in all elephant ivory

Figure 7. This chess piece was carved from walrus tusk.

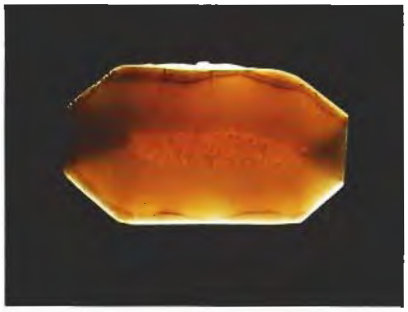


Figure 9. The base of the carving in figure 7 reveals the characteristic structure of walrus ivory.

Figure 8. The entire chess set was represented to have been carved from mammoth ivory.

was missing. In addition, very fine parallel layers of dentine surrounded a central area of spongy dentine that closely resembled the clot-like lacunae and canals in bone (figure 9). According to *Pictures of Ivory and Other Animal Teeth, Bone and Antler,* by T. K. Penniman (Pitt River Museum, Oxford, England), this cross-section is characteristic of walrus tusk. *KH*

CULTURED PEARLS

Irradiated

An unusually well matched rope of 9-mm gray saltwater cultured pearls (figure 10) was submitted to the East Coast laboratory to determine whether the color was natural or treated. The X-radiograph was normal, showing no evidence of dye. When we looked down the drill holes, however, we could see that the nuclei were dark, which proved irradiation.


Figure 10. The well-matched 9-mm black cultured pearls in this rope necklace were colored by irradiation.

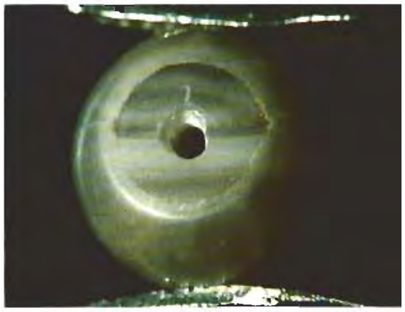


Figure 11. The darkened bead nucleus of this irradiated saltwater cultured pearl provides the color; the nacre is unaltered. Magnified 10×.

As mentioned in the Fall 1986 Lab Notes section, irradiation darkens freshwater shell, but not shell or nacre grown in saltwater. Figure 11 shows a loose saltwater cultured pearl that was exposed to gamma-ray irradiation. Notice the darkened freshwater shell nucleus, as compared to the unaltered color of the saltwater nacre.

The irradiation of freshwater tissue-nucleated cultured pearls results in a wide range of colors from blue-gray to black. Figure 12 shows that, in addition to imparting the dark body color, irradiation markedly enhances the orient in some cases. This effect contrasts with the fairly monotonous appearance of the dyed tissue-nucleated freshwater cultured pearls in figure 13. *RC*

Figure 12. Irradiation seems to enhance the orient of freshwater tissue-nucleated cultured pearls.


Figure 13. The monotonous tones and orient of these dyed freshwater tissue-nucleated cultured pearls contrast sharply with their irradiated counterparts in figure 12.


Pear-Shaped, Saltwater

Rarely has the Gem Trade Laboratory identified saltwater nucleated cultured pearls that were grown using other than round shell bead nuclei. On one occasion we were able to confirm the use of round plastic bead nuclei, which caused the pearls to feel light in weight; these cultured pearls evidently were grown experimentally and were never commercially produced. We also can recall two incidents many years ago when the nuclei of button, or lentil-shaped, cultured pearls proved to be lentil shaped. One can appreciate our surprise, then, when we determined that each of 10 pear-shaped cultured pearls spaced along a chain necklace had a pear-shaped nucleus. The nacre on some of the pearls was so thin that the straight bands of the shell bead could be seen easily by candling. The X-radiograph in figure 14 shows this rarity in three of the pearls.

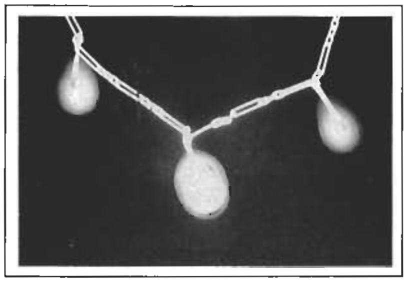
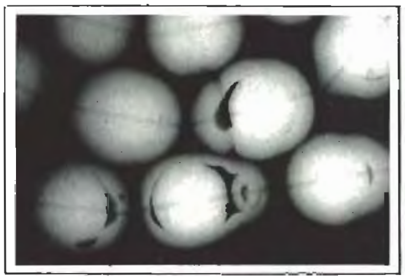


Figure 14. It is unusual to encounter pear-shaped nuclei in pear-shaped cultured pearls (here, approximately 9–10 mm long).

Figure 15. This X-radiograph shows both the nuclei normally found in pear-shaped cultured pearls and a rare tissue-nucleated growth that caused the nacreous layer to form a pear shape.



We have been told that the mortality rate of the host mollusks is greatly increased with the use of other than round nuclei. Another factor may be the added cost of manufacturing shell nuclei in lentil or pear shapes.

Ordinarily, pear-shaped saltwater cultured pearls have either a void or a concentration of conchiolin at the point. Less common are pear shapes without a void where the shape is caused by concentration of the nacre itself. The X-radiograph of another necklace that was also seen in the East Coast laboratory (figure 15) illustrates these types of pear shapes, as well as yet another cause of pear-shaped growth we had not seen before: what appears to be a large bead nucleus with a tissue-nucleated entity that has grown to form the point. *RC*

Large Flux-Grown Synthetic RUBY

Recently seen in the East Coast laboratory was an oval mixed-cut flux-grown synthetic ruby that weighed more than 17 ct. Previously, the largest cut stone of this material we had identified was about 12 ct. Assuming that, at best, recovery from flux-grown crystals would be 50%, this stone must have been cut from one weighing at least 30 ct. We have no record of the largest flux-grown synthetic ruby crystal produced to date, but this certainly would have to be considered for the title. *RC*

Synthetic SPINEL Represented as Topaz

It is not surprising to encounter synthetic spinel offered as a substitute for aquamarine or blue sapphire. Indeed, it has been used to imitate a number of stones.

Figure 16. Both of these synthetic spinels were originally sold as topaz. The stone set in the ring measures 11.0 × 6.8 × 7.5 mm; the loose preform measures 15.0 × 10.0 × 10.0 mm.

A manufacturer recently purchased a large quantity of blue "topaz," which he subsequently cut into preforms and then into cushion-shaped bent-top stones that he had mounted into yellow metal rings (figure 16). When a friend mentioned that the stones did not look "right," the manufacturer submitted them to the East Coast laboratory for identification. The "topaz" turned out to be synthetic spinel. The identification of synthetic spinel is relatively easy, with its very distinctive long- and short-wave ultraviolet luminescence, anomalous double refraction, and a refractive index of 1.728. *DH*

SYNTHETICS and "Modern" Gems in Period Jewelry

Over the years, synthetics have been set in jewelry for a variety of reasons. People who could not afford natural stones could at least enjoy the beauty of the less costly synthetics. Synthetics or other simulants have been used to replace more valuable stones that were either lost or removed to use the cash value when needed. At one time, synthetics were even set into fine jewelry as a proud symbol of scientific progress.

The fine platinum and diamond bracelet shown in figure 17, seen in our East Coast laboratory, was probably made during the 1920s. It is set

Figure 17. This 1920s-era diamond bracelet is set with synthetic as well as natural rubies.

Figure 18. Flux inclusions prove that this 6.9-mm "ruby," set in a ring inscribed with a 1922 date, is synthetic. Magnified 30×.

with flame-fusion synthetic rubies as well as with fine natural rubies with Burma characteristics. We do not know why synthetic and natural stones were mixed in this piece, but because of the ever-present possibility of mixed stones, it is always necessary to test all of the stones, even in an antique setting.

Evidence of tampering with a setting is the most common indication that a synthetic was used as a replacement stone. The stone shown in figure 18 was set in a lady's ring that also was submitted to our East Coast laboratory. Engraved in the shank of the ring is the date October 15, 1922. Although it is possible that this date could have been inscribed recently, it is not likely. As indicated by the reworked prong tip, as well as the flux inclusions shown in figure 18, a modern flux-grown synthetic ruby has been reset in this period ring. *DH*

FIGURE CREDITS

Figure 1 was taken by Shane McClure. David Hargett supplied the photos used in figures 2, 5, 6, 10, and 16–18. John I. Koivula is responsible for the photomicrographs in figures 3 and 4. The pictures used in figures 7–9 were provided by Robert Weldon. Robert Crowningshield took the photos of the X-radiographs that were used in figures 14 and 15. Clayton Welch did the photography for figure 11. Figures 12 and 13 were taken from the photo library on the West Coast. The photo of the dendritic diamond in the Historical Notes section was taken by Andrew Quinlan, while Mike Havstad supplied the photo of the eroded pearl.

