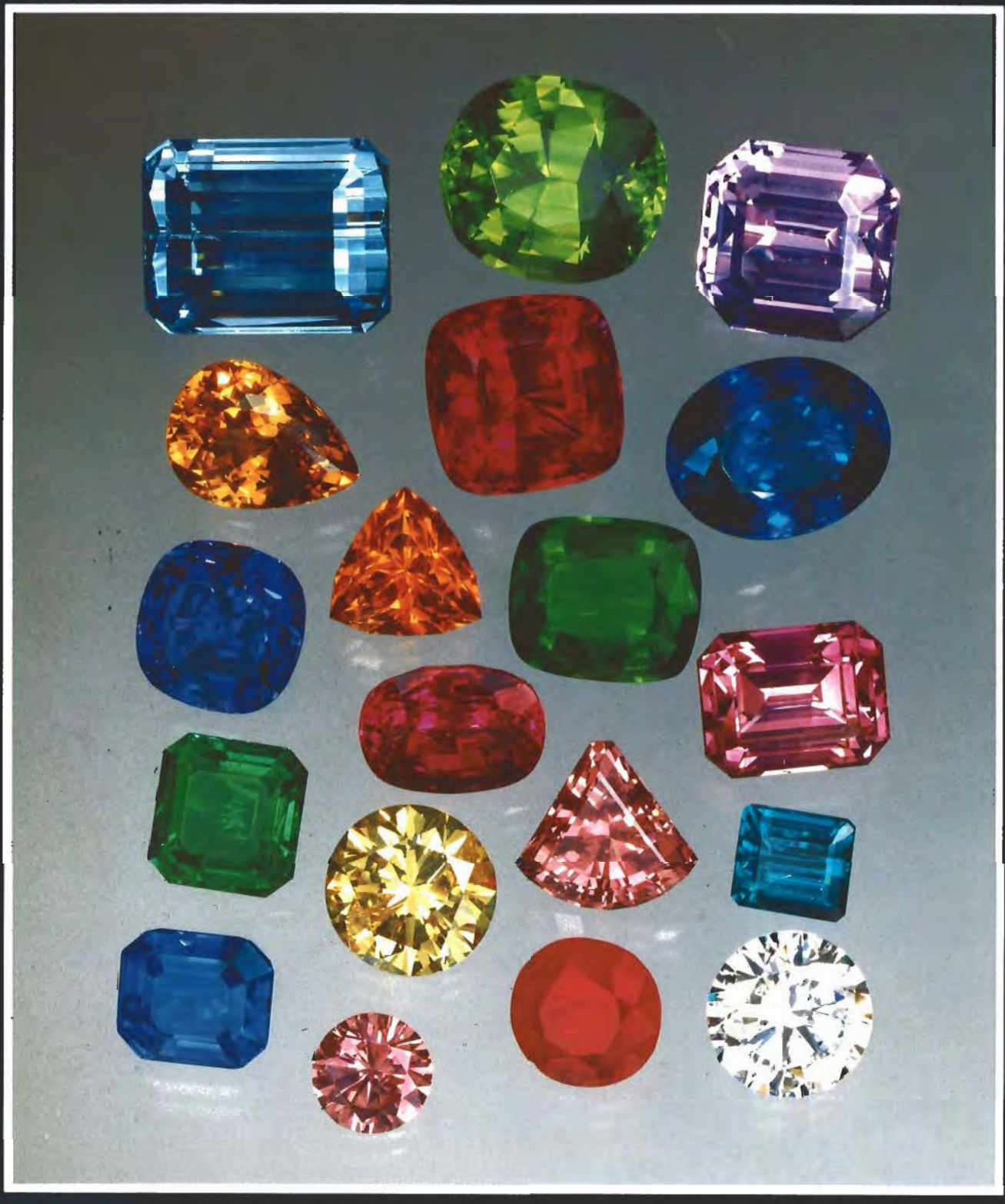
Gems & Gemology

VOLUME XXVI SPRING 1990



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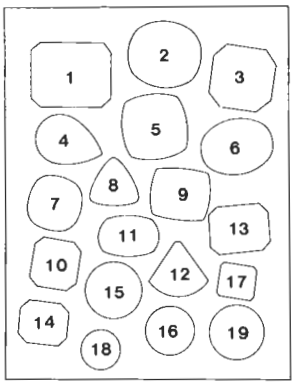

ABOUT THE COVER: The 1980s saw continued production from many historically important localities, plus the addition of several new ones. This cover photo includes some of the most popular gemstones of the decade (all localities indicated are as reported by the owners of the stones): (1) 25.43-ct aquamarine, Santa Maria mine, Brazil; (2) 20.10-ct peridot, Burma; (3) 21.09-ct kunzite, Brazil; (4) 8.14-ct grossular garnet, Kenya; (5) 16.28-ct rubellite tourmaline, Queen Mine, Pala, California; (6) 15.18-ct tourmaline, Paraíba, Brazil; (7) 10.42-ct tanzanite, Tanzania; (8) 6.09-ct spessartite, Ramona, San Diego County, California; (9) 10.45-ct tsavorite, Kenya; (10) 4.82-ct emerald, Colombia; (11) 8.31-ct pink sapphire, Sri Lanka; (12) 5.79-ct pink spinel, Pamir Mountains, USSR; (13) 10.15-ct pink topaz, Pakistan; (14) 6.70-ct sapphire, Kashmir, India; (15) 6.14-ct fancy intense yellow diamond; (16) 6.38-ct ruby, Burma; (17) 3.08-ct tourmaline, Paraíba, Brazil; (18) 1.85-ct fancy purple-pink diamond, Argyle diamond mine, Western Australia; (19) 5.05-ct D-color, internally flawless diamond.

Stones 1, 2, and 5 are courtesy of William F. Larson; 3 and 11 are courtesy of Pala International, Inc.; 4, 8, 13, and 14 are courtesy of the Natural History Museum of Los Angeles County; 6 is courtesy of DuQuet Jewelers, Inc.; 7 is from GIA; 9 is courtesy of Julio Zerkowitz; 10 is courtesy of R. Esmerian, Inc.; 12 is courtesy of Justina; 15 is courtesy of Ballreich & Kantor and Kazanjian Brothers, Inc.; 16 is courtesy of Ronny Levy Gem Co.; 17 is courtesy of Evan Caplan & Co.; 18 is courtesy of Argyle Diamond Sales Ltd.; 19 is courtesy of William Goldberg Diamond Group.

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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.

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The 1980s in Review: New Realities of the Gem and Jewelry Industry

In the gem and jewelry industry—as throughout the world—the 1980s was a decade of unparalleled change. Many new products entered the market, and the processes that service and enhance them were radically altered. The entire face of gemology and the jewelry trade shifted: Change dominated jewelry-chain operations, mass merchandising fostered new growth areas, and demographics became a buzz-word of the decade. Successful retailers moved to re-emphasize quality products and superior service as the consumer became more jewelry conscious, more knowledgeable, and more sophisticated than in years past. These consumers enjoyed getting a deal, but were willing to pay more for quality—if they knew they were getting value. They also had more money, but less time, and convenience became essential.

As the decade progressed, more retailing formats began to chase a growing gem and jewelry "pie." The traditional jewelry industry had to cope with deep discounting, deceptive pricing and advertising, underkarating of gold, misgrading of diamonds, and the shortweighting of mounted goods. Nonconventional gem and jewelry outlets—such as discount operations, direct-mail sales, and even home shopping—proliferated, opening gems and jewelry to more and more people. One result was a massive new market for enhanced stones, such as irradiated blue topaz and heat-treated sapphire, which were now available in hundreds of thousands—even millions—of carats.

In the diamond industry alone, the 1980s ushered in tremendous changes. Over the course of the decade, production increased almost 2 1/2 times, from about 40 million carats to almost 100 million carats per year. Australia went from almost no production at the beginning of the decade to 34 million carats per year at the end; Botswana, too, went from nil to over 15 million carats per year. With its supply of low-cost labor, India has emerged as one of the most effective cutting centers. This has brought a new dimension to the quality of diamond that can be cut and still produce a profit, with many pieces of rough that were formerly considered industrial grade now being faceted. According to S. N. Sharma, president of Hindustan Diamond, 60 to 70 million carats of diamonds passed through India in 1987; at the end of the decade, India boasted a mind-boggling 700,000 diamond cutters.

With the dynamics of the industry during the last several years, the very nature of what a gemologist must know has changed. Taking its roots from the earth sciences of geology and mineralogy, gemology is a unique hybrid, a commingling of the technical, the aesthetic, and even the commercial. Judgment has become as important as scientific knowledge. In fact, a gemologist's stock in trade—whether buying, selling, grading, identifying, or appraising—is an informed opinion. But in addition to great varieties of gems and jewelry today, a gemologist is confronted with grading standards, price lists, computer trading, data bases, information dissemination, globalization, telecommunications networks, and the proliferation of markets. These are the new realities.

We hope the articles in this retrospective issue will help clarify many of the changes that have taken place over the past decade, in all areas of gemology. The decade began on an economic high, only to witness a withering of the traditional jewelry

industry. We saw the rise, fall, and rise again of the diamond industry, the growth of colored stone sales, a rebirth of interest in fancy-color diamonds, new power for the auction market, gemstone enhancement defined and refined, and remarkable advances in technology. To give you a flavor of just how unique a period this was, we have chosen several key gemological topics to review.

Major localities are always a bellwether for future sources and new products in the marketplace. The 1980s did not disappoint us. Brazilian finds such as the alexandrite from Minas Gerais and the tourmaline from Paraíba were gemologically important, while the massive production of diamonds in Australia had a major impact throughout all levels of the gem and jewelry industry. The article "Gem Localities of the 1980s," by Jim Shigley, Dona Dirlam, Alan Jobbins, and Karl Schmetzer, reviews both new sources and the most important producing localities of the decade. It also includes a world map of key localities as a complement to the comprehensive table they have compiled.

In "Gemstone Enhancement and Its Detection in the 1980s," Bob Kammerling, John Koivula, and Bob Kane review the key gem enhancements of the decade and methods of detecting them using standard gemological techniques. Included in their work is a comprehensive chart describing ways to detect many of the treatments that played an unparalleled role in the gem industry. We think it will become a standard reference guide for jewelers and gemologists.

For the subject of "Synthetic Gem Materials in the 1980s," we sought the expertise of noted author and scholar Kurt Nassau. Dr. Nassau reviews the important synthetics from the point of view of newness on the scene and marketing impact. At first thought, it might seem that the 1970s was the decade of synthetics – that not much in the way of new products emerged during the 1980s. But who can deny the potential of a gem-quality synthetic diamond? Or the market impact of massive amounts of fine-quality synthetic emerald and ruby? Or the role that synthetic cubic zirconia has played throughout the industry?

In "New Technologies of the 1980s," Emmanuel Fritsch and George Rossman review new technologies for manufacturing synthetic gem materials, enhancing natural stones, and identifying the origin and nature of puzzling materials. In most instances, they are technologies that are "new" to gemology but have been used in other industries. During the 1980s, we learned to borrow and borrow well. You will note, in particular, the unique perspective that Drs. Fritsch and Rossman give to advances in gem identification, especially to the different types of spectroscopy.

To conclude the retrospective, jewelry historian Elise Misiorowski reviews "Jewelry of the 1980s." She focuses on the impact of new supplies of gems on fashion jewelry, and describes trends in cutting, jewelry design, and key designers. Ms. Misiorowski's contribution is unique in that she takes on the difficult task of documenting trends for a time period that is so close behind us.

As we look forward to the 1990s in gemology, let's first look back on the 1980s. The promise of the past is really the hope of the future. Facing the future with a new vision is certainly on our agenda, and we trust it's on yours, too.

Richard T. Liddicoat
Editor-in-Chief, Gems & Gemology

William E. Boyajian
President, GIA

THANK YOU!

This issue, the largest *Gems & Gemology* ever published, was first conceived more than a year ago, at an editorial meeting of the journal. At that time, GIA President Bill Boyajian stressed the importance of the 1980s in the development of gemology and the need to chronicle these events as our relatively young field moves into maturity. The editors at the meeting were unanimous in their support of this concept and their willingness to do the work to bring the project together. Hundreds of hours were eventually invested by GIA authors Dona Dirlam, Dr. Emmanuel Fritsch, Robert Kammerling, Robert Kane, John Koivula, Elise Misiorowski, and Dr. James Shigley, and we were pleased to also get the participation of *Journal of Gemmology* Editor Alan Jobbins, Dr. Kurt Nassau, Dr. George Rossman, and Dr. Karl Schmetzer, to make this issue our most comprehensive ever.

To represent as broad a perspective as possible, we not only relied on the many members of our regular review board (listed on the masthead page) to critique the papers, but we also enlisted the aid of prominent experts worldwide. Dr. Edward Gübelin interrupted an important project to review the localities article quickly and with the great thoroughness for which he is so well known. The Gem Testing Laboratory of Great Britain's Kenneth Scarratt, jewelry historians Ettalgale Blauer and Penny Proddow, synthetics manufacturers Judith Osmer and Virginia Carter, and Professors Giorgio Graziani (of the Universita Degli Studi di Roma) and Anne Hoffmeister (of the University of California at Davis) also provided valuable input. Within the GIA Gem Trade Laboratory, we tapped the experience of gem identification specialists David Hargett, Christopher Smith, and Shane McClure.

But, as our regular readers know, *Gems & Gemology's* reputation is based on more than our prose. The photos for this issue were also a major undertaking. As is evident in the credits to the more than 130 illustrations, dozens of people contributed photos; many more provided specimens for photography. Special thanks go to Tino Hammid, Shane McClure, Robert Weldon, and Harold and Erica Van Pelt for the many photos they provided to make this issue one of the most powerful ever. The cover is a story unto itself. The gems were gathered by Robert Kane and others at the GIA Gem Trade Laboratory in Santa Monica from stone dealers across the country. The samples were selected based on their historical significance to gemology and their representativeness of the gem industry over the last 10 years. The Van Pelts required an entire day to set up and shoot this special grouping, to our knowledge one of the best and broadest collections of fine diamonds and colored stones ever gathered in a single photograph.

I would also like to take this opportunity to thank the people "behind the scenes" at the journal who worked many hours of overtime to get this publication out, especially Assistant Editor Nancy Hays, Art Director Lisa Joko, Word Processor Ruth Patchick, Technical Editor Carol Stockton, and Production Artist Carol Winkler.

The issue would not be what it is, however, both as an expanded issue of *Gems & Gemology* and, another first for the journal, as a hardbound book, without the willingness of senior GIA officials Bill Boyajian, Dennis Foltz, Richard T. Liddicoat, and Court Walker—and GIA Gem Trade Laboratory Chief Executive Officer Tom Yonelunas—to support the additional costs involved. This issue is GIA's way of thanking all of you in the gem and jewelry industry for the support you showed us during the very exciting—and turbulent—decade of the 1980s.

Alice S. Keller, Editor

GEM LOCALITIES OF THE 1980s

By James E. Shigley, Dona Mary Dirlam, Karl Schmetzer, and E. Alan Jobbins

The 1980s saw major developments in new sources for diamonds and colored stones, as well as expanded production at many existing mines. This article identifies important new discoveries, as well as localities that were major gem producers, during the decade. Brief descriptions are provided for many of these, and their impact on the jewelry industry is reviewed. The article also provides an index to key recent publications on these occurrences.

ABOUT THE AUTHORS

Dr. Shigley is director of research, and Ms. Dirlam is senior librarian, at the Gemological Institute of America, Santa Monica, California. Dr. Schmetzer is a research scientist residing in Petershausen, near Munich, Germany. Mr. Jobbins, former curator of minerals and gemstones at the Geological Museum in London, is presently a consultant and editor of the Journal of Gemmology; *he lives in Caterham, England.*

Acknowledgments: The authors wish to thank several individuals (cited in the text by name and as "personal communications") who provided information to the ongoing "Gem Locality Atlas" project, some of which is briefly cited here. We are especially grateful for valuable assistance from G. Becker, J. Byrne, B. Curren, P. Flusser, Dr. E. Fritsch, Dr. H. Höllander, R. Kammerling, Dr. J. Kanis, J. Koivula, C. Kremkow, R. Naftule, R. Patchick, S. Patty, E. J. Petsch, Dr. L. Snee, and K. E. Wild. Very helpful reviews of an early version of this article were provided by G. Austin, Dr. N. Barot, Dr. E. Gübelin, R. Kane, Dr. P. Keller, and Dr. J. Sinkankas.

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The past decade has witnessed an unprecedented increase in the availability and popularity of many varieties of gemstones. The greater appreciation of all aspects of color in today's society has been reflected in the gem market by both new enhancement techniques and new synthetics, as discussed elsewhere in this issue, and has been supported by important discoveries in a number of new localities. Fine alexandrites from Brazil, sapphires from Southeast Asia and Australia, emeralds from Colombia and Zambia, and pegmatite gemstones (tourmaline, aquamarine, etc.) from Brazil, Pakistan, Afghanistan, and several countries in Africa were key components of the gem market during the last 10 years. At the same time, major quantities of colorless diamonds emerged from new mines in Australia and Africa, joining traditional suppliers to more than double the production of rough over the course of the decade.

This article highlights a number of these major gem deposits. It identifies important gem localities that were found during the last decade, and also those that were known before but either reached or continued at a major level of production during the 1980s (figure 1). In general, the discussion is restricted to the more commercially important inorganic gem materials, with the text organized alphabetically by gemstone. Of necessity in some instances, the decision as to which localities to include has been somewhat subjective. To minimize redundancy, most references to specific localities and gem materials are not included in the text, but rather are provided in table 1, which follows the text portion of this article.

A number of excellent books published in recent years include information on gem localities (as indicated at the end of the reference list). A comprehensive world map of gem localities, showing the types of gem materials produced and an indication of their geological settings, was created by Dr. E. Gübelin and published in 1988 by the

Figure 1. The excitement colored stones produced in the 1980s in large part grew out of the greater availability of gemstones from both traditional and new gem localities. East Africa emerged as one of the most important gem-producing regions. These six stones represent the remarkable variety of gems found there. From top to bottom, left to right, are a 42.33-ct pyrope-spessartine garnet, a 28.41-ct tanzanite, a 22.69-ct tourmaline, a 27.03-ct yellow scapolite, a 9.73-ct tsavorite garnet, and a 7.02-ct purple scapolite. From the John Jago Trelawney Gem Collection at the Los Angeles County Museum of Natural History; photo © Harold & Erica Van Pelt.

Swiss Gemmological Society. A simplified map of the major sources for important gem materials is provided in figure 2.

BERYL

Emerald. Major expansion has occurred in the sources of this very important gemstone. Colombia, long recognized as the principal supplier of high-quality material, must now compete with new localities in Brazil, Zambia, Zimbabwe, Madagascar (Malagasy Republic), Pakistan, and Afghanistan. However, important new mining developments helped Colombia retain a 30% share of the world output in the late 1980s (Barot, 1987). For example, under the direction of lessee companies Tecminas and Coesminas, the Muzo mine is now fully mechanized and has introduced a sophisticated tunneling operation. Prospecting in the region continues to provide new data on the geology and origin of these Colombian deposits, and there is every indication that they will remain an important source of high-quality emerald (figure 3).

Even so, newer sources now account for most of the emeralds on the world market. In the 1980s, deposits of major significance came into full operation in Brazil. The Carnaíba mine, first found in the 1960s, continued to be active during the 1980s. A major deposit found in 1981 at Santa Terezinha, in the state of Goiás, was highly productive throughout the decade. The Santa Terezinha crystals are generally small (less than 1 cm) and range from pale to very dark green, with a distinct bluish green tone (Cassedanne and Sauer, 1984). In 1988, new emerald discoveries were made in Bahia at Socotó, in Ceará at Tauá, and in Minas Gerais at Nova Era. The Nova Era deposit, which may be an

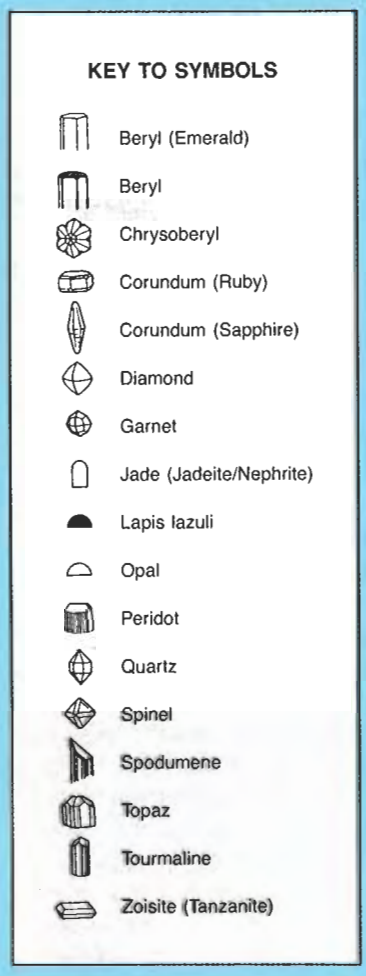


Figure 2. The symbols on this simplified world map indicate the important gem materials produced during the 1980s in the countries designated. For details on the specific locations within a country, please refer to the references listed in table 1. For a comprehensive map of historic and contemporary gem materials and their formation environments, see Gübelin (1988). Art by Carol Winkler.

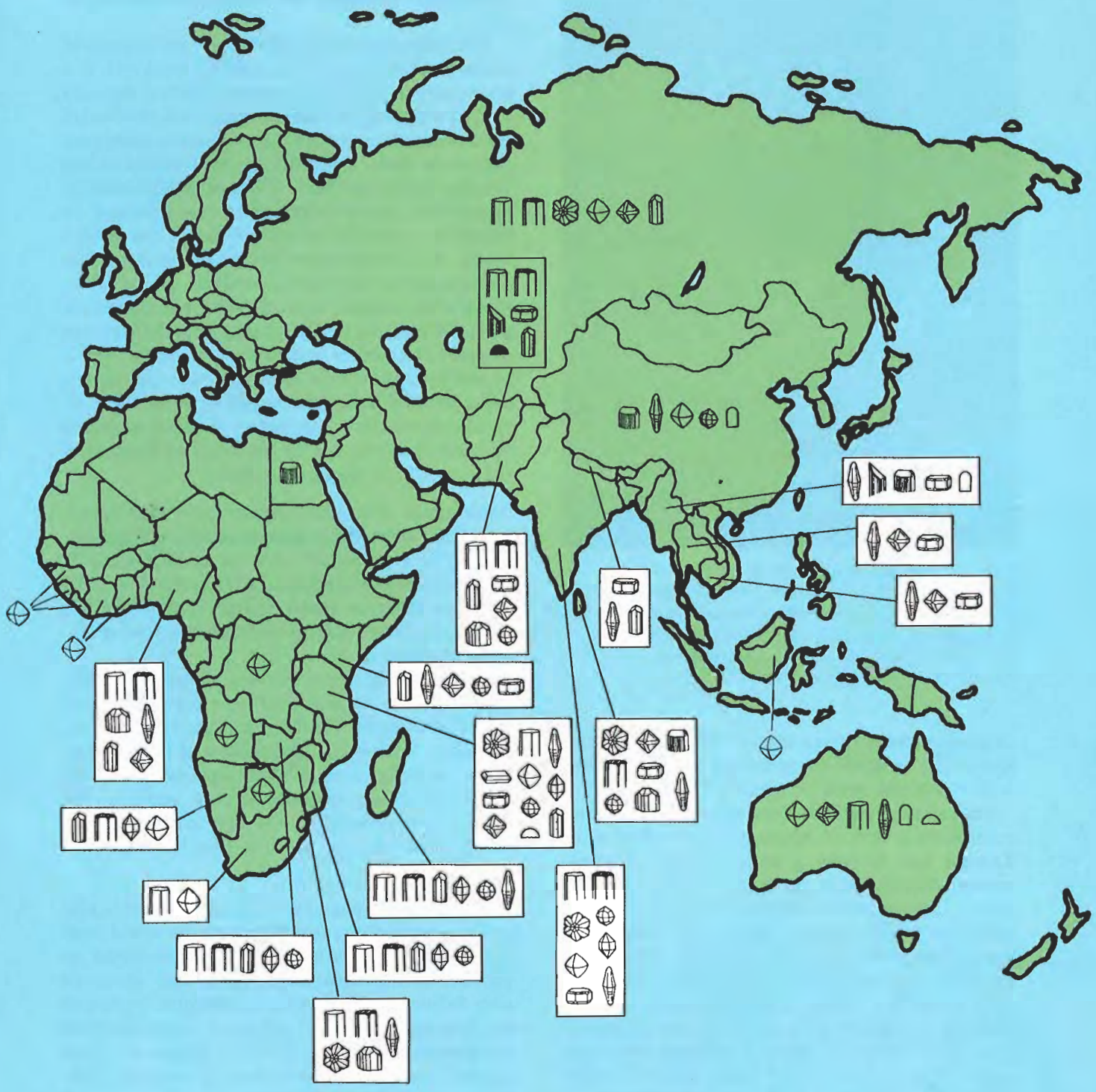


Figure 3. Colombia continues to produce some of the world's finest emeralds. One example of the spectacular specimens recovered in the latter part of the decade is this 6.03-cm emerald crystal. Courtesy of Tecminas; photo © Harold & Erica Van Pelt.

extension of the Itabira deposit discovered in the late 1970s, is noted for relatively large emeralds, with many cut stones exceeding 5 ct.

Important emerald deposits were found on other continents as well. In Africa, the Kitwe district in Zambia has become a major source of good, strongly bluish green, material. At Kafubu, crystals as large as 130 ct have been found; they are noted for being very dark green, with high R.I.'s (Sinkankas, 1981, p. 603). By 1989, 40% of all emeralds imported into the U.S. came from Zambia (Berenblatt, 1989). The Mberengwa area of Zimbabwe continues to produce fine material, particularly from the older Sandawana and more recently discovered Machingwe and Adriadne mines (Kanis, 1986). The emerald deposits of Madagascar occur in the southeast part of the island, at Ankadilalana, in a biotite schist. Hänni and Klein (1982a,b) described them as blue-green in color, similar to Zambian emeralds. Cavey reported in the 1989 *Mining Annual Review* that Madagascar produced the largest emeralds in Africa.

The 1980s also saw the first major influx into the world market of emeralds from Pakistan and, to a lesser extent, from Afghanistan. Several deposits in the Swat Valley of Pakistan produced material of good to excellent quality, although some stones are extremely dark. Emeralds are also mined in the Panjshir Valley northeast of Kabul in Afghanistan. Meanwhile, sparse information has appeared on emeralds recently recovered from the Soviet Union. All of these deposits produce material that rivals some of the best Colombian emeralds, although not, perhaps, with the same consistency. It is also interesting to note that most of these recent emerald discoveries occur in metamorphic rocks, in environments very different from the classic hydrothermal vein-type deposits found in Colombia; an excellent discussion of the occurrences of emerald worldwide can be found in Kazmi and Snee (1990) and Sinkankas (1981).

Aquamarine. The major source of gem aquamarine continued to be Minas Gerais, Brazil, where aquamarine is a principal constituent of numerous weathered pegmatite deposits (Proctor, 1984). The states of Espírito Santo, Bahia, Ceará, and Rio Grande do Norte also produce commercial quantities of aquamarine.

During the decade of the '80s, additional significant amounts of gem-quality aquamarine were found in Nigeria, Zimbabwe, Zambia (figure 4), Namibia, Madagascar, Pakistan, and India. Much of the material from Nigeria emerges from the ground in classic aquamarine blue, and does not require (nor respond to) the heat treatment routinely used on the greener Brazilian material (Barot, 1987).

Morganite. The pegmatites of Minas Gerais also provide most of the morganite on the world market. While the Urucum deposit continued to produce during the decade, a major find was made near Salinas in 1986. This occurrence, known as the Bananal mine, produced many large, bicolored morganite-aquamarine crystals. Many of these crystals contained large nodules of virtually flawless morganite at their centers—the first reported occurrence of gem nodules in a material other than tourmaline (Kampf and Francis, 1989). Early in the decade, significant amounts of light orange mor-

ganite were also mined in Mozambique, but supplies have been erratic in recent years because of the political turmoil in that country (Barot, 1989).

Other Beryls. The yellow variety, known as heliodor, also occurs in the pegmatites of Minas Gerais. Although much rarer than aquamarine, some attractive crystals were recovered in the 1980s. While pale stones were heat treated, those with good color survived as specimens or were cut into faceted stones (Proctor, 1984). Red beryl is the rarest of all the gem beryls. Commercial mining in the Wah Wah Mountains of Utah, begun in the late 1970s, continued sporadically during the 1980s. By the end of the decade, annual production averaged more than 200 stones greater than 0.25 ct and about 2,000 smaller stones (R. Harris, pers. comm., 1990).

CHRYSOBERYL

The gem fields of Sri Lanka continued to be the major source of fine chrysoberyl, particularly cat's-eye material. Alexandrites were occasionally found as well.

However, the 1980s saw several major new finds of chrysoberyl, cat's-eye chrysoberyl, and alexandrite in Brazil. Cassedanne (1984a,b) discusses the main localities and their geologic settings. Proctor (1988) describes the exciting discoveries of alexandrite in Minas Gerais, first in the Malacacheta region (1975) and then at the deposit near Lavra de Hematita (1986). The latter occurrence has furnished some of the finest alexandrite ever found (figure 5).

Although Russia has historically produced fine chrysoberyl and alexandrite, no reliable production information for this decade is available.

CORUNDUM

Ruby. The classic ruby occurrences of Southeast Asia (i.e., Mogok, Burma [Myanmar]; Chanthaburi, Thailand; and Pailin, Cambodia) continue to be major producers of ruby, but the 1980s also saw the exploitation of new occurrences in East Africa, specifically Kenya, Tanzania, and, more recently, Malawi (figure 6). Although the quality of material from these African localities may not always equal that of stones from Southeast Asia, it is regularly encountered in the trade. Cavey reports in the 1988 *Mining Annual Review* that heat treatment has been used extensively on stones from Thailand and Africa to improve color and clarity. Small amounts of ruby have also come from Pakistan, Afghanistan, India, and Nepal.

Figure 4. Aquamarine was one of the gems that benefited from increased mining throughout Africa. These two fine aquamarines are from Zambia: The pendant contains a 10.12-ct pear shape, while the ring is set with a 6.91-ct emerald cut. Jewelry courtesy of Andrew Sarosi; photo © Harold & Erica Van Pelt.

Sapphire. As with ruby, much of the sapphire in the jewelry trade today comes from Southeast Asia. During the 1980s, significant amounts continued to be found in Sri Lanka and Burma, with the Cambodian deposits largely remaining dormant until the end of the decade. The sophisticated operation at Kanchanaburi, in southwest Thailand, is a major new producer of natural-color blue sapphire (figure 7).

Two localities played a major role in the greater availability of sapphires during the 1980s: Australia and East Africa. Although both Queensland and New South Wales have long been known as sources of gem sapphire in a wide range of colors, only within the last 10 years did they reach a significant level of commercial production.

In East Africa, expanded production was seen from Kenya, Tanzania, Malawi, Burundi, and Rwanda. Particularly noteworthy are the sap-

Figure 5. In late 1986, gemologists enthusiastically welcomed the discovery of alexandrite at Lavra de Hematita, in Minas Gerais, Brazil. The attractive color change of two Brazilian stones (1.06 ct, center; 1.32 ct, right) is shown compared to a Russian alexandrite (1.29 ct, left). The two Hematita alexandrites are courtesy of Mayer & Watt, while the Russian stone is courtesy of Mary Murphy Hammid. Photo © Tino Hammid.

phires found along the Umba River in Tanzania, which occur in a wide range of colors (figure 8), with the orange and color-change varieties being especially interesting. These relatively new sources of corundum have contributed greatly to our understanding of the relationship between color, absorption spectra, and trace-element chemistry in this important gem material (see Schmetzer and Bank, 1981a). More recently, fine-quality material began to come out of the Kaduna area of Nigeria (Kiefert and Schmetzer, 1987b). In 1989, sapphires and star sapphires from new deposits in northern Kenya, close to the Ethiopian border, began to appear (N. Barot, pers. comm., 1989).

During the 1980s, more than ever before, heat treatment was used to alter the appearance or improve the color of sapphires of virtually every hue. While some of the blue material from Australia is of good color and clarity, much of the remainder—which is often affected by heavy silk—can be improved by heat treatment (Coldham, 1985). Large quantities of low-quality starting material, such as the pale white "geuda" that can be transformed into deep blue stones, originate in Sri Lanka (Gunaratne, 1981), as do considerable amounts of fine-quality untreated yellow sapphire, "padparadscha" sapphire, and asteriated stones.

Heat treatment has also contributed to the availability of sapphire from Montana. The past few years have seen a major effort to exploit the sapphire occurrences at a number of deposits in the areas of Rock Creek and the Missouri River as well as Yogo Gulch. Although the stones found typ-

Figure 6. In the 1980s, rubies continued to be produced from classic occurrences such as Burma and Thailand, as well as from newer localities such as Kenya and Tanzania. Many of these were cut en cabochon *as depicted here in a stunning ruby and diamond necklace. The pendant stone is 47.69 ct. Courtesy of Color by Design, B. Laird and B. Forrest; photo © Harold & Erica Van Pelt.*

Figure 7. Kanchanaburi, in southwest Thailand, emerged as a major producer of natural-color blue sapphire in the 1980s. It is noteworthy for both the large-scale production and the sophisticated mining operation. Note the size of this one excavation by the S.A.P. Company at Bo Phloi. Photo by Robert C. Kammerling.

Figure 8. From the Umba River valley in northeast Tanzania, comes this array of ruby and fancy-color sapphires. These unusual colors were widely marketed in the 1980s. Courtesy of Tsavo Madini, Inc.; photo © Tino Hammid.

ically are very small, heat treatment produces a variety of interesting colors. Using sophisticated retrieval techniques, mining concerns in Montana increased gem production over the course of the decade 1200%, from $100,000 to $1.3 million, primarily due to sapphire production (Austin, 1990).

In 1981, for the first time in almost four decades, Westerners visited the historic Kashmir deposits (Atkinson and Kothavala, 1983). Although it appears that these famous deposits still have significant mining potential, there has been little recent production.

New deposits with considerable future potential have been found in Fujian and Hainan Island, China. The first detailed report on Colombian sapphires was published in 1985 (Keller et al., 1985). Small sapphires recovered during gold-dredging operations in Minas Gerais, Brazil, were encountered at the 1990 Tucson Gem and Mineral Show.

DIAMOND

Some of the most exciting discoveries in the 1980s involved diamonds. At the end of the preceding decade, the three top producers (in quantities of rough) were the Soviet Union, Zaire, and South Africa. During the 1980s, Russian production remained significant and production in Zaire more than doubled (but continued to be primarily industrial-quality stones). Production also continued steadily at most of the classic South African mines, although there was some increase later in the decade with the reopening of the Koffiefontein mine and the expansion of operations in Namaqualand. Also during the 1980s, however, several relatively new areas completely changed the production hierarchy. Within three years after it opened in 1982, the Jwaneng mine—in conjunction with the operating Orapa and Letlhakane mines—had propelled Botswana to third rank in total production and second in value (Boyajian, 1988). Among all diamond mines in this decade, the Jwaneng mine had the highest average mining grade (154 ct of diamonds per ton of kimberlite; "Diamonds," 1989). And Australia, which had no significant production at the beginning of the decade, by the end was the top producer.

Western Australia, in fact, is one of the most exciting areas developed in the 1980s. After extensive exploration, diamond-bearing volcanic "pipes" of lamproite composition and some accompanying alluvial deposits were discovered at several localities—including Ellendale and Argyle—in the late 1970s and early 1980s. Because of the occurrence of the diamonds in lamproite host rocks, these discoveries caused a major revision in the scientific understanding of the conditions of diamond formation. The quantities of diamonds that have been processed since Argyle's AK-1 pipe became fully operational in 1985 (figure 9) have had a dramatic impact on the world market. For 1986, Australia was the number one source, and by 1988 it was producing 35 million carats annually ("Diamonds," 1989). Even though most of this material is industrial quality, the large quantities of gem and near-gem stones that became available stimulated the development of a mammoth diamond-cutting industry in India to process them efficiently and inexpensively (Boyajian, 1988). Australia is also notable for a relative abundance of colored diamonds, in particular pinks (figure 10), but also brownish ("champagne"), blue, and violet stones.

Figure 11. This attractive brown 7.66-ct diamond from the Xiyu mine, in the Mengying Province of China, gives some idea of the diamond potential of this Asian nation. It is likely that China will emerge as a major gem force in future decades. Courtesy of Gary R. Hansen; photo by Robert Weldon.

Figure 12. As new localities such as those in East Africa produced unusual hues of garnet—as well as sapphire and tourmaline—jewelers created dramatic designs that incorporated these rainbow hues in calibrated stones. Jewelry courtesy of The Collector, Fallbrook and La Jolla; photo © Harold & Erica Van Pelt.

for diamonds (and colored stones) in response to easier exchanges of technology. Elsewhere, exploration is being conducted worldwide, throughout the United States and Canada as well as in traditional producing countries, to locate diamond-bearing kimberlite and lamproite pipes.

GARNET

Gem garnets continue to be produced from numerous major deposits in India, Sri Lanka, Mozambique, and Madagascar, but the most exciting development of the 1980s was the emergence of East Africa as a principal source and the discovery there of a number of "new" species and varieties of this complex gem group. Following the discovery of green grossular ("tsavorite" or "tsavolite") in both Kenya and Tanzania in the early 1970s, this region continued to produce gem garnets in a range of composition and color beyond that previously encountered. Among these remarkable new types are the reddish brown "umbalite" or "malaia" ("malaya") garnets, which have been shown to be members of a solid-solution series between pyrope and spessartine. Their discovery led to a re-evaluation of the chemistry of this gem material, and to a revised system of classifying gem garnets on the basis of their refractive index, specific gravity, color, and absorption spectra (Stockton and Manson, 1985; Hänni, 1987a, b).