A HISTORICAL NOTE

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

WINTER 1963

The New York lab discussed the bleaching and dyeing of both cultured and natural pearls. An explanation was offered for the several angled drill holes originating from the main drill hole on some pearls, that is, that they facilitate the treatment of certain areas between the nacre and the nucleus that can be reached through the drill hole. Also covered were the numerous variations on the standard brilliant cut that are commonly seen on fancy-shaped diamonds.

The Los Angeles lab was asked to identify some rough diamond fragments that the client hoped would prove to be synthetic. The material had been represented to be synthetic diamond made by a new process that could produce larger rough than had previously been manufactured. Examination with a microscope together with other tests revealed that the samples were natural bort.

This issue also included a detailed discussion of the methods used to estimate the weight of a damaged diamond, both before it was damaged and after recutting. By using table reflection size, crown angles, girdle thickness, and whatever other measurements are possible, one can arrive at a very close estimate of the weight of the stone before damage. Measuring the present size of the diamond will enable calculation of the size of stone that can be cut from it. Application of the appropriate weight estimation formula will lead to the estimated weight of the recut stone.

WINTER 1973

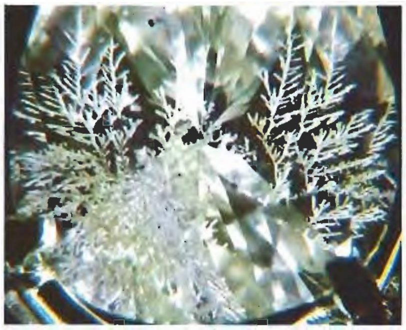
Laser drill holes in diamond, as well as the different types of damage that can occur as a result of improper setting, were covered by the New York lab. The section also included an account of the difficulties of testing carvings, as well as illustrations of several beautiful carvings.

The Los Angeles lab reported on a very unusual ring that could be turned to reveal a textured gold surface in one position and a lovely chrysoprase in the other. Other oddities discussed include pieces of amber imbedded in plastic, a coarse jadeite crystal as an inclusion in a cut stone, and some unusual glass beads. The appearance of two six-ray stars side-by-side in a star ruby was believed to be the result of the usual inclusions forming one star and twinning causing the second star.

WINTER 1983

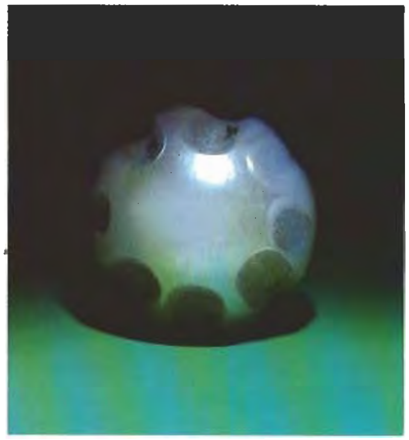
A very unusual dendritic diamond, mounted in an attractive pin, was encountered in New York. The inclusions were reflected throughout the 4-ct stone. The New York lab also saw a most unusual comet-design brooch set with numerous fancy yellow to yellow-brown diamonds, all of which fluoresced to ultraviolet radiation. The effect when seen by UV was one of a brilliant comet flashing across the night sky.

The dendritic pattern of this 4-ct diamond can clearly be seen. Magnification here is 12×.



Another item of interest was a severely eroded pearl, originally set in a ring, that was seen by the Santa Monica lab. The owner must have had an extremely acidic skin condition to cause this kind of damage. This should serve as a warning to all who wear pearls that they should clean them on a regular basis.

Severe erosion, probably caused by extremely acidic skin, has damaged this 8.5-mm pearl.



GEM NEWS

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

DIAMONDS

China. A new diamond-polishing factory has been set up by the Hong Kong–based jewelry firm of Chow Tai Fook in the city of Shunde, Guangdong Province. The new cutting facility will be fully operational as soon as the first 10 diamond cutters and polishers return from training courses in Thailand. Chow Tai Fook expects to increase the work force at this new plant to 300 workers in 1989.

Diamond mining activity in India. Mining and exploration are being carried out again in the ancient Panna diamond fields in northern India, reportedly due to the recent increases in the price of diamond rough. The government's National Mining Development Corp. does most of the mining, although some small plots have been leased out to private prospectors. Some of the diamonds mined by the government are sold at auction.

The Geological Survey of India has recently been exploring areas of the Panna district that contain pipe rocks, several districts of Andhra Pradesh, and the recently discovered kimberlites in the Anantapur district near Venkatampalle and Wajrakarur.

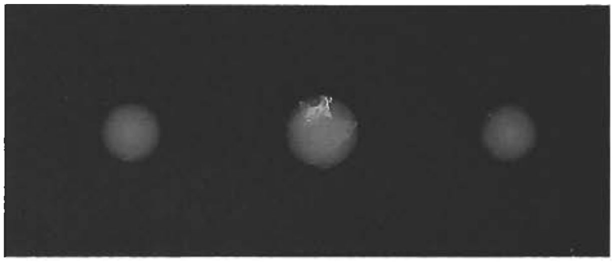
"Filled" diamond update. The Fall 1987 Gem News column reported on the filling of cleavages and fractures in faceted diamonds. The purpose of this treatment is to replace the air that normally fills such breaks with a transparent, essentially colorless substance that has a refractive index much closer to that of diamond, thus resulting in a less visible separation. At the time of this first report it was speculated that perhaps silicone was being used as the filling agent.

Recently, Robert Crowningshield and Tom Moses, of the GIA Gem Trade Laboratory, decided to investigate the possibility that X-radiography would reveal new information about the filled diamonds, since different materials exhibit varying degrees of transparency to X-rays. They subsequently obtained three diamonds known to be treated in this manner and did a standard X-radiograph on them using a lower voltage and current than is normally used on pearls. On the processed film (figure 1), the filled areas of the diamonds proved to be completely opaque to X-rays and appeared as distinct white areas. Next, because of the reports that silicone was involved, they coated an untreated diamond with silicone grease to see if the silicone coating would affect the X-ray transparency. It did not, so silicone was ruled out as the possible filling agent. Further work is now being done at GIA to determine what the composition of the filling material is.

India to synthesize diamonds. During the opening of a Soviet science exhibition in Bombay, Soviet delegates announced plans to teach Indian scientists how to synthesize diamonds for industrial and other uses. [**Editors' Note:** At present we do not know if this technological package includes the methodology required to synthesize gem-quality diamonds.]

Remarkable diamond. A natural diamond with highly unusual inclusions (figure 2) was recently examined by Anthony de Goutière of de Goutière Jewellers, Ltd., in Victoria, British Columbia. Mr. de Goutière at first suspected that these tube-like inclusions in the 0.06-ct round brilliant cut were the result of laser drilling. On further examination, he ruled out laser drilling because the tubes had brown radiation stains, their surface openings lacked the conical appearance normally associated with laser drilling, and drag lines extended from each of the holes (indicating that they were there when the diamond was last polished). His conclusion was further supported by the fact that no remnants of inclusions (i.e., the potential targets) could be seen at the sharp corners of the geometric patterns, and by the questionable economics of laser drilling such a small stone. Careful examination of the evidence strongly

Figure 1. The white areas in this X-radiograph represent the filled cleavages and cracks in these three treated diamonds (the largest weighs 1.49 ct). X-radiograph by Tom Moses.



suggests that these inclusions are of natural origin, possibly fission tracks. Mr. de Goutière has donated the diamond to GIA's Byron C. Butler Inclusion Collection for further study.

Synthetic diamond thin-film update. A number of firms are making continued advances in vapor-deposited synthetic diamond thin films. Japanese companies such as NEC Corp., Seiko Instrument Co., and Sumitomo have been exploring the possible applications for this technology since learning of its discovery in 1975 by Soviet scientists. Crystallume, an American firm in Menlo Park, California, has found a way to make an ultra-thin (less than 1 μ) synthetic diamond window that is ideally suited for X-ray instruments used for materials analysis. This represents the first industrial product out of this technology. Other possible applications include computers and diamond-coated tools.

Presently, two low-pressure methods are used to deposit synthetic diamond films on almost any object. The first requires that a metal filament be heated to incandescence in the presence of a mixture of hydrogen gas and a hydrocarbon vapor, such as methane. At the filament, the hydrogen molecules split into individual atoms and the hydrocarbon molecules break, freeing some carbon. The subject to be coated is also heated to at least 1000°F (546°C). When the hot mix of gases encounters the heated object, a thin coating of carbon, in the form of synthetic diamond, is deposited over the exposed surface area. The other method uses the same mix of gases but irradiates them by a radio frequency field and/or a microwave beam, at which point a thin film is deposited on a heated subject.

The greatest drawback is that the subject must be heated to a high temperature for either process to work. However, the Beamalloy Corp., of Dublin, Ohio, uses a technique known as ion-beam enhanced deposition to deposit a super-hard carbon coating on almost any subject, including those with low melting points such as plastics. Recently, Beamalloy has been working closely with GIA Research to place ion beam–enhanced thin-film coatings on materials such as opal and emerald so that the properties of the coatings can be carefully studied and their potential gemological effects better understood.

COLORED STONES

Pyrope or spinel . . . a question of identity. Mr. Donald Clary of Rancho Palos Verdes, California, recently brought *Gems & Gemology*'s technical editor, Carol Stockton, a pink stone that had been sold to him as garnet. While it resembled the pear-shaped pink pyrope illustrated in the Summer 1988 issue of *G&G* (figure 1, page 105), its refractive index of 1.718 seemed too low for the depth of color displayed, and suggested instead that the stone was spinel. In addition, it contained some wispy-looking inclusions not at all typical of garnet.

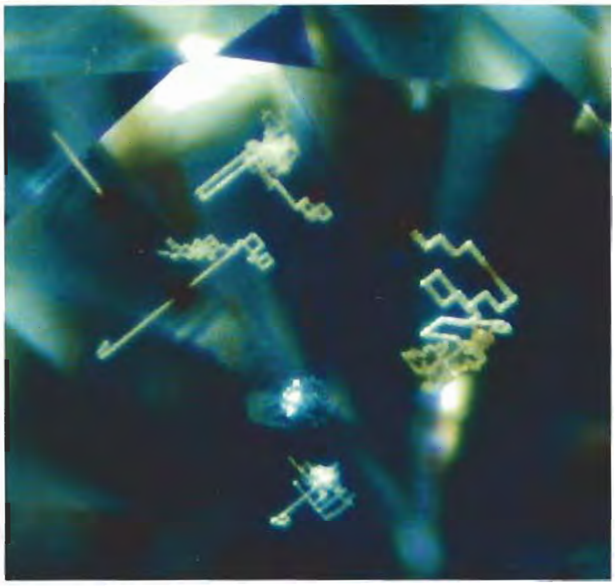


Figure 2. These intricately patterned thin tubes were initially believed to be caused by laser drilling. The radiation stains and the small size (0.06 ct) of the diamond were two of the indications that these tubes are, in fact, natural. Photomicrograph by Anthony de Goutière.

Energy dispersive X-ray fluorescence chemical analysis revealed that the stone was, in fact, a spinel with a trace of chromium to provide the pink color. Gemologically, the only means to distinguish such a spinel from a pink pyrope would be a combination of refractive index, inclusions, and possibly U.V. fluorescence. Pink pyropes have been observed to have refractive indices between 1.730 and 1.742. Below this range, they become very pale and ultimately colorless. Gem-quality pink spinels have a fairly constant refractive index of 1.718. Only in the presence of appreciable chromium, enough to produce the much-desired "flame" red color, does the R.I. rise toward the range of pink pyrope. In this case, of course, color will preclude confusion.

Since pure, colorless pyrope has an R.I. of 1.714, and pure, colorless spinel has an R.I. of 1.712, it is theoretically possible for similar-appearing stones to exist with equally similar indices of refraction. Thus, inclusions provide the best means of separating the two species.

Continued tsavorite mining. Contrary to rumors that have circulated recently, the supply of tsavorite garnet in East Africa appears plentiful. According to geologist Campbell Bridges, tsavorite is becoming so popular that even the more included material is now being cut and marketed.

Mr. Bridges is the discoverer of tsavorite and still one of its major producers. According to him, "It is

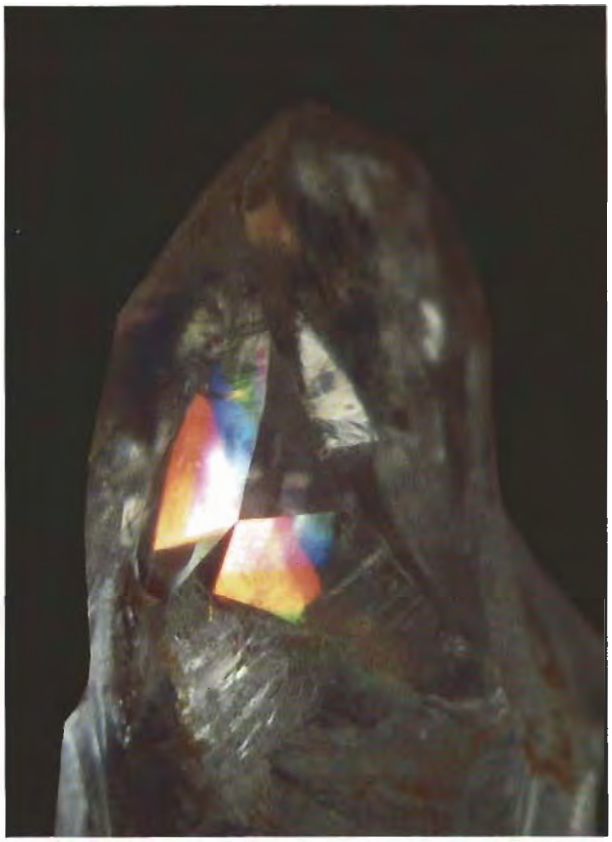


Figure 3. This 6.5-mm-wide near-colorless quartz crystal from near Poona, India, displays brilliant diffraction-caused colors. Photo by John I. Koivula.

expensive to mine . . . [because it] is confined to erratic shoots that, when the overburden becomes too great, have to be followed underground by tunneling. This involves careful blasting and progressively expensive removal of waste as well as the necessity of ventilation to considerable depths. It is possible that in the best of the tsavorite mines in East Africa, the shoots will persist for several hundred and even thousands of feet underground, thereby assuring regular commercial production over the next several years."

Unusual Indian quartz. The Winter 1987 Gem News column reported on Jack Lowell's discovery of an adularescent-like phenomenon observed in some amethysts from Artigas, Uruguay. In these amethysts, this colorful "Lowell Effect" is strictly confined to the minor rhombohedral faces and the areas immediately surrounding them. Now it appears that another source of quartz showing this phenomenon has been discovered.

While on a buying trip to India, Meg Easling and Julie Wellings, the proprietors of Gem Quest Jewelers in Ojai, California, came across some crystal-covered geode sections of colorless quartz from near Poona that displayed what looked like brilliant iridescent colors when viewed in certain directions (figure 3). At first they thought that the colors were a thin-film effect caused by small fractures in the crystals, similar to what is observed in both quench-crackled and natural "iris quartz." Closer examination, however, proved that this was not the case. The colors were confined to the minor rhombohedral faces and zones immediately surrounding them, just as in the amethysts from Uruguay.

Figure 4. Delicate twinned sprays of rutile such as these are the most common inclusions observed in a new find of smoky quartz from California. The largest rutile clusters are approximately 1 mm across. Magnified 15×; photomicrograph by John I. Koivula.

California quartz. In February 1988, while tracing quartz float up a ravine in the Inyo National Forest in Inyo County, California, Michael and Cora Anderson of Lomita discovered a small pocket containing a few small crystals of smoky quartz near "Crystal Ridge," at the west end of the Santa Rita pluton. Continued exploration showed that the pocket was actually a quartz vein that ranged in thickness from a few inches up to 3 ft. (approximately 1 m) and seemed to contain numerous crystal-bearing pockets.

Following the vein, the Andersons have excavated a small (3 ft. × 10 ft.) adit into the granite mountain. So far, approximately 300 lbs. (135 kg) of single crystals and crystal clusters have been mined. Of these, 20% to 30% are of good specimen quality, while many are facetable. The crystals, which range from transparent to opaque, are most commonly smoky brown; some are near-colorless.

The crystals average about 1 ½ in. (2.2 cm) long, but individual crystals as large as 2 in. × 6 in. have been recovered. Many of the crystals are doubly terminated. A few are wedge-shaped, while others have almost perfectly equidimensional prism faces and nearly ideal terminations. Some show selective or directional etching effects on their surfaces, and many show facial- and etch-produced evidence of Dauphiné twinning, such as the repetition of *s* and *x* faces.