East Africa also produced quantities of previously rare color-change garnets as well as unusual hues such as "raspberry" rhodolites. Multi-color suites of garnets are often transformed into dramatic pieces called "rainbow" jewelry (figure 12).

OPAL

During this decade, the major source of gem opal continued to be Australia (figure 13) and, specifically, the territories of New South Wales, South Australia, and Queensland. Mining activity at White Cliffs, New South Wales, famous for "crystal opal" (a transparent, colorless variety that displays intense play-of-color), was revitalized by the introduction of heavy equipment in the mid-1980s. Lightning Ridge, best known for black opal, showed a small increase in production in the late 1980s, also due to improvements in mining techniques.

The most important development in Australian production, however, has been the intense mining activity at Mintabie, South Australia, where a

Figure 9. The Argyle mine entered full production in December 1985, and within a year Australia was the number one source of rough diamonds worldwide. This occurrence of a diamond pipe in a lamproite has caused geologists to re-examine many of their theories about diamond formation. Photo by James Lucey.

Exploration in recent years suggests that there will be even greater production from alluvial deposits. For example, Consolidated Diamond Mines Proprietary Ltd. continues to expand mining of alluvial diamonds along the coast of Namibia between Swakopmund and the Orange River. For the first time in many years, an organized effort is being made to exploit the alluvial fields (as well as to determine the kimberlite source) in Kalimantan in southeast Borneo. Sophisticated alluvial mining has also been successful in parts of Brazil and Venezuela, as well as in Sierra Leone. In 1987, the first mining in Brazil of a diamond-bearing pipe began 20 km from Julina in the Alto Paraguai District of Mato Grosso (Austin, 1987).

While diamond mining in China is still in its infancy, preliminary reports indicate significant potential at a variety of locations throughout the country (figure 11). The changing political scene in the Soviet Union and Eastern Europe is likely to open these areas to more sophisticated exploration

Figure 10. The 1980s saw an increased awareness and appreciation of color in diamonds. This coincided with the greater availability of colored diamonds from Australia. Particularly notable is the relative abundance of pink and brownish pink stones, as well as the blues and greens. These diamonds range from 0.51 ct to 1.20 ct. Courtesy of Argyle Diamond Sales; photo © Harold & Erica Van Pelt.

Figure 13. New mining techniques, as well as new discoveries, have increased the availability of opals, especially black opals, in the 1980s. These opals from Australia and Mexico (the largest is 17.84 ct) are courtesy of the American Gem Trade Association; photo © Harold & Erica Van Pelt.

series of new deposits were found at the end of the 1970s (Keller, 1990). In addition to the fine white opal for which South Australia is known, Mintabie also produced black opal in qualities and colors similar to the Lightning Ridge material. Mintabie and the classic deposit at Coober Pedy are now the most important producers of opal in the world.

One of the more interesting developments of the past decade was the mining of commercial amounts of contra luz, hydrophane, and rainbow opal at Opal Butte, Oregon. During this period, some unusual colors of opal, including green and blue, came from Piauí, Brazil. Discovered in the 1960s, green opal from Tanzania first became available in commercial quantities during this last decade. Traditional deposits elsewhere in the U.S. and in Mexico continued to be active.

QUARTZ

Amethyst and Citrine. Brazil was the major producer of fine amethyst and citrine during the 1980s (figure 14). As summarized by Franco (1981) and Cassedanne (1988a), amethyst occurs in both igneous and sedimentary geologic environments, principally in the states of Pará, Goiás, Ceará, Bahia, Minas Gerais, and Rio Grande do Sul. Epstein (1988) described the occurrence of amethyst in fractures in quartzite in Marabá, the alluvial deposits at Pau d'Arco, and the mining of amethyst geodes from basalt near Santa Maria and at Iraí. Amethyst is also produced in Uruguay in colors comparable to fine "Siberian" grade.

Figure 14. The quartz family of gemstones experienced renewed appreciation in the 1980s, fueled by the popularity of purple and yellow in the fashion palette, as well as by the enthusiasm of New Age groups. Brazil exported millions of carats of amethyst and citrine over the course of the decade. Stones courtesy of Kalil Elawar; photo © Harold & Erica Van Pelt.

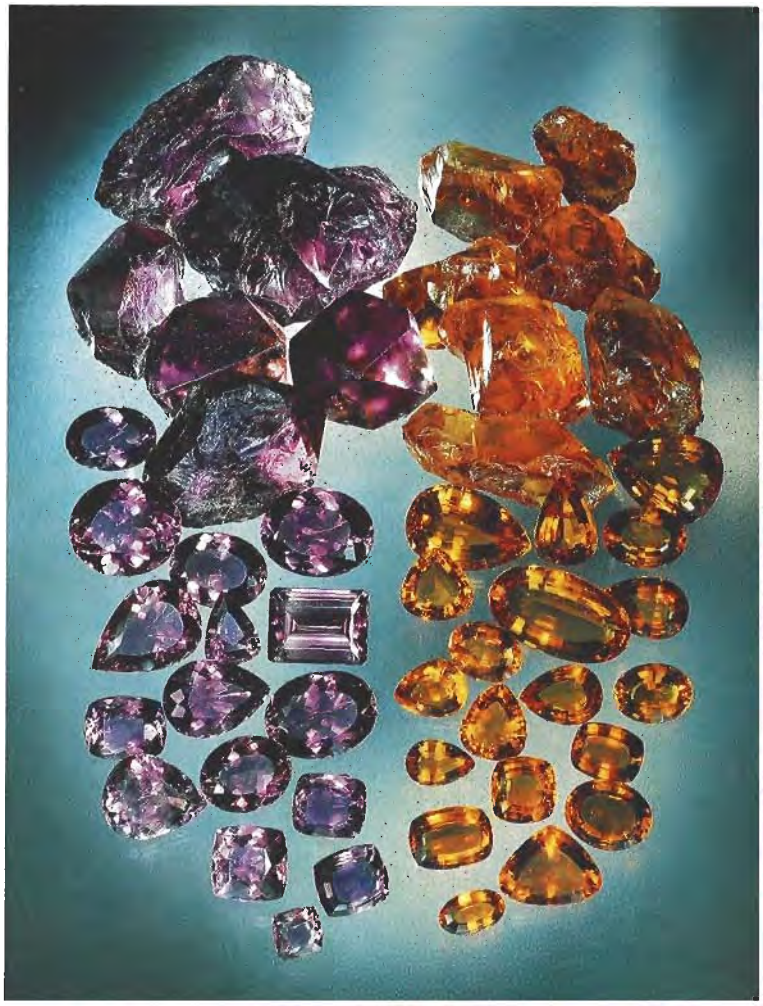


Figure 15. With the rapidly changing political situation in Eastern Europe, the USSR promises once again to be a major source of colored gems. Recently, a number of fine pink spinels emerged from the Pamir Mountains of the Soviet Union. The 27.80-ct cushion-shaped mixed cut in the pendant is shown here with a 146.43-ct cushion-shaped step cut from this locality. Stones courtesy of A.G.T. International; faceting by Justina. Photo © Harold & Erica Van Pelt.

New in the 1980s were major deposits of intensely colored, reddish purple amethyst in Zambia. As is the case in many Third World countries, the rough crystals must be purchased through a state agency, in this instance known as Mindico. A new locality near Port Hedland in Western Australia has also produced fine material (R. Kane and W. L. Cotton, pers. comm., 1990).

The great majority of citrine available during the past decade was actually heat-treated amethyst from Brazil. In 1986 alone, more than 15 tons of cobbed citrine was shipped from Rio Grande do Sul (Epstein, 1988).

One of the most interesting materials to emerge in the gem market of the '80s was bicolored amethyst-citrine ("ametrine"). Although reports early in the decade speculated that these stones were produced by treatment (Nassau, 1981), crystals displaying both colors have been confirmed from a deposit known as La Gaíba, in the Rincón del Tígre region of Bolivia, near the border with Brazil (R. Weldon, pers comm., 1989).

Rose Quartz. At the beginning of the decade, rose quartz was found in relatively small amounts of average quality, principally in Brazil. Toward the end of the decade, increased mining in Namibia, Mozambique, and Madagascar, as well as Brazil, made available fine gem-quality material and phenomenal varieties, both star and cat's-eye stones (G. Becker, pers. comm., 1990).

SPINEL

During the past decade, spinel came principally from traditional sources, including both primary and secondary deposits in Southeast Asia (Burma, Cambodia, Thailand) and secondary (alluvial) deposits in Sri Lanka. Some material also came from Tanzania and Brazil. Characterization of material from old and some new localities led to a better understanding of the causes of color and the range of properties among gem spinels. For example, 1980 saw the first description of color-change spinel (Schmetzer and Gübelin, 1980). Anderson (1972), Jackson (1982), and Schmetzer and Bank (1985) reported the properties of gem-quality, zinc-bearing gahnite and gahnospinel from Nigeria and Sri Lanka. The 1980s also saw the rediscovery of an intense blue spinel from Sri Lanka that contains the element cobalt as a coloring agent (Shigley and Stockton, 1984; Harder, 1986).

In the mid-1980s, demand for red spinel increased dramatically as it gained appreciation as a medium-priced red stone. One of the newest and most promising developments has been the discovery of exceptionally large, transparent pink spinels from the Pamir Mountains of the Soviet Union. At least one fine stone of 146 ct has been cut (figure 15).

SPODUMENE

Because gem spodumene occurs in granitic pegmatites, its distribution is similar to that of other pegmatite gems such as beryl and tourmaline. Major production of kunzite is centered in Brazil, with lesser amounts originating from Afghanistan and Madagascar. The principal Brazilian deposits are in Minas Gerais—Urucum, Kunzita, and

Urupuca. Although these localities were discovered prior to this decade, they have continued to be important producers. In 1989, kunzite was discovered at Resplendor near Governador Valadares in Minas Gerais. A 10.2-kg crystal was displayed at the 1990 Tucson Gem and Mineral Show.

Throughout the political turbulence of the 1980s, Afghanistan continued to supply superb crystals of kunzite (figure 16). With the changing political climate at the end of the decade, Westerners were again able to enter the pegmatite district (G. Bowersox, pers. comm., 1989), and it is anticipated that more material will emerge.

Figure 16. Afghanistan, which continued to produce during the decade, promises to be even more important now that Westerners have been allowed back into the country. This 31.12-cm-high kunzite crystal from Afghanistan is courtesy of Sam Goldowski and Osorio Neto. Photo © Harold & Erica Van Pelt.

TOPAZ

Topaz production in the 1980s involved three distinct color groups: colorless and light blue topaz used for treatment, golden yellow to "sherry" red Imperial topaz, and pink topaz. Brazil, Sri Lanka, and Nigeria produced millions of carats of colorless to light blue topaz for treatment by irradiation and annealing to create various intensities of blue. Not all topaz yields the desired result when treated, but exploration is constantly being undertaken worldwide to identify new sources of treatable material.

Brazil continues to be known for its famous Imperial topaz mines in the vicinity of Ouro Preto, in Minas Gerais. First documented in the 1700s, these mines are the only source of material in this attractive range of orange-to-red colors (figure 17). Of the eight or more mines active in this area, Capão do Lana is technologically the most advanced, and was characterized in the 1980s by sophisticated mining and processing techniques (Keller, 1983a).

Small quantities of fine pink topaz were mined from the Katlang district of Pakistan in a deposit that produces material ranging from colorless to light brown, and from pale pink to deep pink. Under the auspices of the Gemstone Corporation of Pakistan, which controls all gem mining in that country, tunneling began in the mid-1980s. By 1986, production of gem-quality material ranged from 20,000 to 30,000 ct, at least double what it was in 1980. The largest known pink topaz to be cut from Pakistan material in the 1980s is a 37.76-ct emerald cut stone (Spengler, 1985). Other topaz deposits were found about 20 km from Katlang, at Shakertangi. As more of the mountainous area of northern Pakistan is explored, it is likely that additional deposits will be found. The gem potential of this region seems high.

Even with the increased mining in Pakistan, most of the pink topaz on the market during the last decade was produced by heat treating yellow

Figure 17. While blue stones dominated the topaz market in terms of total production, fine yellow to "sherry" red Imperial topaz continued to emerge from the historic localities near Ouro Preto, Brazil. This Imperial topaz crystal is 4 cm high; the faceted stone is 32 ct. Courtesy of Kalil Elawar; photo © Harold & Erica Van Pelt.

topaz from Brazil (Nassau, 1985). Gübelin et al. (1986) stated that the pink stones from Pakistan could be distinguished from their heat-treated Brazilian counterparts by the presence of a violet component in the natural-color stones.

TOURMALINE

Brazil is by far the most important source of gem tourmaline, which occurs there in an astonishing range of colors. Proctor (1985a,b) described the major tourmaline-producing areas, principally in Minas Gerais. The most productive districts are Araçuaí-Itinga, Araçuaí-Salinas, and the region around Governador Valadares (including the famous Cruzeiro mine).

Perhaps the most exciting tourmaline discovery of the decade was made in the late 1980s in another area of Brazil, the state of Paraíba, where the São Jose da Batalha mine has produced significant amounts of tourmaline in a variety of unusual violet, blue, and green colors (figure 18). Research is now being conducted to determine the extent to which some of these colors are produced by heat treatment (see also Koivula and Kammerling, 1990).

Commercial amounts of tourmaline also continued to come from long-recognized sources such as Afghanistan, Namibia, Sri Lanka, and the United States. In the U.S., the 1980s witnessed the opening of exciting new gem "pockets" in the famous Himalaya mine of California, the most recent in spring 1989 (figure 19). Particularly important discoveries of tourmalines of unusual color and composition (some rich in chromium

and some in manganese) were made in East Africa, specifically in Kenya, Zambia, and Tanzania. Nigeria is now producing interesting bicolored tourmaline (figure 20), with commercial amounts of other colors also coming from Mozambique. Madagascar continued to produce a broad range of tourmaline species and varieties, and is experiencing an increase in exploration and mining activity (S. Salerno, pers. comm., 1989). In 1989 and 1990, excitement was generated at the Tucson Gem and Mineral Show by the appearance of pink, purple, "watermelon," and orange tourmalines from Namibia. The deposit, located 50 miles (80 km) from Windhoek, is described as the largest gem-bearing pegmatite ever found. Twelve-ton plates of quartz with tourmaline are being mined there (G. Austin, pers. comm., 1990).

Figure 18. No group of gem materials is more complex than tourmalines. Therefore, it was with great enthusiasm that the gem community worldwide embraced the dramatic new colors that emerged from Paraíba, Brazil, at the end of the 1980s. These stones, which range from 2.45 ct to 26.58 ct, are courtesy of Kalil Elawar. Photo © Harold & Erica Van Pelt.

ZOISITE

Tanzanite, the gem-quality blue variety of zoisite from East Africa (figure 21), is experiencing a resurgence of popularity. Discovered just over 20 years ago in Tanzania, tanzanite has been plagued by irregular production. Although this situation persisted throughout the 1980s, as the government periodically added and withdrew sanctions, the decade ended with fewer restrictions and a new find, a combination that has produced a significant increase in supply as well as in the availability of larger stones. This was especially noticeable at the 1990 Tucson shows.

OTHER NEW MATERIALS AND NEW LOCALITIES OF THE DECADE

It is impossible to review the key events in mining and production of the 1980s without mentioning some of the new materials that entered the marketplace during this decade. These include iridescent andradite from Mexico and New Mexico, rainbow moonstone from India, blue pectolite from the Dominican Republic, and sugilite from

Figure 19. Increased production from the Pala District has brought California tourmalines to markets around the world. A number of major pockets were found at the Himalaya mine in the course of the decade. This 10.8-cm-high crystal of tourmaline with microcline and cleavelandite was one of the fine specimens recovered in spring 1989. Courtesy of Pala International; photo © Harold & Erica Van Pelt.

Figure 20. Bicolor tourmalines were once destroyed to recover only the more salable of the two colors. Now, bicolored tourmalines are treasured for the unique combination of colors in each piece. Nigeria is a new source to emerge in the 1980s, represented here by this 11.43-cm-high crystal. Courtesy of Alex Blythe; photo © Harold & Erica Van Pelt.

South Africa. New localities were also reported for many gemstones. Some examples are peridot from China, cat's-eye scapolite from Sri Lanka, and zircon from Tanzania. Details can be found in the books, yearly reports, conference proceedings, and journals listed in the reference section.

CONCLUSION

The past decade was one of intense activity in gemstone mining and production. Expanded enhancement operations opened new markets for low-grade gem materials, such as colorless to pale-color sapphires and topaz. Advances in mining technology reopened previously dormant deposits, such as the diamond fields of Kalimantan, and led to increased production at many historic deposits, such as Muzo (for emeralds), Ṃontana (for sapphires), and Capão do Lana (for Imperial topaz). A growing awareness by developing countries of the important economic role gem resources can play led to major discoveries in various parts of Africa and Pakistan, both of which hold great promise for the future. Exploration in Australia revealed an abundance of gem riches.

The dynamic political developments of the last years of the decade may have the greatest impact on discoveries and production in the future. The "opening" of Afghanistan promises the increased availability of emeralds, tourmalines, and lapis lazuli from that country. During the 1980s, the more relaxed political climate in China revealed dozens of areas, such as the Shandong Province diamond deposits and the sapphire fields of Hainan Island, that have great potential for the future. Changing attitudes in Laos and Cambodia suggest the possible greater availability of sapphires from those historic localities. Perhaps the most exciting prospects are in the hitherto closed territories of the Soviet Union, which historically produced some of the finest amethysts, alexandrites, demantoid garnets, and other gem materials from long-inactive deposits. The recent identification of large pink spinels from the Pamir region is just one indication of the riches that may be found in the future (see, e.g., Root, 1986).

Another force in the 1980s that is likely to have an impact on gem mining and distribution in the years to come is the environmental destructiveness of certain mining techniques. For example, strip mining for emeralds in the Muzo district of Colombia destroyed mountains and clogged local rivers. The desire to reduce the damage of such

Figure 21. The 1980s witnessed the rise in popularity of another East African gemstone, tanzanite. Although production was erratic for most of the decade, toward the end large stones of intense color again entered the market. Both this 43-cm-high crystal and the 22-ct faceted stone are from Tanzania. Courtesy of Pala International; photo © Harold & Erica Van Pelt.

mining techniques was a contributing factor in the decision to begin a major tunneling operation there. In 1989, environmentalists promised to physically block earth-moving vehicles at Arkansas's Crater of Diamonds if any commercial mining was undertaken (B. Videto, pers. comm., 1990). In East Africa, mining of rubies and green garnets in the Taita Taveta area of Kenya was halted by the government because ivory poachers were posing as miners (Barot, 1989).

The 1980s will be remembered as a decade of development of many new localities throughout Africa—and particularly East Africa—as well as Australia. It will be remembered for important discoveries in historical producers such as Brazil and Southeast Asia, and for the potential glimpsed in once-"closed" areas such as China and the Soviet Union. Finally, it will be remembered for the global response to environmental issues related to mining. The decade of the '80s has provided a window to a very exciting future in gem exploration and mining worldwide.

TABLE 1. Important gem localities of the 1980s with references to the contemporary literature.[a]

Gem material/locality	Reference
BERYL—Emerald	
Africa	
Madagascar (Malagasy)	Sinkankas (1981)
Ankadilalana district	Hänni and Klein (1982a,b)
Mozambique	Sinkankas (1981), Pers. knowl. of author (KS)[b]
Murrua mine	Bank (1986f)
Nigeria—Jos district	Lind et al. (1986)
South Africa—Transvaal: Gravelotte district	Mumme (1982), Webster (1983)
Tanzania—Lake Manyara district	Pers. knowl. of author (KS), Bank (1986f)
Zambia	Bank (1981), Kanis (1986)
Kitwe district: Miku mine	Mumme (1982), Graziani et al. (1983), Sliwa and Nguluwe (1984)
Kafubu district, Kamakanga mine	Mumme (1982)
Zimbabwe	Sinkankas (1981), Webster (1983), Kanis (1986), Bank (1986f), Ncube (1988)
Bikita district: Chikwanda mine	
Mberengwa district: Adriadne, Filabusi, Machingwe, and Sandawana mines	
Victoria district: Novello mine	
Asia	
Afghanistan—Panjshir Valley district	Bowersox (1985)
India—Orissa district	Pers. knowl. of author (KS)
Pakistan	Kazmi and Snee (1989)
Swat Valley district: Charbagh, Khaltaro, Makhad, and Mingora mines	Gübelin (1982), Kazmi et al. (1986), Bank (1986a), Henn (1988)
Gujar Killi mine	Bowersox and Anwar (1989)
Mohmand district	Rafiq and Qasim-Jan (1985)
Soviet Union—Ural Mountains region: Sverdlovsk district	Sinkankas (1981), Mumme (1982)
Australia	
Western Australia: Poona district	Mumme (1982), Webster (1983), Kazmi and Snee (1989)
South America	
Brazil	Franco (1981), Sinkankas (1981), Sauer (1982), Kazmi and Snee (1989)
Bahia: Brumado and Salininha mines	
Carnaíba mine	Cassedanne (1985a), Eidt and Schwarz (1988), Schwarz and Eidt (1989)
Socotó mine	Cassedanne (1985a), Schwarz et al. (1988b)
Ceará: Fazenda Boa Esperança, Tauá	Schwarz et al. (1988c)
Goiás: Fazenda das Lajes, Mara Rosa, Pela Ema, Pirenópolis, and Porangatu mines	Cassedanne and Barros (1986)
Santa Terezinha de Goiás mine	Hänni and Kerez (1983), Cassedanne and Sauer (1984), Cassedanne (1985a), Bank (1986c), Cassedanne and Barros (1986), Miyata et al. (1987)
Minas Gerais	Schwarz et al. (1988a), Epstein (1989), Schwarz (1989)
Nova Era district: Capoeirana mine	
Itabira district: Belmont mine	Hänni et al. (1987)
Colombia	Keller (1981, 1990), Sinkankas (1981), Barot (1987)
Boyacá	
Muzo district: El Chulo, Peñas Blancas, Santa Barbara, and Tequendama mines	
Coscuez mine	Ringsrud (1986)
Chivor district: Buena Vista, Chivor, Las Vegas de San Juan (Gachalá), and Mundo Nuevo mines	
Somondoco mine	Kozlowski et al. (1988)
BERYL—Aquamarine	
Africa	
Madagascar (Malagasy)—Ankazobe, Berere-Tsarantanana, Lac Itasy, and Sahatany River Valley-Mont Bity regions	Sinkankas (1981), Webster (1983)
Betafo-Antsirabe region: Tongafeno district	Duroc-Danner (1989)
Mozambique—Alto Ligonha (Muiane mine) and Mocuba districts	Sinkankas (1981), Kanis (1986)
Namibia—Karibib, Klein, Spitzkopje, and Swakopmund districts	Sinkankas (1981), Kanis (1986)
Nigeria—Jos district	Lind et al. (1986), Bank (1984, 1986d)
Zambia—Luangwa Valley	Kanis (1986)
Zimbabwe—Miami district	Kanis (1986), Ncube (1988)
Asia	
Afghanistan—Nuristan region: Kolum River district	Bariand and Poullen (1978), Bowersox (1985)
India—Orissa district	Pers. knowl. of author (KS)
Pakistan—Gilgit region: Dusso and Shingus districts	Kazmi et al. (1985)
Soviet Union—Altai Mountains, Transbaikalia, and Ural Mountains regions	Sinkankas (1981)
Sri Lanka	Sinkankas (1981)
South America	
Brazil—Bahia, Ceará, Espíritu Santo, and Rio Grande do Norte	Franco (1981), Sinkankas (1981), Bank (1983)

Independent miners sort rough rubies at Bo Rai in Thailand. Note the bottle of "ruby oil," a temporary coloring agent. Photo by Peter C. Keller.

Gem material/locality	Reference
Minas Gerais: Araçuaí River-Capelinha-Malacacheta, Governador Valadares, Jequitinhonha River, and Teófilo Otoni-Marambaia districts	Proctor (1984), Cassedanne (1986a)
BERYL—Morganite	
Africa	
Madagascar (Malagasy)	Sinkankas (1981), Webster (1983)
Mozambique—Alto Ligonha district: Muiane mine	Kanis (1986), Barot (1989)
South America	
Brazil	Sinkankas (1981)
Minas Gerais: Calisto and Jequitinhonha River districts; Minas Novas, Salinas, and Sapucaia mines	Proctor (1984)
Bananal mine	Kampf and Francis (1989)
Urucum mine	Cassedanne (1986b)
BERYL—Red	
North America	
United States	Sinkankas (1981)
Utah: Wah Wah Mountains	Shigley and Foord (1984)
BERYL—Yellow (Heliodor)	
South America	
Brazil	Sinkankas (1981)
Minas Gerais: Marambaia district; Sapucaia and Urubu mines	Proctor (1984), Cassedanne (1988b)
CHRYSOBERYL	
Asia	
India—Orissa and Sinapoli districts	Bank (1987a), Pers. knowl. of author (KS)
Sri Lanka—Sabaragamuwa Province: Ratnapura district	Zoysa (1981), Zwaan (1982), Webster (1983)
Central Province: Elahera district	Gunawardene and Rupasinghe (1986)
South America	
Brazil	Webster (1983), Cassedanne (1984a,b)
Bahia: Teixeira de Freitas district	
Espirito Santo: Colatina district	
Minas Gerais: Coimbras, Fogo Valley, Jacinto, and Lambuza districts	Bank (1986e)
Americana Valley district	Proctor (1988)
Santana Valley district	Proctor 1988)
CHRYSOBERYL—Alexandrite	
Africa	
Tanzania—Lake Manyara district	Bridges (1982)
Zimbabwe—Masvingo district	Kanis (1986), Ncube (1988)
Victoria district: Novello mine	Sinkankas (1981)
Asia	
India—Orissa district	Pers. knowl. of author (KS), Bank (1987a)
Soviet Union—Ural Mountains region: Sverdlovsk district	Bancroft (1984)
Sri Lanka	Pers. knowl. of author (KS)
South America	
Brazil—Minas Gerais: Lavra de Hematita and Malacacheta districts	Bank (1986e), Proctor (1988), Bank et al. (1988)
CORUNDUM—Ruby	
Africa	
Kenya—Amboseli and Mangari districts	Bridges (1982), Bank and Henn (1988), Barot (1989)

Lapis lazuli has long been treasured for its remarkable color. This 19th-century piece is 3 cm long and inscribed in gold. Courtesy of Paris School of Mines; photo © Nelly Bariand.

Gem material/locality	Reference
Malawi—Lake Nyassa district	Bank et al. (1988), Barot (1989), Pers. knowl. of author (KS)
Tanzania	Bank and Henn (1988)
Lake Manyara district	
Longido district	Bridges (1982)
Morogoro district	Schmetzer (1986)
Ngorongoro district	Althier et al. (1982), Bank and Henn (1988)
Umba Valley district	Hänni (1987a)
Asia	
Afghanistan—Sorobi district, Jegdalek	Bowersox (1985)
Burma (Myanmar)—Mogok district	Keller (1983b, 1990)
Cambodia (Kampuchea)—Pailin district	Jobbins and Berrangé (1981)
India—Orissa district	Bank and Henn (1987)
Nepal—Taplejung district	Harding and Scarratt (1986), Kiefert and Schmetzer (1987a), Bank et al. (1988)
Pakistan—Hunza Valley district	Bank and Okrusch (1976), Okrusch et al. (1976), Gübelin (1982)

[a]This chart includes key producing localities of the decade and references to their description. Where no reference accompanies a district or mine, refer to those listed for the respective country or region. Localities are listed in alphabetical order by continent, country, and then state, region, or district.
[b]Pers. knowl. of author = personal knowledge of author followed by initials of author involved.

Gem material/locality	Reference
Sri Lanka	Zoysa (1981), Zwaan (1982), Barot (1989)
Thailand	Jobbins and Berrangé (1981)
Chanthaburi-Trat Provinces: Nong Bon-Khong Phaya-Bo Rai and Welu Klang-Bo Nawong districts	Keller (1982, 1990), Hoskin (1987)
CORUNDUM—Sapphire	
Africa	
Burundi	C. Bridges (pers. comm., 1989)
Kenya—Lodwar district	Barot et al. (1989), Pers. knowl. of author (KS)
Malawi—Lake Nyassa district	Kanis (1986), Barot (1989)
Nigeria—Kaduna district	Kiefert and Schmetzer (1987b)
Tanzania—Umba Valley district	Jobbins et al. (1978), Schmetzer and Bank (1981a), Bridges (1982), Gunawardene (1984), Hänni (1987a)
Zimbabwe	Mumme (1988)
Asia	
Burma (Myanmar)—Kyankpyathat and Mogok districts	Mumme (1988), Barot (1989)
Cambodia (Kampuchea)—Chamnop, Khum Samlot, Pailin, and Phnum Chnom districts	Jobbins and Berrangé (1981), Mumme (1988)
China	Keller and Wang (1986), Chikayama (1986)
Fujian Province: Mingxi district	Liu (1981), Keller and Keller (1986)
Hainan Island: Penglai district	Wang (1988)
India	
Kashmir: Paddar district	Atkinson and Kothavala (1983)
Madras: Kangyam district	Mumme (1988)
Nepal	Kiefert and Schmetzer (1987a)
Sri Lanka	Zoysa (1981), Zwaan (1982), Schmetzer (1988), Mumme (1988), Barot (1989), Keller (1990)
Central Province: Elahera district	Gunawardene and Rupasinghe (1986)
Sabaragamuva Province: Ratnapura district	Gunaratne (1981)
Thailand	Jobbins and Berrangé (1981), Mumme (1988), Barot (1989)
Chanthaburi-Trat Provinces: Khao Wao-Khao Ploi Waen-Bang Kha Cha, Welu Klang-Bo Nawong, and Nong Bon-Khong Phaya-Bo Rai districts	Keller (1982), Hoskin (1987)
Chiang Rai Province: Mae Sai district	
Kanchanaburi Province: Bo Phloi district	Gunawardene and Chawla (1984)
Phrae Province	
Australia	Mumme (1988)
New South Wales: New England district	Broughton (1979), Coldham (1985)
Queensland: Anakie district	Broughton (1979), Coldham (1985)
North America	
United States—Montana: Missouri River and Rock Creek districts	Austin (1990)
Yogo Gulch district	Baron (1982)
South America	
Colombia—Mercaderes district	Keller et al. (1985)
DIAMOND	
Africa	
Angola—Luanda Norte region: Andrada, Camafuca-Camazombo, Cuango, and Lucapa districts	Webster (1983), Mitchell (1986), Endiama (1990)
Botswana—Jwaneng and Letlhakane mines	De Beers Annual Report (1988), J. Harris (pers. comm., 1988)
Orapa mine	Furney (1982)
Central African Republic	Mitchell (1986)
Ghana—Birim River region	Webster (1983)
Guinea—Aredor mine and Baule Basin district	Webster (1983)
Ivory Coast	Webster (1983)
Lesotho	Mitchell (1986)
Liberia	Webster (1983)
Namibia—Consolidated Mines Ltd. Complex; and Elizabeth Bay and Orange River districts	De Beers Annual Report (1988), J. Harris (pers. comm., 1988)
South Africa	De Beers Annual Report (1988), J. Harris (pers. comm., 1988), Boyajian (1988)
Cape of Good Hope Province: Finsch mine	
Kimberley district: Bultfontein, De Beers, Dutoitspan and Wesselton mines	
Namaqualand district, Kleinzee: Buffels Marine and Koingmaas Complexes; Langhoogte mine	
Orange Free State Province: Koffiefontein mine	
Transvaal Province: Pretoria district, Premier mine	
Sierra Leone	Webster (1983), Mitchell (1986)
Swaziland—Dokolwayo mine	Webster (1983), Mitchell (1986)
Tanzania—Mwadui mine	Webster (1983), Mitchell (1986)
Zaire—Kasai Province	Webster (1983), Mitchell (1986)
Asia	
China	Chikayama (1986)
Hubei Province: Ying Chen district	
Hunan Province: Yuan Jiang River district	
Laoning Province: Bin Hai district	

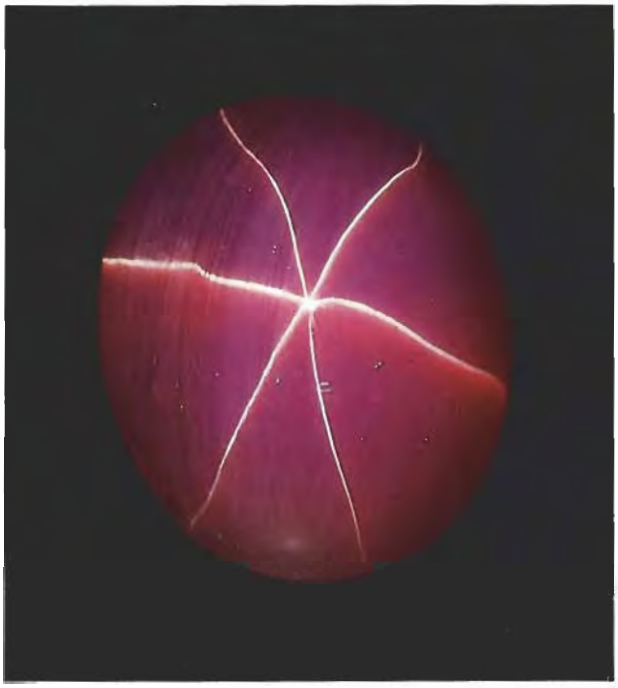
This 4.94-ct spessartine is an example of the exciting garnets now emerging from Madagascar. Courtesy of Pala International; photo by Robert Weldon.

Gem material/locality	Reference
Mengying Province: Xiyu mine	
Shandong Province: Changma district	Liu (1981), Keller and Wan (1986)
India	Webster (1983), Scalisi and Cook (1983)
Andhra Pradesh: Golconda district	
Madhya Pradesh: Bundalkhand district	
Indonesia—Borneo, Kalimantan	Spencer et al. (1988)
Soviet Union—Siberia: Yakutia, Aikhal, Mirny, and Udatchnyy mines; Vilyuy River district	Sobolev and Sobolev (1981), Huddlestone (1984), Mitchell (1986)
Australia	
Western Australia: Ellendale district	Hofer (1985), Geach (1986), Mitchell (1986), Atkinson (1987), Jaques (1989), Keller (1990)
Argyle district	Harris and Collins (1985), Fumey (1985)
North America	
United States—Arkansas, Colorado, and Wyoming	Mitchell (1986)
South America	
Brazil	Cassedanne (1985b, 1989b)
Bahia: Chapada Diamantina district	
Goiás: Coromandel district	
Mato Grosso: Alto Paraguai, Diamantino, Nortelandia, and Poxoreú districts	
Minas Gerais: Diamantina district	
Pará: Tocantins River district	
Paraná: Tibagi River district	
Roraima: Tepequém district	
Guyana—Cuyuni, Mazaruni and Potaro River districts	Lee (1981), Webster (1983)
Venezuela—Cuyuni and Mazaruni rivers; Guaniamo, Mahdia, Pacaraima, and Roraima districts	Webster (1983), Themelis (1987)
GARNET	
Africa	
Kenya—Voi district, Tsavo	Bridges (1974), Key and Hill (1989), Heppe (1989)
Madagascar (Malagasy)	Rouse (1986)
Mozambique—Cuamba district	Kanis (1986)
Tanzania—Kangala and Komolo mines	Bridges (1974)
Umba Valley district	Jobbins et al. (1978), Schmetzer and Bank (1981b), Bridges (1982), Hänni (1987b), Heppe (1989)
Zambia	Pers. knowl. of author (KS)
Asia	
China	Chikayama (1986)
Jiangsu Province: Donghai district	Keller and Wang (1986)
India—Orissa district	Rouse (1986), Pers. knowl. of author (KS)
Pakistan—Gilgit Regions Dusso and Shingus districts	Kazmi et al. (1985)
Sri Lanka	Zoysa (1981), Zwaan (1982)
Central Province: Kataragama district	
Elahera district	Gunawardene and Rupasinghe (1986)
North America	
Canada—Quebec: Asbestos; Jeffrey mine	Rouse (1986)
United States—California: Ramona district	Stern et al. (1986)
South America	
Brazil—Bahia and Minas Gerais	Rouse (1986)

Gem material/locality	Reference
JADE (Jadeite/Nephrite)	
Asia	
Burma (Myanmar)	Desautels (1986)
Mogaung Region: Hpakan district	
Tawmaw district	Khin (1987), Keller (1990)
China	Chikayama (1986)
Australia	
South Australia: Eyre Peninsular region	
Central America	
Guatemala	Desautels (1986)
North America	
Canada—British Columbia	Desautels (1986)
United States	Desautels (1986)
Alaska: Kobuk River region	
California: Monterey district	
Wyoming: Lander district	
LAPIS LAZULI	
Asia	
Afghanistan—Badakhshan: Sar-e-Sang district	Bariand and Poullen (1978), Wyart et al. (1981), Yurgenson and Sukharev (1985)
OPAL	
Africa	
Tanzania	Koivula and Fryer (1984)
Australia	E. R. Segnit (pers. comm., 1990), Keller (1990)
New South Wales: Lightning Ridge and White Cliffs districts	Broughton (1979), Segnit (1981), Dabek (1985), Barot (1989)
Queensland: Eromanga, Quilpie, and Winton districts	Broughton (1979), Segnit (1981), Dabek (1985), Barot (1989)
South Australia: Andamooka district	Broughton (1979), Segnit (1981), Dabek (1985), Barot (1989)
Coober Pedy district	Robertson and Scott (1988)
Mintabie district	Townsend (1981)
North America	
Mexico	Webster (1983), Gübelin (1986)

Ruby is one of many important gem materials being mined in East Africa. At the Tsavo National Park, in Kenya, most mining is still done with rudimentary tools. Photo courtesy of ICA/E. J. Petsch.