One of the most unusual features of these quartzes is their suite of inclusions. Chlorite, calcite, hematite, and rutile have been identified so far. The rutile is the most obvious inclusion; it appears as exceptional twin sprays reminiscent of "golden stars" (figure 4). The rutile also appears to be directionally deposited and of late-stage syngenetic origin, because it is found only on certain prism and rhombohedral faces, and always just beneath or right at the surface. Although now the Andersons are finding fewer crystals and more of what looks like ordinary chalcedony, they recently found signs of additional quartz deposits nearby.

"Aqua Aura" quartz. Peter and Bobbi Flusser, of Overland Gems in Los Angeles, showed the Gem News editors a new form of treatment being used on rock crystal quartz. The treatment consists of coating both single crystals and crystal clusters with a thin film of gold so sheer that the opacity normally associated with this dense metal is negated and the actual transmitted-light color of gold, a blue to greenish blue, becomes apparent (figure 5). In addition, the crystals acquire a superficial, colorful iridescence that is readily visible in surface reflected light. Because of the obvious bluish color, these treated quartzes are being promoted under the name "Aqua Aura," meaning blue gold, by the supplier, Bob Jackson Minerals of Renton, Washington. Testing by the editors has shown that the coating is very durable and does not seem to affect any of the gemological properties (R.I. and S.G.) of the underlying quartz.

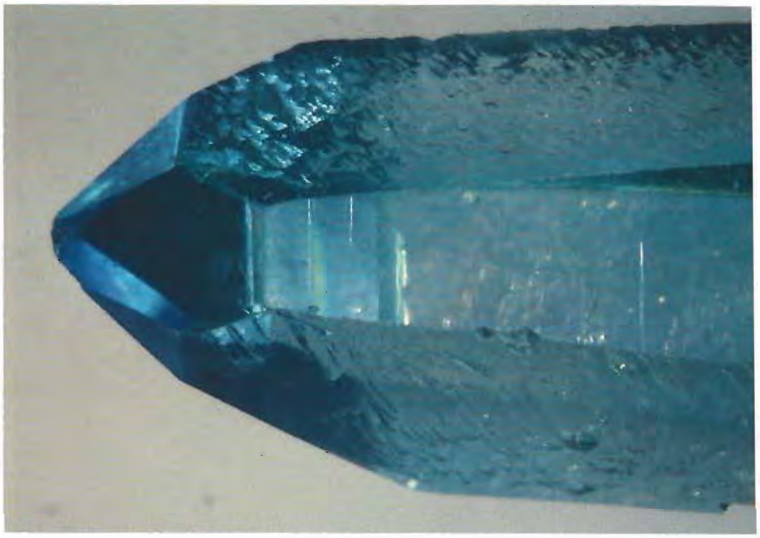


Figure 5. The color in this "Aqua Aura" quartz crystal results from a thin-film coating of gold. Photo by William Videto.

New evidence of treatment in Umba sapphires. Any evidence that provides absolute proof that a sapphire has or has not been heat treated is always of value to gemologists. A recent investigation done by one of the Gem News editors (JIK), which was published in the *Journal of Gemmology* (Vol. 20, No. 7, 1987), showed just such evidence in the form of colored halos surrounding solid mineral inclusions in sapphires from Sri Lanka and Montana. The halos result from the heat-induced theft, by the sapphire host, of color-causing ions from the mineral inclusions.

After reading the above-mentioned article, Dr. Henry A. Hänni, of the University of Basel and the Swiss Foundation for the Research of Gemstones, contacted Gem News and reported his discovery of similar internal diffusion halos surrounding tiny mineral inclusions in blue sapphire from the Umba River region in Tanzania, East Africa (figure 6). Dr. Hänni's observation provides positive evidence that at least some of the sapphires from this locality are being heat treated.

Largest faceted gemstone. In his recent *Gems & Gemology* article (Spring 1988) on faceting large stones, Michael Gray reported that a 22,982-ct topaz, since named the "American Golden," had just become the largest gem ever cut. This gem has now been donated to the Smithsonian Institution in Washington, D.C., by Drs. Marie and Edgar Borgatta together with the American Federation of Mineral Societies.

Dr. Edgar Borgatta preformed the stone from the original 26-lb. (12 kg) piece of rough, and then commissioned Leon M. Agee, of Walla Walla, Washington, to facet it. The cut designed by Mr. Agee has 62 crown facets and 110 pavilion facets; the finished stone measures 17.3 × 14.9 × 9.2 cm. The overall color is basically light yellow, but three light blue chevrons of color zoning provide a slightly chartreuse tinge under some lighting conditions.

Figure 6. Proof of color enhancement in this sapphire from the Umba River region in Tanzania, East Africa, is shown by the dark blue spots that result from internal diffusion. Magnified 30×; photomicrograph by Henry A. Hänni.

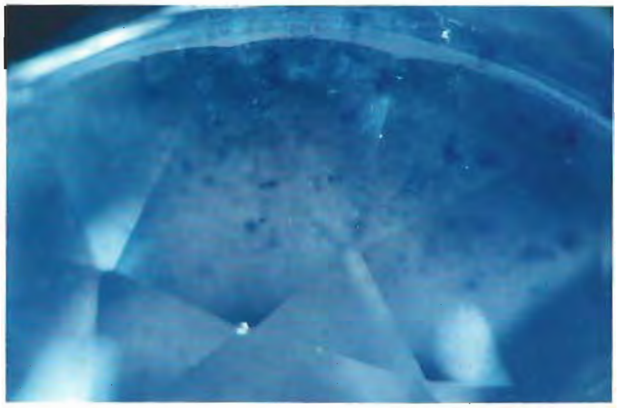


Figure 7. The world's largest faceted gem, a 22,982-ct topaz named the "American Golden," was cut by Leon M. Agee. Photo by Ken Nicoles Photographers, Walla Walla, WA.

Mr. Agee designed the machine used to cut the "American Golden" around an older-model Prismatic faceting machine, which he had to modify extensively. The problems of counter-balancing such a large machine with such a large preform were not trivial (figure 7). Approximately 1,000 hours were needed to complete the project.

Ruby receives highest price at auction. A 15.97-ct Burmese ruby (figure 8) was sold at Sotheby's October 18, 1988, jewelry auction in New York for a record price of $3,630,000 – the highest price ever paid at auction for a colored stone.

Figure 8. This 15.97-ct Burma ruby sold for $3,630,000 at the October 1988 Sotheby's auction. It is the highest price ever paid at auction for a single colored stone. Photo by Tino Hammid.

SYNTHETICS

Unusual synthetic beryls from the Soviet Union. A selection of unusual hydrothermally grown synthetic beryl crystals, in a variety of colors (figure 9), were provided to Gem News for study by Dr. Nikolai Sobolev of the USSR. The beryls were grown in the Laboratory for Hydrothermal Growth, at the Institute of Geology and Geophysics, Siberian Branch of the USSR Academy of Sciences, in Novosibirsk, under the supervision of Dr. V. A. Klyakhin and Dr. A. S. Lebedev.

Deposited over colorless seeds, these crystals are the product of growth experiments involving the coloration of synthetic beryl using a variety of ionic dopants. The purple results from doping with a combination of chromium and manganese. The bright, intense pink is caused by manganese alone (like morganite and the natural red beryls from Utah). The blue is the product of copper coloration, and the rich, slightly orangy red crystal owes its color to a trace of cobalt.

We do not know how much of this material has been grown and whether or not it will ever be commercially available. Recently, however, Dr. Karl Schmetzer of Heidelberg, West Germany, showed GIA's Dr. Emmanuel Fritsch a 1-cm fragment of a synthetic hydrothermal "aquamarine" grown in the Soviet Union at the same Laboratory for Hydrothermal Growth. Dr. Fritsch described it as a dark "sapphire blue," strongly pleochroic, millimeter-thick overgrowth on colorless beryl. So it appears that, in addition to the crystals shown here, at least one other unusual color of hydrothermal synthetic beryl has been grown in the USSR.

The specific gravities and refractive indices of these crystals are similar to those already reported for hydrothermal synthetic emeralds and some natural beryls. However, their absorption spectra and internal characteristics would be sufficient to identify them as synthetic if faceted stones should ever be cut.