Gem material/locality	Reference
United States—Oregon: Opal Butte district	Smith (1988)
South America	
Brazil—Piauí	Webster (1983)
PERIDOT—Olivine	
Africa	
Egypt—Zabargad Island	Gübelin (1981), Keller (1990)
Asia	
Burma (Myanmar)—Mogok district	Scalisi and Cook (1983), Keller (1990)
China—Hebei Province	Keller and Wang (1986)
Sri Lanka—Sabaragamuva Province: Ratnapura district	Gunawardene (1985)
North America	
United States—Arizona: San Carlos district	Koivula (1981)
QUARTZ—Amethyst, Citrine and Ametrine	
Africa	
Namibia—Platveld district	Kanis (1986), Barot (1987, 1989), E. Petsch (pers. comm., 1990)
Tanzania	E. Petsch (pers. comm., 1990)
Zambia—Kalomo district	Kanis (1986), Barot (1989)
Asia	
India—Orissa district	E. Gübelin (pers. comm., 1990)
Australia	
Western Australia: Port Hedland district	R. Kane and W. L. Cotton (pers. comm., 1990)
South America	
Bolivia—Rincón del Tigre district	R. Weldon (pers. comm., 1989)
Brazil	Franco (1981), Cassedanne (1988a)
Bahia: Bom Jesus dos Meiras district	
Espírito Santo: Baixo Guandu district	
Goías: Catalao, Cristalina, Santa Luzia, Serra Dos Cristais, and Xamboiá districts	
Pará: Marabá district (Alto Bonito mine); Pau d'Arco district (Villa Esperança mine)	Epstein (1988)
Rio Grande do Sul: Santa Maria district	Epstein (1988)
Iraí district	Cassedanne and Cassedanne (1977)
Uruguay	Webster (1983)
QUARTZ—Rose	
Africa	
Madagascar (Malagasy)	Barot (1989)
Mozambique—Alto Ligonha district	E. Gübelin (pers. comm., 1990)
Namibia—Warmbad district	Kanis (1986), G. Becker (pers. comm., 1990)
South America	
Brazil—Paraíba: Alto Feio, Picuí	Cassedanne and Cassedanne (1978)
SPINEL	
Africa	
Kenya—Amboseli district	Barot (1989)
Nigeria—Jemaa district	Jackson (1982)
Tanzania—Matombo district	Barot (1989), Schmetzer et al. (1989)
Umba Valley district	Bank and Henn (1989b)
Asia	
Burma (Myanmar)	Webster (1983)
Cambodia (Kampuchea)	Webster (1983)
Pakistan—Hunza Valley	Gübelin (1982), Harding and Wall (1987)
Soviet Union—Pamir Range	Bank and Henn (1989a), Koivula and Kammerling (1989a)



Phenomenal stones such as this 42.84-ct star sapphire from Sri Lanka were significant in the 1980s. Courtesy of Leon Mason Co.; photo by Shane McClure.

Although mining of Imperial topaz at Capão do Lana, near Ouro Preto, is among the most sophisticated in Brazil, garimpeiros *continue to work the streams below the mining operation in the hopes of recovering a few stones. Photo by D. Vincent Manson.*

Gem material/locality	Reference
Sri Lanka	Anderson (1972), Schmetzer and Gübelin (1980), Zoysa (1981), Zwaan (1982), Schmetzer and Bank (1985)
Central Province: Elahera district	Gunawardene and Rupasinghe (1986)
Sabaragamuva Province: Ratnapura district	Shigley and Stockton (1984), Harder (1986)
Thailand	Webster (1983)
SPODUMENE	
Asia	
Afghanistan—Nuristan region: Kolum River district	Rossovskii et al. (1978), Bowersox (1985), Barot (1989)
Burma (Myanmar)—Mogok district	Webster (1983)
South America	
Brazil	
Minas Gerais	Proctor (1985b), Cassedanne (1986b,c)
Governador Valadares district: Kunzita, Urucum, and Urupuca mine	
Resplendor mine	E. Fritsch (pers. comm., 1990)
TOPAZ	
Africa	
Nigeria—Jos district	Pers. knowl. of author (KS)
Zimbabwe—Miami district	Webster (1983), Bancroft (1984)
Asia	
Pakistan	
Gilgit Region	Kazmi et al. (1985)
Katlang Valley district	Spengler (1985)
Swat Valley district	Gübelin et al. (1986)
Sri Lanka—Matale district	Pers. knowl. of author (KS)
South America	
Brazil	Ruplinger (1983)
Minas Gerais	
Ouro Preto district	Keller (1983a), Nassau (1985), Cassedanne and Sauer (1987), Cassedanne (1989a)
Virgem da Lapa district	Cassedanne and Lowell (1982)
TOURMALINE	
Africa	
Kenya	Dietrich (1985)
Narok district: Osarara	Bank (1987b)
Voi district	Hänni et al. (1981)
Madagascar (Malagasy)—Mount Bity region	Dietrich (1985)
Betafo-Antsirabe region: Anjanabonoina mine	Strunz (1979), Wilson (1989), S. Salerno (pers. comm. 1989)
Mozambique—Alto Ligonha (Muiane mine) and Nacala districts	Dietrich (1985), Kanis (1986)
Namibia—Karibib, Klein Spitzkopje, and Usakos districts	Dietrich (1985), G. Austin (pers. comm. 1990)
Nigeria	Barot (1989)
Zambia—Chipata, Lundazi, and Nyimba districts	Bank (1982), Thomas (1982), Schmetzer and Bank (1984), Koivula and Fryer (1985), Kanis (1986)
Asia	
Afghanistan	Dietrich (1985)
Nuristan region: Kolum River district	Bariand and Poullen (1978), Bowersox (1985)
Nepal	Dietrich (1985)
Sankhuwa Sabha district	Bassett (1985)
Pakistan—Gilgit region: Dusso and Shingus districts	Kazmi et al. (1985)
Soviet Union— Transbaikalia and Ural Mountains regions	Dietrich (1985)
North America	
United States	
California: Mesa Grande district	Marcussen (1985)
Maine: Androscoggin and Oxford counties	Francis (1985)
South America	
Brazil	Cassedanne and Lowell (1982)
Minas Gerais:	Proctor (1985a,b), Keller (1990)
Araçuaí-Salinas district (Salinas mines)	
Virgem da Lapa district	Cassedanne and Lowell (1982)
Araçuaí-Itinga district	
Governador Valadares district: Golconda, Jonas-Itatiaia, and Santa Rosa mines	
Cruzeiro-Aricanga mine	Cassedanne et al. (1980)
Paraíba: São Jose da Batalha mine	Koivula and Kammerling (1989b)
ZOISITE—Tanzanite	
Africa	
Tanzania—Arusha: Mererani district	Bridges (1982)

As more localities are discovered in Pakistan, beautiful gem mineral specimens such as this 4.6-cm aquamarine crystal with muscovite are being recovered. Courtesy of L. Wagner; photo by Jeffrey Scovil.

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Additional information (sometimes in the form of yearly country-by-country production data) can be found in sources such as:

1. The gemstone chapter of the Bureau of Mines *Minerals Yearbook*, published annually by the United States Department of the Interior.
2. *Mining Annual Review*, published by the Mining Journal.
3. For diamond information, *Proceedings of the Kimberlite Conference*, published quadrennially in the country where the conference is held.
4. *Proceedings of the International Gemmological Conference*, published approximately every two years in the country where the conference is held.

Following are other general texts suggested as additional reading on the key gem sources of the decade.

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GEMSTONE ENHANCEMENT AND ITS DETECTION IN THE 1980s

By Robert C. Kammerling, John I. Koivula, and Robert E. Kane

The impact that enhancements had on the gem market in the 1980s may be unparalleled in the history of the industry. Heat treatment brought hundreds of thousands of carats of blue and fancy-color sapphires and rubies to the trade, irradiation turned literally millions of carats of white topaz into attractive blue stones, and the filling of surface-reaching separations introduced an entirely new variable to the evaluation of color and clarity in diamonds. One of the key challenges to the gemologist during this decade was the identification of these and other enhancements. This article reviews the enhancements that were introduced or played a major role during the 1980s, focusing on their detection by standard gemological techiques.

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Concern about gemstone enhancements and the search for methods to detect them are not new. Written descriptions of treatment methods date back almost 2,000 years, and reports on enhancement detection were being published as early as 1502 (Nassau, 1984).

However, a number of developments in the last decade have brought greater attention to the subject of gemstone enhancement. These include the proliferation of enhanced stones in the market, the increasing sophistication of the treatment methods used, the need to relay accurate information both within the trade and to the consumer, and government interest in mandatory enhancement disclosure.

Because treatment can significantly affect the value of a gem, this article focuses on the one aspect of enhancement that is the gemologist's primary concern: detection. Through a review of the literature and the authors' own experience, this article examines those enhancements that were new in the 1980s or had a major impact on the gem market during the decade, and describes the detection methods that are now available. The emphasis is on tests that can be performed using standard gemological equipment; reference will be made to tests introduced in the 1980s or new variations on previously known techniques (for more information on the "classic" tests, we recommend that the reader consult Liddicoat, 1989, or Anderson, 1980). However, some discussions will necessarily include techniques that require more advanced instrumentation. We will also consider some enhancements for which there are currently no practical, nondestructive tests. The chart included with this article lists many of the key identifiable treatments currently in the trade and the principal methods available to detect them.

HEAT TREATMENT

Corundum. The 1980s witnessed an extraordinary influx of sapphires and rubies onto the market—over 95% of

Figure 1. Heat treatment brought great numbers of attractive blue and fancy-color sapphires to the gem market. All of the sapphires shown here have been heat enhanced. Courtesy of Gemsource International, Miami, FL; photo © Tino Hammid.

which were believed to have been heat treated by one method or another (Abraham, 1982; figure 1). Nassau (1981) has described no fewer than nine specific treatments used on natural or synthetic corundum.

Heat treatment is most widely used to develop blue color in light or near-colorless corundum ("geuda") by means of an intervalence charge transfer involving iron and titanium ions (Moon and Phillips, 1986). Thermal treatment also came into extensive use in the 1980s to induce or enhance yellow to orange to brown colors in corundum. The resulting stones are often of a color that has been described as "rare and somewhat unnatural" (Keller, 1982).

With magnification, the following identifying features may be seen in both blue and yellow (unless otherwise noted) heated sapphires: (1) internal stress fractures (figure 2) or cotton-like features around inclusions (may have lacy fringes); (2) stubby, partially absorbed (dot-like; figure 3) silk; (3) pockmarked, melted facets, and abnormal multi-plane girdles where part of the original surface was missed in repolishing; (4) blotchy color banding or diffused zoning in blue stones (rarely, with brown color zoning); and (5) colored halos surrounding solid mineral inclusions (Crowningshield, 1980, 1981c, 1982b, 1983b, 1987; Nassau, 1981; Gübelin, 1983; Schmetzer et al., 1983; Scarratt, 1985; Koivula, 1987e; Hurwit, 1987; Koivula and Kammerling, 1988b).

Heat-treated blue sapphires may show a dull, chalky green fluorescence to short-wave U.V. radiation, and may lack both the orange fluorescence to long-wave U.V. and the 450-nm absorption line associated with some natural-color blue sapphires. Heat-treated "golden" sapphires typically show no iron absorption and only weak

GEMOLOGICAL INSTITUTE OF AMERICA — DETECTION OF GEMSTONE ENHANCEMENT

Gem Material	Enhancement	Purpose	Color After Enhancement	IDENTIFICATION				Comments
				Magnification	Spectrum (nm)	Ultraviolet Fluorescence	Other	
AMBER	Heat	Improve clarity, darken color, induce "sun spangles"	C P R O Y G B V Br W Gr Bl	"Sun spangles" discoid fractures.				May also be dyed: look for color concentrations in surface-reaching fractures.
	Recon.	Produce larger, workable pieces	C P R O Y G B V Br W Gr Bl	"Roiled" structure, flattened elongated gas bubbles, grain boundaries, irregular clear and cloudy areas.		LW: strong, patchy, chalky blue	Polariscope: irregular strain patterns	Also called "pressed" amber.
BERYL Emerald	Oil	Improve apparent clarity, conceal fractures	C P R O Y G B V Br W Gr Bl	Very low relief of surface-reaching breaks; possibly slight outlining of breaks. Decomposed oils may leave whitish/yellowish dendritic patterns.[1]		LW: chalky yellowish green possible in fractures	Heat may cause oil to "sweat" from fractures. May stain stone papers.	Surface-reaching fractures, pits may be filled with plastic or resin; magnification key to detection. "Hot point" to test emeralds strongly discouraged.
	Dye	Deepen/induce green color; improve apparent clarity	C P R O Y G B V Br W Gr Bl	Color concentrations in surface-reaching fractures.	630–670 band possible	LW: chalky yellowish green possible in fractures	Oiled stones may have oily odor. Heat may cause oil to "sweat" from fractures. May discolor stone paper, acetone-dipped cotton swab.	Dye concentrations best detected using diffused transmitted light.
CHALCEDONY	Dye	Alter color	C P R O Y G B V Br W Gr Bl	Rarely, uneven color distribution.	Dyed green: fine lines at 640, 670 Dyed blue: bands at 540, 585, 640		Dyed blue, green: appear red to orangy red through Chelsea color filter.	May be dyed any color. May be selectively or uniformly treated. Treatment often not detectable by routine tests.
CORUNDUM Sapphire	Heat	Deepen/induce color	C P R O Y G B V Br W Gr Bl	Cotton-like features around inclusions[2]; melted/burst solid inclusions[3]; ruptured fluid inclusions; "dot-like" silk; diffused color zoning, blotchy color banding (blues); internal color diffusion around solid inclusions; sintered, unpolished surfaces and pockmarked, melted facets.	Blue: very weak or no 450 line Yellow to brown: no iron lines	Blue: LW—lacks orange reaction; SW—dull chalky green, yellowish green Yellow to brown: LW & SW—inert		"Geuda" material usually used to produce blues. Yellow-to-orangy brown stones typically show neither iron absorption of Thai/Australian stones nor strong orangy LWUV reaction of Sri Lankan stones.
Ruby, Sapphire	Heat	Lighten color, remove secondary hues, improve clarity	C P R O Y G B V Br W Gr Bl	Discoid fractures[3]; melted/burst solid inclusions[3]; ruptured fluid inclusions; dot-like silk; internal color diffusion around solid inclusions; sintered surfaces.		SW: patchy bluish zones possible in ruby		Treatment typically performed on iron-rich stones like those from Thailand/Australia. Inclusions best seen with darkfield illumination.
	Diffusion	Induce surface color and/or asterism	C P R O Y G B V Br W Gr Bl All colors possible	Color diffusion: color concentrations along facet junctions, girdle edge[4]; localization/blotchiness of color; color "bleeding" in pits and surface-reaching fractures. Star diffusion: rutile needles confined to thin surface layer.		SW: chalky yellowish green possible in blue stones; may be patchy	May have unnatural, watery appearance; higher relief of facet junctions, girdle outline in methylene iodide than untreated stones.	Immersion key to detection. Magnification may show other evidence of high-temperature treatment. Repolishing may remove color. Star may be unnaturally sharp.
	Cavity filling	Improve appearance, add weight, seal voids	C P R O Y G B V Br W Gr Bl All colors possible	Difference in surface luster, polish, transparency, and/or relative relief (when immersed) between host and filling material[5]; gas bubbles in contact zone.		LW & SW: filling material inert (also to X-rays)	Always reaches surface of stone.	Don't confuse cavity fillings with included crystals/natural glass inclusions breaking surface.
	Dyeing	Deepen/induce color	C P R O Y G B V Br W Gr Bl All colors possible	Color concentrations in surface-reaching fractures.				
DIAMOND	Cleavage/fracture filling	Improve apparent clarity	C P R O Y G B V Br W Gr Bl All colors possible	Filled breaks may exhibit: "flash effects"—orange/blue[6] or purple/green; flattened, trapped gas bubbles (may have fingerprint pattern); flow structure; crackled texture; slight yellowish color; no broad-spectrum iridescence or feathery texture.			Treatment may lower apparent color grade; acid, extreme heat may remove filling.	Body color of colored diamonds may mask "flash effect."
	Laser drilling	Vaporize or bleach dark inclusions	C P R O Y G B V Br W Gr Bl All colors possible	Laser drill "holes" appear as thin white lines, usually perpendicular to a facet near the inclusion.[7]			Lasering may be followed by a chemical bleaching of inclusions reached.	Laser drill holes may be filled (see above).
	Coating	Deepen/induce color	C P R O Y G B V Br W Gr Bl All colors possible	Dark lines parallel to pavilion main edges; scratches in coating; uneven color.				Repolishing may remove color.
	Irradiation	Induce/modify color	C P R O Y G B V Br W Gr Bl	Cyclotron-treated stones may exhibit color concentration around culet or outlining facets.[8] Possible spotted surface coloration on greens colored by exposure to radioactive salts. Some blue to green electron-irradiated stones show color concentration at culet/keel line. Treated pinks lack characteristic "pink graining" of natural pinks; some show pink and yellow color zoning.	May show 595 line, 496/503 pair Pink may show fluorescent line at 570, absorp. lines at 595, 610, 622, 637	LW: treated pinks fluoresce orange	Some treated stones (typically yellow) show diagnostic features in near-IR; some treated greens may be radioactive; treated blues are electrically nonconductive and have unnatural greenish blue color.	Most of these colors result from annealing after irradiation. Cooling may resolve absorption features; yellows, greens most common colors produced. Origin of color in most green diamonds cannot be determined.

JADEITE	Dye	Induce or improve color	All colors possible	Dye concentrations sometimes seen in surface-reaching fractures.[9]	Diffused band at 630–670 nm in green stones	LW: lavender may fluoresce moderate to strong orange	May discolor acetone- and/or acid-dipped cotton swab. Green may appear red through Chelsea filter. Lavender shows bluish purple X-ray fluorescence.	Magnification key to detection. Nephrite, serpentine, quartzite, and other materials may be dyed green; detection similar. Moderate heat may remove lavender color.
	Coating	Improve apparent luster, polish		Scratches in coating; wax or other applied substance concentrated in surface pits, cavities.			Thermal reaction tester will cause wax, paraffin, oil coatings to melt/flow. Best seen under magnification.	Amazonite, malachite, nephrite, rhodochrosite, serpentine, other ornamental gem materials may be surface coated. Detection similar.
LAPIS LAZULI	Dye	Improve color appearance, conceal white calcite		Dye concentrations in surface-reaching fractures and porous areas.[10]		Inert	May discolor acetone- or acid-dipped cotton swab; may appear bright brownish red through Chelsea filter.	Chemical tests may be negative if material has been wax coated; wax must be removed to obtain positive test for dye.
OPAL	"Dye"	Produce dark background for play-of-color		Sugar treatment: peppery, speckled appearance, dark color concentrations in cracks.[11] Smoke treatment: dark brown, mottled appearance with "unnatural" play-of-color.			Smoke treatment: used on porous material, so absorbs liquids, temporarily loses color, and gains weight on wetting. Low R.I. (1.38–1.39), S.G.	Smoke, sugar treatments superficial; true body color seen on fracture surfaces. Black plastic impregnation: unnatural transparency with black, wisp-like inclusions; unnaturally low S.G. Surface of smoke-treated opals damages easily.
PEARL (Cultured)	Irradiation	Modify color		Saltwater cultured: dark bead nucleus but unaltered light-colored nacre may be seen when drill hole is examined.				Colors in irradiated freshwater pearls unlike those produced in nature.
	Dye	Produce various body colors		Color concentration around drill hole/surface irregularities[12]; possibly extending into veins from hole and/or staining stringing thread.		Dyed black: LW & SW usually inert; may be dull green or chalky white	May discolor weak nitric acid-dipped cotton swab rubbed in drill hole. May show unusually even color distribution.	Dyed black with silver nitrate: may show white (X-ray opaque) conchiolin ring on X-radiograph.
QUARTZ	Dye	Alter color to imitate other gems	All colors possible	Dye concentrations in surface-reaching fractures. In quench-crackled and dyed rock crystal, dyed fractures appear as web-like network.	Dyed green: may exhibit absorption band around 630–670		May discolor stone paper, acetone-dipped cotton swab. Dyed green: may appear red through Chelsea color filter.	Dyed green quartzite used to imitate jade.
Citrine	Heat	Produce citrine from amethyst		Dehydration alters goethite inclusions to reddish brown hematite with surrounding pressure-induced cracking.				Heat-treated amethyst-citrine, green quartz ("praseolite") may show similar dehydrated iron-based inclusions.
SPODUMENE	Irradiation	Alter color to imitate hiddenite			No chromium absorption		Color unstable, fades when exposed to light and/or heat.	Irradiated stones lack saturated green color of true hiddenite. Artificial irradiation also used to intensity kunzite color; not detectable by standard tests.

PURPOSE OF CHART

This chart covers only major gems for which there are detection criteria available using standard gemological procedures. It does not include those common enhancements (e.g., irradiated and/or heated topaz, tourmaline, zircon, and tanzanite) for which treatment cannot be confirmed by such techniques; nor does it describe in detail all the tests to which it refers. Rather, it is a working guide to be supplemented with additional references such as those listed in "Gemstone Enhancement and Its Detection in the 1980s" (R. C. Kammerling, J. I. Koivula, and R. E. Kane, *Gems & Gemology*, Vol. 26, No. 1, pp. 32–49).

KEY

ENHANCEMENT (Process Used)

Cavity filling: Filling surface-reaching cavities, pits, other depressions with glass, plastic, or other substance. **Cleavage/fracture filling:** Filling surface-reaching breaks with glass, plastic, or other substance (see also Oil, below). **Coating:** Treating surface with colorless substance, e.g., wax, paraffin, oil, lacquer. **Diffusion:** Using high temperature to diffuse color- and/or asterism-causing compounds into a shallow surface layer. **Dye:** Introducing colored substance; includes dyes, colored oils, and impregnations. **Heat:** Subjecting material to elevated temperatures. Varies with material/treatment. May be as low as 200°C or up to/exceeding 2,000°C. **Irradiation:** Using high-energy particles or electromagnetic waves to alter color. **Oil:** Filling surface-reaching breaks with oil or other liquid.

Reconstruction (Recon.): Combining pieces of similar material through heat and/or pressure to produce larger pieces. A binder may or may not be used.

GEM MATERIAL: Listed in alphabetical order by species and, within species, by variety where applicable.

COLOR AFTER ENHANCEMENT: Lists color of end product; no reference is made to color of untreated starting material; red includes pink.

Color Range – (Horizontal line) = Common treated color
| (Vertical line) = Uncommon treated color
½ box = Modifying color

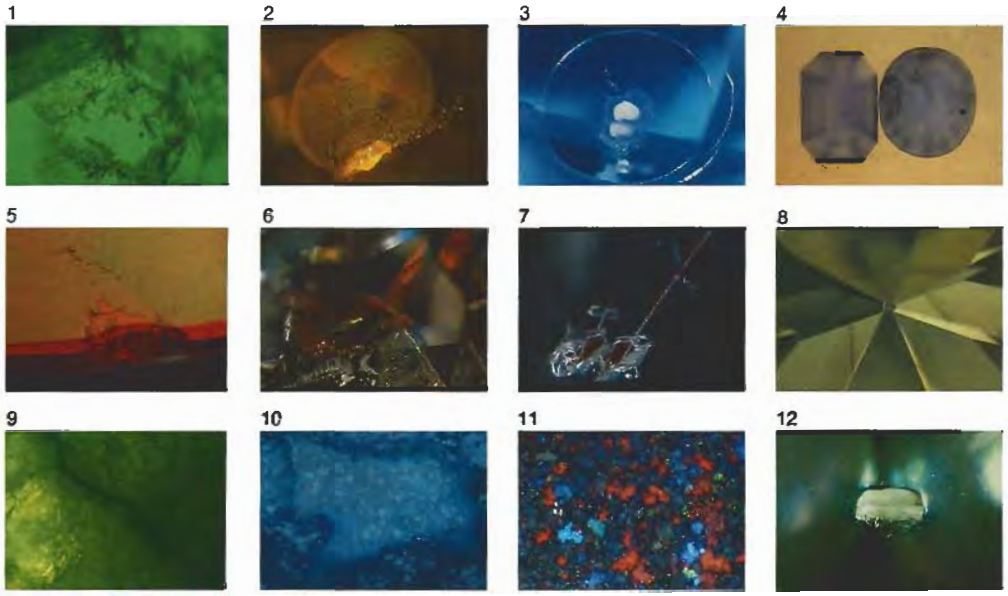
MAGNIFICATION: Superscript number refers to representative photomicrograph shown here.

SPECTRUM: Visible spectrum only; as observable with a hand-held type of spectroscope. All band/line locations given in nanometers (nm).

ULTRAVIOLET FLUORESCENCE:
LW = Long-wave ultraviolet
SW = Short-wave ultraviolet

OTHER: Other useful gemological tests, including polariscope, reaction to thermal tester, reaction to acetone- or acid-dipped cotton swab, appearance through the Chelsea filter, and X-ray fluorescence.

COMMENTS: Includes other materials that are also routinely subjected to the particular enhancement.



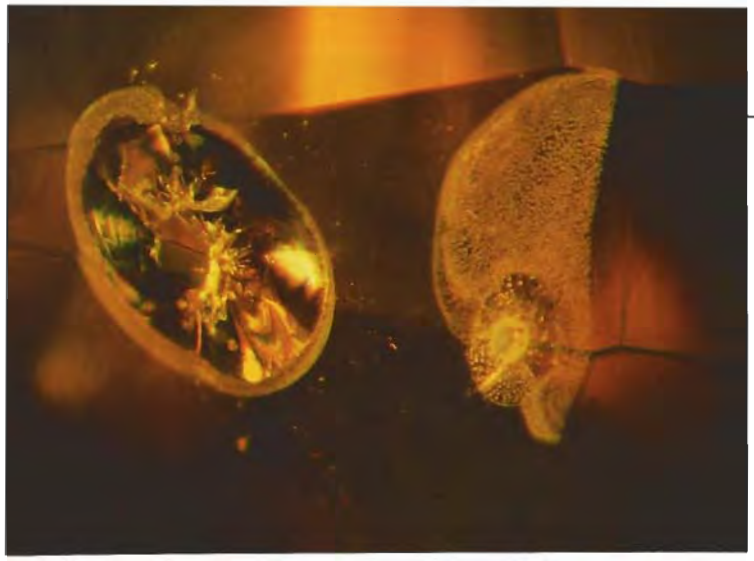


Figure 2. Internal stress fractures, sometimes with lacy fringes, are diagnostic of heat treatment in corundum. Here, they are shown in a "golden" sapphire. Photomicrograph by John I. Koivula; magnified 25×.

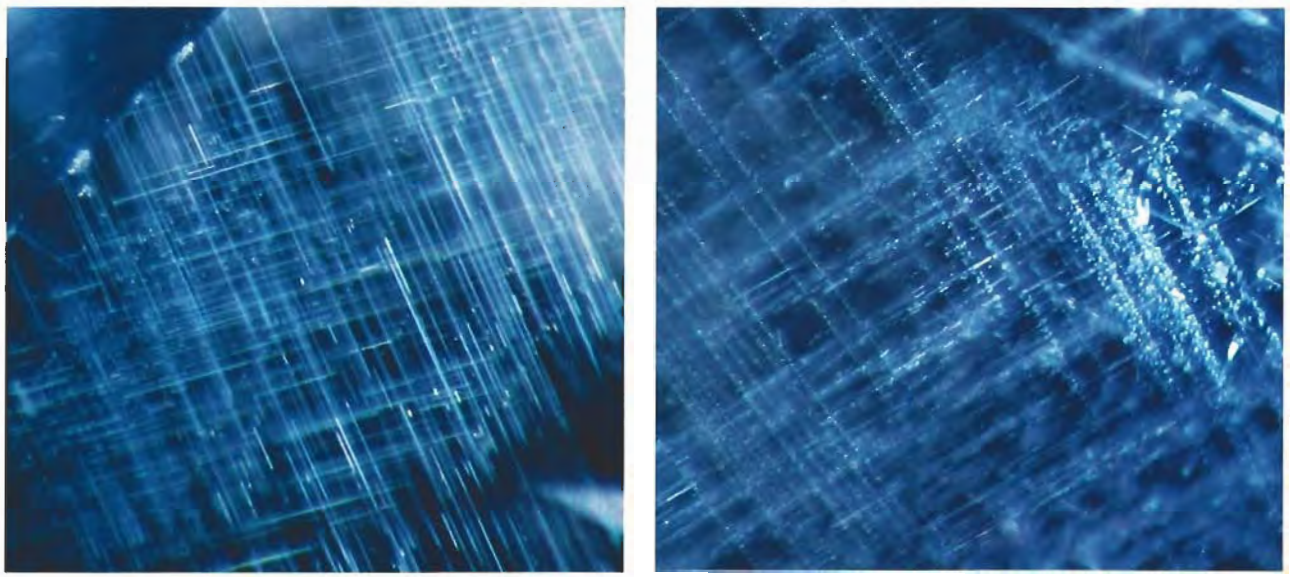
red-orange or no fluorescence to long-wave U.V. (Crowningshield, 1981c, 1982b, 1984d).

The 1980s also saw other varieties of corundum that apparently owed their color at least in part to heat treatment. These include red-purple and pinkish orange ("padparadscha") sapphires. The presence of strain discs and zones of chalky short-wave U.V. fluorescence helps confirm treatment (Crowningshield, 1984e). When a pinkish orange sapphire was heated to improve the clarity by reducing a dense concentration of tiny (apparently rutile) particles, the treatment produced an "unnatural-appearing intense orange color" (Kane, 1986a). The stone exhibited a strong, slightly reddish orange fluoresence to both short- and long-wave U.V., as well as chromium-related absorption lines in the red end of the visible spectrum.

Another major application of heat treatment is to partially or totally remove a blue color component from corundum, that is, to lighten the color of dark blue sapphires (commonly those from Australia, as described in Tombs, 1982, and Coldham, 1985) or remove the blue component from purplish stones to produce a purer red ruby (Nassau, 1981; Abraham, 1982; Currie, 1988). Many Sri Lankan pink sapphires also have been heated to drive off any secondary blue overtones (Koivula, 1987c). Identifying characteristics seen with magnification are similar to those listed above for other heat-treated corundum (figure 4). In addition, unusual blue hexagonal color zoning has been observed in blue sapphires heated to reduce the depth of color (Hargett, 1988a; Coldham, 1989). Heat-treated rubies may also exhibit an abnormal reaction to short-wave U.V.: a bluish patchiness and concentric rings (Crowningshield, 1984d).

Often, however, heat treatment to diminish or remove a blue component cannot be detected, as the stones are not heated to the extent that repolishing is necessary. Furthermore, the iron-

Figure 3. The distinctive rutile "silk" in a Sri Lankan sapphire before heat treatment (left) became stubby, partially absorbed, and dot-like (right) after the same stone was submitted to a heating procedure. Photomicrographs by John I. Koivula; magnified 30×.



rich blue sapphires that are commonly heat treated to produce a lighter color can display strong iron absorption both before and after treatment (Crowningshield, 1987) and remain inert to U.V.

Research conducted in the 1980s also contributed to the identification of features that would prove that a stone had *not* been heat treated. Specifically, unruptured carbon dioxide fluid inclusions in ruby and sapphire (figure 5) provide conclusive proof that no heat treatment has taken place (Koivula, 1986). Yet the "coarse, well-formed, undisturbed needle-like" or wedge-shaped inclusions once believed to prove that a stone had not been heated (Welch, 1988) have been observed in heat-treated sapphires from Australia, Sri Lanka, and the Kanchanaburi district of Thailand (Coldham, 1989).

One precaution to keep in mind when examining the surface of corundum for heat damage is that similar damage may result when jewelry repair or sizing is performed with the stone still in the mounting. As a final step in such work, the solder joint is often cleaned in a borax-containing hot pickle solution that may produce surface etching (Liddicoat and Fryer, 1980).

Synthetic corundum may also be altered using heat-treatment processes. For example, Chatham flux-grown synthetic dark blue sapphires and dark rubies are reportedly heat treated to lighten the color (Koivula and Kammerling, 1988a).

Figure 4. The lacy "fingerprint" surrounding a melted crystal inclusion in this Thai ruby is indicative of heat treatment. Photomicrograph by John I. Koivula; magnified 40×.

Quartz. For decades now, most citrine on the market has been produced by heat treating amethyst. While this treatment is generally not detectable, the presence of altered iron-based inclusions may provide proof in some cases. Experimentation has shown that when amethyst containing brownish yellow goethite inclusions is heated, the

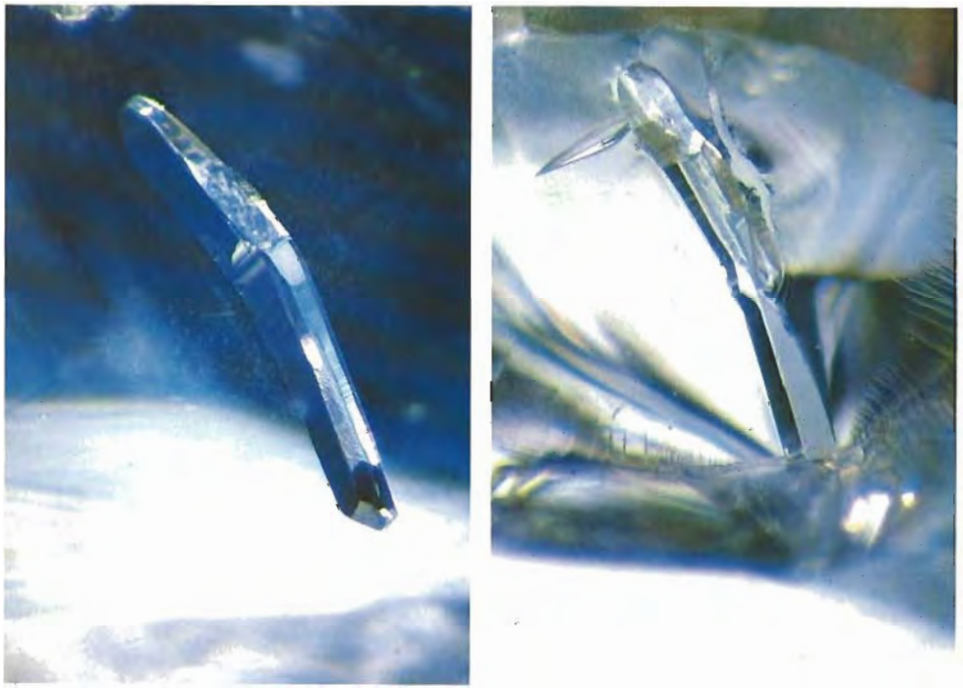


Figure 5. The presence of an unruptured CO_2-containing negative crystal (left) in this Sri Lankan sapphire proves that the stone has not been heat treated. When heated to only 270°C, the same inclusion burst (right), producing a large fracture. Photomicrographs by John I. Koivula; magnified 45×.

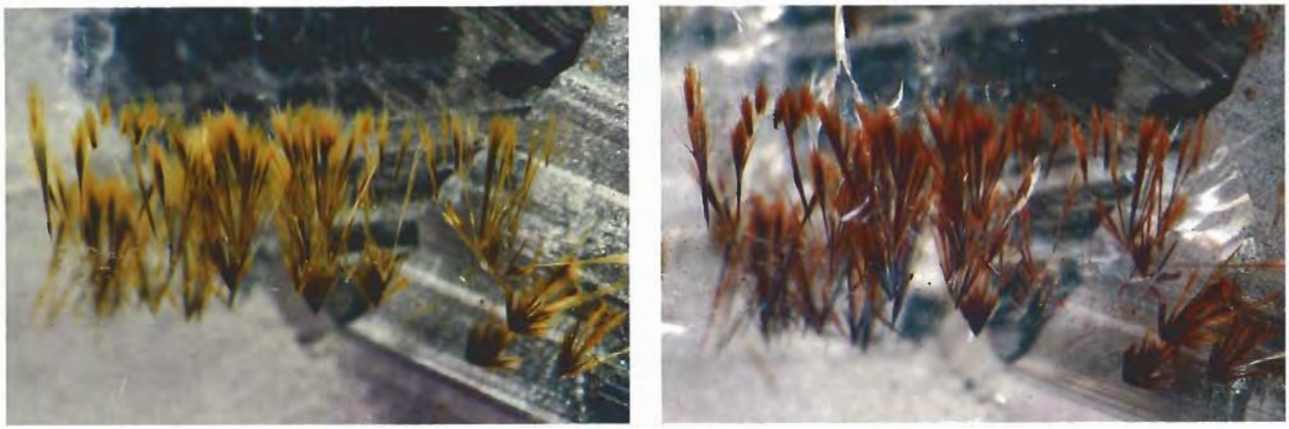


Figure 6. Unaltered yellowish goethite (left) is observed in amethyst that has not been heat treated. Heat treatment to lighten the color of the amethyst or to convert it to citrine (right) dehydrates the goethite, altering it to hematite. Photomicrographs by John I. Koivula; magnified 25×.

goethite dehydrates to reddish brown hematite, often with the accompanying formation of stress cracks (figure 6). Therefore, the presence of reddish brown "brush-like" radiating groups of hematite fibers in citrine is a strong indication that the color was produced by heat treating amethyst (Koivula, 1987d).

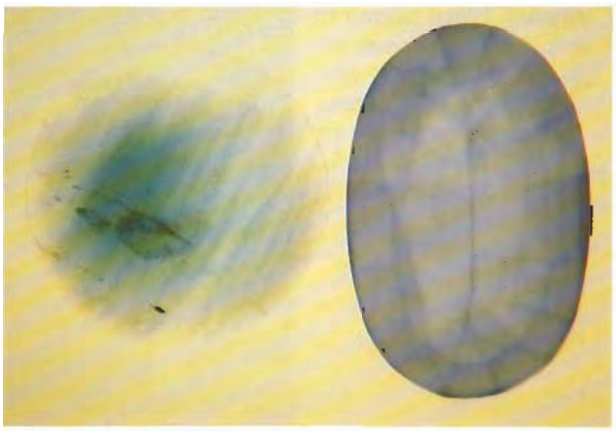
Zircon. The heat treatment of various natural colors of zircon to produce blue, as well as some "golden," red, and colorless gems, has been practiced for many years (Rupasinghe and Senaratne, 1986). Recently, however, heat treatment has been used to produce cat's-eye stones. While natural chatoyant zircons do occur rarely in nature, heat-treated stones contain diagnostic inclusions in the form of parallel oriented stress fractures around inclusions of thermally decomposed apatite crystals (Hänni and Weibel, 1988).