The Pool synthetic emerald. In August 1988, International Colored Gemstone Association (ICA) Alert No. 18 addressed "Pool Emeralds," specifically, "the way in which these laboratory grown emeralds are being promoted [widely in Australia] . . . as the 'treated Pool Emerald.'" A follow-up alert was issued in October 1988 by Australian gemologist Dr. Grahame Brown, who concluded that "the gemmological properties, and the characteristic inclusions, of the Pool Emerald were virtually identical to those of the Biron hydrothermally-grown emerald . . . another product of Equity Finance Ltd." This was followed by a report in *Jewellery News Asia* from a gemological laboratory in Hong Kong which identified the "Pool Emerald" as synthetic. A preliminary study of the gemological properties of the "Pool

Emerald" carried out at GIA's West Coast Gem Trade Laboratory (and confirmed by EDXRF chemical analyses) also showed that these synthetic emeralds have properties virtually identical to those reported for Biron hydrothermal synthetic emeralds by Robert E. Kane and Richard T. Liddicoat, Jr., in the Fall 1985 issue of *Gems & Gemology.*

The promotional material for this product has been revised considerably, apparently in response to criticism. The first literature read: "The Pool Emerald . . . From the Emerald Pool Mine of Western Australia (1929) . . . Source of natural and treated emeralds . . . The Pool Emerald (R) is refined by recrystallising 100% natural emerald from the Emerald Pool Mine . . . . The Pool Emerald (R)—available either clean, or slightly included." The most recent advertisment, however, reads "The Pool Emerald . . . A Laboratory Grown Hydrothermal Emerald . . . . The laboratory grown Pool Emerald is recrystallised emerald from the Emerald Pool Mine, Western Australia."

Figure 9. These synthetic beryls grown in the Soviet Union range from 14.48 ct (purple) to 31.63 ct (pink). Photo by Robert Weldon.

ANNOUNCEMENTS

Great Britain's National Association of Goldsmiths (NAG) has announced its plan to register qualified jewelry appraisers in the United Kingdom. In a program designed to protect the public, the association says it will register only those jewelers who are qualified to produce competent evaluations, and will give them a special red and orange symbol showing the words "NAG registered valuer" to display.

The new journal, Gemological Digest, is no longer being offered free of charge, reportedly because of the higher production costs involved with the new format. For further information, please contact the journal's editor, Richard Hughes, at the Asian Institute of Gemological Sciences, 987 Silom Rd., Rama Jewelry Bldg., 4th Floor, Bangkok, Thailand 10500.

The 1989 International Colored Gemstone Association Congress will be held May 21–26 at the Hilton International, Colombo, Sri Lanka. Planned events include the first ICA Intertrade Auction, voting on several nomenclature issues and trade rules and regulations, and an ICA forum with the association's board of directors. For more information, contact the ICA office at 22643 Strathern St., West Hills, CA 91304; telephone (818) 716-0489.

Also from the ICA comes the Gembureau, a gemstone promotion and information service that will be responsible for international media relations on behalf of the gemstone industry and will serve as a resource for both consumer and trade publications. The funds to establish the Gembureau were contributed by ICA members. For more information, contact Cheryl Kremkow, Gembureau, 609 Fifth Ave., Ste. 905, New York, NY 10017; telephone (212) 688-8452.

INHORGENTA–Autumn München 89 (The Munich Watch and Jewellery Days) will be held September 23–25, 1989, at the Munich Trade Fair Center. This annual event (always the last weekend of September) is organized by the Munich Trade Fair Corp. There is room for 400 exhibits, but the registration deadline is April 15. For more information, contact the sponsors at Messegelande, Postfach 12 10 09, D-8000 München 12, West Germany; telephone (089) 51 07-506.

Hong Kong is the site for several trade shows in 1989. The 2nd World Gems Expo will be held June 3–6, at the Hong Kong Convention and Exhibition Centre. The expo will accommodate over 700 manufacturers, suppliers, cutters, and miners from around the world. The World Fashion Jewelry & Accessories Expo, planned for July 1–4, is a showcase of high fashion/costume jewelry, personal ornaments and accessories, gift items, and much more. The 7th Hong Kong Jewelry and Watch Fair will be held September 19–22; it features jewelry and gems as well as all types of clocks and watches, and even manufacturing equipment. For more information on all of the above, contact Headway Trade Fairs, Ltd., 9/F, Sing-Ho Finance Bldg., 168 Gloucester Rd., Hong Kong.

Mr. Donald Feldpush's name was mistakenly left out of the list of people who received a perfect score on the 1988 *Gems & Gemology* Challenge. We regret the error and congratulate Mr. Feldpush on his accomplishment.

GEMOLOGICAL ABSTRACTS

Dona M. Dirlam, Editor

COLORED STONES AND ORGANIC MATERIALS

"Citron chrysoprase." G. Brown and H. Bracewell, *Australian Gemmologist*, Vol. 16, No. 6, 1987, pp. 231–233.

"Citron chrysoprase" is the local name used for a massive lime-green mineral found in association with common opal and chrysoprase in Western Australia. This report covers the gemological investigation of the material from Yundamindera Station.

Properties were determined to be as follows: color—lime green, tending to be strongest near the external surfaces of nodules and veins, and "fading" toward their centers; luster—waxy on polished surfaces; hardness—4–5; fracture—brittle, low conchoidal to uneven; streak—white; S.G.—2.90; spot R.I.—1.60, with a birefringence blink indicating a large birefringence; U.V. fluorescence—strong bluish white (long-wave), pale whitish (short-wave); solubility—effervesces slowly with cold hydrochloric acid. All veins and nodules examined exhibited external coatings of brownish limonite, which also filled fractures.

On the basis of their examination and of chemical analyses of similar material from an adjacent group of claims, the authors conclude that "citron chrysoprase" is nickeloan magnesite and should be described as such. Four photographs and one map accompany the article.

RCK

Esmeraldas en las minas y en la historia (Emeralds in the mines and in history). L. S. Tocancipa, *Geomundo*, Vol. 12, No. 2, February 1988, pp. 92–105.

A unique opportunity was granted to Ms. Tocancipa to investigate and photograph the mysterious emerald world of Colombia. The resulting report is accompanied by an impressive collection of photographs, taken mostly by Mauricio Mendoza.

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

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

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

The article begins with Ms. Tocancipa's views of being the only woman among 43 men working at the Cosquez mine, as she relates her experiences and struggles for survival in an otherwise male-dominated mining job. This eye-opening introduction is followed by a history of the emerald industry in Colombia, including the uses of emerald during pre-Columbian times. A subsequent, and somewhat cryptic, section talks about the properties of beryl. Vague references are made to coloring agents and crystal form, but no mention is made of specific gravity, refractive index, or even typical inclusions. This section is followed by interesting data about the mines themselves, as well as government involvement and commercial aspects. The emeralds illustrated include the collection at the Bank of the Republic in Bogotá. *RW*

Une gemme métamicte: l'ékanite (A metamict gem: ekanite). J.-P. Gauthier and P. Fumey, *Revue de Gemmologie a.f.g.*, No. 94, 1988, pp. 3–7.

Ekanite, a thorium and calcium silicate of formula ($ThCa_2Si_8O_{20}$), is a rare gem material. Because it contains radioactive thorium, and sometimes uranium, its structure is often metamict due to radiation damage. Minerals with analogous chemical formulas have been discovered: $ThK(Na,Ca)Si_8O_{20}$, formerly called kanaekanite, now bears the official name steacyte. $ThK(Ca,Na)Si_8O_{20}$ has not been named. Both also have a slightly different structure from ekanite.

Ekanite was named after F. L. D. Ekanayake, who discovered it in Sri Lanka in 1953. The Eheliyagoda deposit remains the only source of gem-quality material. Most of the radiation damage to the crystalline structure is due to the heavy alpha particles; beta and gamma particles usually create color centers. Metamict ekanite shows halos in X-ray diffraction instead of distinct lines. Its density is lower, but can be restored by heat treatment. Most of the birefringence is lost in the course of irradiation, and some opalescence might appear together with color centers.

One yellowish brown to mustard green 5.35-ct stone from Sri Lanka showed an R.I. of 1.590, with a birefringence of 0.001 to 0.002 and an S.G. of 3.32 to 3.34. Two sets of tiny needles perpendicular to each other were observed at 20× magnification. This stone is metamict and shows a gamma activity of 1600 ± 200 becquerels or 43 ± 5 nanocuries.

Electron microscope examination of a few millimeter-size crystals from the Tombstone Mountains, Yukon Territory, Canada, did not reveal any internal structure, which is undoubtedly a result of radiation damage. *EF*

Nomenclature of pyroxenes. N. Morimoto and others, *American Mineralogist*, Vol. 73, No. 9/10, 1988, pp. 1123–1133.