Other Gem Materials. Heat treatment continues to be used extensively to alter the appearance of a number of other gem materials. For example, heat treatment produces: a pink color in chromium-bearing orangy brown topaz, a purer blue hue in greenish blue aquamarine, lighter colors in some dark blue to green tourmaline, and the blue-violet colors of tanzanite from greenish brown zoisite. It was only recently reported (see Koivula and Kammerling, 1990b) that heat treatment was being used to produce unusual, "electric" blue and green colors in tourmaline from the new locality in Paraíba, Brazil. In general, however, these alterations require lower temperatures, so the physical evidence, especially damage or alteration of inclusions associated with heat treatment of corundum, is generally lacking in these materials (the color produced usually is the only indication of treatment).

DIFFUSION TREATMENT

Another heat-related enhancement of corundum that came to the fore in the 1980s was the diffusion of color-causing agents into the surface layer of an already preformed or fashioned stone. The use of different chromophores produces different colors, including blue, red, yellow, and pinkish orange, although only the blue has been seen in the trade

Figure 7. Immersion in methylene iodide reveals the high relief characteristic of a diffusion-treated sapphire (right), as exemplified by a blue outlining of facet junctions and the girdle edge. The heat-treated blue sapphire (left) does not show any outline facet junctions except near the girdle where some areas are slightly abraded. Photomicrograph by Robert E. Kane; magnified 10×.



with any frequency. One of the first identifying features noted in some of these stones was a patchy fluorescence to short-wave U.V. where the diffused color had been removed during repolishing (Crowningshield, 1981b; Hänni, 1982). Diffusion-treated blue sapphires may also show an unnatural "watery" appearance, that is, decreased transparency that is not due to inclusions. Examination of such stones using diffused illumination and immersion in methylene iodide also reveals the areas where color has been removed during repolishing, as well as a higher relief than stones that have not been diffusion treated (as evidenced by a dark outlining of facet junctions) and a blotchiness of color from one facet to another (figure 7). Another characteristic, noted with magnification, is a "bleeding" of color around pits and surface-reaching fractures. Also seen are stress fractures around inclusions, pockmarked facets, and abnormal girdles (Nassau, 1981), although these are a result of the high temperatures used and are not specific to the diffusion process.

Diffusion treatment may be more difficult to detect in cabochons than in their faceted counterparts because cabochons lack the many sharp junctions on which color irregularities can occur. Such treatment is best detected on cabochons at the girdle (i.e., setting) edge (Crowningshield, 1982a).

Diffusion treatment may also be used to create asterism by adding titanium oxide to the surface layer of a stone. Such treatment is identified by: (1) an unnaturally sharp star; (2) uneven color; and (3) bleeding of color around pits, cavities, and fractures—as well as by other evidence of high-temperature treatment as described above. Because the treatment usually affects only a relatively thin surface layer, repolishing can remove the star (Crowningshield, 1985).

Diffusion treatment has also been identified in a synthetic blue sapphire. Immersion in methylene iodide revealed the curved color zoning and tiny gas bubbles typical of Verneuil synthetics, as well as the uneven color from one facet to another that is characteristic of diffusion treatment (Hurwit, 1982).

IRRADIATION

One of the most significant developments during the 1980s was the widespread use of laboratory irradiation to induce or alter color in gemstones. Today, nondestructive detection (i.e., without removing the color or damaging the stone) of such irradiation is one of the gemologist's greatest challenges. Also of concern is the stability of the color obtained to normal conditions of light and heat.

Figure 8. During the 1980s, irradiation was used to change pale-colored sapphire (top) to a golden yellow (bottom). The color, however, is not stable and will fade on exposure to light. Photos by Shane F. McClure.

Corundum. Irradiation has been used to produce an unstable golden yellow color in corundum (Rossman, 1981; figure 8). Although some dealers recommended detection by placing the stone in a flame for about one minute or in direct sunlight for several hours, either of which would cause an irradiated sapphire to fade (Keller, 1982), the heating test has since been discouraged. Nassau and

Figure 9. The detection of treatment in diamonds that had been irradiated to produce fancy colors was a major problem during the decade of the '80s. These diamonds, 0.65 to 1.45 ct, have all had their color enhanced by laboratory irradiation. Courtesy of Theodore and Irwin Moed; photo © Tino Hammid.

Valente (1987) recommend only exposure to light, "typically two days of bright sunlight or longer for less intense (natural or artificial) illumination."

Diamond. A major issue of the '80s was the identification of radiation-induced color in diamonds (figure 9). Although detection of some color-treated diamonds has become relatively straightforward, other stones still cause considerable problems.

Cyclotron-treated diamonds, which continued to have a presence on the market during this decade, can still be readily identified by the shallow color confined to a layer near the surface and, in some stones, a concentration of intense color paralleling the edges of facets on the crown or around the culet or girdle (as illustrated in Kane, 1981a; Scarratt, 1982).

The use of radium or other radioactive salts to produce green color in diamond dates back to the turn of the century. These stones, too, are readily identifiable, because they retain residual radioactivity, which can be detected with a Geiger counter or by the autoradiograph produced when they are placed in contact with photographic film. Historically, these stones have also been known to exhibit mottled dark green stains on facet surfaces. Given the known high radioactivity of diamonds treated by this method, it was surprising to see in the 1980s the release of diamonds color-enhanced by the radioactive salt americium. These stones do not show the mottled, or "mossy," green stains described above (Moses, 1989).

The 1980s witnessed a proliferation of diamonds irradiated by electrons and neutrons, followed by annealing. Many diamonds treated by these methods—producing such colors as yellow, brown, and orange—can only be identified by spectral analysis. Often, a hand-held type of spectroscope in conjunction with an aerosol refrigerant for cooling the diamond is sufficient to identify treatment in these stones; during the 1980s, most major gemological laboratories also had access to a recording spectrophotometer equipped with a liquid-nitrogen cooling unit. In the great majority of diamonds, treatment is evidenced by the presence of a strong line at 595 nm (historically cited by gemological researchers dealing in Angstrom units as the "5920"), accompanied by a pair of bands at 496 and 503 nm (previously known to gemologists as the "4980/5040 pair"). During the 1980s, it was determined that the 595-nm line could be removed by further annealing at much higher ($\geq$ 1000°C) temperatures (Collins, 1982). Yet even in these rare cases, two characteristic absorption bands have been observed in the near infrared—at 1936 nm and 2026 nm, designated H1c and H1b, respectively (Woods, 1984; Woods and Collins, 1986; Collins et al., 1986). Unfortunately, the sophisticated instrumentation required to detect these bands is not readily available to the jeweler/gemologist.

Another development of the 1980s was the intensification of color in natural fancy-color diamonds by laboratory irradiation. One natural fancy light yellow diamond examined in the GIA Gem Trade Laboratory had its depth of color increased to the equivalent of a fancy intense

yellow. When the stone was resubmitted to GIA-GTL after treatment, spectroscopic examination revealed both a strong 595-nm line, proving artificial irradiation, and a moderate Cape spectrum (Kane, 1983b).

In rare instances, the treatment process inadvertently produces pink stones (L. Perlman, M. Fuchs, and I. Moed, pers. comm., 1986). Such treated pink stones are readily identified with a hand-held spectroscope by—in all stones—a fluorescent line slightly above 570 nm and a 595-nm absorption line, plus—in most stones—610-, 622-, and 637-nm absorption lines. Treated pink diamonds also typically fluoresce orange to long-wave U.V. radiation. It was first reported in the 1980s that some treated pink diamonds with the above spectral pattern also showed distinctive yellow and pink color zoning, which appeared to be related to a zoned long-wave U.V. (Hargett, 1988b).

Determining origin of color in most green diamonds is one of the greatest challenges in gem identification. Small green to brown radiation stains on the surface of light green diamonds used to be considered a strong indication (but not proof) of natural color, as such stains have not been reported to have been produced artificially. However, the possibility exists that near-colorless and light green or yellow diamonds with these stains may be irradiated to induce or intensify (to light, medium, or dark) a green color. In fact, the authors examined several diamonds with brown radiation stains both before and after treatment. Even though the originally faint green and near-colorless stones developed a dark green color with irradiation, there was no change in the radiation stains.

It was also long believed that color was a good indication of enhancement, with treated green diamonds commonly having an unnatural brownish, grayish, or bluish hue in dark tones. Today, though, the fact that more lighter-toned green stones are seen in the market suggests that color is no longer a reliable indicator (Fritsch et al., 1988).

However, the decade did produce some criteria that can be used to separate treated green diamonds from their natural-color counterparts. Most important was the observation of distinct color zoning in the pavilion or culet of an irradiated diamond. With magnification and diffused lighting, this characteristic is readily visible in some electron-treated blue and green diamonds (Fritsch and Shigley, 1989; figure 10).

Unfortunately, the origin of color still cannot be determined with certainty in the vast majority of green diamonds. Detection of this treatment will be one of the greatest challenges of the 1990s.

Pearl (Cultured). In the 1980s, irradiation was commonly used on off-color saltwater cultured pearls to produce bluish gray colors. Gamma rays darken the freshwater bead nucleus of the relatively thin nacre Akoya cultured pearls to influence the overall body color. Detection requires examining the pearl through the drill hole, where the darker bead nucleus may be seen to contrast with the lighter (unchanged) nacre.

Irradiation of tissue-nucleated cultured freshwater pearls produces a range of colors from blue-gray to black. This treatment is readily identifiable because the colors produced are rarely seen in such pearls naturally.

Quartz. A number of colors have been produced in quartz using artificial irradiation, most notably "smoky" and amethystine. To date, however, we know of no method by which natural-color "smoky" quartz and amethyst can be separated from their artificially irradiated counterparts.

Figure 10. The distinct blue zone at the culet of this bluish green diamond—visible with magnification and diffused lighting—proves that it was treated. Photomicrograph by John I. Koivula.

Figure 11. This 57.3-ct topaz derives its color from irradiation (in a linear electron accelerator) and subsequent heat treatment. It originally resembled one of the white topaz preforms on which it sits. Stones courtesy of P. Flusser, Overland Gems, Los Angeles, CA. Photo © Tino Hammid.

Spodumene. Kunzite, the best-known gem variety of spodumene, ranges from light to medium pink to lavender. Hiddenite is the rare, chromium-colored green variety. Laboratory irradiation has been used to intensify the color of kunzite (Ashbaugh, 1988). However, it can also turn kunzite deep green to mimic hiddenite. A simple (but color destructive) fade test will separate chromium-colored hiddenite from the unstable irradiated material, as the latter will commonly bleach out in a matter of one to a few hours in sunlight.

In 1982, Rossman and Qiu reported that neutron irradiation of spodumene had produced an unusual range of colors, from brownish orange through orange to brownish yellow, orange-yellow, and even greenish yellow. This treatment can be identified both by the unnatural colors of the stones and, with a Geiger counter, by their detectable radioactivity.

Topaz. Probably no treated material had as broad a presence in the gem and jewelry market of the 1980s as irradiated topaz (figure 11). Millions of carats of irradiated blue topaz were processed and sold in the course of the decade. Almost any colorless or light yellow topaz can be altered to a range of colors from yellow to dark brown by gamma, high-energy electron, or neutron irradiation. None of these colors is stable to heat or light (Nassau, 1985). However, heating these stones to approximately 200° to 300°C for as little as one and a half hours will turn some of them blue. While these blue colors appear to be stable, the decade of the '80s produced no definitive gemological test to separate all of the irradiated stones from natural blue topaz.

We do know that the irradiated colors are usually darker and more intense than those seen in nature; no natural-color blue topazes of a medium dark or darker tone have been observed in jewelry-size stones. In addition, some artificially irradiated stones contain residual radioactivity. As early as 1981, Crowningshield (1981a) reported on the presence of radioactive blue topaz in the trade and suggested routinely testing parcels of stones with a Geiger counter. By the end of the decade, a variety of more sophisticated, and more sensitive, radiation detectors were also available (Ashbaugh, 1988). In France, the Centre d'Etudes Nucléaires de Grenoble has developed an instrument that can measure the residual radioactivity of large quantities of gemstones (Robert, 1987).

Research into the application of more advanced technology to identify irradiated topaz continued throughout the 1980s, but with little success. A test based on the property of thermoluminescence, that is, light caused by heat, showed some promise. Unfortunately, the heat required for the measurement bleaches the blue color from the specimen (Rossman, 1981); it is also possible that the effect could be negated by a selective preliminary heating (Nassau, 1985).

Tourmaline. Also during this decade, reports emerged about the artificial irradiation of colorless to light pink tourmaline to produce dark pink to red material (Ashbaugh, 1988). Currently, we know of no method by which this treatment can be detected.

DYEING

Throughout the decade, dyeing of a variety of materials was observed. Perhaps most prevalent was the dyeing of a number of porous minerals, such as calcite, dolomite, and magnesite, for use in beads to imitate more expensive (e.g., turquoise, lapis lazuli) materials (figure 12). Dye in such materials can usually be identified by the use of acetone and, in some cases, a 10% hydrochloric acid solution on a cotton swab. Dyes were also

detected in a number of other gem materials, as described below.

Beryl. Emerald or colorless beryl may be treated with a green oil or dye to enhance or induce a green color. With magnification and diffused transmitted light or immersion, such treatment is detected as color concentrations in fractures (Brown and Snow, 1985; figure 13). However, dark-colored reflections in untreated fractures in emerald should not be confused with dye colors in treated stones. Note that changing the angle of observation should negate any reflection effect, whereas true color concentrations in fractures should be visible at any angle (Ringsrud, 1983).

Jade. Jadeite may be dyed any number of colors, but, not surprisingly, green and lavender are the most common. The detection of dyed green jadeite is relatively straightforward, as discussed in the various identification texts. Detecting dyed lavender jadeite has proved more of a challenge. In a 1982 study, however, specimens believed to be colored with an organic dye fluoresced strong to very strong orange to long-wave U.V. radiation (figure 14), and weak brownish orange to brownish red to short-wave U.V.; had a moderate bluish purple X-ray fluorescence; and showed evidence of color concentrations in microscopic surface cracks. In addition, the color bleached when the specimens were exposed to heat exceeding 220°C for no more than half an hour (Koivula, 1982).

Although much less common, dyed green nephrite has also been seen. This was first reported in "potentially commercial quantity" in 1984. The dyed material shows a broad absorption band in the 660- to 700-nm region and, with magnification, green color concentrations in fine surface-reaching cracks. Under the Chelsea color filter, such dyed nephrite may appear a faint brown (Hurwit, 1984; Crowningshield, 1984c).

Lapis Lazuli. A great deal of lapis, much of it dyed, was seen on the gem market in the 1980s. Although commonly dyed to impart color to whitish (calcite) areas, some lapis is so heavily dyed that it virtually owes its color to the treatment. With magnification, evidence of blue dye may be seen in fractures and some porous areas. Heavily dyed material may show unnatural color in patches not associated with such areas. On beads, dye may concentrate in drill holes. Heavily dyed material

Figure 12. The beads in these strands are composed of a variety of materials, such as dolomite and magnesite, that have been dyed to alter their color. Photo by Shane F. McClure.

may not exhibit the chalky green fluorescence to short-wave U.V. associated with lapis lazuli, and may appear an unnaturally bright brownish red when viewed through the Chelsea color filter (Crowningshield, 1986).

Often the dye can be detected when color appears on an acetone-dipped cotton swab that has

Figure 13. Colored oils, like that shown here in an emerald, may be detected as color concentrations in surface-reaching fractures. Photomicrograph by Robert E. Kane; magnified 25×.

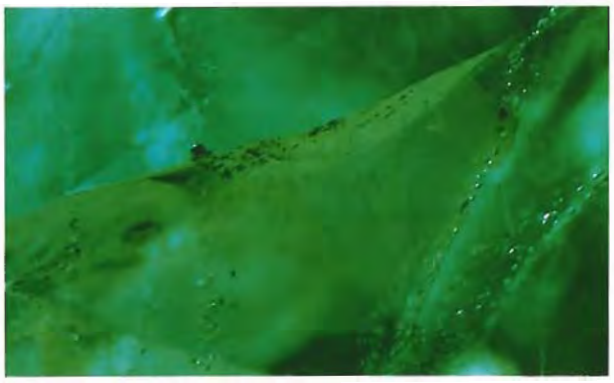


Figure 14. The strong orange fluorescence to long-wave U.V. radiation of this lavender jadeite indicates that the color is a result of dye treatment. Photo by Tino Hammid.

been rubbed on an inconspicuous spot. Some dyes used on lapis lazuli, however, do not yield a positive test to acetone but do produce a blue discoloration when tested with a 10% hydrochloric acid solution (Kane, 1986c) or denatured alcohol (Borgardt, 1986). Some lapis is wax treated to conceal the dye from chemical tests and improve apparent luster. With magnification, however, the wax coating may be detectable by its unevenness and the presence of areas of calcite or pyrite where the wax cannot penetrate. After the wax has been removed from a small area with a needle probe, the stone can be retested for dye (Kane, 1981b).

OILING/FRACTURE FILLING

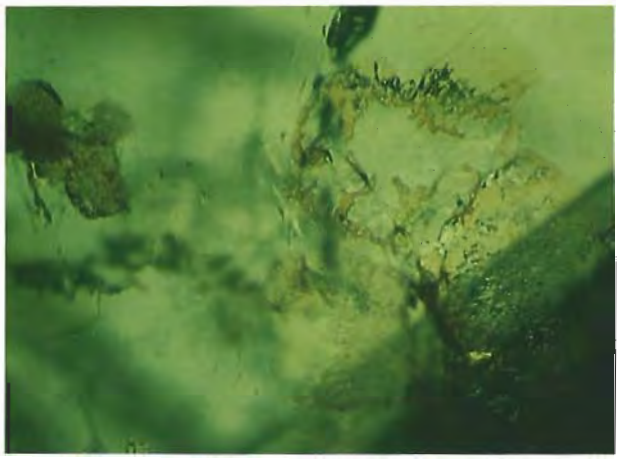
This general treatment category refers to the introduction of any substance into surface-reaching fractures in gems for the primary purpose of lowering the relief of the fractures, thereby making them less noticeable. The substances used may be colorless or slightly tinted. Their primary purpose, however, is to improve apparent clarity and appearance, not to add color, and in some instances they may even have a negative effect on apparent color.

Beryl. To most gemologists, the term *oiling* is automatically associated with emerald. Reports published during this decade have helped fine-tune some of the tests traditionally used to detect oiling in emerald.

The two most commonly used substances for emerald treatment in Colombia are cedarwood oil and Canada balsam (figure 15). The latter fluoresces dull yellow to long-wave U.V. radiation, which is used as an indication of oiling. When examined from the side with pinpoint illumination, some oiled emeralds reveal dull areas indicating fracture filling. If the refractive index of the oil differs significantly from that of the stone, careful manipulation of the light source under magnification may produce an iridescent effect. If the oil has not completely filled the fracture, gaps may be seen in the filling material (Ringsrud, 1983). White dendritic deposits may be noted in fractures after oiled stones have been "dried out" by ultrasonic cleaning or exposure to high temperatures (Crowningshield, 1984a).

In the 1980s, reports began to appear of emeralds that had surface-reaching fractures filled with a plastic substance, possibly introduced in liquid form and then hardened by exposure to light or U.V. radiation (Koivula, 1987b). One commercially available prepolymer plastic resin, Opticon, is hardened using a chemical catalyst (Jones, 1986). An early observation relevant to the separation of plastic-filled from oiled emeralds was that oiled stones tend to "sweat" oil when exposed to even slight temperature increases, such as those produced by a microscope lamp, whereas plastic-filled stones would not be expected to "sweat." Such plastic-treated fractures might be detectable by a characteristic fluorescent reaction and diagnostic infrared spectrum (Koivula, 1987b).

Figure 15. The dendritic patterns and yellowish color seen in this surface-reaching fracture are typical of emeralds treated with Canada balsam in which the treatment material has partially decomposed. Photomicrograph by John I. Koivula; magnified 35×.



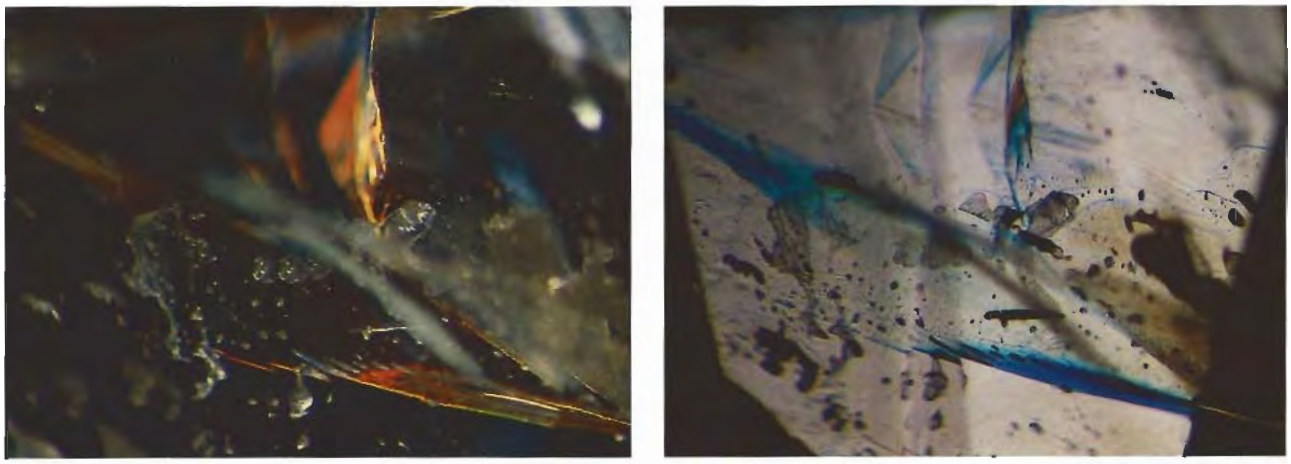


Figure 16. A "flash effect" is one of the most important visual features of filled separations in a diamond. In many fracture-filled diamonds examined to date, this effect is a characteristic yellowish orange in darkfield illumination (left); it changes to a distinctive blue when the stone is rotated slightly to a position where the background becomes bright (right). Photomicrographs by John I. Koivula; magnified 20×.

Diamond. One of the most significant enhancements introduced in the '80s is the filling of surface-reaching separations in diamonds (commonly called the Yehuda treatment). This was first reported from Japan in 1987, on diamonds imported from Israel. Later that year, all three locations of the GIA Gem Trade Laboratory had examined stones with treated surface-reaching breaks. One had a subsurface white cruciform pattern where some of the treatment material had been removed when the stone was boiled in concentrated sulfuric acid (Koivula, 1987a).

A comprehensive investigation found that this treatment did improve apparent clarity in many stones, but often at the expense of the overall color (Koivula et al., 1989). These authors subsequently identified a number of diagnostic features. Some treated stones have a slightly greasy or oily appearance with a very slight yellowish overtone. With the microscope, at least one of the following was noted in all of the filled diamonds studied: (1) an interference "flash effect" that appears in most stones as yellowish orange in darkfield illumination but changes to a vivid "electric" blue when the stone is rotated slightly (figure 16; as reported in Koivula and Kammerling, 1990a, some filled diamonds may show a pinkish purple/yellowish green pair of "flash effect" colors); (2) a flow structure of the filling material; (3) flattened gas bubbles trapped in the filling material; (4) a crackled or web-like texture in the filling material; (5) a light brown to brownish or orangy yellow appearance where the filling material is unusually thick; and (6) a cloudy white surface residue. In some stones, the filled areas were opaque to X-rays. The treatment material is not stable to extremely high temperatures (Koivula et al., 1989).

CAVITY FILLING

Beryl. Although cavity fillings in corundum were first noted in the mid-1980s (see below), recently an emerald was found to have a cavity filled with a plastic-like substance. The filling material contained gas bubbles, fluoresced a strong bluish white, and was easily indented with a pin (Hurwit, 1989).

Corundum. The last decade saw the introduction of the filling of surface pits and cavities with a glass-like substance to seal open voids, add weight, and improve the overall appearance of rubies and sapphires (Hughes, 1984a, b; Scarratt and Harding, 1984; Kane, 1984; Scarratt et al., 1986). Because of the difference in refractive index and hardness between the host corundum and the filling material (R.I. 1.52, hardness 6 1/2), large filled cavities may be detected with the unaided eye by a difference in surface luster (figure 17). The effect is best seen with magnification using surface-reflected light from a fluorescent overhead illuminator. The filling material was found to be inert to both U.V. and X-radiation (Kane, 1984).

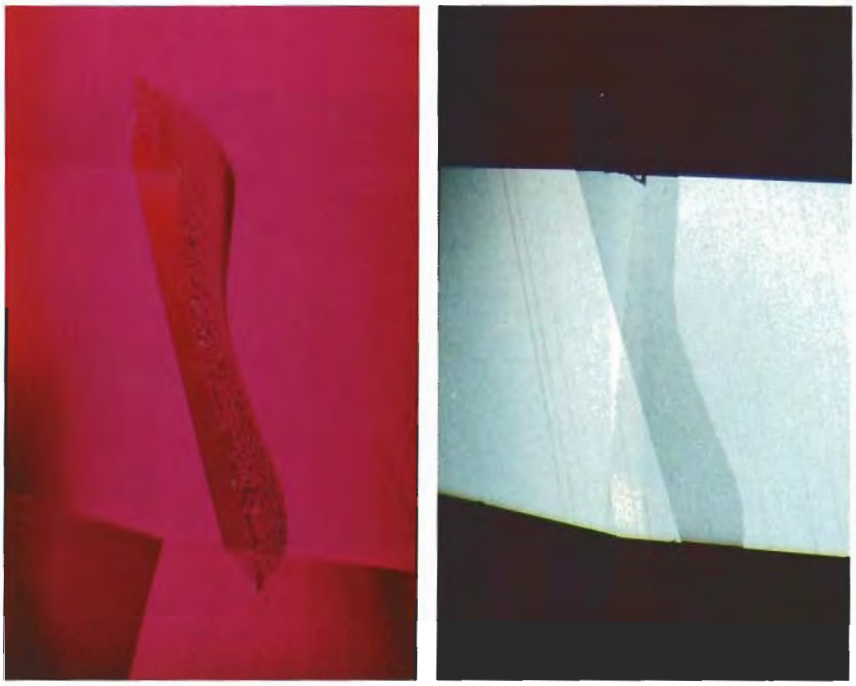


Figure 17. These two photomicrographs of a 2.8 × 0.4-mm glass-filled cavity in a 7.01-ct Burmese ruby illustrate how the glass filling appears when different illumination techniques are used. On the left, darkfield illumination shows the difference in transparency between the glass and the ruby, but there is no apparent difference in luster. On the right, reflected illumination from a fiber-optic light source reveals the great contrast in surface luster. Photomicrographs by Robert E. Kane; magnified 60×.

Microscopic examination provided several additional clues. With darkfield illumination, a difference in transparency between the glass and the host corundum may be seen. With immersion and diffused transmitted light, the filled areas often stand out in high relief; at some viewing angles the glass may appear colorless. Magnification may also reveal gas bubbles in the filling material. Some filled cavities have uneven voids of trapped gas or a "heat-wave" appearance at the junction of the filling and the host material (Hughes, 1984a, b; Koivula, 1984c; Kane, 1984).

Care must be taken not to mistake included crystals or glassy two-phase inclusions that break a stone's surface for such treated areas. Natural glassy inclusions tend to be no longer than 1 mm and have very irregular shapes (Koivula, 1984c; Kane, 1984).

Opal. Cavity fillings have also been seen in opal. A black opal cabochon examined in the GIA Gem Trade Laboratory had what appeared to be matrix on the base. However, this material was soft, with a waxy luster, and magnification revealed several hemispherical cavities. A scraping of the material flowed easily when a hot point was applied, proving that it was a wax-like substance (Kane, 1981c).

Tourmaline. Historically, shellac has been used to seal the growth tubes in cat's-eye tourmaline. A stone examined in 1984, however, had tubes filled with a plastic. The treatment was detected by the presence of gas bubbles in the filling and by the odor produced when a hot point was applied (Koivula, 1984b).

COLORLESS IMPREGNATIONS

Colorless impregnations have been used to enhance color and/or improve stability of porous aggregate materials to a greater extent in the 1980s than ever before. Although plastic impregnation of turquoise per se is not new to the 1980s, the treatment of higher-quality material is. Here the purpose is to improve both color and stability. Research has shown that plastic-impregnated turquoise can be identified by X-ray diffraction (which shows the presence of an $AlPO_4$ phase with berlinite structure) and by infrared spectroscopy (which reveals absorption due to the plastic impregnating material; Lind et al., 1983).

SURFACE COATINGS

A number of gem materials have had their color altered or induced through the use of colored surface coatings. These include faceted natural beryl that has been coated with a green substance to imitate emerald (Kane, 1982); corundum beads that have had their drill holes coated with a red substance (Koivula, 1984a); and faceted quartz with a red plastic coating, white jadeite with a thin layer of dark green plastic, and near-colorless star sapphire with a red plastic coating (Hughes, 1987). Black dye was put in the paraffin used to coat a turquoise carving, and applied selectively to simu-

late matrix (Kane, 1986b); a similar treatment has been used on magnesite dyed blue to imitate spiderweb turquoise (Koivula and Misiorowski, 1986a). Coated diamonds have plagued the gem market for decades, with old stones continuing to reappear in the 1980s. Apparently, coating gemstones continues to be a common practice in India (Tatiwala, 1985).

Such surface coatings are usually detectable with magnification, by the presence of near-colorless areas where the coating has partially worn off (figure 18). Such coatings may also be scratched with a brush probe; they will often leave a discoloration on an acetone-dipped cotton swab (Kane, 1982, 1983a). Note on diamonds that only some surface areas may be coated (e.g., only the pavilion facets) or only a thin band on one or both sides of the girdle (Crowningshield, 1983a, 1984b).

Rough gem crystals, especially beryl, have also been surface coated to alter their color. The coatings are generally detectable using the same methods described above. In addition, the coatings on rough materials may be seen to concentrate in surface fractures, cavities, and depressions (Kane, 1982).

In 1988, a new enhanced gem material known as "Aqua Aura" quartz appeared on the market. Natural colorless quartz crystals (and, more recently, faceted stones) are coated with a very thin, transparent film of gold, so that they exhibit a blue to bluish green color with a superficial iridescence. The coating is durable and does not affect other gemological properties; in addition to the fact that such material does not occur in nature, the coating can be detected by some of the same methods described above (Kammerling and Koivula, 1989a).

INDUCED/ALTERED INCLUSIONS

The 1980s also saw examples of inclusions that were artificially induced or altered. One such process that seemed to resurface during this decade was the use of staining and electrolysis on whitish chalcedony to induce both a blue-green color and dendritic inclusions. The material is identified by the combination of its color, inclusions (Koivula and Misiorowski, 1986b), and the presence of precipitated copper on the surface, extending from the otherwise internal mass (Koivula and Kammerling, 1989).

Heat treatment has also been used to induce "fingerprints" into surface-reaching fractures in Verneuil synthetics (Koivula, 1983). Typical identifying features of such materials are the simultaneous presence of "fingerprints," curved but diffused Verneuil banding, and occasional gas bubbles (Crowningshield, 1980; Nassau, 1981).

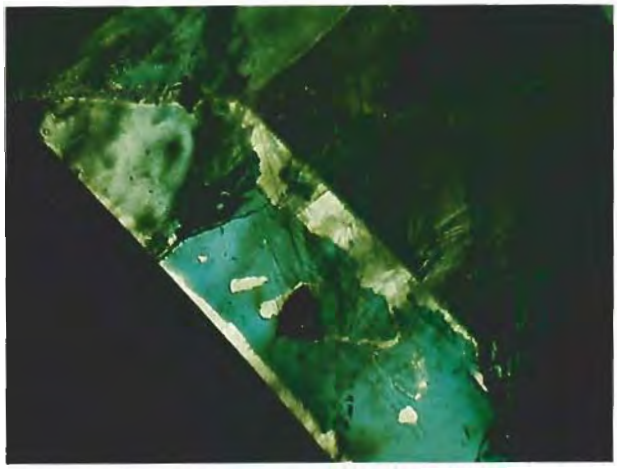


Figure 18. Magnification reveals surface areas of this coated beryl where the green coating has been removed. Photomicrograph © GIA.

Topaz with limonite-stained etched dislocation channels to make the inclusions darker and more noticeable was heated. In the process, the limonite was altered to hematite. The presence of red-brown hematite-stained etch channels is sufficient evidence that the stone has been heated (Kammerling and Koivula, 1989b).

CONCLUSION

The above discussion focused on a number of the gemstone enhancements that challenged gemologists in the 1980s and continue to challenge them today. What new treatments might face us in the not-too-distant future? A number of recent developments indicate some areas that must be monitored closely.

Plasma-enhanced chemical vapor deposition has been used to produce thin films of polycrystalline synthetic diamond and diamond-like carbon. While such materials appear to be relatively easy to detect, the possibility exists that a transparent layer of colorless monocrystalline synthetic diamond might in the future be grown on various gem materials (Fritsch et al., 1989). One obvious application would be to produce a highly durable surface layer on a relatively soft gem material. Such technology might also be used to produce a layer of synthetic diamond on cubic zirconia in an attempt to "fool" a thermal reaction

tester, or on a near-colorless (or off-color) diamond to alter the apparent body color. Note that, with diffusion treatment, only a thin layer of color is required to drastically alter the appearance of otherwise pale corundum.

Recently it was reported in the trade press that the firm offering commercial fracture filling of diamonds was beginning to offer a fracture filling treatment for emeralds (Everhart, 1989; "Yehuda launches 'permanent' treatment for emeralds," 1989). Although the filling materials are undoubtedly different, a 14+-ct emerald described in the Gem Trade Lab Notes section of this issue exhibited a number of features visually identical to those seen in filled diamonds: an orange and blue "flash effect," a crackled texture, and trapped bubbles in the filling material. As an extension of this, might we reasonably expect to see a series of new, perhaps more durable, fracture-filling treatments in other gem materials as well?

Artificially irradiated blue topaz has become a staple of the colored stone market. Yet concern over possible health risks associated with such enhanced gems has caused some to look for alternative methods of producing this now-popular blue color in topaz. In this regard the authors have recently seen faceted topazes that have been treated with the "Aqua Aura" process, that is, coated with an ultra-thin layer of gold, resulting in an attractive greenish blue color with overlying iridescence. Whether or not this enhancement will have any real commercial significance has yet to be seen.

Certainly, detection will continue to face many challenges in the coming decade. Even if no new enhancements were to emerge, the need continues for definitive tests to identify heat-treated rubies and sapphires, artificially irradiated diamonds and tourmaline, and topaz that has been heated or artificially irradiated and annealed. Important strides were made in the 1980s; important strides must be made in the years to come.

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SYNTHETIC GEM MATERIALS IN THE 1980s

By Kurt Nassau

Although the 1980s did not experience the emergence of several totally new synthetics that characterized the preceding decade, it was during this period that synthetics matured, with many new manufacturers and greater manufacturing capacity. The highlights of this decade include the introduction of a number of new synthetic sapphires, rubies, and emeralds, as well as the appearance of the first commercially available cuttable synthetic diamond. The 1980s also saw the influx into the market of literally tons of synthetic amethyst and thousands of tons of synthetic cubic zirconia. As new synthetic products emerged, so did the need for new detection techniques. Developments during this decade will provide major challenges in the years to come.

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The 1980s followed a decade that experienced a peak in arrivals of new laboratory products. A series of synthetic gem materials were perfected during the 1970s, including synthetic alexandrite, cuttable-quality synthetic diamond, synthetic amethyst, and flux-grown synthetic sapphire. There were also two new diamond imitations, gadolinium gallium garnet (GGG) and synthetic cubic zirconia (CZ), as well as some near-synthetic imitations made of ceramic or glass: imitation turquoise, imitation lapis lazuli, "Opal-Essence," and imitation coral. Details of these materials are provided in Nassau (1980).

Although the only totally new synthetic material introduced during the 1980s is synthetic cat's-eye alexandrite, this is the decade when synthetics matured, with the first significant commercial availability of a variety of new products developed from earlier technologies including:

1. Chatham flux-grown synthetic orange sapphire and synthetic blue sapphire
2. Ramaura flux-grown synthetic ruby
3. Lechleitner synthetic overgrowth corundums
4. Knischka flux-grown synthetic ruby
5. Biron hydrothermal synthetic emerald
6. Russian hydrothermal synthetic emerald
7. Russian flux-grown synthetic emerald

Also during the 1980s, literally tons of synthetic amethyst "haunted" the gem and jewelry industry. In addition, the decade brought the first, if limited, *commercial* availability of synthetic diamonds (for industrial purposes) in a quality and size that could be suitable for use in jewelery. Each new product possessed a new set of characteristics, so that the gemologist was faced with the need in many cases for new "rules of identification" and even the development of new tests. Even though synthetics and imitations represented only about 5% of the total dollar value of the U.S. retail trade (estimated per Nassau, 1980), they continued to generate great concern through the industry.

Figure 1. Large amounts of relatively low-cost Verneuil synthetic ruby and sapphire were available during the 1980s and were even used, in conjunction with cubic zirconia, in reproductions of fine jewelry. Jewelry courtesy of Our Secret Creations, Beverly Hills, CA; photo by Shane F. McClure.