This represents the final report on the nomenclature of pyroxenes by the Subcommittee on Pyroxenes established by the Commission on New Minerals and Mineral Names of the International Mineralogical Association. Pyroxenes are orthorhombic or monoclinic silicate minerals with the general formula $M2M1T_2O_6$ (where $M2 = Mg^{2+}$, Fe^{2+}, Mn^{2+}, Li^+, Ca^{2+} or Na^+; $M1 = Al^{3+}$, Fe^{3+}, Ti^{4+}, Cr^{3+}, V^{3+}, and so on; and $T = Si^{4+}$, Al^{3+}, or Fe^{3+}). Important gem pyroxenes include jadeite and spodumene.

This report identifies 20 accepted and widely used names that have now been formally adopted as mineral species names of the pyroxene group. Thirteen of these species represent definite end-member compositions; the remainder are solid-solution members of specific intermediate composition. These 20 species are grouped into six chemical subdivisions on the basis of cation occupancy of the M2 sites and crystal-chemical similarity. Their species names may be qualified by certain adjectival modifiers to denote specific important departures from normal compositional ranges. Rules are presented to determine the name of a pyroxene on the basis of its chemistry and crystal structure.

This report includes a list of 105 previously used pyroxene names (some of which are encountered in the gemological literature, such as chloromelanite, kunzite, and ureyite) that have formally been discarded by the IMA Commission and are therefore now obsolete for proper mineralogic classification. *JES*

Paua shell: New Zealand's distinctive organic gem. G. Brown, *Australian Gemmologist*, Vol. 16, No. 10, 1988, pp. 367–370.

Paua is a species of New Zealand abalone noted for its large shell, the continuous border of its peristome (mouth), and the strong iridescence of its nacre. This well-illustrated article reviews the sources, structure, gemological properties, and commercial uses of paua shell.

Paua shell is currently used in a variety of forms. It is carved to produce jewelry items such as earrings. Shell fragments are inlaid in black epoxy resin. It is used in composite stones called "sea opals": Doublets consist of a thin slice of shell with a domed colorless cap of quartz, glass, or plastic; triplets consist of a shell slice sandwiched between a colorless cap and a flat, nontransparent base. Buttons are produced from thin slices of dyed (blue or brown) shell encased in a mass of colorless plastic. Paua shell is also commonly dyed to mask unsightly brown patches that occur.

The author concludes that while paua shell is visually distinctive, hand lens examination may be required to identify the various composite forms described above. *RCK*

Rubies of Thailand. P. Bancroft, *Lapidary Journal*, Vol. 42, No. 7, October 1988, pp. 45–57.

Dr. Bancroft provides a definitive, concise look at Thai rubies. He includes history, localities, mining methods, geology, and mineralogy, as well as fashioning and finishing, marketing, and the trading around Chanthaburi, Bangkok, Bo Rai, and Bang Ka Cha. All is described with the unmistakable insight of one who has been there. The article is illustrated with four color photos and contains extensive references.

Bill Videto

DIAMONDS

Famous diamonds of the world XXX: Pigot. I. Balfour, *Indiaqua*, Vol. 46, No. 1, 1987, pp. 149–153.

Named after George Pigot, a controversial figure in the history of British administration in India, this diamond is described as an oval shape weighing approximately 187.5 grains (48.63 metric carats). After Pigot's death in 1777, the diamond passed to his siblings, who disposed of it in the unusual manner of a lottery in 1790. The winner of the diamond was a consortium, who eventually sold the Pigot in 1802 to the company of Rundell and a private individual named Parker.

At this point in the diamond's history, two separate accounts emerge. In one version, the gem was sold in 1822 by Rundell (which had since merged with Bridge) to the Pasha of Egypt; he allegedly presented it to the Sultan of the Ottoman Empire for political reasons. In the second version, the Pigot was purchased from Rundell & Bridge by an Albanian named Ali Pasha. According to this version, on his death bed in 1822, Ali Pasha ordered the gem destroyed.

Balfour concludes that it is more likely that the Pigot made its way to Turkey and was not pulverized due to the "technical impossibility" of this action. To date, the stone is considered to have vanished. *JLC*

Famous diamonds of the world XXXI: Eugénie. I. Balfour, *Indiaqua*, Vol. 47, No. 2, 1987, pp. 117–119.

This article begins with a brief history of the rule of Empress Catherine the Great, Tsarina of Russia from 1762 to 1796. According to Balfour, the empress enjoyed fine jewelry and gems, and wore this 51-ct oval-shaped diamond as the center stone of a hair ornament. The diamond became known as the Potemkin after the empress gave it to her one-time lover and political aide, Prince Grigori Aleksandrovich Potemkin. He willed the diamond to his favorite niece, who eventually gave it to her daughter, Princess Coloredo, the great-niece of Napoleon III.

It is reported that Napoleon III purchased the Potemkin from his great-niece as a wedding gift for his bride Eugénie in 1853, from whom the diamond received its new name. On the collapse of Napoleon's Second Empire, Empress Eugénie escaped to England with a small cache of jewels, including the diamond, which was eventually sold to Mulhar Rao in 1872. Eventually the Eugénie diamond became the property of Mrs. N. J. Dady of Bombay. Its current whereabouts are unknown.

JLC

GEM LOCALITIES

Notes on Tasmanian gemstones. C. Thrower and D. Steane, *Australian Gemmologist*, Vol. 16, No. 6, 1987, pp. 223–224.

This brief article reports on the examination of sapphire, chrysoberyl, and turquoise from Tasmania. The sapphires examined included material from two localities. Two large specimens (74 ct and 94.2 ct) from the Weld River were very dark and exhibited polysynthetic twinning. Specimens from the Upper Gordon River ranged from pale to dark blue to black; these, too, exhibited polysynthetic twinning as well as strong angular color zoning, and many exhibited six-rayed asterism. None of the sapphires examined was of faceting quality.

The chrysoberyl specimen revealed the following properties: color – green (daylight), red (artificial light); hand lens examination – strong color change in translucent areas from green to red, with an opaque, silky, silvery central core; form – waterworn crystal fragment showing good orthorhombic shape; polariscope reaction – distinctly doubly refractive in nonopaque areas; dichroscope – strongly trichroic (green, muddy yellow, and red); Chelsea filter reaction – red; density – 3.33 (low reading attributed to probable nature of the core); spectrum – strong absorption in orange/yellow/yellow-green range with broad absorption from the violet into the blue; U.V. fluorescence – inert to long-wave and short-wave radiation). The authors conclude that the specimen is alexandrite with a cymophane core.

The turquoise specimen exhibited a mottled pattern of two tints of pale greenish blue with flecks and patches of light brown and white. Properties include a white streak, a hardness of approximately 4, an uneven fracture, a density of 2.44 (attributed to the stone's porosity and numerous powdery white clay-like inclusions), dull green/yellow long-wave U.V. fluorescence, and no diagnostic spectrum. The authors stated their intention to perform enhancement experiments on this rather low-quality material. *RCK*

INSTRUMENTS AND TECHNIQUES

Impiego della 'xeroradiografia' nell'indagine gemmologica qualitativa delle perle (The use of "xeroradiography" in the qualitative gemological study of pearls). E. Butini, *La Gemmologia*, Vol. 12, No. 1–4, 1987, pp. 6–22.

This article represents the paper Mr. Butini originally delivered at the National Gemological Convention 1986 in Valenza, Italy. First, the author discusses the principle of xeroradiography, the instrumentation required, and its application to pearls. Similar to conventional X-radiography, with xeroradiography a structural image of the pearl is obtained on paper in an automated closed-cycle process in the "Xerox 125" system. Comparative studies employing both conventional X-radiographic and xeroradiographic methods were carried out using various round bead- and tissue-nucleated cultured pearls as well as natural pearls. The results are shown in 33 impressive black-and-white and color figures.

The article concludes with a discussion of the advantages and disadvantages of this new procedure. Since xeroradiography permits a higher resolution, greater detail is shown. To obtain these details though, a higher level of radiation is necessary, which excludes the use of low-voltage generators. Another disadvantage appears to be a low response for extremely thick samples. The author is continuing his research in this area. *KNH*

A numerical approach to gemstone identification. H. S. Pienaar, *Australian Gemmologist*, Vol. 16, No. 10, 1988, pp. 374–378.

This paper, read at the 21st International Gemmological Conference in Rio de Janeiro, Brazil, begins with a brief overview of two basic gem identification processes: those based on a gem's appearance and those based on nondestructive diagnostic tests. It then proceeds to describe a set of numerical indices that can be used to "characterize any given gem species," the Stellenbosch Gem Index (S.G.I.).

Starting with the concept of the Gladstone-Dale relationship between the refractive index and specific gravity of a material, the system calculates an S.G.I. value for each species using a simple formula. This discussion is followed by samples from four lists of S.G.I. values: (a) a standard working list arranged by increasing S.G.I. values, (b) a "1.81" list for gems with R.I.'s above 1.81, (c) a separate list for glass and plastics, and (d) a list in alphabetical order by species.

The author concludes that the system offers a number of procedural advantages in gem testing, especially for novices. *RCK*

Quantitative cathodoluminescence—A modern approach to gemstone recognition. J. Ponahlo, *Journal of Gemmology*, Vol. 21, No. 3, 1988, pp. 182–193.

After providing a brief history of cathodoluminescence (CL), Dr. Ponahlo describes the two types of CL apparatus available ("hot" and "cold" cathodes). He then gives the basics of CL, the emission of light under an electron beam excitation, and cites a few common activators and quenchers. A simple mathematical formulation of CL intensity is also explained.

Studies showed that cathodoluminescence could help separate natural from synthetic emeralds and Thai rubies from their synthetic counterparts. However, rubies from Burma, India, Kenya, and Tanzania give inconsistent results. CL has also been used to separate jadeite from green grossular and amazonite.

Dr. Ponahlo states in conclusion that the cost of the CL equipment is negligible compared to the money involved in some of the stones CL helps to separate. He also emphasizes the need for more research in this field. *EF*

JEWELRY ARTS

Heritage section—Art Deco jewelry: Its past, present and future. N. Letson, *Jewelers' Circular-Keystone*, Vol. 154, No. 8, August 1988, pp. 232–236.

In his delightful narrative style, Neil Letson presents an overview of Art Deco jewelry. With broad strokes he paints a vivid picture of the time, complete with flappers, gangsters, prohibition, and the birth of jazz. With the stage set, he condenses primary design influences on the Art Deco style, popular materials, and leading designers into three pages to give the reader a quick overview of this distinctive period.

The article continues on a more pensive note, with the author musing on the fact that Art Deco jewelry is currently more popular than it was when it was made. This has inspired copies by "Hong Kong knockoff artists," which could pose problems for jewelry appraisers. Speculation about the future popularity of Art Deco jewels wraps up this interesting article. Seven classic examples of Art Deco jewels illustrate the text. *EBM*

Heritage section—What jewelry marks reveal. J. Sataloff, *Jewelers' Circular-Keystone*, Vol. 154, No. 8, August 1988, pp. 245–248.

The subject of jewelry marks and their meaning has increased in importance with the heightened popularity of antique jewelry. Sataloff points out that a good dealer must be able to distinguish between an antique and a reproduction. He then proceeds to briefly sketch the history and development of hallmarks, which he follows with a discussion of the basic meanings of marks from England, France, and Russia.

The article gives us some clues on how to distinguish marks that signify metal fineness and country of origin, as well as importation stamps and maker's marks, but it does not tell us where to go for further research; a list of references would have been helpful. Nevertheless, this is an important article for anyone handling antique or period jewelry. *EBM*

Heritage section—Vintage wrist watches: Their history and appeal. H. B. Fried, *Jewelers' Circular-Keystone*, Vol. 154, No. 8, August 1988, pp. 238–244.

This informative article chronicles the history of vintage wristwatches. The term *vintage* is used rather than *antique* because the wristwatch as an innovation is barely a century old. Fried traces the earliest placement of a watch on the wrist to a pair of bracelets given by the Empress Josephine of France to her daughter at the beginning of the 19th century. One of the bracelets had a small watch placed in it, and the other was set with a dial that indicated the month and day. However, wristwatches were no more than novelties until the Franco-Prussian War, when German naval officers had them made by the Swiss firm of Girard-Perregaux.

After describing the stages that wristwatches went through on their way to universal popularity, the author discusses the reasons for the sudden boom in vintage watch collecting and offers some pointers on what to look for when starting a collection. The article concludes with a list of three books that Fried recommends for further research. Fifteen photos of vintage wristwatches and antique pendant watches nicely illustrate this article. *EBM*

The revival of Art Deco. M. M. Hammid, *Lapidary Journal,* Vol. 42, No. 5, August 1988, pp. 20–22.

This article provides a concise summary of the recently repopularized style of Art Deco. Given the current demand for Art Deco jewelry, it is difficult to imagine that up until the late 1960s it was out of vogue and many pieces were broken up for their gems.

Ms. Hammid does an excellent job of distilling Art Deco into a few easily recognizable elements. She provides brief historical information, setting the period roughly between the two world wars, and isolates key design features in terms of cultural influences and materials.

Essentially geometric and stylized, Art Deco jewels were a direct contrast to the naturalistic "nymphs and flowers of Art Nouveau and the delicate garlands and wreaths of Belle Epoque" jewelry. Design motifs were often inspired by ancient Egyptian archaeological discoveries (scarabs and sphinxes are common) and the Orient (dragons, pagodas, and other chinoiserie are frequently seen). Stark color contrasts were provided by the use of gems in primary colors: diamonds, rubies, sapphires, emeralds, onyx, and red coral. These were set primarily in platinum. Four color photos of typical jewels accompany the text.

Although abbreviated and general, the article provides insight and prompts the reader to pursue the topic further. *EBM*

JEWELRY RETAILING

Baubles, bangles and beads. S. Young, *Los Angeles,* Vol. 33, No. 10, October 1988, pp. 160–170.

Mr. Young describes the Los Angeles jewelry district as "an amalgam of the Emerald City and the Tower of Babel." He gives a reasonably accurate account of the day-to-day business transactions in this unique area of downtown Los Angeles.

Illustrated with a number of black-and-white photographs of professionals in the jewelry district, much of the article concentrates on the diamond business and the prestigious Diamond Dealers Club. Some attention is also given to diamond cutters, jewelry manufacturers, and booth owners, who make up the menagerie of the jewelry district.

The article concludes with a discussion of the security aspects of the high visibility of the Los Angeles jewelry district, with stories of million-dollar insurance claims and the use of bullet-proof glass in the high-rise diamond offices. *JLC*

SYNTHETICS AND SIMULANTS

A coconut pearl? G. Brown, S. M. B. Kelly, and J. Snow, *Australian Gemmologist,* Vol. 16, No. 10, 1988, pp. 361–362.

Beginning with a review of the legends surrounding the so-called "coconut pearls," the investigators surmise that these would seem to be clam pearls that had been fraudulently transplanted into coconuts. This conjecture is followed by an examination of a "coconut pearl" that was purportedly of Indonesian origin.

The 24.75-ct specimen is described as egg shaped, semi-baroque, opaque, whitish, and nonnacreous ("porcellanous"). It showed a pattern of 8–10 mm long vertical incisions around its circumference. Gemological properties include an S.G. of 2.87 and a spot R.I. of 1.50; it was inert to short-wave ultraviolet radiation, but fluoresced whitish to long-wave U.V. radiation. Hand-lens examination revealed no "flame" patterning; an X-radiograph showed that it was formed from a structureless radiopaque material. Intense fiber-optic illumination revealed a pattern of fine, wavy, parallel banding.

The investigators conclude that this particular "coconut pearl" had been manufactured from a piece of thick sea shell. A photograph and two radiographs accompany this report. *RCK*

An interesting hematite imitation. G. Brown and J. Snow, *Australian Gemmologist,* Vol. 16, No. 10, 1988, pp. 371–373.

This report briefly reviews the gemological properties previously reported for hematite and some of its simulants, and then investigates a glass imitation currently held in a Gemmological Association of Australia Branch Reference Collection.

Gemological properties for the imitation are as follows: color – black; diaphaneity – opaque, with thin sections displaying purple color in transmitted light; luster – metallic; R.I. – 1.52; S.G. – 2.57; hardness – 6–7; streak – white; fracture – conchoidal. It was also nonmagnetic and inert to long-wave ultraviolet radiation. Hand lens examination revealed mold marks on the girdle and a scratched, iridescent, thin, external coating on its polished surfaces.

The report includes a table comparing the gemological properties of gem hematite with this effective glass imitation. Five photographs illustrate the article. *RCK*

A jade miscellany. G. Brown and J. Snow, *Australian Gemmologist,* Vol. 16, No. 10, 1988, pp. 381–385.