Synthetic materials may be separated into two groups. The term *luxury synthetics* refers to difficult-to-grow, high-cost materials, including some synthetic alexandrite, synthetic emerald, and flux-grown synthetic ruby and sapphire. *Lower-cost synthetics* encompasses materials such as synthetic star ruby and sapphire; synthetic opal; synthetic citrine, amethyst, and other varieties of quartz; as well as synthetic cubic zirconia and Verneuil-grown synthetic ruby, sapphire (figure 1), and spinel. While the decade of the '80s has seen a greater variety and quantity of luxury synthetics on the gem and jewelry market, it has experienced an explosion of lower-cost synthetics. By the end of the decade, production of cubic zirconia had increased about 20-fold over production in the late 1970s, to about 100 million carats per month (J. Wenckus, pers. comm., 1989).

This article examines the major developments in gem synthesis and production during the last decade. While most synthetics manufacturers do not divulge their processes, knowledge of crystal-growth techniques and examination of the product can usually provide identification of the process used, if not all the details of the specific procedure. This article will also consider those products (such as Ardon Associates' Kashan synthetic rubies and the Linde hydrothermal synthetic emeralds) that are no longer being manufactured, since old material or pre-existing stock is still likely to be seen by the gemologist. In addition, some of the discussion refers to products first made on an experimental

TABLE 1. Synthetic ruby products and producers, with references to the recent literature.[a]

Process	Name/current producer	References
Melt		
Verneuil flame fusion	Many[b]	Nassau, 1980
Float zone	Bijoreve/Seiko	Koivula, 1984
Czochralski pulling	Many	Nassau, 1980
	Inamori/Kyocera[b]	Koivula and Kammerling, 1988a; Schmetzer, 1986c
Flux[c]	Chatham	Nassau, 1980; Gübelin, 1983a,b; Schmetzer, 1987
	Gilson/Nakazumi	Schmetzer, 1986c
	Kashan/Ardon	Nassau, 1980; Gübelin, 1983a,b; Burch, 1984; Henn and Schrader, 1985
	Knischka	Gübelin, 1982, 1983a,b; Gunawardene, 1983; Galia, 1987
	Lechleitner "overgrowth"	Kane, 1985; Gunawardene, 1985a; Schmetzer and Bank, 1988
	Ramaura/J.O. Crystal	Kane, 1983; Bosshart, 1983; Gunawardene, 1984; Schmetzer, 1987

[a]*For general reference, also see Schmetzer (1986a,b).*
[b]*Asteriated material also produced.*
[c]*A number of these processes also employ synthetic overgrowth over a synthetic or a natural seed.*

basis some years ago (e.g., the General Electric synthetic jadeite), about which information was released only recently.

It is not possible to cover in detail the preparation techniques of all synthetic products, current as well as recent manufacturers. Since my book on the subject (Nassau, 1980) appeared exactly at the beginning of the decade, it can be used as a point of departure for this article, with the materials discussed in the same sequence as there used. For the most part, I have not included the identifying characteristics of these products and the methods by which they can be separated from their natural counterparts (as well as from each other, should it be required); this aspect alone would easily fill an entire issue of *Gems & Gemology*. Some individual items are discussed, however, when their nature is related to special manufacturing aspects or to important developments of the decade. As much as possible, the reader is referred to the published literature in this regard.

SYNTHETIC RUBY AND SAPPHIRES

Ruby was the first synthetic gem material to be produced commercially, with the Geneva and Verneuil flame-fusion products both appearing at the turn of the century. Verneuil's synthetic blue sapphire followed in 1911. A large Verneuil flame-fusion industry has risen over the decades, with bearings and cover "glasses" for watches the major products. Today, production exceeds 200 metric tons—or one billion carats—per year worldwide (J. Wenckus, pers. comm., 1989). The need for high optical-quality synthetic ruby for use in lasers has resulted in a variety of alternative melt-growth techniques; the products of some of these have also been faceted. Table 1 lists those products that are currently available in the gem trade, together with their manufacturers and recent publications where they (and, in some instances, their identifying characteristics) have been described; the discussion by Schmetzer (1986a) is particularly comprehensive.

Flux growth of synthetic ruby dates back only to the 1960s. Schmetzer (1986a) published the results

Figure 2. Large Knischka flux-grown synthetic crystals, like the one from which this 52.06-ct cushion cut was faceted, have been grown recently. Stone courtesy of P. O. Knischka; photo by Shane F. McClure.

Figure 3. One of the attractive synthetics to reach the gem market in the 1980s is the Ramaura flux-grown synthetic ruby. This 23.86-ct crystal, the largest Ramaura rhomobohedron grown to date, is courtesy of Ramaura Cultured Ruby, Judith Osmer; photo © Tino Hammid.

of his research into the nature of the fluxes used by different manufacturers, that is: Li_2O-MoO_3-PbX, where X is F_2 or O (Chatham, Gilson, Lechleitner); Na_3AlF_6 (Kashan); Li_2O-WO_3-PbX (Knishka); and Bi_2O_3-La_2O_3-PbX (Ramaura). The high cost of producing this luxury synthetic has kept demand, and therefore production, of this as well as of the analogous blue and orange flux-grown synthetic sapphires relatively low. Production of Kashan synthetic ruby was halted by bankruptcy proceedings in 1984. Continued research on the Knischka product, however, recently resulted in the growth of some extremely large crystals, such as the one from which the 52.06-ct cushion cut in figure 2 was faceted. For the experimental synthetic flux ruby overgrowth by Lechleitner, under way since 1983, both natural seeds (Schmetzer and Bank, 1988) as well as Verneuil synthetic seeds (Kane, 1985) have been reported.

It should be noted that the Ramaura synthetic ruby (figure 3) is reported to be tagged with a small amount of a rare-earth element to make it more readily identifiable by a yellowish orange fluorescence. This fluorescence is not always detectable using standard gemological methods, however, and it could easily be absent in a cut stone depending on how the stone was fashioned from the rough (Kane, 1983; Gunawardene, 1984).

A wide range of colored synthetic sapphires can be readily grown by the Verneuil technique (Nassau, 1980). Both synthetic blue sapphire as well as synthetic orange "padparadscha" sapphire have been grown using other methods as well: from the flux by Chatham (Kane, 1982; Gübelin, 1983b; Gunawardene, 1985b; figure 4) and by Lechleitner (including overgrowth); and with the Czochralski

Figure 4. In the early 1980s, Chatham Created Gems, known for its production of flux-grown synthetic emeralds, introduced flux-grown blue, orange, and pinkish orange synthetic sapphires to the market. The Chatham synthetic emerald shown here weighs 4.15 ct; the synthetic sapphires range in weight from 1.91 to 6.20 ct. Photo © Tino Hammid.

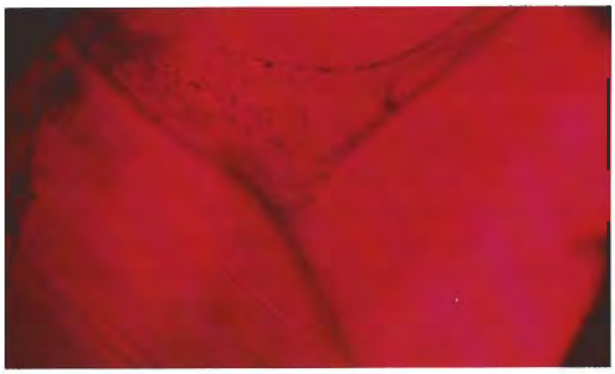


Figure 5. A flux healing process was used to induce this "fingerprint" in a Verneuil synthetic ruby. Also note the curved striae characteristic of the Verneuil flame-fusion process. Photomicrograph by John I. Koivula; magnified 45×.

and/or float-zone techniques by the Bijoreve division of Seiko and the Inamori division of Kyocera (Gunawardene, 1985b).

During the 1980s, two potentially misleading characteristics of flame-fusion synthetic ruby and sapphire were described: (1) natural-appearing fingerprint-like inclusions that can be induced after growth by a flux healing (Koivula, 1983; figure 5); (2) natural-appearing needle-like inclusions that were identified as the edges of twinning planes (Hargett, 1989).

Figure 6. Major amounts of synthetic amethyst (the largest here is 10.86 ct) entered the gem trade during the 1980s. Photo by Shane F. McClure.

SYNTHETIC QUARTZ

Giorgio Spezia accomplished the earliest successful growth of synthetic quartz by the hydrothermal method about 1905 in Italy (Nassau, 1980; Trossarelli, 1984). Colorless synthetic quartz was successfully commercialized about 1950 and, because of its piezoelectric properties, has been used in large quantities in a variety of communications devices since then. Today, some 1,000 metric tons are grown worldwide each year, although only a small part of this production, about 20 metric tons, or 100 million carats, is used in the gem trade, mostly as synthetic amethyst (figure 6) and citrine (B. Sawyer, pers. comm., 1990). Figure 7 shows one of several large modern Japanese synthetic quartz factories currently in operation.

Colorless synthetic quartz can be irradiated to produce a synthetic smoky quartz; since the same can be done with natural colorless quartz, which is plentiful, there should be no significant gem market for either the colorless or the smoky synthetic product, although the author has seen some in the trade. Both synthetic citrine and synthetic amethyst have been manufactured since the 1970s in the USSR (Nassau, 1980; Balitsky, 1980). This production was joined in the 1980s by a Japanese product (Lind and Schmetzer, 1987). A synthetic rose quartz has been produced experimentally by adding both iron and titanium (Hosaka et al., 1986).

The observation of inclusions, when present, to separate natural and synthetic amethyst and citrine was augmented in the 1980s by the examination of growth and twinning structures. An identification technique based on Brazil-law twinning, present in natural amethyst and absent in synthetic amethyst, was described by Schneider et al. (1983) and Schmetzer (1986c). The use of a simple polariscope to determine the presence or absence of twinning in amethyst/synthetic amethyst (figure 8) was subsequently proposed by Crowningshield et al. (1986) and has since been widely adopted. It is possible, however, that the twinning test could be negated if the manufacturers of synthetic amethyst were to use carefully chosen natural twinned seeds, as has already been done on an experimental basis (see, e.g., Koivula and Fritsch, 1989).

SYNTHETIC EMERALD AND OTHER BERYLS

Although work in this area started in France in the 19th century, the first commercially successful synthetic emerald was produced, by C. C. Chatham of San Francisco, only about 1940. P. Gilson of France introduced his product some 20 years later. Both of these manufacturers use a flux process, based on lithium di-molybdate, $Li_2Mo_2O_7$ (Nassau, 1980).

In the 1960s, J. Lechleitner of Austria introduced a hydrothermal technique to add a thin coat of synthetic emerald to the surface of a faceted pale natural beryl. By 1970, Linde Air Products Co. had created a hydrothermal synthetic emerald; this was originally released under the Quintessa name and subsequently reactivated as Regency synthetic emerald by Vacuum Ventures. Next, the Inamori Division of Kyocera, a Japanese firm, began marketing a synthetic flux-grown emerald under the name Crescent Vert.

A whole series of new manufacturers, using either flux or hydrothermal (figure 9) processes, have come on the scene in the 1980s, as shown in table 2. Perhaps the most interesting of these new products is associated with the names Biron and Pool (see, e.g., Hicks, 1988). The Biron hydrothermal synthetic emerald, which contains both chromium and vanadium as well as some chloride, was first produced in Western Australia early in the decade (Kane and Liddicoat, 1985; Kane, 1988; Bank et al., 1989). About 1988, the Emerald Pool Mining Company (Pty.) Ltd. of Perth, Australia,

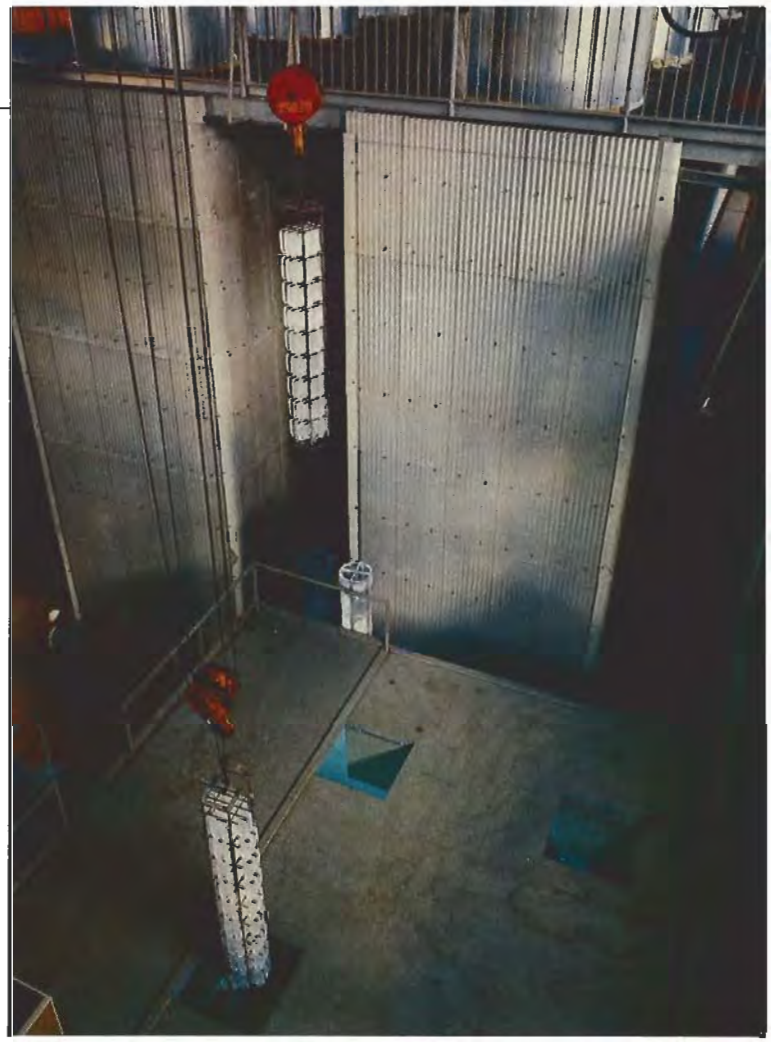
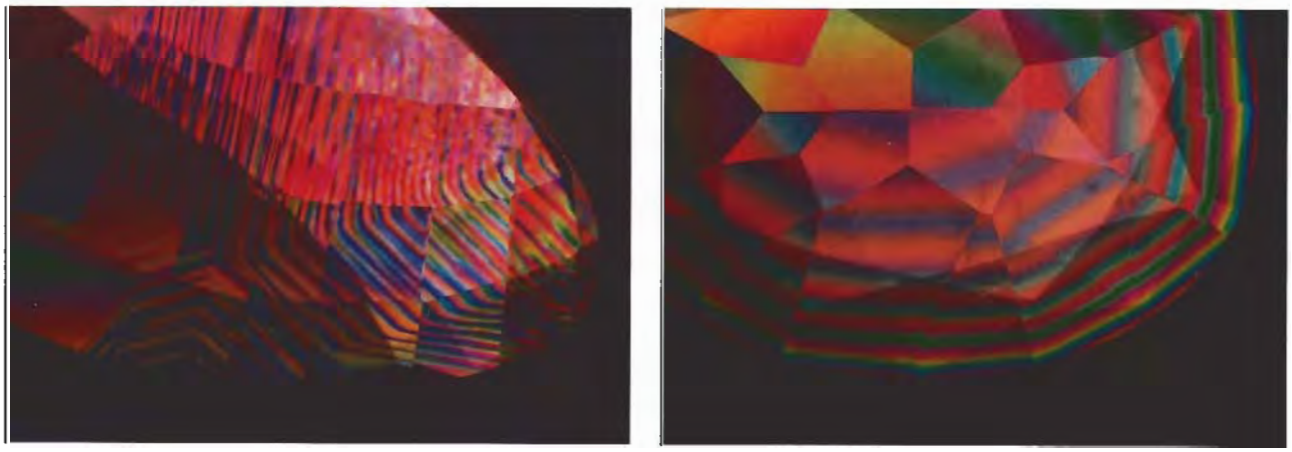


Figure 7. The growth of synthetic quartz is a major industry, as represented by this large quartz-growing facility of Daiwa Shinku Corp., the Ichikawa plant. Only about 2% of the annual production of synthetic quartz is used in the gem trade, primarily as synthetic amethyst. Photo courtesy of Daiwa Shinku Corp.

Figure 8. The difference between the twinned natural (left) and the untwinned synthetic (right) amethyst is clearly seen looking in the optic axis direction of each under crossed polarizers. Photos by Shane F. McClure.



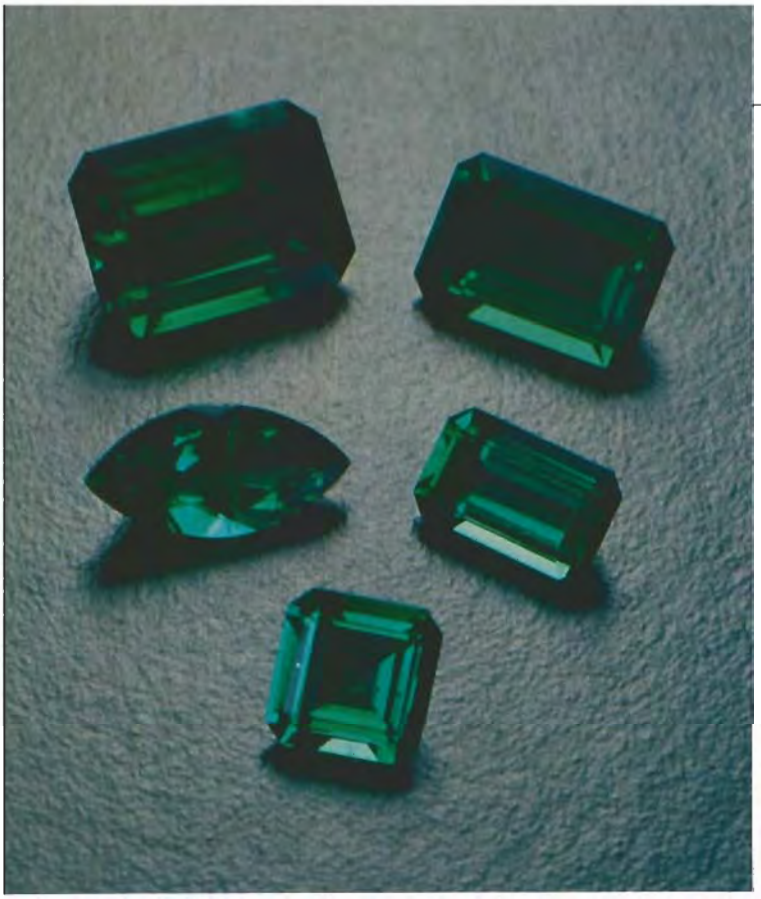


Figure 9. Russian hydrothermal synthetic emeralds were introduced to the gem market in the 1980s. Photo © Tino Hammid.

began an intense marketing campaign in which they implied that some of their product was natural emerald, claiming that a "unique and secret treatment process" was used to convert some of the lower-grade crystals from their mine into high-quality material. However, Brown and Snow (1988), found that all the Pool material they examined was Biron-type synthetic emerald.

In response to complaints that their advertising contravened the laws of many countries, Pool spokespeople merely asserted that natural emerald from their mine was "recrystallized" (Koivula and Kammerling, 1988b). Because the use of natural feed-stock with its attendant impurities makes growth much more difficult, I do not believe that any gem manufacturing technique can afford to use more than an insignificant trace of natural feed. It has been reported (J. Birkner, pers. comm., 1990) that following a reorganization, the name "Biron synthetic emerald" was reintroduced in October 1988.

In the past, Gilson has produced two types of flux-grown synthetic emerald, one with chromium as the colorant and another with iron added as well to reduce the intense red fluorescence (Nassau, 1980). More recently, they have also manufactured a flux-grown product with chromium and nickel present, giving a yellowish green color (Schmetzer, 1989). Also during the 1980s, the Gilson operation was acquired by the Japanese firm Nakazumi Earth Crystals Corp.

TABLE 2. Synthetic emerald and other beryls, products and producers, with references to the recent literature.

Process	Name/current producer	References
Synthetic Emerald		
Solution		
Flux	Biloxi/Seiko	Kennedy, 1986
	Chatham	Nassau, 1980
	Gilson/Nakazumi[c]	Nassau, 1980; Schmetzer, 1989; Kelly and Brown, 1987
	Inamori/Kyocera	Nassau, 1980
	Lechleitner[a]	Schmetzer and Bank, 1982
	Lennix/Lens[b]	Graziani et al., 1987; Hodgkinson, 1988; Attanasio et al., 1989
	USSR[b,c]	Koivula and Keller, 1985
	Zerfass	Nassau, 1980
Solution		
Hydrothermal	Lechleitner "overgrowth"	Schmetzer et al., 1981
	Biron/Biron Minerals[b] (previously Pool)	Kane and Liddicoat, 1985; Kane, 1988; Bank et al., 1989
	Quintessa/Linde	Nassau, 1980
	Regency/Vacuum Ventures	Brown and Snow, 1983; Koivula, 1986
	USSR[c]	Schmetzer, 1986b; Brown et al., 1989
(Chemical vapor deposition?)	ANICS/Adachi Shin	Koivula and Misiorowski, 1986; Hiss and Shor, 1989
Other Synthetic Colored Beryls		
(Chemical vapor deposition?)	ANICS/ Adachi Shin	Koivula and Misiorowski, 1986; Hiss and Shor, 1989
Solution		
Hydrothermal	Regency/Vacuum Ventures	Bank and Becker, 1981; Nassau, 1989
	USSR	Koivula and Kammerling, 1988b

[a] *Also overgrowth over pale natural beryl.*
[b] *Contains or may contain vanadium in addition to chromium.*
[c] *Contains or may contain iron in addition to chromium.*

Considerable research was conducted during the last decade on the use of synthetic emerald for tunable lasers, for which large, high optical–quality hydrothermal synthetic emerald crystals are needed (Buchert and Alfano, 1983). A continuation of this work may in time provide the stimulus for yet larger and better-quality production.

It has long been known by crystal growers that the addition of chromium is responsible for the color of synthetic emerald and omitting it will give colorless beryl. The addition, then, of other impurities to colorless beryl should give other colors, such as those of iron in blue or green aquamarine and golden beryl, manganese in pink and red beryl, and so on. A number of manufacturers have experimented with such colors, as summarized in table 2. The specific colors that have been achieved in synthetic beryl are given in table 3, modified after Nassau (1980, p. 156) and reflecting the reports indicated in table 2. It is interesting to note that the Adachi Shin ANICS product has even been made in "watermelon" form, with a green synthetic emerald layer over a deep pink synthetic beryl core (Koivula and Misiorowski, 1986); the data provided by the manufacturer in that report and elsewhere (Hiss and Shor, 1989) suggest a chemical vapor deposition technique, but as given these data are not convincing to a crystal growth expert.

TABLE 3. Color varieties achievable in synthetic beryl.[a]

Impurity	Color (variety)	Producer[b]
None	Colorless (goshenite)	R
Cr, Cr + V	Deep green (emerald)	U, etc.
V	Deep green (emerald[c])	U
Fe	Pale blue to greenish (aquamarine)	A, U
	Yellow to greenish (heliodor)	A, U
Mn	Pink (morganite)	A, R, U
	Red	A, U
	Gray-green[d]	—
Mn + Cr	Purple[d]	U
Ni	Pale green[d]	A, U
Co	Pink to violet[d]	A, U
Cu	Blue[d]	A, U
Color center	Deep blue to green[e] (Maxixe and Maxixe type)	—

[a] *As modified from Nassau (1980), including current data from K. Schmetzer (pers. comm., 1990).*
[b] *See table 2: A is ANICS, R is Regency, U is USSR; see table 2 for others.*
[c] *Not universally accepted designation.*
[d] *Probably does not occur in nature.*
[e] *Irradiation caused, fades in light; opposite dichroism to aquamarine.*

SYNTHETIC DIAMOND

Although based largely on technology developed by General Electric in the 1970s and earlier, the gem-quality, single-crystal synthetic diamonds produced by Sumitomo Electric Industries in the 1980s represent the first commercial availability of such material. The most important developments have been the steady increase in the size, quality, and quantity of gem-quality material that can be grown affordably by the high-pressure technique (Shigley et al., 1986). As with so many advances in gemstone synthesis, this product was not developed for the jewelry industry but rather for high-technology applications: primarily as heat sinks for semiconductor devices. A later report (Shigley et al., 1987) revealed that De Beers has been conducting research in this area since the 1970s, and has accomplished the production of crystals as large as 11.14 ct.

The high-pressure product can be made in colorless, yellow, green, and blue. To date, however, only the yellow gem-quality synthetic diamonds (figure 10) have been released into the industrial market commercially. The working volume inside the belt apparatus is now quite large (about 10 cm in diameter and 15 cm high), and growth is as much as one-half carat per day on each crystal. Where a yellow color is acceptable, several crystals can be grown in each of several layers at one time by using the wide range of iron-based alloys as solvents. The much more limited range of aluminum-based alloys reduces the number of colorless or blue crystals that can be grown at one time.

A production rate is not available for present single-crystal growth, but the potential scale of operations can be gauged from that for synthetic diamond grit, estimated at about 300 million carats per year, representing about 90% of the diamond grit market for cutting, grinding, and polishing tools. The scale involved can be seen from figure 11, exterior and interior views of the De Beers synthetic diamond factory in Rand, South Africa; these are the first published photos showing close-up details of such a facility. The identification characteristics for recent Sumitomo and De Beers products have been published by Shigley et al. (1986, 1987).

To date, synthetic gem-size and gem-quality

Figure 10. For the first time in the 1980s, gem-quality synthetic diamonds were sold commercially, although not generally for gem use and only in various shades of yellow. These synthetic diamond crystals (0.63–1.07 ct), and the ones from which their faceted counterparts (0.16–0.24 ct) were cut, were obtained by GIA from Sumitomo Electric Industries. Photo © Tino Hammid.

diamond has not presented a problem to the jewelry trade. However, every large-scale synthetic diamond manufacturer (De Beers, Sumitomo, the Russians, and, no doubt by now, the Chinese) could aim part of their production at this market. Whether the result would make economic sense for the producer (luxury synthetics usually market at about one-tenth the price of the equivalent natural stones, while thus far the Sumitomo synthetics have been sold for prices comparable to similar-colored natural diamonds) remains to be seen.

Single-crystal synthetic diamond thin films have shown "promise" since early work by Derjaguin and Spitsin in the USSR about 1956 (Nassau, 1980). To this day, even when grown on single-crystal diamond, the new film grows to a thickness of just one or two microns (one micron is one-hundredth of a millimeter) and then stops being single crystal! Instead, there forms a polycrystalline, granular-type layer, which can be grown quite thick. Alternatively, thick layers can also be grown by incorporating hydrogen, thus forming a "diamond-like" hydrocarbon film, which definitely is *not* diamond and is significantly softer, although in some cases it may be harder than corundum (Nassau, 1989).

The idea of growing a thin, hard, synthetic diamond film on another material, perhaps on a faceted cubic zirconia, may seem exciting to the gemologist. As discussed elsewhere (Nassau, 1989), however, there have been problems of adhe-

sion, transparency, and appearance (e.g., Koivula, 1987), of the temperatures required, and so on. For the immediate future, there should be no trade concerns on this matter.

SYNTHETIC CUBIC ZIRCONIA

Cubic zirconia (CZ) does occur rarely in nature (Stackelberg and Chudoba, 1937; Nassau, 1980), so this widely used diamond imitation is properly classified as a synthetic. As a diamond imitation, synthetic CZ is far superior to a sequence of synthetic products that has included colorless sapphire, spinel, rutile, strontium titanate, YAG (yttrium aluminum garnet), and GGG (gadolinium gallium garnet). It is, in fact, so close in appearance to diamond and produced at such a low price—just one to two cents per carat wholesale in large quantities, that it is unlikely that a more effective material (short of a very inexpensive synthetic diamond!) could ever compete with it.

By 1980, only four years after the first synthetic CZ was identified in the U.S. (Nassau, 1976), the production rate was already some 50 million carats per year (Nassau, 1980), while today it is over one billion carats per year, with the Ceres Corp. accounting for almost one-half of this total (J. Wenckus, pers. comm., 1989).

It is likely that the great production and availability of synthetic CZ in the 1980s was enabled by the events surrounding U.S. patent No. 4,153,469, issued May 8, 1979, to the USSR group of V. I. Alexandrov, V. V. Osiko, V. M. Tatarintsev, and V. T. Uovenchik for the growth of synthetic CZ. This was curious, since the material patented had been previously described in a 1969 French report (Nassau, 1980). When both the Ceres Corp. and their distributor, MSB Industries, ignored Russian demands that they purchase a license or cease production, the Russians brought suit. The U.S. district court found that the application and testimony on the basis of which the patent had originally been granted to the Russians contained misrepresentations and that "what was done could be characterized as fraud. . . ." The court concluded that the patent was unenforceable (Carter, 1983).

A variety of colors, including yellow, orange, red, purple, and a range of greens, have long been available in synthetic CZ (Nassau, 1981). Not until the 1980s, however, were good deep sapphire-blue and emerald-green colors introduced, accomplished with the use of a much larger amount of stabilizer than usual (figure 12). This product was called C-Ox by the original USSR manufacturer (Fryer, 1983a); these colors are also produced by Ceres Corp.

Figure 11. The potential scope of the gem synthetic diamond market is evident in these exterior and interior views of the De Beers synthetic diamond factory in Rand, South Africa. Courtesy of De Beers.

SYNTHETIC ALEXANDRITE

At the beginning of the 1980s, there were two types of synthetic alexandrites in the gem market: Creative Crystals' flux product (production was discontinued in 1985), and Czochralski-pulled material from Kyocera (Allied also pulled such mate-

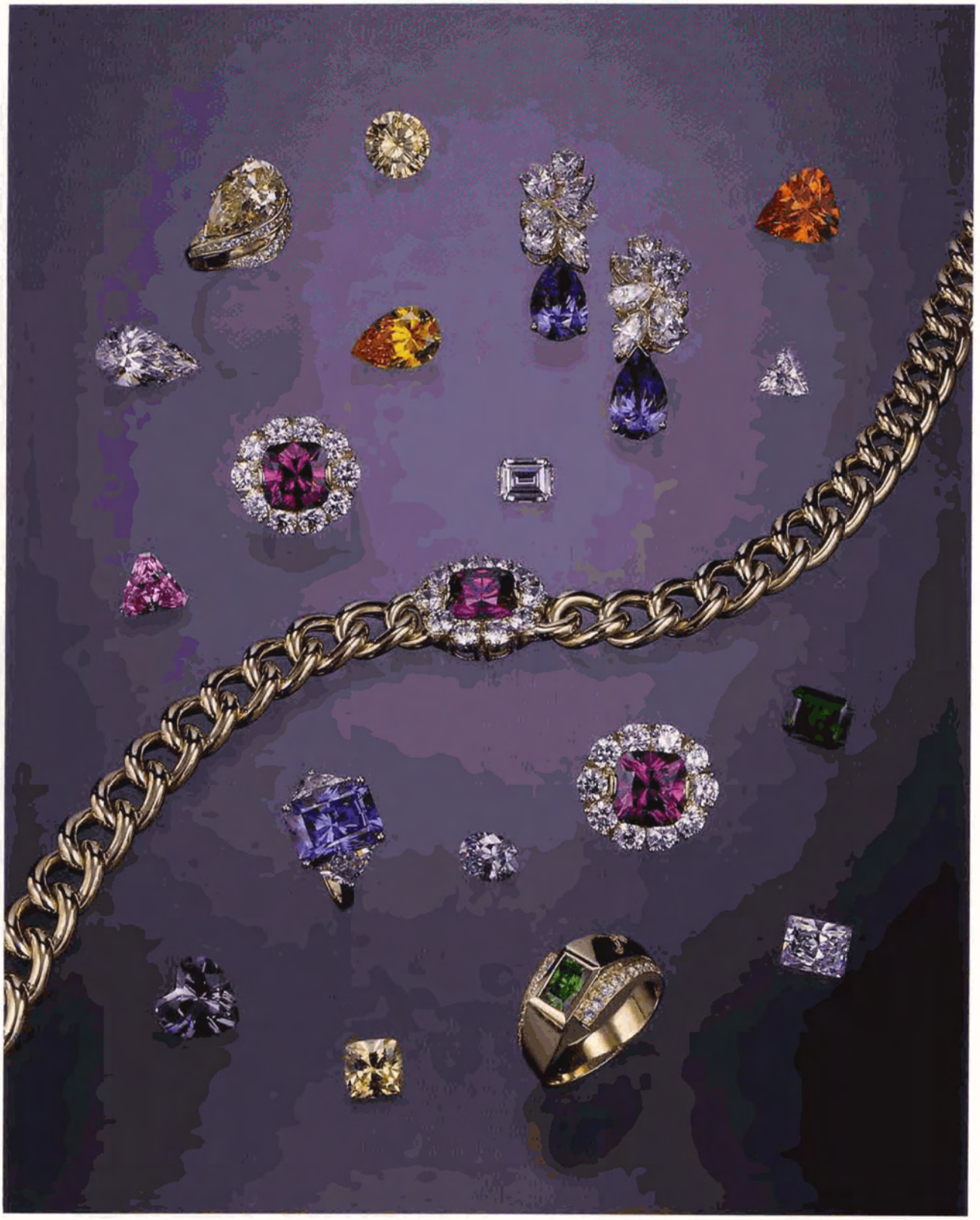


Figure 12. Synthetic cubic zirconia is purple when cobalt is present. With increased stabilizer concentration, the color becomes a deep blue and can also be changed to a dark green by a second yellow-producing addition. During the 1980s, large quantities of many different colors of synthetic cubic zirconia appeared in the jewelry trade, some in elaborate reproductions of fine jewelry, as illustrated here. Jewelry courtesy of Our Secret Creations, Beverly Hills, CA; photo by Shane F. McClure.

rial for use in laser research). Today, there are six synthetic alexandrite products that a gemologist might see (table 4). Float-zone growth, used by Seiko, is a melt-growth alternative to Czochralski pulling; the latter produces a product that is optically better, but the former can be more convenient in that it avoids the need for a crucible (although it is more difficult to control).

The two melt techniques listed in table 4 also lend themselves to making synthetic cat's-eye alexandrite. Chatoyancy is derived from the precipitation of a foreign phase by a heat treatment after growth, similar to the technique used in making synthetic star ruby and sapphires. With magnification, one can see minute particles oriented in parallel planes; these are quite different from the parallel growth tubes or needles present in the natural material (Kane, 1987).

SYNTHETIC OPAL, JADEITE, AND MALACHITE

Gilson made white and black synthetic opal by a chemical precipitation and settling process from about 1974 (Nassau, 1980). In 1983, his product was improved to appear much more natural (Fryer et al., 1983b; figure 13); shortly thereafter, a synthetic fire opal was also seen (Gunawardene and Mertens, 1984). The Gilson production has since been taken over by Nakazumi Earth Crystals. There is also a new synthetic opal from Kyocera that is marketed under the Inamori name (Fryer et. al., 1983c; Schmetzer and Henn, 1987). A synthetic opal manufactured in Australia has been reported recently as well (Downing, 1988).

Figure 13. During the 1980s, Gilson synthetic opal was improved to appear much more natural. Courtesy of J.O. Crystal Co., photo © Tino Hammid.

TABLE 4. Synthetic alexandrite products and producers, with references to the recent literature.

Process	Name/current producer	References
Synthetic Alexandrite		
Solution		
Flux	Alexandria/ Creative Crystals	Nassau, 1980
	USSR	Trossarelli, 1986; Henn et al., 1988
Melt		
Czochralski pulling	Allied Signal	Nassau, 1980
	Inamori/Kyocera	Nassau, 1980
	USSR	Trossarelli, 1986
Float zone	Bijoreve/Seiko	Koivula, 1984
Synthetic cat's-eye Alexandrite		
Melt		
(Czochralski?)	Sumitomo Cement	Dillon, 1983
(Float zone or Czochralski?)	Inamori/Kyocera	Kane, 1987

The jadeite form of jade has been synthesized on an experimental basis by General Electric in green and lavender by using a jadeite-composition glass crystallized at medium pressure (Nassau and Shigley, 1987). This material has not been produced commercially.

A Russian synthetic malachite was reported in 1987, said to be manufactured commercially in pieces up to 8 kg (Balitsky et al., 1987). So far, I know of no independent examinations of this material.

THE FUTURE OF SYNTHETICS

Modern technology has had a tremendous impact on the gem industry: Virtually all of the many synthetic gem materials that emerged over the last

half century originated as spin-offs from technological research in other areas. Since the mid-1970s, however, there has been a strong worldwide contraction of exploratory materials research, which explains the scarcity of totally new synthetic gem materials in the 1980s. Since there is little likelihood of a reversal of this trend in the near future, the arrival of many new synthetics is, in my opinion, not to be expected. Only in synthetic diamond films is intense research continuing, based on U.S. government funding for the "Star Wars" Strategic Defense Initiative program. As discussed above, however, I do not believe that synthetic diamond—in either bulk or thin-film form—will be used widely in the gem trade in the foreseeable future.

A variety of other gem materials have been synthesized on an experimental basis over the years without ever reaching the marketplace. In addition, enough is known about the growth conditions of materials such as topaz and tourmaline that gem-size and gem-quality synthetics would be possible. It is undoubtedly the absence of a demand for these synthetics at the price that would have to be charged that prevents their becoming trade items.

The appearance of synthetic cubic zirconia as a diamond imitation is so close to the "real thing" to anyone other than an expert that a better imitation is unlikely. It would hardly pay to perform the extended development work required to bring a new product to the market and obtain at best a marginal improvement, especially given the low cost of CZ rough.

The last two decades have been a trying time for gemologists, filled with problems brought on by new and improved synthetics, as well as by new treatment technologies. I believe that the period ahead may be less hectic, enabling gemologists to catch up with the flood of recent changes and develop new tests to ease the problems of identification.