This well-illustrated report covers a number of interesting specimens of assembled, treated, and imitation jade that were examined by the authors. The first piece was a jadeite doublet consisting of a colorless quartz cabochon cemented with a green, jelly-like dyestuff to a flat, oval jadeite back; the jadeite slice had also been dyed. The second specimen was a brownish mottled jade carving that had been wax-coated to improve surface luster; the authors warn that all jade carvings should be examined for wax coating before a spot R.I. is attempted. Several opaque, round, mauve-colored jadeite beads were also tested; magnification revealed dye in surface fractures as well as in cracks within the stringing holes.

The authors also examined five square cabochons purchased as different colors of "jadeite" in Burma more than 20 years ago; yellow and orange specimens turned out to be dyed quartz-like materials, while one of the greenish cabochons was dyed jadeite. A ring that resembled mottled green translucent jadeite turned out to be an effective glass imitation. Finally, several specimens of "tangiwai" (bowenite serpentine) from New Zealand are described as "rather dull and uninteresting" in incident light but quite beautiful in transmitted light. *RCK*

A new synthetic emerald. S. M. B. Kelly and G. Brown, *Australian Gemmologist,* Vol. 16, No. 6, 1987, pp. 237–238.

This report covers the examination of five synthetic emeralds believed to have been produced in Japan by the Gilson process. Properties were determined to be as follows: color – bluish green; diaphaneity – transparent, but heavily included, to semitransparent; luster – vitreous; S.G. – 2.628–2.647; R.I. – ω = 1.555–1.561 and ϵ = 1.550–1.558; birefringence – 0.005; optic character – uniaxial negative, two specimens exhibiting strong strain birefringence under crossed Polaroids; dichroism – ω=blue green, ϵ=green; Chelsea filter reaction – red; U.V. fluorescence – inert (to both long-wave and short-wave); spectrum – characteristic of emerald, varying in intensity of absorption from distinct to faint.

With magnification, the specimens exhibited planar, intersecting, partially healed fractures consisting of solid flux and two-phase inclusions; strong growth zoning caused by linear arrays of various-sized phenakite crystals; and phenakite crystals often of large size. These features are illustrated with photomicrographs.

The authors conclude that the specimens were flux-grown and that the manufacturer probably did not have complete control over the growth process. *RCK*

Qu'est-ce que l'emeraldonite? (What is emeraldolite?). D. Robert, *Revue de Gemmologie a.f.g.,* No. 95, June 1988, pp. 19–20.

Emeraldolite is a neologism developed as a trade name to describe a gem material formed by two constituents: a common beryl seed and a flux synthetic emerald epitaxial overgrowth. Fluoberyllates are essential in the growth process. The epitaxy allows for strong adhesion. EDXRF analyses revealed that Cr_2O_3 concentrations ran from 1.76 to 4.15%, which is above that encountered in natural emeralds. The very low concentration of Mg and the absence of Na are typical of synthetic emeralds.

Emeraldolite is completely different from any other gem material, natural or synthetic. It lends itself to different fashioning styles, with or without polishing, sometimes using the contrast of the green overgrowth with the white seed. Hardness is claimed to be as high as 8. One color and four black-and-white photographs illustrate this article. *EF*

TREATMENTS

Origin of the cat's-eye effect in heat-treated zircons from Sri Lanka. H. A. Hänni and M. Weibel, *Australian Gemmologist,* Vol. 16, No. 10, 1988, pp. 363–366.

Beginning with a brief review of the relevant literature, the authors proceed with an investigation of a cat's-eye zircon to determine the nature of the phenomenon-causing inclusions. Using optical microscopy, the authors resolved numerous minute "disclets" or "flakes." These were oriented in two directions, both parallel to the c-axis; the authors theorize that they lie in the two cleavage directions perpendicular to the zircon's basal plane.

EDX-spectroscopy revealed the presence of Si, Zr, and minor Hf; the electron beam diffraction pattern was that of monocrystalline zircon. Transmission electron microscopy on the {010} plane revealed extremely fine fissures at right angles to the plane. In the center of the fissures in {010} are crystal-like inclusions exhibiting a slightly rounded prismatic habit. No electron diffraction patterns could be obtained from the inclusions, which indicates that they are amorphous; the EDX spectrum established the presence of Ca (not present in the zircon matrix). The investigators believe these inclusions were originally apatite.

The authors theorize that the zircon had been thermally treated, and that the fissures formed as a result of strain encountered during heating or cooling around the inclusions. Four photographs and one graph accompany the article. *RCK*

Padparadschas traités par irradiation (Irradiation-treated padparadschas). D. Robert, *Revue de Gemmologie a.f.g.,* No. 96, September 1988, p. 4.

Irradiation can turn a pink sapphire into a so-called "padparadscha," but the orangy color is unstable to daylight. Given the same initial color, natural pink sapphire and Verneuil synthetic sapphire react the same. Moreover, the change-of-color happens only for a limited range of light pink coloration. The author used ^{60}Co at both 10 and 309 megarad doses to irradiate pink sapphire, and obtained similar results in both cases. He considers two questions to be unresolved: Why does this change occur only for a certain range of Cr concentration? Why is natural padparadscha color stable?

The author then reminds the reader that gamma-ray irradiation does not induce radioactivity, and states that the Centre d'Etudes Nucléaires de Grenoble recommended an upper limit of 75 Becquerels/gram for the radioactivity of neutron-treated gemstones. *EF*

Radiation induced structural damage in beryl. J. I. Koivula, *Journal of Gemmology,* Vol. 21, No. 3, 1988, pp. 165–166.

Colorless beryl is occasionally (and usually inadvertently) irradiated in a linear accelerator, which produces a golden yellow color. Build-up of excess electrical charge and heat during the treatment process apparently can induce structural damage, two examples of which are illustrated with black-and-white photomicrographs. *CMS*

MISCELLANEOUS

Una miniera di diamanti in biblioteca (A diamond mine in a library). P. P. Colonna, *Gioielli,* Vol. 11, No. 36, 1988, pp. 54–59.

Christie's recent auctions of portions of Joseph Gill's personal gemological library served to underscore the flourishing interest in rare books. Colonna notes especially the record sums of money paid for various literary masterpieces in the Gill collection, which included such authors as Jean Baptiste Tavernier and John Mawe. Books that even obscurely relate to precious gems or mineralogy made their way into Gill's comprehensive collection, a product of 20 years of dedicated work. Colonna points out the sadness of seeing it disassembled.

The article, written in Italian, is mostly Colonna's perspective, although Neil Letson (who wrote the introduction to the Gill Collection catalogue prepared by Christie's) is quoted quite often.

Conchita Candela and RW

Expeditions/Brazil, the ultimate field trip. J. L. Ramsey, *Lapidary Journal,* Vol. 42, No. 5, August 1988, pp. 32–40.

Mr. Ramsey reports on a 1987 field trip to some important gem-producing areas in Minas Gerais, Brazil, focusing on Belo Horizonte (Ouro Preto), Governador Valadares, and Teófilo Otoni. For each area, he briefly describes the geology of the deposits and the materials recovered. Writing from a faceter's point of view, he also provides some tips on the fashioning of topaz, tourmaline, aquamarine, and andalusite, as well as some excellent advice regarding the selection of rough. Eight color photographs illustrate the stones and localities. *Bill Videto*

The crystal contingent. M. Berk, *Lapidary Journal,* Vol. 42, No. 3, June 1988, pp. 54–68.

Ms. Berk provides an overview of "New Age" interest in mineral crystals. She examines crystal healing, channeling energies, and various metaphysical properties attributed to natural crystals. The fact that these concepts are not new, but are gaining in popular acceptance in a technical society, is fascinating.

A long article, including many interview excerpts, it reports rather than editorializes, and reminds this reviewer that well-documented properties such as piezoelectricity or pyroelectricity would have been considered "mystical" a few dozen years ago.

Bill Videto

Index to Volume 24

Numbers 1–4, 1988

SUBJECT INDEX

This index gives the first author (in parentheses) and the *first page* of the article, Gem News (GN), or Gem Trade Lab Notes (GTLN) section in which the indexed subject occurs. The reader is referred to the author index for the full title and the coauthors, where appropriate, of the articles cited. The pages covered by each issue are as follows: Spring (1–66), Summer (67–132), Fall (133–194), Winter (195–264).

AUTHOR INDEX

This index lists, in alphabetical order, the names of authors of all articles that appeared in the four issues of Volume 24 of *Gems & Gemology*, together with the inclusive page numbers and the specific issue (in parentheses). Full citation is provided under the first author only, with reference made from joint authors.

Indexes prepared by Dona Dirlam