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NEW TECHNOLOGIES OF THE 1980S: THEIR IMPACT IN GEMOLOGY

By Emmanuel Fritsch and George R. Rossman

The 1980s witnessed great development in the application of new technologies to gemology. These technologies provided new or better ways to grow synthetic gem materials and to treat natural ones. They also permitted numerous breakthroughs in gem identification, in areas where classical gemological methods were no longer sufficient to make a positive identification. In particular, various types of spectroscopy proved to be of important practical value, for example, infrared absorption, X-ray fluorescence, Raman scattering, and cathodoluminescence.

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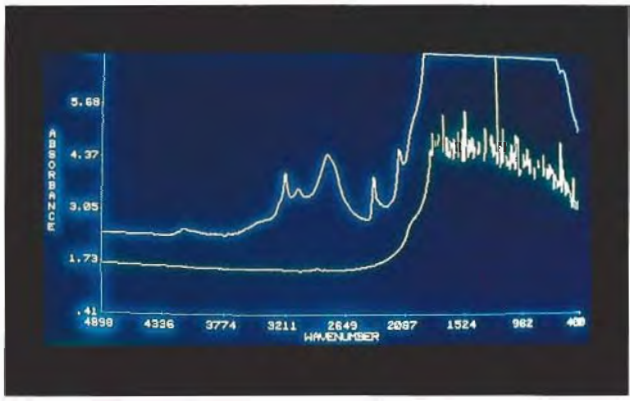
The decade of the 1980s was marked by the development of existing technologies for crystal growth and gem treatment, and by the introduction of a number of new technologies to the field of gem identification (figure 1). Improvements in melt and hydrothermal growth techniques put new and better synthetic gemstones on the market, while new applications of irradiation technology resulted in a dramatic increase in the availability of different hues of irradiated blue topaz and other gem materials. Even as well known a technique as the oiling of emeralds reemerged in another application as the filling of surface-reaching fractures in diamonds. Prior to this decade, traditional instruments—such as the refractometer and the microscope—were the principal means of gemological study. Only a few advanced testing techniques were used, and only in major gemological laboratories, to supplement traditional methods: U.V.-visible spectrophotometers recorded quantitative absorption data, and the electron microprobe provided detailed, nondestructive chemical analyses. For the most part, the combination of these methods proved adequate to fully characterize natural gemstones as well as the limited variety of synthetic and treated gem materials then available.

In the 1980s, however, new challenges required more advanced techniques for examining gem materials. These challenges arose for several reasons:

1. The range of new technologies available to science markedly increased. For example, the early 1980s witnessed a dramatic rise in the use of computers and microprocessors. These smaller, more powerful, faster machines helped improve both the design and performance of all types of equipment, including those used for growth, treatment, and characterization of gems.
2. A new generation of synthetic gem materials was developed that provided additional challenges in gem identification.



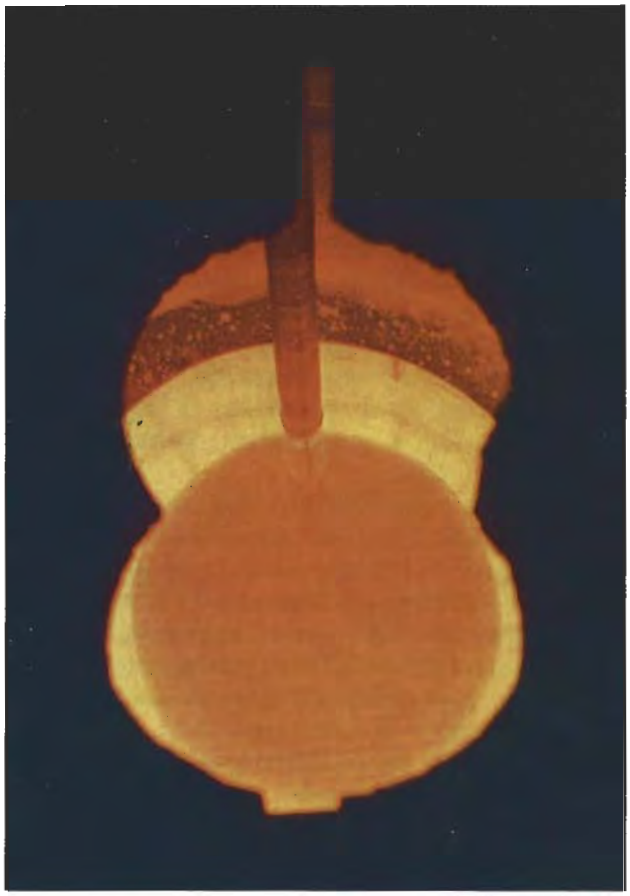


Figure 1. Significant advances in the technology of Czochralski pulling led to the increased production of Czochralski-pulled gem-quality synthetic alexandrite during the 1980s. In the Czochralski-pulling melt growth process, a furnace such as the one illustrated at left is used to grow synthetic alexandrite similar to that produced by Kyocera Corp., shown here to the right of its natural counterpart from Tanzania. Natural alexandrite (top spectrum) can be separated from its synthetic counterpart (bottom spectrum) using infrared spectroscopy, which was applied much more broadly in gemology during the 1980s. Furnace photo courtesy of Union Carbide; stone photo by Robert Weldon.

3. The spectacular growth in the volume of the colored stone market acted as an incentive both to treat natural materials and to improve synthetic ones.

4. The emergence of consumerism, and in particular the increased knowledgeability of the general public, created a demand for more and better information on gem materials, especially in areas such as radioactivity that assumed new importance with the increased volume of treated stones.

In this article, we review new technologies that had a demonstrable impact in gemology during the 1980s. Several of these technologies existed prior to 1980, but at that time had little effect on gemologists or on the gem-buying public. Although most of the recent advances in technology for gem identification are used almost exclusively in sophisticated gemological testing laboratories, it is important that the jeweler-gemologist understand the principles of these techniques and the new capabilities they represent. We will not dwell on those technologies demonstrated during the

search has been conducted into the growth of diamonds with a minimum of defects or inclusions (Kanda et al., 1989). The result is larger crystals of better quality and in greater numbers (Shigley et al., 1987). For example, in 1989, Sumitomo Electric Industries was producing 5-ct gem-quality synthetic yellow diamond crystals on a routine basis using high-pressure technology (Yazu, 1989). At present, however, these are grown for industrial purposes only and are not marketed to the jewelry trade. Major problems are still encountered in the production of large, gem-quality, colorless and blue synthetic diamonds.

The low-pressure synthesis of diamond also received considerable attention in the second half of the 1980s. Using variations of a long-known growth technology called chemical vapor deposition (CVD), very small synthetic diamond crystallites (0.5 to 20 microns in diameter) are grown either isolated to produce powders, or in a continuous layer to produce thin films. Plagued at first with serious limitations, such as poor adherence of the film to its substrate, this new growth technique is now used to place synthetic diamond films on consumer products such as drill bits; free-standing synthetic diamond thin-film tweeters have been produced by several companies (Obata and Okamura, 1989). Also, although these films were initially thin and opaque, rapid advances are now being made to produce thicker, colorless and transparent films (figure 2). This same process is also being used to produce another material, diamond-like carbon, a type of amorphous carbon with high hardness and low deposition temperature. This new low-pressure technology may have a number of applications in the gem trade, as discussed in Fritsch et al. (1989).

Treatment Processes. Treatment of gem materials has been practiced for literally hundreds of years (Nassau, 1981a). Over the last decade however a number of efforts were made to improve known treatment methods or develop new ones.

Irradiation technologies, in particular, played a major role in this area. The use of gamma rays to enhance the color of tourmaline became more prevalent during the last decade (Ashbaugh, 1988; figure 3). Although the first commercial electron-irradiation operation for gemstones began in 1976 (J. Borden, pers. comm., 1989), only a small portion of this early production was seen on the U.S. market. During the 1980s, however, electron irradiation facilities (figure 4) were responsible for dramatic increases in the amount of irradiated material in the U.S. market, especially blue topaz (Schmetzer, 1987). Worldwide, there was a spectacular increase in the production of neutron-irradiated blue topaz. During this same period, gemologists became aware of multistep enhancement processes, in which combinations of irradiation in either a nuclear reactor or a linear accelerator (or both) were used to produce materials called in the trade "American," "California," "Electra," or "Swiss blue" topaz (Ashbaugh, 1988; Fournier, 1988). Other gemstones, such as diamonds, are also treated in nuclear reactors to modify their color (Kammerling et al., 1990). Because reactor treatment can be less costly than electron irradiation, large volumes of gem material have been treated in this way.

Figure 2. By the end of the 1980s, free-standing transparent, near-colorless synthetic diamond thin films as large as 2 cm (3/4 in.) in diameter were being grown by the new low-pressure technology. Such thin films are now used in masks for X-ray lithography (bottom) or as windows for X-ray fluorescence spectrometers (top). Photo courtesy of Crystallume.

Another relatively new gem-enhancement variation is the treatment of synthetic material to make it look more natural (Kammerling et al., 1990). In addition, the centuries-old practice of oiling emerald has been creatively revisited. Better documentation of optical properties of materials (a consequence of increased interest in materials science during the decade) has led to the develop-

Figure 3. Today, pale tourmalines (left) are commonly irradiated to darker pink to red colors (right) using gamma irradiation, a technology that became more widely used for gem enhancement during the 1980s. Some of these stones (largest is 5.91 ct) are courtesy of George Drake; photo © Tino Hammid.

ment of new filling materials to make surface-reaching fractures less apparent. The late 1980s provided us with two examples: Opticon, a product marketed as an industrial fracture sealer that has been used to fill fractures in emeralds (Koivula and Kammerling, 1989); and a low-melting-point lead oxychloride–based glass, with an index of refraction close to 2.4, that has been used to fill fractures in diamond (Koivula et al., 1989).

Figure 4. During the 1980s, great quantities of gem materials were irradiated in an electron accelerator for the purpose of inducing or enhancing color. This computer-generated image is the electron accelerator at the Rensselaer Polytechnic Institute, Troy, New York. Photo courtesy of Rensselaer Polytechnic Institute.

NEW TECHNOLOGIES IN GEM IDENTIFICATION: PROVIDING SOLUTIONS

When classical gemological methods do not provide enough clues to solve a gem identification problem, laboratory gemologists turn to more sophisticated techniques. During the 1970s, these were U.V.-visible absorption spectroscopy and electron microprobe analysis. While some progress has been made in these techniques, especially microprobe analyses, other new technologies are now routinely used in some gemological laboratories.

Electron Microprobe. The chemical composition of most gem materials can be determined with an electron microprobe (see, e.g., Dunn, 1977). In recent years, the gemological applications of this instrument have also benefited from the introduction of new technologies. One of the long-standing limitations of the electron microprobe was its inability to measure the concentration of light elements, in particular oxygen. The 1980s saw the development of detection systems, such as multilayered diffraction crystals, that greatly improved the detection efficiency for light elements (Arm-

1980s for which there are no immediately apparent commercial applications to gemstone production, treatment, or testing.

The article is divided into two major sections. The first deals with new technologies in the field of gem material synthesis and treatment. The impact of these technologies on gemology can be estimated in terms of the volume, quality, or availability of material produced.

The second section discusses new technologies available for gem identification. We will briefly describe the new technologies being used, the types of information they provide, and their limitations. Examples are provided to illustrate how each technique has helped improve our means of identifying gem materials.

NEW TECHNOLOGIES IN SYNTHESIS AND TREATMENT: THE CHALLENGES

A major development that affected all techniques of crystal growth during the 1980s was the introduction of computer controls, especially through microprocessors and personal computers, for furnaces and other growth devices. This resulted in a better reproducibility and yield of crystals, thereby lowering the cost of synthesis (B. Chai, pers. comm., 1989). In the U.S. over the past 10 years, most industrial crystal growers have shifted their focus to the growth of thin films on silicon and other semiconductor materials for electronic applications, so the number of people involved in growing "bulk" transparent crystals has significantly decreased. In contrast, research groups in China have initiated an ambitious program to grow synthetic crystals for the jewelry industry, building on their experience in the growth of other types of oxide crystals (D. Elwell and B. Chai, pers. comm., 1989). Currently much effort is being devoted there to the growth of colored synthetic rare-earth garnets (see, e.g., Zhang and Liu, 1988).

The new synthetic gem materials that appeared on the jewelry market during the 1980s are described elsewhere in this issue (Nassau, 1990); therefore, we will concentrate here on the recent changes in technology that made their synthesis possible.

Growth Processes. The Czochralski pulling technique, invented in 1918, is certainly not a new technology (Nassau, 1980). However, important advancements have been made recently, centered around furnace design and new refractory materials. These have resulted, for example, in the production of colorless sapphire crystals 15 cm in diameter, three times the size of the 5-cm-diameter oxide crystals typically grown during the 1970s (Heikkinen, 1989). Motivated by the demands of the laser industry for less light distortion, producers greatly improved the quality of the crystals as well. This was accomplished primarily by a better understanding and control of the thermal gradient in the furnace and by improved pregrowth treatment of the melt (K. Heikkinen, pers. comm., 1989). These improvements in growth techniques have led to the development of Czochralski-pulled alexandrite in the USSR (Bukin et al., 1981), China (Guo et al., 1987), Japan, and the United States (R. Kane, pers. comm., 1989). Although grown primarily for laser applications, some of these products have already appeared on the jewelry market (Trossarelli, 1986; again, see figure 1).

Hydrothermal synthesis of gem-quality materials such as quartz (amethyst) and emerald continued during the 1980s. In general, the high cost of hydrothermal synthesis makes it economically less attractive than Czochralski pulling when that alternative exists.

Image furnaces became commercially available during the last decade. Such furnaces focus intense light to provide the heat needed to grow synthetic crystals. Although a few synthetics grown by this technology have been faceted, especially synthetic corundum of different colors produced by Seiko, it is not yet appropriate for mass production. Nevertheless, image furnaces have been widely used experimentally to produce limited amounts of single-crystal spinel, ruby, cubic zirconia (NEC Corp.), and olivine (peridot; Hosoya and Takei, 1982), some up to 7 cm long. The decade has also witnessed significant progress in skull-melting technology, which has resulted in dramatic increases in the production of cubic zirconia (Nassau, 1990).

Of all the new technologies, the jewelry industry has probably paid closest attention to that which produced cuttable synthetic diamonds. Major strides made in high-pressure technology resulted in presses with an effective volume of one liter and holding pressures appropriate for diamond growth. Many crystals can be grown in the same cell, and several cells can be stacked up in one press (Yazu, 1985), improving considerably the productivity of this type of equipment. Moreover, extensive re-

Figure 5. Although not a new technology, infrared spectroscopy has recently provided solutions to many tough gemological problems. The GIA Research Department has used this Nicolet 60SX FTIR spectrometer to identify treated materials such as irradiated diamonds and plastic-impregnated turquoise, as well as to separate some natural from synthetic emeralds, diamonds, and alexandrites. Photo by Robert Weldon.

strong, 1988) and therefore the accuracy of the entire analysis.

Spectroscopy. The appeal of spectroscopic methods, which involve detecting and measuring the absorption or emission of electromagnetic radiation by a material, is that they can be used nondestructively on most gems. In the 1980s, the materials-science community adopted many techniques that had previously been used primarily in chemistry—such as infrared, X-ray, and Raman spectroscopy—to study a wider range of materials, including gems.

Infrared Spectroscopy. This technique probably brought the most new solutions to gem identification problems during the 1980s. Originally developed by organic chemists, infrared spectroscopy was first applied to mineralogy during the 1950s. Many applications to gem identification problems were developed by French and German scientists during the 1980s (Leung et al., 1983). Also at this time, Fourier transform infrared spectrometers (FTIR) became widely available (figure 5). Their speed of execution made them easier to use, and their greater sensitivity permitted the detection of weak features in the spectrum that were significant for many gem identification problems. The principles of infrared spectroscopy as they relate to gemology have been described by Fritsch and Stockton (1987).

Many materials can be identified rapidly by their infrared absorption spectra. For example, turquoise can be separated from its simulants by this technique (see, e.g., Arnould and Poirot, 1975), amber can be distinguished from plastic simulants (Fraquet, 1987), amethyst can be separated from purple scapolite (Martin et al., 1989), and glass can be distinguished from nonphenomenal opal (C. Stockton, pers. comm., 1987; figure 6). These tests are difficult, even sometimes impossible, using classical gemological techniques.

In some cases, infrared spectroscopy can distinguish natural from synthetic materials. This is particularly important when the material contains few or no inclusions. In a number of cases, this distinction is possible because of differences in the way water is incorporated. Wood and Nassau (1968) demonstrated how flux-grown synthetic emerald could be distinguished from its natural equivalent: The incorporation of water during growth in natural stones causes absorption around 3600 cm^{-1} in the infrared spectrum, whereas the flux material uses no water so the corresponding synthetics lack absorption in this region. This technique has been refined to the point that not only can natural emeralds be distinguished from their synthetic hydrothermal equivalents, but also the products of various hydrothermal synthetic emerald manufacturers can be separated from one another (Leung et al., 1983; Stockton, 1987).

The distinction between natural and synthetic alexandrite is based on the same principle (Leung et al., 1983; Stockton and Kane, 1988). The fact that water was incorporated during growth in natural alexandrite results in an infrared spectrum that is different from that of most synthetic alexandrites (grown by a melt technique), which lack "water."

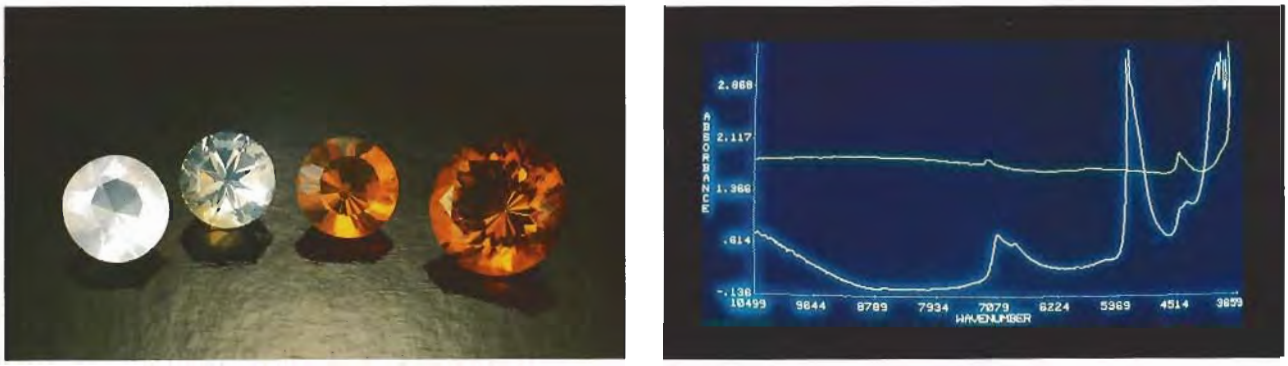


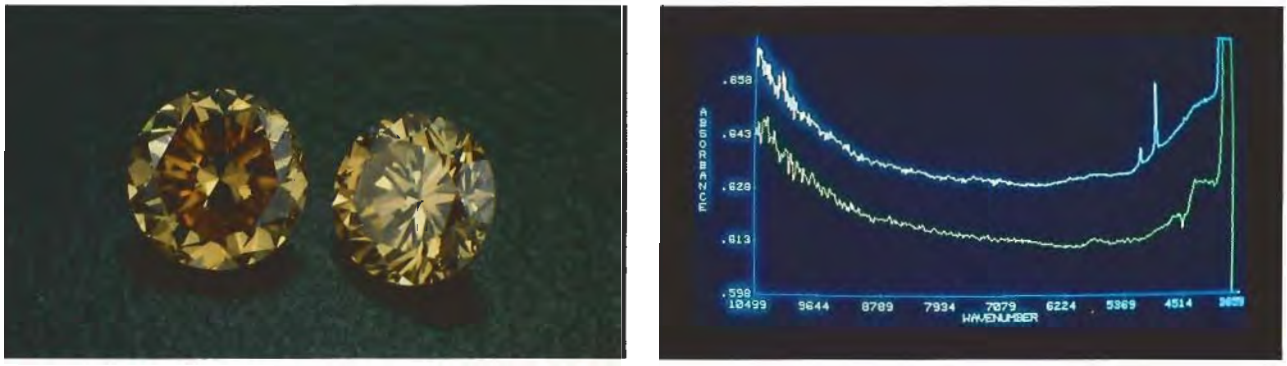
Figure 6. These orange and near-colorless opals (center) are difficult to separate from their glass imitations (either side). However, the infrared spectra of natural glass (top) and opal (bottom) differ significantly, providing a ready means of identification. Photos by Robert Weldon.

Numerous attempts have been made to separate natural and synthetic amethyst on the basis of their infrared spectra (Zecchini, 1979; Schmetzer and Bank, 1980; Lind and Schmetzer, 1983). In the vast majority of cases, the spectrum of synthetic amethyst will show an absorption band around 3540 cm^{-1}, probably related to a potassium-bonded hydroxyl group (Kats, 1962). This band is absent from the spectrum of most natural stones (Fritsch and Koivula, 1987).

Infrared spectroscopy can also detect the presence of polymers in materials that have been impregnated to improve their appearance or physical cohesion, such as opal (Fritsch and Stockton, 1987), turquoise (Dontenville et al., 1985), and jadeite (Hurwit, 1989). Other types of treatments are occasionally detectable; for example, sugar-treated opals show a typical infrared spectrum (C. Stockton, pers. comm., 1987).

Quite possibly the most important application of infrared spectroscopy in the last few years has been the detection of treatment (irradiation followed by annealing) in yellow to brown nitrogen-containing diamonds. In 1957, Crowningshield demonstrated that the presence of a band at 5920 Å (since determined on more accurate instrumentation to be 595 nm) in the visible range is proof of treatment in such stones. It appears, however, that the defect creating this absorption can be annealed out at high temperature, so that the indications of treatment provided by the visible spectrum are less clear. The presence of two sharp peaks in the near infrared (at 1936 and 2026 nm, called H1c and H1b, respectively), can then be taken as a positive

Figure 7. These treated (by irradiation and annealing) yellow diamonds were subjected to a second heating to high temperatures to make the 595-nm band—considered proof of treatment in yellow diamonds—disappear. However, infrared spectroscopy helped identify two sharp bands in the infrared (top spectrum), caused by the annealing process, that are absent from the spectrum of a natural yellow diamond (bottom). Photos by Robert Weldon.



proof of treatment in yellow to brown (Collins et al., 1986; Woods and Collins, 1987; figure 7) and reirradiated green (Fritsch et al., 1988) diamonds.

X-ray Spectroscopy. Energy dispersive X-ray fluorescence (EDXRF) analysis is another relatively sophisticated technology that was first applied to gemology during the last decade (Hänni, 1981). In an XRF spectrometer (figure 8), an X-ray beam directed at a sample causes the individual chemical elements in the sample to emit X-rays of a characteristic energy. The instrument's solid-state detector and multichannel analyzer sort the X-rays, making it possible to detect which elements are present. When the instrument is carefully calibrated, the intensity of a given peak can be quantified to indicate the concentration of the corresponding element. One of the major advantages of this technique is that a cut stone requires no sample preparation; the gem is simply placed table down in a holder above the beam.

The chemical analysis provided by XRF can have important applications in gemology. Gemological papers early in the decade refer to the separation of natural from synthetic ruby and alexandrite on the basis of the presence of molybdenum from the flux (Stern and Hänni, 1982) and the presence or absence of trace elements such as gallium, thought characteristic of natural origin, (Ohguchi, 1981; Stern and Hänni, 1982). XRF has also been used to separate natural freshwater from saltwater pearls on the basis of the much larger concentration of manganese in freshwater pearls (Miyoshi et al., 1986; figure 9). Other examples are provided in Stern and Hänni (1982).

One must be cautious when interpreting XRF spectra, however, because of the abundance of diffraction peaks and other artifacts that may lead to expensive mistakes. For example, figure 10 shows the spectrum of a flame-fusion synthetic ruby, which has no gallium, with a diffraction peak exactly at the energy expected for this element. Some laboratories use XRF as a complementary technique, for example, to separate natural from synthetic ruby (C. Schiffman, pers. comm., 1988; S. McClure, pers. comm., 1990).

X-ray fluorescence instruments historically could not detect elements lighter than sodium. The recent development of extra-thin detector windows or windowless detectors has made light-element detection possible. Interestingly, one of the materials used for very thin XRF windows is a synthetic diamond thin film, produced by the low-pressure technology (Pinneo and Conner, 1989; see figure 2).

Figure 8. XRF technology was used throughout the 1980s by a number of advanced gem testing laboratories. The GIA Research Department found this Tracor X-ray Spectrace 5000 energy dispersive X-ray fluorescence (XRF) spectrometer to be useful, for example, in the separation of freshwater from saltwater pearls (see below) and untreated from fracture-filled diamonds. Photo by Robert Weldon.

Raman Spectroscopy. Raman spectroscopy has seen increased application to gemological research during the 1980s. Like infrared spectroscopy, it is a nondestructive vibrational spectroscopy that requires expensive equipment, especially if data are obtained with a Raman microprobe. Raman spectroscopy is extensively used in mineralogy and geochemistry (McMillan, 1989). In gemology, it has been used to identify gemstones, to distinguish between crystalline and amorphous materials, and to separate natural stones—for example, diamond and jade—from their simulants (Nassau, 1981b;

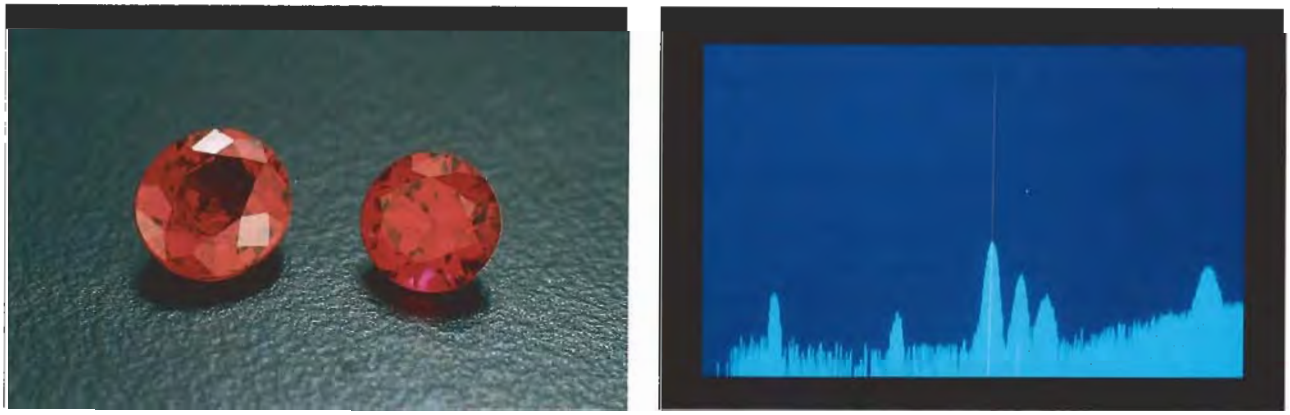
Figure 9. XRF technology can separate freshwater (left) from saltwater (right) cultured pearls on the basis of their chemical composition: Freshwater pearls (blue spectrum) contain significantly more manganese (indicated by the vertical red lines at left) than saltwater pearls (red dotted line). Photos by Robert Weldon.

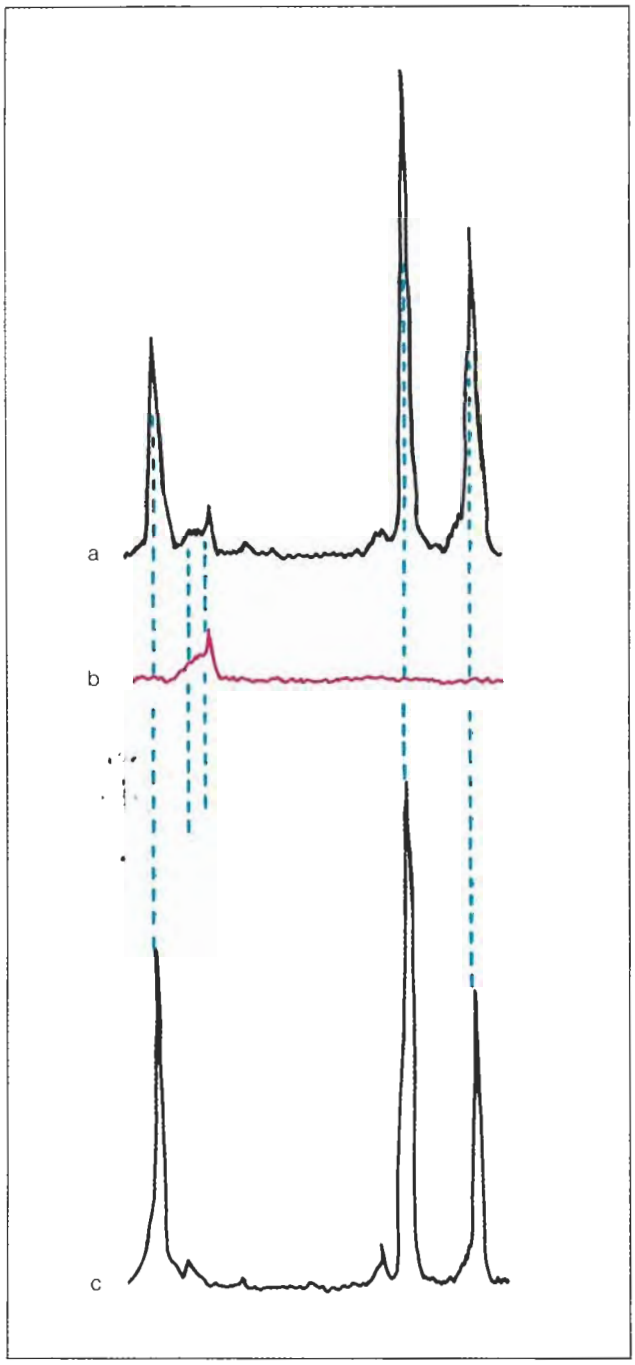
Dhamelincourt and Schubnel, 1977). It can also nondestructively identify pigments in gem materials (Délé-Dubois and Merlin, 1981).

The most important use of Raman spectroscopy in gemology is the identification of inclusions (figure 11). The Raman microprobe can focus on and identify an individual inclusion even when it is beneath the surface of a stone. This is particularly valuable in the separation of natural from synthetic materials (Délé-Dubois et al., 1986). To help with these identifications, the Gemology Laboratory of Nantes University, France, is preparing a catalog of Raman spectra for all gem materials and their most common inclusions (B. Lasnier, pers. comm., 1989).

Cathodoluminescence. First reported by Crookes in 1879, this technology was not applied to gemological problems until the late 1970s, when a simple commercial instrument became available (Gaal, 1976–1977). Its use became more widespread during the 1980s (Ponahlo, 1988). Cath-

Figure 10. XRF has been used to separate natural (left) from synthetic (right) rubies on the basis of their trace elements. However, the gemologist must be careful of the artifacts in the XRF spectra when making a determination. For example, the XRF spectrum of a flame-fusion synthetic ruby shows (at the far right) a band at the position expected for gallium, an element presumed to be typical of natural rubies, and (closest to the first, on the left) a band at the exact position expected for iron, an element generally not present in flame-fusion synthetic rubies. Both peaks are actually due to diffraction, not gallium or iron. Photos by Robert Weldon.





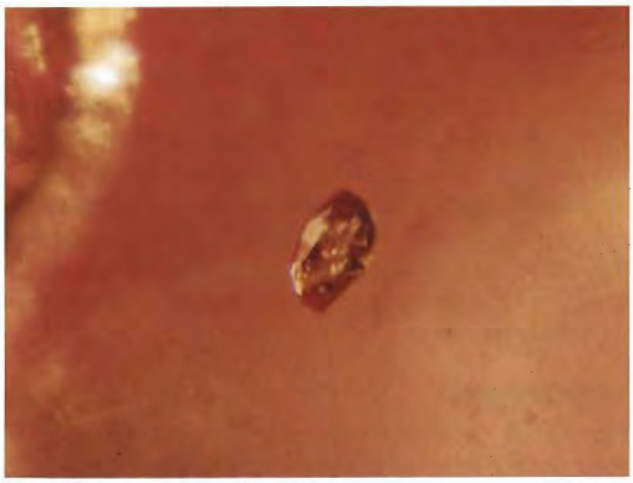


Figure 11. This sulphur inclusion in a Burmese ruby (right) was identified using Raman spectroscopy (left), one of the technologies new to gem identification in the 1980s. Spectra: a = inclusion in matrix, b = matrix alone, c = reference sulphur. This is the first time sulphur has been identified as an inclusion in ruby. Photo and spectra courtesy of J. Dubois-Fournier, Gemology Laboratory, Nantes University, France.

odoluminescence is the emission of visible light by a material excited with an electron beam in a vacuum chamber. It does not require any sample preparation, and does not affect most common gem materials. Visual observation of the color (or distribution of color) of the emitted light is enough, for example, to distinguish clearly between natural and synthetic yellow diamonds on the basis of the distribution of their various growth sectors (Shigley et al., 1987). Emission spectra and quantitative measurements of the emissions can also be recorded and used for some gem identification purposes, such as the separation of natural from synthetic rubies, emeralds, and alexandrites (Ponahlo and Koroschetz, 1986; Ponahlo, 1988, 1989).

A number of additional technologies have been used experimentally in the characterization of gem materials. These include nuclear magnetic resonance (NMR), electron spin resonance (ESR), and proton-induced X-ray emission (PIXE). Thus far, none of these methods has helped solve gemological problems that could not be handled in a simpler fashion. Research into the gemological applications of these methods is still in its infancy, however, and the potential for future important contributions exists.

CONCLUSION

The 1980s witnessed greater opportunities for more and better synthetics and enhancements, which provided new challenges for gem identification. For example, improvements in Czochralski pulling and high-pressure diamond synthesis brought new and better products into the commercial scene. The application of various irradiation techniques resulted in the processing of large amounts of blue topaz, in a number of different shades; developments in filling materials produced new treatments in emeralds and diamonds. Several of the technologies described in this article have provided new approaches to meet these challenges. Even so, at the end of this decade the following challenges still remained:

- The distinction between natural colors and those created by laboratory irradiation. Prominent problems involve green diamonds, blue topaz, and pink and red tourmalines.
- The detection of heat treatment in gem materials such as sapphire or beryl when microscopic characteristics do not provide conclusive evidence.
- The detection of dye in gem materials.
- The determination of the geographic origin of gem materials.
- The reproducible measurement of the color appearance of a faceted gem.

New technologies developed in the 1990s will undoubtedly help address some of these outstanding problems. It is equally as likely that new technologies will generate new problems for the gemologist. We will probably see more synthetic gem materials, possibly large synthetic hydrothermal emeralds developed for laser applications. We will also need to follow closely developments in the fields of diamond synthesis, optics (especially coating technology), electro-optics, and electronics that traditionally have provided materials of potential use in the gem market.

During the past decade, gemologists tried to respond to changes imposed on them by the outside world. In the years to come, gemologists must learn to anticipate these changes. At the end of the 1980s, much of the available technology and the vast network of technological information was under-utilized by gemologists. Although the equipment required is usually expensive and may not be readily accessible, there is nevertheless a tremendous potential for new developments by exploiting techniques already available in materials science and building the data bases that will make their results useful to the jeweler-gemologist.

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JEWELRY OF THE 1980s: A RETROSPECTIVE

By Elise B. Misiorowski

Fluctuations in the diamond market brought a new focus in jewelry on small diamonds and colored stones. The large quantities of blue topaz, amethyst, and citrine available made these gem materials especially popular. Cultured pearls saw a phenomenal rise, especially early in the decade. A broad mix of design trends included a return to older metal techniques such as granulation, as well as experimentation in new metals and metal-working techniques. While classical European houses were credited with some important new designs, exciting innovations emerged from elsewhere in Europe as well as Asia and the U.S.

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The 1980s was an exciting, and at times turbulent, era for the gem and jewelry world. In 1980, prices for large, fine diamonds were at an all-time high. The boom, and subsequent bust, of this segment of the diamond market had a profound effect on the jewelry world: It shifted the focus to pearls and colored stones, as well as to smaller, commercial-grade diamonds. The emergence of new cuts for gems, the increased use of pavé- and channel-set melee diamonds, and the continued interest in new textures and coloration techniques for metals characterize jewelry of the 1980s. As the decade advanced, the fashion trend of wearing many little items of jewelry gradually changed to wearing fewer but more important pieces that made bolder fashion statements, reflecting the wearer's individual taste and style. In the 1980s, more women than ever before pursued careers and high-profile positions. These women, in buying their own jewelry, became an important new market (Eisman and Hinge, 1988).

Education and the appreciation of tangible assets with lasting quality also influenced the buying decisions of the now more knowledgeable consumer. Gem associations and the international auction houses have played an important role in heightening this awareness. This retrospective, based on a review of major jewelry publications worldwide, examines the key trends in the use of diamonds, colored stones, and precious metals, and highlights some of the designers that advanced these trends in the 1980s.

DIAMONDS

The year 1980 saw diamond prices fluctuate radically. To steady the market, De Beers cut back on the number of rough diamonds offered to sightholders in larger sizes of good color and clarity (Shor, 1988b). Since melee diamonds were less expensive and more readily available, jewelry designers looked for more ways to use them (figure 1). Pavé and channel settings utilized small diamonds to great advantage. The multi-stone anniversary ring became espe-

*Figure 1. This group of jewelry includes some of the most popular styles introduced in the 1980s. Note especially the various uses of melee diamonds, mabe pearls, freshwater cultured pearls, and colored stones. Shown here are: (top left to right) a multistrand, twisted necklace (*torsade*) of natural-color freshwater cultured pearls with a channel-set sapphire and diamond clasp; a spool-cut green tourmaline and ancient-style gold bead necklace; mabe pearl earrings with pavé-set diamonds; (middle left to right) dangling earrings with bezel-set, cabochon-cut tourmalines; an ancient-style gold ring set with tourmalines; stackable rings of sapphires, diamonds, and emeralds; a cultured pearl necklace with a centerpiece of diamonds pavé-set around a 3-ct sapphire; (bottom left to right) a bezel-set "tennis" bracelet; a wide engagement ring–wedding band with channel-set baguette diamonds; a 2.53-ct sapphire ring with oval diamonds; a 2.54-ct emerald ring with baguette diamonds channel set down the wide shank; and a 5.34-ct tanzanite ring with calibrated tsavorite garnets, channel-set baguette diamonds, and pavé-set round diamonds. Jewelry courtesy of The Collector, Fallbrook and La Jolla, CA; photo © Harold & Erica Van Pelt.*

cially popular, as did the tennis bracelet later in the decade. Annual jewelry design competitions offered by the Diamond Information Center—Diamonds Today, Diamonds International, and Diamonds of Distinction—continued to stimulate creative efforts to make the most of diamonds.

The aftermath of the diamond investment fad found buyers more aware of the importance of proportions in cutting (Shor, 1989). Although the round brilliant remained the industry standard, diamond cutters promoted a variety of new cuts designed to maximize weight retention while still producing a pleasing gem. Triangular-shaped brilliants, for example, were developed to make best use of the diamond macle; introduced in the 1970s, the Trilliant and the Trillion, among others, became very popular during the '80s, especially in matched pairs as side stones in a ring to set off an important stone. The Radiant cut, which gave additional life to straight-edge cut diamonds, contributed greatly to the acceptance of fancy-color diamonds, especially yellows and pinks, during the

Figure 2. This group of diamond rings and earrings illustrates the increased interest in fancy-color diamonds that arose in the 1980s. All of the pink diamonds in the earrings are from Australia. Note the use of triangular brilliants as side stones for two of the rings, and the "unmatched" pair of earrings, with a 1.90-ct. fancy blue diamond in one and a 2.10-ct. fancy yellow diamond in the other. The largest stone in this photo, the fancy yellow diamond in the ring on the left, is 12.65 ct. Courtesy of Harry Winston, Inc.

'80s (R. Crowningshield, pers. comm., 1990). Square-cut brilliant diamonds were developed partly because they could be calibrated to fit snugly in channel settings, and partly because their retention of weight from octahedral rough is considerably greater than for a round brilliant. The Quadrillion, introduced in 1981, and the Princess, introduced in 1984, are two trademarked square-cut brilliants available in the diamond trade.

Later in the decade, the Central Selling Organization commissioned Marcel Tolkowsky's grandnephew, Gabi Tolkowsky, to develop new diamond cuts for odd-shaped and off-color rough. Five cuts were officially presented at the 24th World Diamond Congress in 1988—Zinnia, Dahlia, Marigold, Sunflower, and Fire Rose ("Clever diamond cuts launched by the CSO," 1988).

The 1980s also saw a renewed interest in fancy-color diamonds (figure 2), stimulated in part by the publicity given to fancy pink diamonds from Australia (see, e.g., Hofer, 1985). The excitement surrounding fancy-color diamonds reached a peak in April 1987, when Christie's auctioned a 0.95-ct fancy purplish red diamond for the unprecedented price of $926,000 per carat (Kane, 1987). Large colorless diamonds made a comeback toward the end of the decade and also sold well at auction after 1987. Following their red diamond success, in October 1987 Christie's sold a D-color internally flawless 64.83-ct pear shape for $6,380,000. Not to be outdone, in April 1988, Sotheby's auctioned an 85.91-ct D-color internally flawless pear shape for $10,043,000.

COLORED GEMSTONE TRENDS

Colored Stones. Compared to the previous two decades, the 1980s saw a much greater use of colored stones in jewelry. This could be attributed

to a number of factors in addition to the higher diamond prices mentioned earlier. In 1981, the blue sapphire engagement ring given to Lady Diana Spencer by Charles, Prince of Wales, helped stimulate global interest in colored stones. Education in gemology on the part of both the jeweler and the consumer has generated greater awareness of the many attractive and affordable varieties in the marketplace. As the decade progressed, the availability of many colored stones in larger sizes (e.g., blue topaz, amethyst, and citrine) also met the trend for larger, bolder jewels, thereby satisfying the growing interest in dramatic-colored jewelry. Competitions such as the Spectrum Award, offered annually by the American Gem Trade Association, encouraged jewelry designers to use a greater number and variety of colored stones.

Fine-quality sapphires, rubies, and emeralds maintained their supreme status among colored gems, and as demand increased so did their prices. This stimulated a wider use of more affordable gemstones that, prior to the 1980s, often were purchased only as birthstones. Topaz, amethyst, citrine, and tourmaline experienced the greatest growth in buyer recognition and salability. In particular, the large quantities of color-enhanced blue topaz that entered the market in the '80s made this gemstone tremendously popular because of the affordable prices. Although the greater supplies provided by enhancements were a significant factor in gemstone marketing during the decade, the public was generally unaware that treatments were involved. In fact, as the decade progressed, heat treatment of corundum put greater numbers of fine blue and yellow sapphires on the market (figure 3), making them more affordable as well.

Tsavorite and rhodolite garnets, as well as tanzanite, were also seen more frequently in jewelry during the '80s (see figure 1). In addition, there was greater use of opaque and translucent gems—such as lapis lazuli, malachite, black onyx, hematite, and jade—for beads, cabochons, and inlay work. Translucent and cryptocrystalline quartz, opal, and tourmaline were also used in this way. Sugilite, the purple opaque-to-translucent by-product of manganese mining in South Africa, was introduced as a gem material during the 1980s (Shigley et al., 1987) and found some popularity, especially in jewelry from the American Southwest.

Organic Gem Materials. More than any other gem during this decade, pearls enjoyed a renaissance of interest. Pearl imports into the U.S. grew from $80 million in 1980 to over $240 million in 1984 ("Pearl sales up," 1988). Before 1980, cultured pearls were mostly seen as 16-inch single-strand necklaces of graduated or 5- to 6-mm pearls. Into the '80s, opera-

Figure 3. Heat-treated yellow and blue sapphires were commonly seen in the jewelry market during the 1980s. In this fine necklace, they are set off by prong- and channel-set diamonds in yellow and white gold. Courtesy of Gem Source International; photo © Tino Hammid.

Figure 4. Baroque-shaped cultured pearls gained in popularity during the 1980s, as demand for all pearls grew. The torsade, *or twisted choker, a major new style of the 1980s, used pearls or gem beads. These multiple strands of pink baroque pearls and matching earrings are accented by 18K gold "funnels" with back enamel detailing. Jewelry designs © Elizabeth Gage, Ltd.*

length strands of slightly larger pearls became more common, worn either as one long strand or wrapped twice around the neck. The Pearl Promotion Society's annual pearl jewelry design competitions encouraged new ideas on how to wear pearls, resulting in pearl jewelry that was more versatile and contemporary.

Round, unblemished, saltwater cultured pearls have always commanded a premium price. As demand increased during the '80s, declining production of the finer qualities led to even higher prices. This caused the more affordable baroque-shaped cultured pearls, with their exceptional orient and luster, to gain greater acceptance (figure 4).

Initially harvested in Japan, enormous quantities of freshwater cultured pearls are now coming primarily from China. Besides the white, rice-shaped cultured pearls that have appeared in profusion, freshwater cultured pearls come in a variety of baroque shapes and natural pastel colors. Pale pink, peach, apricot, mauve, and lavender have been combined in mixtures of hues (see figure 1), sometimes strung with gold or gemstone beads as accents in the strand.

Naturally colored black pearls, cultured in French Polynesia, were first harvested and sold in the late 1970s but came into their own during the 1980s. These large (9+ mm) pearls range in color from silver to black, with a variety of overtones (Goebel and Dirlam, 1989; figure 5). The warm South Seas also favored the cultivation of large (12–19 mm) creamy white, yellow, and brownish pearls.

Mabe pearls and cultured blister pearls appeared often in jewelry during the 1980s. Mabe pearls are ideally suited for the larger look, particularly for earrings (see figure 1). Cultured blister pearls, cut with some of the surrounding mother-of-pearl showing, have been used as the focal point in clasps for twisted pearl necklaces and in dramatic brooches.

Ivory, coral, and tortoise shell have come under scrutiny because of environmental issues. Heavy poaching and smuggling of ivory in recent years severely threatens the African elephant. After

Figure 5. Polynesian black cultured pearls gained great popularity over the course of the decade, especially in fine jewelry. These 11-mm black cultured pearls, surrounded by 10 ct of channel-set baguette diamonds, are courtesy of Harry Winston, Inc.

much controversy, the Convention on International Trade in Endangered Species announced in October 1989 that a formal ban on ivory trading had been approved ("Ban on ivory trade gets formal approval," 1989). Because of the negative publicity, consumer interest in jewelry and artifacts of ivory in the U.S. dropped considerably.

Tortoise shell comes from the epidermal layer that covers the shell of the hawksbill marine turtle and has been used for centuries to make jewelry and trinkets. In recent years, due to pollution and overfishing, the hawksbill turtle has been placed on the endangered species list (Weiss, 1988); tortoise shell jewelry and other objects can no longer be imported into the U.S.

Fine coral is becoming harder to find, also due to pollution and overfishing. The Mediterranean, the traditional source for fine "oxblood" red coral, has been seriously depleted. The Sea of Japan now produces most of the coral on the market, with the Taiwanese doing a majority of the harvesting and cutting. As this area, too, is at risk, the Japanese have begun to enforce stricter quotas in these waters (Federman, 1990). Environmental issues are demanding more attention as the 20th century draws to a close. Perhaps the use of organic materials from endangered species will be phased out in the years to come.

New Colored Stone Cuts. During the 1980s, a variety of new cuts for colored stones became popular. The most notable among these is the fantasy cut introduced by German lapidary Bernd Munsteiner (figure 6). The gems, usually transparent, are cut with a free-form outline and given a number of indented, grooved facets, which provide visual texture and interest. Munsteiner, raised in the famous gem-cutting center of Idar-Oberstein, has also been credited with developing the "negative cut" (a cabochon crown with a carved or faceted pavilion; Thomas, 1987). Many other gem-cutting artists have followed Munsteiner's lead and have developed their own styles and techniques.

Figure 6. The fantasy cut was initiated by Bernd Munsteiner in the early '80s. These three fantasy-cut ametrines—a pendant and brooch set in 18K gold and a sculpture—are examples of Munsteiner's style. Courtesy of H. Stern, New York; photo © Harold & Erica Van Pelt.

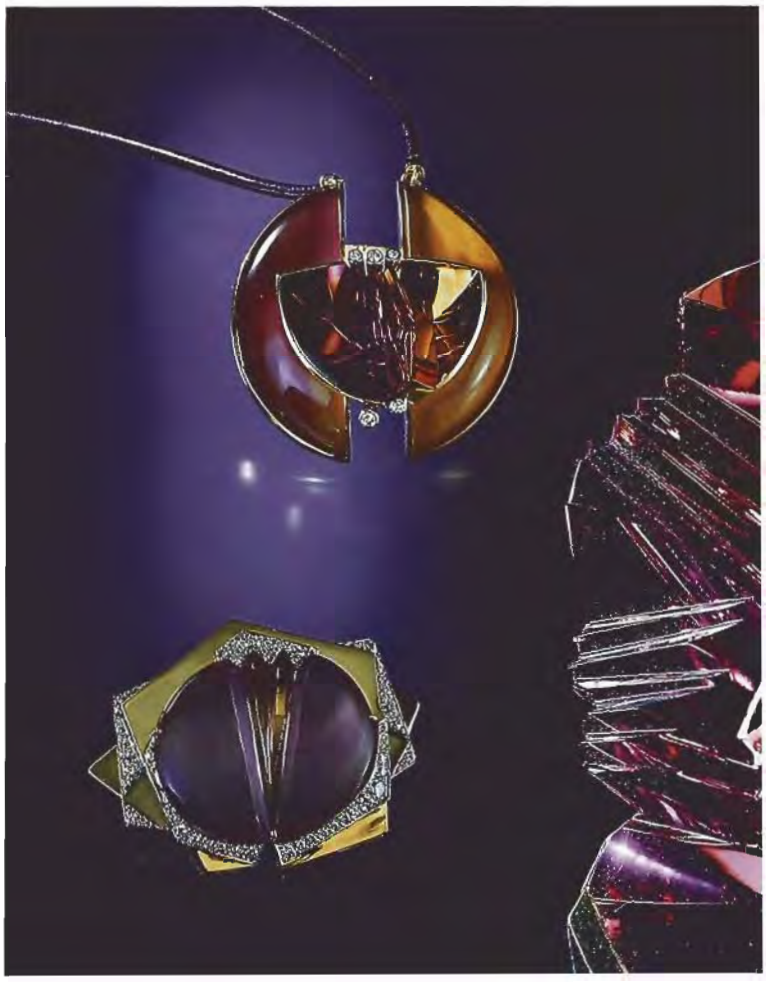

Figure 7. These four pendants and box are excellent examples of contemporary intarsia. Lapis lazuli, malachite, opal, turquoise, and sugilite are precisely cut and inlaid to produce these beautiful pieces. Intarsia by Nicolai Medvedev, goldwork by Janet Vitkavage. Pieces courtesy of E. F. Watermelon Co.; photo © Harold & Erica Van Pelt.

As the '80s progressed, cabochon-cut stones were used more frequently in jewelry (see figure 1). New variations appeared, with names evocative of their shapes: bullets, tongues, sugarloafs, and buff-top baguettes. Cabochon-cut rubies, emeralds, and sapphires, rarely seen in jewelry prior to the '80s, also became very popular. A number of jewelry manufacturers worked directly with cutters to create custom-cut gems to suit a specific design. Gemstones were also worked into mosaics in a variety of applications. Intarsia saw a revival in jewelry and *objets d'art*, too (Elliot, 1986; figure 7).

Crystal "Fever." The end of the 1960s marked the "dawn of the Age of Aquarius," and the corresponding revival of many esoteric schools of thought. One of these philosophies, crystal consciousness, had a definite impact on the gem and jewelry trade in the 1980s. Lore regarding the spiritual and healing powers of gemstones, particularly in their original crystal form, attracted many followers. In 1986, crystal consciousness was stimulated by the publication of Shirley MacLaine's book *Out on a Limb*, in which she promoted the metaphysical properties of gemstones ("Catering to today's crystal craze," 1988). Crystals of all sorts, but particularly quartz, were fashioned into jewelry. Small clusters of crystals or slices of geodes were also incorporated into "wearable art" (Edelstein, 1989b). Although the actual fad for crystal jewelry was shortlived, the residual interest it focused on gems and jewelry was felt throughout the industry.

METAL TRENDS OF THE 1980s

The decade also saw a number of changes in the use of precious metals for jewelry. Fashion shifted from dainty and delicate, where the show of metal was minimal, to strong and assertive, where precious metals made a powerful statement.

Gold was the most popular metal, but price fluctuations affected the way it was used. For example, fashion was dictating the "big" look in jewelry just as gold prices began to climb. The use of hollow chains and electroforming techniques allowed a more massive look without excessive weight. The more affordable metal, silver, also made a comeback; the "big silver" look was often set with amethyst and blue topaz, as well as cubic zirconia, in bright pinks and blues as well as colorless.

Colored gold alloys also came back into vogue, and tri-color gold (yellow, white, and rose) was a major trend in all types of jewelry. An interest in the look of dark metal led to experimentation with alloys, including ones for blue and black gold that proved to be brittle and hard to work with. Ultimately, the dark metal look was provided by the use of surface-coloring techniques such as patination (antiqueing) and enameling in opaque black and in rich jewel-toned reds, blues, and greens (figure 8).

Platinum, traditionally reserved for important high-end pieces, began to be used more extensively throughout the industry. To make this metal more accessible to a larger market, jewelers began to combine platinum with gold to provide richness and a pleasing visual contrast.

Other, nontraditional metals also appeared in

jewelry of the '80s. Titanium, developed for use in the aerospace industry, was found to be a light, strong metal that could be anodized to a variety of vivid colors. It was not widely used, however, and was incorporated more as an accent metal rather than for entire pieces. Tungsten carbide, also from the aerospace industry, was used for watches, while stainless steel cable, occasionally rhodium plated, was worked into a variety of bracelets, neckwear, rings, watchbands, and cufflinks, primarily for men. Many of these pieces were augmented by gold findings in the form of tiny screws for the industrial "high-tech" look, or toggle clips for the nautical effect. Cabochon-cut sapphires or flush-set melee diamonds were sometimes added as well.

During the 1980s, the U.S. customer developed a greater interest in higher-karat gold, which traditionally has been preferred in Europe and Asia. With the emphasis on high-karat gold alloys, there was also an interest in making jewelry of 24K gold. As a solution to the softness of pure gold, the World Gold Council (formerly Intergold) sponsored the development of a new alloy, 990 gold, that incorporates 1% titanium with 99% gold. While this alloy satisfies the Asian standard for pure gold (99% gold, 1% impurity), it has the durability of a much lower karatage (Tasker et al., 1987). "Nine-ninety gold" is still in the experimental stages, however, and is not yet in widespread use.

Although the great majority of settings in the jewelry market of the '80s were cast, a number of goldsmiths experimented with forming and working metals. Borrowing from jewelry styles of the 1940s, metals were folded, pleated, ruffled, and sculpted to imitate textiles and give the appearance of having been woven or formed into intricate lace or mesh. Texturing of metals was explored further during this period: Against bright polished gold, matte, brushed, and satin finishes provided a softened effect (figure 9), while reticulated, "distressed," and crystallized finishes gave a strong visual impact to artistic, modern pieces (Kremkow, 1988). Bright-cutting, or diamond-cutting, was another surface texture that was most commonly seen on mass-produced gold jewelry designed for the popular market. Stamped textures, imitating natural surfaces such as basket weave, crocodile skin, or leaves and scattered flowers, were also used to enhance the bold metal look of the '80s.

Exhibitions of ancient and antique jewelry awakened a new appreciation for early metal-

Figure 8. Opaque and jewel-toned enameling was one of several surface-coloring techniques of the 1980s. The "Metropolitan Collection" of four 18K gold bangle bracelets and a collar necklace, courtesy of the Italian firm La Nouvelle Bague, strikingly demonstrate this.

Figure 9. Texturing of metals was a popular '80s trend. Here, 18K gold with a soft brushed finish is contrasted against pavé-set diamonds and highly polished gold in this elegant collar necklace. Courtesy of Henry Dunay.

Figure 10. The art of granulation was one of the ancient metalsmithing techniques revived during the last decade. In these fine contemporary examples of this technique, cabochon garnets, pink tourmalines, and amethysts have been set in 22K gold embellished with precise patterns of granulation. Jewelry courtesy of Elaine Greenspan, Goldsmith; photo © Harold & Erica Van Pelt.

smithing techniques. Two of these in particular, the Japanese art of *Mokume gane* and the Etruscan technique of granulation, saw limited revival. *Mokume gane*, meaning "wood grain metal," bonds, folds, rolls, and slices stacks of metal strips—usually colored golds or gold, silver, and copper—to achieve a variegated pattern. Pieces that contain silver or copper are sometimes acid etched to augment the wood-grain texture. Granulation embellishes the surface of a piece of jewelry with minute gold beads fused in a pattern. Many jewelers, inspired by the Etruscan originals, closely emulated this ancient style, while others adapted the technique to more modern interpretations (figure 10).

JEWELRY STYLES

Contemporary Trends. As the decade opened, the focus in jewelry was on gold and diamonds. Thin gold chains were worn in multiples as bracelets and, in various lengths, as necklaces, often with gold charms and small gem-set pendants. Taken to the extreme, charm holders enjoyed a brief but immense popularity, allowing collectors to wear 20 or more charms on a single chain. Dainty gold rings, sometimes set with small gems, were in vogue and some women wore them on every finger. As the 1980s progressed, a heavier look for gold jewelry gained momentum. Earrings became larger and more elaborate, replacing small gem-set studs, or supplementing them, as the trend toward multiple piercing of one or both ears allowed many women to wear studs along with large earrings. Doorknocker earrings with large clips and heavy swinging stirrups of hollow stamped gold became a prevalent style. Mirror-image clips, with a right and left motif, were also popular in geometric shapes or sculpted pseudomorphic forms. Large hoops and long dangling earrings in amazing variety were also worn by many women (see figure 1).

Although the majority of earrings produced were in matching pairs, a few jewelers produced "unmatched" pairs of various types. For example, some earrings would be made using identical elements assembled in reverse, such as a square on top with a pendant rectangle for one ear, and a rectangle on top with a pendant square for the other. Or the earrings would be made using similarly cut stones in different colors (see figure 2).

Chain bracelets and necklaces continued to be popular throughout the 1980s. Chains became wider and heavier as the decade advanced, often with more complex links. Chains that appeared woven in a flattened, tightly meshed herringbone pattern were especially accepted. The addition of pavé-set diamonds to alternate links, or bezel-set colored gems interspersed every six inches, gave chains even more variety.

Gold and silver bangle bracelets in various widths were favored items, as were wide cuff bracelets. Both types were available in simple unadorned styles, and embellished with surface textures or gems.

The flexible "tennis bracelet," comprised of a single row of links, each set with a single diamond (see, e.g., figure 1), was enormously popular during the '80s. Chris Evert coined the name when her

straight-line diamond bracelet slipped off during a televised tennis match and she stopped to pick it up. When later interviewed about the incident, she referred to it as her "tennis bracelet" (R. Frankel, pers. comm., 1990). Toward the end of the 1980s, some jewelers offered "jackets" for tennis bracelets in the form of a wide clasp-on bangle designed with a channel into which the tennis bracelet could be slid and secured. Straight-line bracelets of colored stones were also popular, with and without the addition of diamonds. "Rainbow" bracelets and necklaces, incorporating suites of calibrated colored stones, were further adaptations of this '80s style.

Rings of the 1980s generally had a more substantial look. The diamond engagement ring, which continued to be the industry staple, adapted to contemporary trends. Matching engagement and wedding band sets incorporated more diamond melee as accent stones, reflecting the move toward bigger jewelry. Pavé- and channel-set diamonds became indispensable, and the shanks of rings gradually widened to accommodate them (see figure 1). The decade started with the immensely popular, straight channel-set eternity—now called "anniversary"—ring. Toward the mid-1980s, however, channel settings began to follow more curvilinear designs, bending around the center stone, for example, or coiling in a graduated loop. These designs demanded precisely calibrated cut diamonds in straight and tapered baguettes as well as the new square-cut brilliants (figure 11).

"Stackable" rings were also updated for the '80s.

Figure 11. Larger, more substantial rings with channel-set baguette diamonds were very popular with the '80s woman. This 18K gold ring is a 1989 Diamonds of Distinction award winner. Courtesy of Nova Stylings, Inc.

Sold individually, but designed to be worn in groups, these rings were usually produced in the same style but with contrasting gems, that is, one ring set with rubies, one with sapphires, and one with emeralds (see figure 1). A different type of stackable ring offered a variety of stones set in complementary styles that would "nest" neatly together, giving a variety of looks depending on how they were "stacked" on the finger.

During the 1980s, coins were seen more commonly in jewelry (figure 12). Many countries

Figure 12. Antique and modern coins were popular in '80s jewelry for both men and women. This ancient coin is bezel set in 18K gold and accented with pavé-set diamonds and cabochon sapphires. Courtesy of Bulgari.

issued newly minted gold, silver, and even platinum coins, examples of which appeared primarily as pendants but in other forms of jewelry as well. Ancient coins were also used in a variety of jewels. This trend may have been promoted by the consumers' increased exposure to ancient and antique jewelry through exhibitions and auctions as well as foreign travel.

The most notable innovation for necklaces in the '80s was the *torsade*. Several strands of freshwater pearls or gem beads were twisted and fastened, frequently with an ornate clasp in front (see figures 1 and 4). Also popular was the collar necklace or choker. Reminiscent of ancient Celtic torques, these close-fitting necklaces were designed to nestle in the hollow above the collarbone (see figure 9). Styles ranged from simple, sculpted, flexible gold links to elaborate works of art, rigid collars encrusted with colored gems, pearls, and pavé-set diamonds.

Brooches and pins made a comeback in fashion during the '80s. Overall, the look for brooches was large: a way to make a powerful statement. Long bar brooches were also popular worn vertically on jacket lapels, or on the shoulder of a dress, while smaller pins were often worn in groups.

In this decade of innovation, a number of unusual materials made their appearance in jewelry. As a contrast to the rigidity of metal and gems, some jewelry designers used a thick cord of woven silk, black leather, or even black rubber tubing, with gold clasps and massive, gem-set pendants. Another petrochemical product, acrylic plastic, was set with a variety of faceted transparent gemstones in jewelry. Although plastics of various types have been used for some time in costume jewelry and by avant-garde jewelers as "gem" materials, this decade saw its first use as a mounting for precious gems.

Watches were enormously popular for both men and women. They ranged from expensive creations, with jeweled casings and faces of fine lapis or other opaque gem materials, to inexpensive plastic "designer" styles.

Trends in Antique Jewelry. The 1980s saw a heightened interest in antique and period jewelry, to which the prominent auction houses contributed greatly. Previously dominated by dealers and a select group of collectors, auctions are now attracting more private clients. The quiet stream of private buyers became a torrent in 1987, when

Figure 13. Created by Jeanne Toussaint for Cartier in 1940, this flamingo brooch from the collection of the Duchess of Windsor was auctioned by Sotheby's in 1987. Set in platinum and gold with rubies, emeralds, sapphires, diamonds, and citrine, the brooch was valued at $189,000; it sold for $806,667. Photo courtesy of Sotheby's, New York.

Sotheby's sold the jewels of the Duchess of Windsor in Geneva. For the first time, jewelry associated with British royalty was auctioned, and the media blitz had worldwide impact (Shor, 1988a). Experts at Sotheby's conservatively estimated the collection's value at $7 million. When the gavel fell on the final lot, the sale totaled an amazing $50.3 million. The excitement generated made the public aware that, through auction houses, a private individual could purchase a small bit of well-documented history (figure 13).

Well before the Windsor auction, however, the auction houses noticed a growing demand for authentic antique and period jewelry. Art Nouveau's fanciful and naturalistic jewels were in favor

initially, but these were soon eclipsed by the geometric precision of Art Deco that was more in keeping with the high-tech '80s (figure 14). "Retro" jewels—from the 1940s and early 1950s—became popular in the last half of this decade, while Victorian and Edwardian pieces also strengthened in sales. To satisfy the expanded market for these jewels, contemporary manufacturers began to produce exact replicas and close imitations. Modern designers not only used ancient metalsmithing techniques, as discussed earlier, but they also revived ancient and antique styles (see figure 1).

Figure 14. "In a Persian Garden" is the name of this authentic Art Deco bracelet offered at auction by Christie's in 1988. Platinum-articulated links are set with diamonds, emeralds, and rubies, further enhanced by black-enameled flower sprigs. Photo courtesy of Christie's, New York.

DESIGNERS OF THE 1980s

It would be impossible in this brief overview to mention each of the talented jewelry designers worldwide who deserve recognition. However, it is important to note the contributions made by certain designers or design houses to jewelry styling in the 1980s. This section will discuss the general styles of jewelry from various countries and regions, and give examples of one or two designers from each whose innovations had an impact on jewelry trends during the decade.

"Name" Designers. In the 1980s, "designer label" consciousness extended beyond clothing fashion to other luxury items such as cars, watches, and jewelry. A number of new designers emerged, including some whose well-known names, coupled with their talent, brought them immediate acceptance. Paloma Picasso was invited to work under the Tiffany aegis, and her name was attached to a line of bold jewels that use large, richly colored tourmalines, citrines, amethysts, garnets, and kunzites (see cover, *Gems & Gemology*, Summer 1987). Bezel-set simply in the center of a heavy neck chain or a large gold ring, the gem itself is the focus in her jewelry, which can be credited with helping to broaden consumers' acceptance of colored stones other than the ubiquitous ruby, emerald, and sapphire in high-fashion jewelry.

Another designer, with a richer heritage in jewelry design, is known as Marina B. As the daughter of Constantine Bulgari, she was raised in the exotic world of *haute joaillerie*. From an early age, she worked closely with her father and learned the exacting techniques of jewelry design and manufacture. After his death, Marina broke away to start her own jewelry company, with the condition imposed by the family business that she not use the name *Bulgari*. Thus, as Marina B, she opened her first showroom in 1979, and throughout the '80s developed her own recognizable style of distinctive jewels. Heart-shaped figures without the cleft are one of her signatures and appear as the motif in snug chokers and earrings. Her jewelry is comfortable and ingeniously designed, such that in many pieces the central stones can be removed or their backgrounds can be changed (Seebohm, 1987; figure 15).

United States. In the U.S., there were several exceptional artists whose work during the past decade influenced jewelry styles internationally. Among these, New York designer Henry Dunay captured European attention in the early 1980s, when he was one of the first U.S. designers to exhibit at the Basel Jewelry Fair (Edelstein, 1989a). His sculptured and "faceted" gold jewelry led to other textured finishes such as matte or brushed gold. Dunay also introduced a line of braided gold jewelry that extended to men's bracelets and cufflinks as well as to women's necklaces and earrings. His motifs take the form of plump, rounded squares, soft knots, "candy twists," and shell-like whorls, all of which involve a contrast of textured and smooth finishes, some appearing to be tied with thin wires of polished gold (figure 16).

Figure 15. This versatile choker and earring suite—of yellow sapphires, black onyx, and pavé-set diamonds mounted in 18K gold—shows the signature heart-without-a-cleft motif that is prevalent in Marina B jewels. The earrings are designed so that the background can be changed from pavé-set diamonds to black onyx. Courtesy of Marina B.

Frequently, Dunay enriches his jewels by pavé setting them with diamonds, a technique at which he excels. Subtle and understated, Dunay's jewels have led the way for other American designers in the international market.

The Los Angeles–based company Nova Stylings became known for their innovative channel-set baguette diamond jewelry, a major fashion statement of the 1980s. Round diamonds in channel settings were characteristic of jewelry in the late '70s, but taking calibrated baguettes and channel setting them to follow lyric, tapering curves in a ribbon of light, was a technique new to the '80s. Nova Stylings president Martin Gruber and designer Akiko Wakabayashi have been consistent winners of the Diamonds International and Diamonds Today competitions with jewelry incorporating this technique (figure 17).

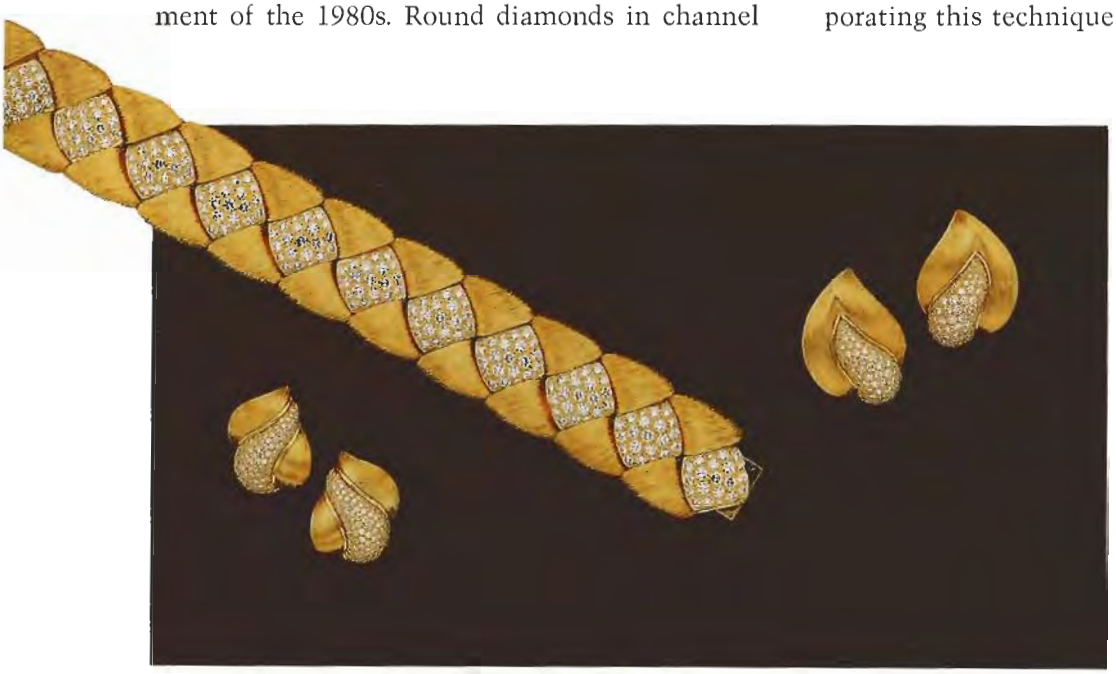

Figure 16. Plump braids, "candy twists," and turbans are frequent motifs in Henry Dunay's jewels. The contrast of textured 18K gold and pavé-set diamonds became a popular trend in the 1980s. Courtesy of Henry Dunay.

Italy. Italy continued to be the largest producer of gold chains during the 1980s. Dozens of Italian companies produced an endless variety of chains, the links becoming more complex and the chains more substantial as the decade progressed.

Many companies in Italy also produced exquisite jewelry. Among these is the firm of Bulgari. Although they have been fine jewelers for generations, many of their designs became signature looks in jewelry fashion of the '80s. With classic simplicity, Bulgari bezel set ancient coins and suspended them from a smooth heavy chain, tastefully reviving this style (see figure 12). Bulgari is also known for their distinctive necklaces of elegant design in a style drawn from ancient Rome. Matched pearls, rubies, emeralds, or sapphires are bezel set and accented with pavé- and channel-set diamonds. These slender necklaces are frequently designed in suites with matching earrings and rings.

Great Britain. Generally speaking, British jewelry in the 1980s followed conservative, traditional lines. Much of the jewelry trade in England was focused on antique and period jewelry from the turn of the last century. However, two exceptional British jewelers attained worldwide recognition during this decade, if for very different reasons.

Laurence Graff became known for dealing in large stones of the finest quality, set in stunning jewels. In 1984, Graff unveiled the "Imperial Blue," a 39.31-ct pear-shaped diamond that he claimed was the world's largest flawless fancy blue. He had it set in a simple pendant surrounded by round brilliants suspended from a *rivière* of pear-shaped diamonds. Later that same year, he presented the "Empress Rose" as the largest (72.79 ct) flawless pink diamond in the world (Vassiltchikov, 1988). Although these rare jewels are accessible only to a very select few, they nevertheless helped whet the public appetite for fancy-color diamonds and fine colored stones.

Elizabeth Gage gained attention by designing highly unusual jewelry in a creative blend of ancient Roman and Renaissance styles (see figure 4). Her unique jewels frequently combine antique coins, carved gemstones, or 18th-century glass intaglios with baroque pearls, diamonds, and a variety of colored stones. Some of her creations are further ornamented with translucent enamels and embellishments to the metal surface. Most of Gage's pieces are large and dramatic: Rings are often high domed, featuring cabochon-cut stones or sculpted gold, and can be as much as an inch wide; brooches are often two to three inches in diameter, of quatrefoil shape with spiral points, sometimes terminating in a lustrous pearl (Watts, 1984). Gage exemplifies the trend of "interpretive" jewelry that became popular again in the 1980s (figure 18).

Figure 17. The "Diva Pin," designed by Akiko Wakabayashi, was an award winner in the 1989 Diamond Today competition. Shown here in three possible variations, the pin is composed of prong-, channel-, and pavé-set diamonds and sapphires mounted in 18K gold, with blue and red enamel. Courtesy of Nova Stylings, Inc.

Germany. German jewelry design of the last decade was quite different from the traditional styles being produced in most European countries. Overall, the look was more avant garde. Several innovative techniques developed for the Germany company Niessing by designers Matthias Monnich, Simon-Peter Eiber, Christian Kube, and Norbert Muerrle have since been adopted by many other jewelers worldwide ("Das Niessing Konzept," 1987). Niessing is recognized as the first company to "marry" gold and platinum, fusing it without solder. Jewelry made by this process usually has a brushed or matte finish to help define the contrast between the two metals. In 1984, Niessing also

Figure 18. During the 1980s, English designer Elizabeth Gage focused on interpreting antique styles. Clockwise from the top (all set in 18K gold): a carved horn scarab ring with red enamel, zodiac ring with bezel-set diamonds, cabochon-cut bicolored tourmalines bezel set in earrings with diamonds and cultured pearls, and two "templar" bands—one set with rubies and the other set with diamonds and using red enamel. The brooch in the center contains an antique glass intaglio, surrounded by tourmalines in spiral points, antique diamonds, and one pearl. Jewelry designs © Elizabeth Gage, Ltd.

introduced "iris" gold alloys: A special technique produces 18K gold that can exhibit up to seven different "colors," graduating from deep yellow to white, in the same piece (figure 19). Niessing designers are also credited with developing the tension setting of diamonds in platinum. They use the "spring" of the metal to hold the stone rather than a structurally fixed seat, so the stone appears to float between the two arms of the ring shank in what they call a "pre-stressed ring" (Schmager, 1987; figure 20). Another Niessing development popularized in jewelry of the late 1980s is the flush setting of round melee diamonds in a "polka-dot" pattern on the shanks of matte-finished gold and platinum rings, and on bracelets, necklaces, and brooches.

Spain. Otherwise conservative in jewelry design, Spain produced one particularly distinctive '80s artist. Although several jewelers worldwide have incorporated sculptural details into their work, few have produced such sensuous, streamlined figures as Carrera y Carrera. Languid, stylized women wrap their long, slender limbs around a gem in a gentle embrace to make a delicate but striking pendant or ring. Other motifs include

Figure 19. This "iris" gold bangle bracelet and ring illustrate the gradual shading from yellow to white that characterizes this unusual alloy. Courtesy of Niessing, Ltd.

Figure 20. The "pre-stressed ring" was a new method of diamond setting developed in the early 1980s by Niessing, Ltd., of Germany. The tension of platinum is used to secure the stone in such a way that the diamond appears to be lightly suspended in air. Courtesy of Niessing, Ltd.

horse heads, appearing to race with the wind, or sleek panthers stalking their prey. Many of these motifs are used to frame a plain, unnumbered watch face. Combining matte and shiny surfaces that are occasionally accented with diamonds, Carrera y Carrera's jewels have stimulated many imitators (figure 21).

France. For centuries, France, particularly Paris, has been the center for high fashion in jewelry. The large French jewelry design houses such as Cartier, Van Cleef & Arpels, and Boucheron were innova-

Figure 21. These sculptured panthers, set in 18K gold with diamonds, are characteristic of the Spanish firm Carrera y Carrera. Courtesy of Carrera y Carrera.

tors during the first half of this century, but in recent years have tended to be more conservative. There are exceptions, of course: Cartier was one of the first jewelers to use stainless steel in a line of men's jewelry, and Boucheron was at the forefront in the evolution of collar necklaces. In the early 1980s, Boucheron began to design parures of close-fitting collar necklace, earrings, and rings made of carved rock crystal set in gold with diamonds, sapphires, and rubies. Van Cleef & Arpels, stimulated by the renewed interest in period jewelry that

Figure 22. This 1936 ruby, diamond, and platinum "holly leaf brooch" is one of the first invisibly set jewels made by Van Cleef & Arpels. Sold at the 1987 auction of the Duchess of Windsor's jewels, the piece helped revive interest in invisible setting during the 1980s. Photo courtesy of Sotheby's.

swept the '80s, once again began using the invisible settings they had developed in the late 1920s (figure 22). This exacting technique involves setting precisely calibrated sapphires, rubies, and, rarely, emeralds, in hidden mountings so that no metal is visible between the stones. The popularity of invisible settings during this decade has prompted many jewelry manufacturers to imitate the style, but none can match the originals for design and execution.

Japan and the Pacific Rim. Japan became a strong presence in the gem and jewelry market of the 1980s. As the yen strengthened against the dollar, the Japanese became important consumers of high-quality diamonds and platinum, especially for engagement rings and other jewelry gifts associated with weddings. Motivated by this demand, Japanese jewelry designers developed a style that integrated Japanese tradition with modern Western culture. Stark color contrasts, with an emphasis on black and white, characterize their pieces. Black onyx, black jade, black lacquer, and black enamel are employed to provide a dramatic background for diamonds and pearls.

Other Asian countries along the Pacific Rim also experienced tremendous growth in their gem and jewelry industries. Major cutting operations in Thailand and Hong Kong were developed to meet the burgeoning trade in colored stones. These countries also expanded their jewelry manufacturing efforts to meet the growing demand for low-cost jewelry in the mass market, including replicas and imitations of fine European antique and period jewelry.

CONCLUSION

The 1980s made some interesting contributions to the evolution of jewelry design: new cuts for both diamonds and colored stones, new and different setting styles (channel-set baguettes, flush-set and tension-set diamonds, and modern adaptations of older techniques (invisible settings and bezel settings). There was also a new look to the precious metals used: Gold, platinum, and other metals were intermingled in the same piece, colored

alloys of gold were popular again, and a variety of surface textures were revived and explored. At the same time, in this eclectic era, jewelry designs ran the gamut from antique and traditional to futuristic, from romantic to starkly modern, with myriad variations in between.

Looking into the '90s and the fast-approaching 21st century, it is interesting to speculate on what changes will take place in jewelry fashion. Current trends suggest a number of possibilities. There will be a continued progression in the trend of unusual cuts for gems coupled with new and ingenious ways of setting them, following the sleek, modern look that developed in the late '80s.

Advances in technology will further facilitate the manufacturing arts. CAD-CAM (computer-aided design/manufacturing) systems, for example, are successfully streamlining the large-scale manufacture of jewelry findings, and hold great potential for artistic applications as well.

Ease of travel and communication has made ethnic art more immediately accessible, and we may see new interpretations of cultural motifs and styles in jewelry.

Men will be wearing more jewelry in distinctive ways. Lapel pins for men are becoming larger and more interesting. Bola ties have graduated from their cowboy beginnings and are appearing in more contemporary form. Men's bracelets and rings, static in design for so long, are overdue for a new look. Earrings for men will probably never evolve past the single gemstone stud or small ring stage, although they may be sported by a greater number. Belt buckles for men are another jewelry item ripe for transformation.

Jewelry for women will expand on the present theme of versatility, giving women more jewelry accessories that can be worn with casual or business clothing as well as evening wear. Rings, bracelets, and earrings will stay large and impressive. Substantial brooches and collar necklaces will continue to grow in popularity. For evening, there will be more jewels worn in the hair. Overall, the look we are moving toward is sleeker: more compact and less cluttered. The gap between artist and manufacturer has been narrowing, and jewelry will undoubtedly reflect this by being less generic and more personalized. In the late 1980s, women were expressing more individuality in the way they wore jewelry and in the jewelry they chose. This trend will strengthen, and jewelers will strive to meet this by designing jewels that women can tailor to their own particular taste.

The steady expansion and development of the jewelry industry during the 1980s will continue. It will be exciting to watch the progression of dazzling jewels that evolve as we enter the 21st century.

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Gem Trade LAB NOTES

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AMETHYST, Simulated

Because of the ever-present problem of synthetic amethyst being mixed with natural amethyst, some dealers now routinely examine amethyst parcels very closely. Many look for Brazil-law twinning, which indicates that the amethyst is natural (see *Gems & Gemology*, Fall 1986, p. 130).

Several dealers recently became alarmed when they encountered unusual amethyst simulants salted into parcels of natural amethyst. The imitations turned out to be synthetic sapphires of a color that matched that of amethyst (figure 1). The presence of purple synthetic sapphires in amethyst parcels should not pose a problem for the gemologist, since routine testing easily proves the identity of these stones. We appreciate the dealers' bringing this method of deception to the attention of the GIA Gem Trade Laboratory and our readers. *DH*

Figure 1. This 2.20-ct synthetic sapphire is one of several found in parcels of natural amethyst.

Figure 2. This 7.34-ct cabochon is a rare example of cat's-eye andalusite.

Cat's-Eye ANDALUSITE

Occasionally, the laboratory has the opportunity to examine a rare variety of a relatively common gemstone. The West Coast laboratory recently saw just such a stone, a fine example of a rare cat's-eye andalusite (figure 2).

The 7.34-ct stone exhibited a refractive index of 1.64, determined using the spot method. Although inert to long-wave ultraviolet radiation, it did fluoresce a weak chalky green to short-wave U.V. The extremely strong pleochroism typical of andalusite was quite evident, and was most visible at the sides when the stone was viewed straight up (again, see figure 2). The dealer had cut the stone from a very fibrous piece of rough that he had picked out of a parcel from Brazil. The fibers were dense throughout the stone, thus giving rise to the relatively sharp eye. *Shane McClure*

DIAMOND

Cutting Risks

As many diamond cutters know, there is always a chance that a diamond will shatter while it is on the cutting wheel, during either major faceting or even a minor touch up. On a large, important stone, the loss could be in the millions of dollars. One cutter was making a minor repair to an internally flawless fancy yellow round brilliant when it suddenly shattered on the wheel; note in figure 3 that one section cleaved and fell off. Before the damage, the stone weighed 3.32 ct and measured 9.57 mm in diameter by 5.86 mm deep. When submitted to the East Coast laboratory in its present condition, it weighed 2.99 ct and measured 9.57 × 8.08 × 5.74 mm. Unfortunately, the stone also had fractured internally, so it was now almost worthless. Even an internally flawless stone can be at risk on the wheel, regardless of the nature of the repair, because of possible strain. *DH*

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

Gems & Gemology, Vol. 26, No. 1, pp. 94–99

Figure 3. The remaining portion of a 3.22-ct flawless fancy yellow diamond that shattered on the wheel during a minor repair to its cut is now almost worthless.

With a Rare Inclusion

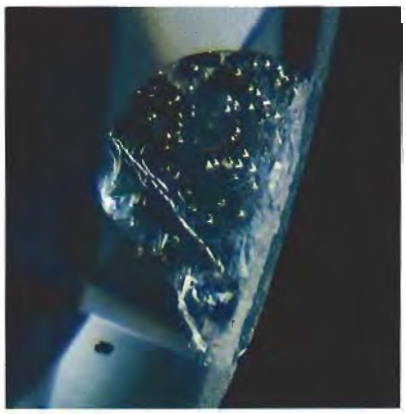
A 1.53-ct round brilliant-cut diamond recently encountered in our East Coast laboratory contained a very puzzling inclusion (figure 4). At first glance it appeared to be a cleavage in the girdle plane that extended into the stone from the center of the girdle. However, as shown in figure 5 (taken at a different angle and under different lighting conditions), a series of triangular figures covers most of the surface of the area first thought to be a cleavage.

In his fine book, *The Mineralogy of Diamond* (translated from Russian in 1977), Orlov maintained that most of the surface features seen on diamond crystal faces are not growth features, but rather are due to dissolution following crystallization. In fact, Orlov even begins one chapter (p. 98) with the statement: "The action of dissolution on diamond crystals sometimes results in narrow etch channels resembling cracks." We could now visualize how dissolution could extend into the interior of a diamond by following a natural cleavage, thus creating the triangular etch figures seen in our stone.

RC and Tom Moses

Figure 4. Darkfield illumination at 60× magnification shows what appears to be a cleavage in the girdle plane of a 1.53-ct diamond.

Figure 5. This background clearly reveals the triangular figures present in the "cleavage" of the stone shown in figure 4. Magnified 50×.



EMERALD, with Filled Fractures

The West Coast lab recently received for identification what visually appeared to be a high-quality, fine-color natural emerald; in the process of testing, we found that fractures reaching the surface of the stone had been filled with a foreign material.

Initial tests of the 14.84-ct stone gave results typical of natural emerald. The only variance was when we exposed the stone to long-wave U.V. radiation: Although it was inert overall, some of the surface-reaching fractures appeared to fluoresce an extremely weak (difficult to see) dull, chalky yellow – much weaker than is typically observed in oiled emeralds. The stone was entirely inert to short-wave U.V.

Magnification revealed a prominent "flash effect" in the surface-reaching fractures that was remarkably similar in visual appearance to the effect seen in fracture-filled diamonds (described in detail in the Summer 1989 issue of *Gems & Gemology*). With darkfield illumination, almost all of the large, surface-reaching fractures showed a yellow to orange interference color that became an intense, vivid blue when the position of the stone was changed to where the background turned bright. As the emerald was tilted back and forth, the colors went from orange to blue and back to orange (figure 6). As with fracture-filled diamonds, the "flash effect" colors were observed only at a very steep viewing angle. Some of the filled fractures also showed flattened trapped gas bubbles in areas where the filling was incomplete (figure 7). Other microscopic features were typical of those for natural emerald, including multiphase inclusions (many three-phase) forming fingerprint patterns, as well as several very thin white needles running parallel to the c-axis.

XRF analysis showed no medium to heavy (atomic weight) elements other than those that are components of emerald. In addition, mid- and near-infrared spectroscopy revealed no recognizable differences between the filled and unfilled areas

We have read in the trade press that Zvi Yehuda is now treating cut emeralds (e.g., *Rapaport Diamond Report*, November 17, 1989, and *Jewelers' Circular-Keystone*, Vol. 161, No. 2, 1990, pp. 15–16). Except for the "flash effect" and the apparent close correspondence in R.I. between the filling material and the host, from our observations to date we are not suggesting that the filling material in this emerald is similar in any way to the filling material in "Yehuda"-treated diamonds. We have no confirmation that this emerald was, in fact, treated by the new "Yehuda" process for

Figure 6. Orange (left) and blue (right) flashes similar to those observed in "filled" diamonds were readily apparent in the surface-reaching fractures of this emerald. Magnified 15×.

Figure 7. Trapped gas bubbles are evident in this area of the fracture where the filling is incomplete. Magnified 20×.

treating emeralds. Right before going to press, however, we received from a reliable source a small number of "commercial grade" emeralds reported to have been treated—fracture filled—by Mr. Yehuda. These treated emeralds showed the same "flash effect" observed in the 14.84-ct emerald described above. *RK*

Unusual Natural OPALS

Two unique opals were recently submitted for identification to the West Coast laboratory (figure 8). At first glance with the unaided eye they appeared to be doublets, with a black top portion and a white bottom portion. On closer examination, though, it became evident that each stone was, in fact, a solid piece of opal.

Reportedly found in the Andamooka region of southern Australia approximately 10 years ago, the two matching free-form cabochons were cut from the same piece of rough. Weighing 11.18 and 10.13 ct, respectively, both stones gave a spot R.I. reading of 1.45. When exposed to long-wave U.V. radiation, the bottom portions fluoresced a strong chalky white, while the tops fluoresced a slightly weaker patchy chalky white. Exposure to short-wave U.V. radiation produced a similar, but weaker, reaction. The opals also exhibited a very strong phosphorescence to both long- and short-wave U.V. The patches of light brown matrix on the unpolished bottom portions were inert to both types of radiation.

As can be seen in figure 9, the top and bottom of each opal showed a beautiful play-of-color, with a sharp

Figure 9. The sharp demarcation between the white and black portions of this 10.13-ct natural opal led us to believe, at first, that it was assembled.

Figure 8. Play-of-color is evident in both the upper black and lower white portions of these two natural, single-piece (not assembled) opals from Australia, which weigh 11.18 and 10.13 ct, respectively.

demarcation between the two portions. The color in the top portion was imparted by innumerable tiny black spheres that had precipitated out of the solution in uniform layers and bands. We do not know why the coloring of the layers would change so drastically during the process of formation, but the results are quite dramatic. *Christopher P. Smith*

Gray Cultured PEARLS

In most instances, gray color in cultured pearls can be attributed to one of several causes: (1) The pearls are a lighter variety of the Polynesian naturally colored black pearls, (2) they have been exposed to gamma radiation from the isotope cobalt 60 to produce a uniform gray coloration, (3) they have been dyed gray, or (4) a dark bead was used as the nucleus. Each alternative has its own method of identification.

Natural-color gray Polynesian cultured pearls have a characteristic faint reddish brown fluorescence to long-wave U.V. radiation and show a sharp contrast between the bead and the nacreous outer layers in an X-radiograph (see Goebel and Dirlam, "Polynesian Black Pearls," *Gems & Gemology*, Fall 1989, p. 143). Irradiation of Japanese cultured pearls darkens the freshwater shell bead so that a gray color is seen through the relatively thin nacre (see p. 244 of the Winter 1988 Lab Notes section). The only way to prove this treatment is to look deep into the drill hole for evidence of the artificially darkened nucleus. The fact that these pearls do not fluoresce red is an indication of treatment.

The presence of silver nitrate in dyed pearls is sometimes seen in an X-radiograph as a pale ring, along with a lack of sharp contrast, between the bead and the outer layers of the pearl. An organic dye can be detected by rubbing the pearl with a cotton swab that has been dipped in a weak (2%) solution of nitric acid.

The cultured-pearl industry has also been known to use dark (nonirradiated) nuclei to produce gray to blue-gray pearls. A relatively thin nacre allows the color of the nucleus to show through.

Figure 10. The 10- to 12-mm gray cultured pearls in this strand were found to be of natural color.

Still another reason that cultured pearls may be gray is the presence of an exceptionally thick layer of conchiolin. It is rare to encounter an entire strand of such naturally colored gray pearls, yet such a strand (figure 10) was seen recently in the East Coast laboratory. Artificial irradiation was ruled out as a cause of the color of these 10- to 12-mm pearls, since a heavy black layer of conchiolin was easily seen in each drill hole (figure 11). Our X-radiograph also showed that the bead centers were covered by thick layers of conchiolin and nacre, which would effectively mask the color of a radiation-darkened bead. *DH*

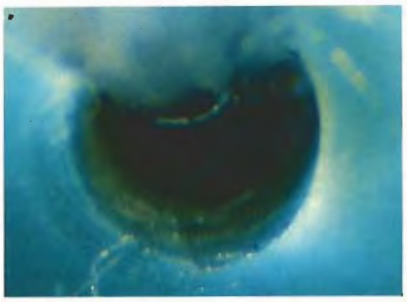


Figure 11. The thick dark layer of conchiolin responsible for the gray color of the cultured pearls in figure 10 can be seen easily when they are examined down the drill hole. Magnified 30×.

Rock Crystal QUARTZ, with Lazulite Inclusions

Ordinarily, the GIA Gem Trade Laboratory does not identify rough gem material. Recently, however, the West Coast lab was asked to identify some unusual blue rough that one of our clients had received from Africa. Visual examination showed that the rough itself was near colorless, but was densely spangled with numerous deep blue, transparent, irregularly shaped crystals that gave the rough its brilliant blue appearance (figure 12). With magnification, we noticed that some of the blue inclusions showed a definite tabular monoclinic habit. In addition, we noticed another type of crystal inclusion that was near colorless, transparent, and hexagonal in outline.

Since a few pieces of the rough had

flat areas, we were able to obtain a vague refractive index reading of 1.54–1.55. With the polariscope, we were able to prove double refraction, but we could not resolve an optic figure because of the numerous inclusions. The specific gravity was estimated with heavy liquids to be approximately 2.65. All these properties indicated that the host material might be quartz.

X-ray diffraction analysis of a scraping of this material confirmed that it was indeed rock crystal quartz. The pattern obtained from a very small powder sample taken from one of the blue crystals that reached the surface matched the standard pattern for lazulite. An X-ray diffraction analysis performed on one of the near-colorless inclusions matched that of mica.

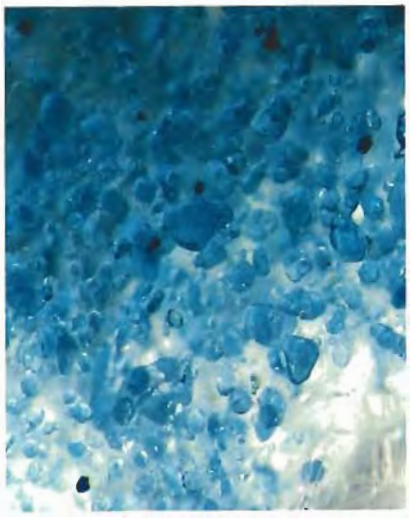


Figure 12. Lazulite inclusions are responsible for the blue color in this otherwise colorless quartz; magnified 8×.

This is the first occurrence of this combination of lazulite and mica inclusions in rock crystal quartz that we have encountered in our lab. Although the material we saw was rough, it should be attractive when cut because of the lovely color. We do not know if there are commercially significant amounts of the material available. *KH*

FIGURE CREDITS

Dave Hargett took the pictures in figures 1, 3, 10, and 11. Shane McClure is responsible for figures 2, 12, and the Historical Note figure. Vinnie Cracco provided figures 4 and 5. Robert Kane produced figures 6 and 7. Figures 8 and 9 are the work of Robert Weldon.

A HISTORICAL NOTE

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

SPRING 1965

The New York lab discussed trapiche emeralds in detail. They also illustrated a ring set with a marquise-shaped "piggy-back" diamond, in which two smaller stones appeared to be a single large one. Of particular interest were two rings set with synthetic emeralds that had been cut as intaglios. Also illustrated were flux-grown synthetic rubies that contained seed crystals of natural corundum. The presence of natural inclusions in the seed crystal and flux wisps in the synthetic portion proved that both types of inclusions are possible in the same stone. Fifty diamond rondelles, an unusual cutting style for diamonds, were seen as separators in a long necklace of natural pearls.

SPRING 1975

Our New York laboratory pointed out that sometimes testing carvings can be a test of one's ingenuity. For example, how does one place a 180-lb. statue of a horse onto a refractometer to get an R.I.? The answer: One doesn't. One puts the refractometer on the statue! Also discussed was the selective dyeing of a calcite bangle bracelet to simulate more closely the color zoning that might be found in natural-color jadeite. An illustration showed the damage that might be done to heat-sensitive stones such as tanzanite if they are not handled properly.

The Los Angeles laboratory encountered an opal that had been sold as an Australian white. However, its appearance when examined in the lab was that of a partially transparent brown stone with a large opaque white core and several similar opaque patches. When the stone was soaked in water, it became completely transparent with little play-of-color. As the stone dried out, it became opaque once again. Other items of interest were ruby in zoisite carvings and a fine green variscite cabochon, the identity of which was confirmed by X-ray diffraction.

SPRING 1985

The various color changes brought about by heat treating amethyst were discussed, accompanied by an illustration of a 55.65-ct triangular-

This damaged mabe pearl (approximately 14 mm) has a very thin nacre shell over a wax-type filler.

shaped faceted amethyst that was changed to citrine when an attempt was made to lighten the original dark amethyst color by gentle heating. An intriguing carving of two dragons holding a ball proved to be massive grossularite garnet. Damaged mabe pearls and shell hinges were discussed and illustrated (see photo). Dyed magnesite as a turquoise simulant was seen in Los Angeles.

New York saw some interesting quartz cabochons with multiple stars. They also noted some inclusions in natural ruby that appeared bubble-like at first glance, but proved to be negative crystals of the type commonly seen in Thai stones.

The Gemological Institute of America extends its sincerest appreciation to all of the people and firms who contributed to the activities of the Institute through donations of gemstones and other gemological materials in 1989. We are pleased to acknowledge many of you below.

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*Maurice S. Vickers
*William Videto
Robert Weldon
Dean M. Willard
*Doreen Wong
M. D. Zainudeen

*Denotes book donation to the GIA Library.
**Denotes donation of books and gemstone materials.

GEM NEWS

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

TUCSON '90

As in years past, the Gem News editors, as well as thousands of other gemologists, jewelers, collectors, and assorted "rockhounds," traveled to Tucson, Arizona, in February for the many gem and mineral shows that take place throughout the city. The following reports are based on the editors' observations and on information provided by other attendees.

Beryl triplet cabochons. Some of the most popular—and convincing—emerald simulants used over the years have been triplets consisting of a colorless crown and pavilion joined with a green cement or, less frequently, with a thin slice of green glass. Among the materials used for the crown and pavilion have been synthetic spinel, rock crystal quartz, and near-colorless beryl. According to Webster's *Gems*, in 1966 the Idar-Oberstein firm of Kämmerling first marketed beryl triplets under the trade name "Smaryll."

At Tucson this year, Manfred Kämmerling showed the Gem News editors some interesting beryl triplets produced by his firm. Unlike the faceted samples usually seen, these were cabochons that had a very convincing green color when viewed face-up (figure 1, right). When viewed parallel to the girdle plane, however, the true (i.e., essentially colorless) nature of the domes became obvious (figure 1, left).

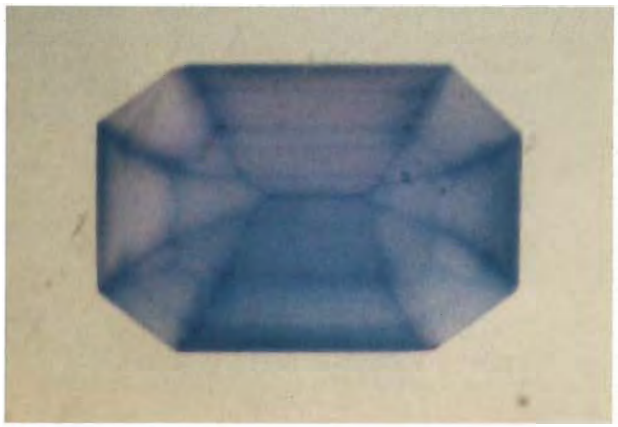
Kämmerling revealed that they had experimented earlier with essentially flawless natural beryl for both the dome and base of the cabochon, which resulted in an apparently flawless triplet. However, because such material, in practice, would normally be faceted, they felt it was not a convincing simulant. Next, they made some stones using included crowns, but this resulted in green cabochons that appeared to have colorless fractures (the color of the glue layer was not reflected by the breaks). They solved this problem by using clean Brazilian beryl for the dome and included Madagascar beryl for the base. The resulting triplets look very much like cabochons cut from natural, included emerald rough.

Figure 1. When viewed face-up (right), these beryl triplets appear green; examined from the side (left), the true colorless nature of the domes becomes apparent. Photo by Robert Weldon.

Diffusion-treated corundum. Jeffrey Bergman, of the firm Gem Source, was selling treated blue sapphires described as having been subjected to "deep diffusion treatment." According to a promotional flier that he made available, these stones had been subjected to "new techniques resulting in much deeper penetration of the metal ions. The penetration is so deep that many stones treated with this method are entirely recut, with a weight loss of over 10%, yet they retain a fine color."

GIA obtained several of these for study and subsequently prepared a preliminary report that was issued by the International Colored Gemstone Association (ICA) as Laboratory Alert No. 32.

Figure 2. Immersion with diffused transmitted illumination reveals the color concentrations along facet junctions and uneven facet-to-facet color that are characteristic of diffusion-treated sapphires. Photomicrograph by John I. Koivula; magnified 3×.



All but two of the 11 stones examined were inert to long-wave U.V. radiation and fluoresced a weak to moderate, chalky yellowish green to short-wave U.V. The other two stones fluoresced a weak to moderate pinkish orange to long-wave U.V. and had a similar, but weaker, reaction to short-wave. Magnification with diffused transmitted lighting showed color concentrations along facet junctions and outlining the girdle edge; there was also some variation in color from one facet to another. With a combination of immersion and diffused lighting, some of these features became significantly more obvious (figure 2).

A more detailed investigation is currently being conducted and will be reported in a future issue of *Gems & Gemology.*

Star ekanite. Sally Gems Colombo, one of the many gem dealers from Sri Lanka, had an unusually large (33+ ct) ekanite with a distinct six-rayed star. It was not possible at the time to determine the cause of asterism in this stone.

Cat's-eye iolite. Kim D. Barr of Inter-Gems, in Sherman, Texas, had another of the more interesting phenomenal gems seen in Tucson: a large (23.65 ct) cat's-eye iolite with a fairly light cloudy blue color and a sharp chatoyant band. We do not know if this is the same type of material that was described in the *Australian Gemmologist* (Vol. 14, No. 10, 1982); cat's-eye iolites are considered quite rare.

Mother-of-Pearl cameos. "Fantasy" cuts were not the only carved gems seen in profusion again this year. A number of dealers were offering shell cameos: not only the traditional two-toned types carved from helmet or conch shell, but others fashioned from mother-of-pearl. These latter had apparently been carved from some of the various types of nacreous shells that are used in pearl culturing, including the pink freshwater *Unio* mussel, the silvery white saltwater *Pinctada maxima*, and the black-lipped saltwater *Pinctada margaritifera* (figure 3).

Dyed green quartzite. Jerry Burkhart of Treasurings, in Bonsall, California, showed the editors an 11.54-ct oval cabochon that had been represented to him as jadeite, an identity he questioned. The stone was a mottled, medium dark, slightly yellowish green color; transparency ranged from translucent in green areas to almost semitransparent in essentially colorless areas (figure 4). Standard gemological testing conducted later at GIA Santa Monica revealed fairly sharp R.I.'s of 1.540–1.549, with a birefringence of 0.009; an S.G. of approximately 2.66; and an aggregate reaction in the polariscope. Magnification revealed green color concentrations in surface-reaching fractures. Using a DISCAN diffraction-grating spectroscope, we noted a diffused absorption band from approximately 662 nm to 688 nm. The stone was inert to both long- and short-wave U.V. radiation,

Figure 3. Cameos are being fashioned from (left to right) Unio, Pinctada maxima, *and* Pinctada margaritifera *shells. Photo by Robert Weldon.*

with no phosphorescence to either. It appeared green through a Chelsea color filter. These properties are all consistent with those reported in the literature for dyed green quartzite. This was, however, one of the most convincing such jadeite simulants either Gem News editor had seen.

New World sapphires. Conspicuous for their relative abundance this year were blue and various fancy-color sapphires from Montana. Sam Speerstra, of Shining Mountain Gem Corp. in Helena, Montana, reported that

Figure 4. Selective dyeing makes this 11.54-ct (19.60 × 15.03 × 5.76 mm) quartzite cabochon an effective imitation of mottled jadeite. Photo by Robert Weldon.

Figure 5. These Montana sapphires range from 0.45 to 1.76 ct. Photo by Robert Weldon.

Figure 6. Sapphires available at Tucson included these 4.61-ct and 4.47-ct stones from Colombia (top) and this 1.06-ct stone from Brazil (bottom). Photo by Robert Weldon.

he mines sapphires at Eldorado Bar, on the Missouri River, near Helena. The stones are recovered from a sapphire-bearing zone in ancient river gravels located near bedrock, a Calaveras-type shale. The operation yields 40–50 ct of corundum per cubic yard of ore, plus small amounts of gold and garnet.

GIA obtained a representative color suite of Mr. Speerstra's sapphires for the collection (figure 5). The fancy-color sapphires are natural color, but the blue sapphire has been heat treated. One stone (1.73 ct) showed a color change from medium dark grayish bluish violet in daylight to medium dark grayish purple in incandescent light. For the most part, the fancy-color sapphires did not exceed 2 ct, and the largest blue sapphire seen from this locality was a little over 3 ct.

A few sapphires from South American sources were also seen. GIA obtained two stones that reportedly came from the Río Mayo area in Mercaderes, Cauca Department, Colombia (figure 6, top). Colombian dealer Gonzálo Jara reported that local miners continue to produce small amounts of sapphire from this area. The largest faceted stone he has seen to date from Mercaderes is a 9.45-ct blue sapphire. Also seen at Tucson were a few small color-zoned blue sapphires that reportedly came from the Jequitinhonha River in Minas Gerais, Brazil (see, e.g., figure 6, bottom).

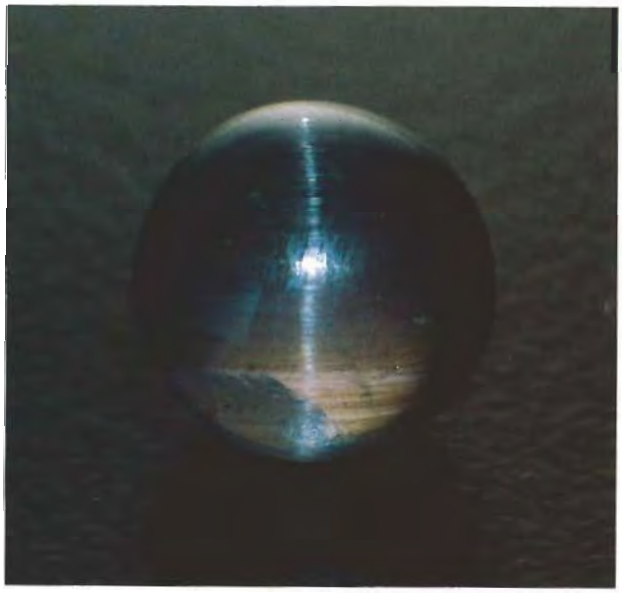
Cat's-eye spinel. The firm of Mark H. Smith A.G., of Bangkok, had an unusually transparent 3.41-ct dark grayish violet spinel cabochon that exhibited distinct chatoyancy across its dome (figure 7). Chatoyancy was caused by numerous large, eye-visible inclusions running in one direction. These were intersected at approximately 70° by a very few additional needle-like inclusions; no doubt, if there had been more of these long, intersecting needles, the stone would have exhibited a four-ray star.

Magnification revealed that the long, acicular inclusions were either limonite-stained etch ribbons or fine growth tubes that contained small, platy, square- to parallelogram-shaped inclusions. The inclusions were highly birefringent when rotated between crossed Polaroids. Other gemological properties determined on this stone were typical of spinel.

Red taaffeite. Mark H. Smith also showed the editors one of the most interesting stones available at Tucson: an attractive red 0.58-ct taaffeite (figure 8). Unlike the grayish violet to "mauve" colors typically associated with this rare gem species, this stone resembled some red spinels we have seen from Sri Lanka.

We were given the opportunity to study the stone and found that the gemological properties agreed with those

Figure 7. This 3.41-ct cat's-eye spinel is unusually transparent. Photo by John I. Koivula.



previously published for taaffeite. Magnification revealed a single black, opaque, included crystal surrounded by a wing-like tension halo that the editors tentatively identified as uraninite.

Treated Paraíba tourmalines. The fact that many of the colors available in the new tourmalines from Paraíba were produced by heat treatment was widely acknowledged at Tucson. The colors attributed to heat treatment are a very bright greenish blue, yellowish green, and a saturated, almost "emerald" green (see, e.g., figure 9). The brightness of these treated colors has caused people to refer to them variously as "neon," "fluorescent," or "electric." The untreated colors of tourmaline from this new locality include a dark violetish blue similar to some fine Sri Lankan sapphire and a bluish violet reminiscent of good-quality tanzanite, as well as the less saturated, somewhat grayish or "inky" greenish blues and yellowish greens.

Gerhard Becker, of F. A. Becker, Idar-Oberstein, conducted experiments on a number of stones to determine the heat required to make significant changes in various colors of starting material (control specimens were retained for all of the starting samples). It is interesting to note in table 1, provided by Mr. Becker, the different colors produced in a single stone at each increase in temperature. Mr. Becker also recorded a slight weight loss (0.002–0.009 ct) in some of the stones tested. Although these stones were heated as high as 600°C, no color changes were noted beyond 550°C. Heat treatment removed or altered bicoloration in all but one of the stones.

Dr. Emmanuel Fritsch, of the GIA Research Department, speculates that the heat treatment converts Mn^{3+}, a common color agent of tourmaline that produces pink to red, to Mn^{2+}, which produces virtually no color. The resulting hues are due to the remaining coloring agents, in particular Cu^{2+}.

Tanzanian zircon. As in previous years, East African gems were well represented. One material we saw for the first time was zircon, which was being offered by a dealer who claimed to have mined it in Tanzania. GIA obtained light yellow (figure 10) and very dark brownish red stones for study; a full range of colors from yellow through orange to dark red were available.

DIAMONDS

Filled diamond update. In the course of further research on diamonds known to have been glass filled, the Gem News editors noted features not previously detected in such enhanced stones. One of these consisted of two new "flash effect" colors which, like the orange and blue interference colors commonly associated with the presence of a filling, were detected using magnification and darkfield illumination.

When some diamonds were examined edge-on in true darkfield, their surface-reaching breaks exhibited a vivid pinkish purple "flash effect" (figure 11, left); this effect changed to a bright yellowish green (figure 11, right) when the stone was rotated slightly so that the background became bright through secondary reflection.

Also noted for the first time were cloudy surface markings that took the form of whitish circular patterns on the tables of some treated stones. The editors hypothesize that these may be residue from the treatment process that inadvertently was left after the filling had

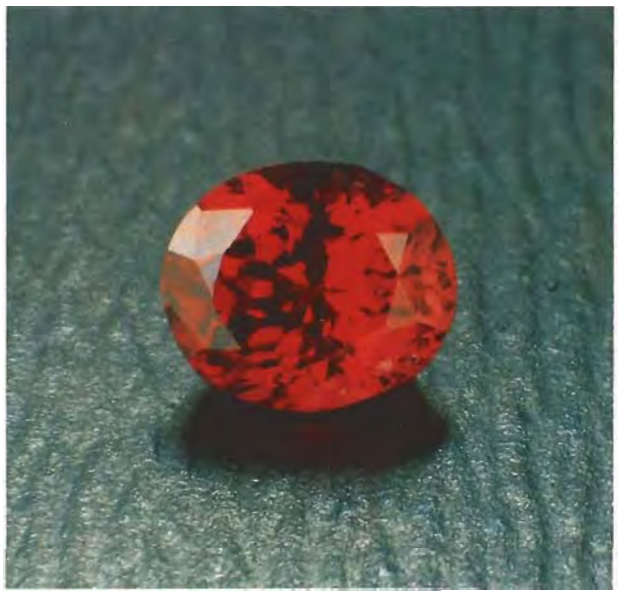


Figure 8. The color of this 0.58-ct taaffeite is extremely rare. Photo by Robert Weldon.

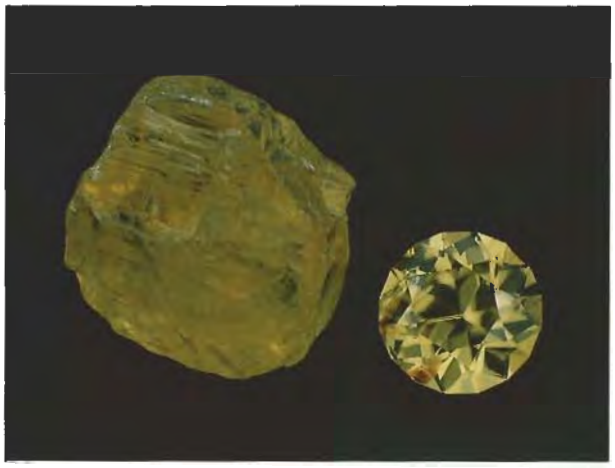
Figure 9. These heat-treated pieces of rough tourmaline from Paraíba, Brazil, represent some of the colors produced by enhancement of this material. The pieces range from 3.75–8.81 ct. Courtesy of Karl Egon Wild, Idar-Oberstein; photo by Robert Weldon.

TABLE 1. Reaction of Paraíba tourmalines to heat treatment.[a]

No.	Original color	Weight (ct)	Color observed at 350°C	400°C	450°C	500°C	550°C	Comments
1a	Violet-blue[b]	3.997	n/c[c]	Slight gray	Greenish gray	Light blue		
1b	Violet-blue	3.008	n/c	Slight gray	Greenish gray	Light blue	Electric green	
2	Bicolor: blue-green/ violet	7.776	n/c	Tendency to green	More to green	Green	Electric green	Center bicoloration fades into one color; crystal rim bicoloration stays visible
3	Gray-blue	8.204	n/c	Tendency to gray	Gray-green	Light greenish blue	Electric green	
4	Bicolor: blue with red rim	3.123	n/c	Grayish green	Gray, more to green	Light blue	Electric green	Bicolor disappeared
5	Bicolor: blue with red rim	1.340	n/c	n/c	Green	Light green	Slightly strong green	Bicolor disappeared
6	Strong blue	2.774	Grayish	Greenish	Light blue	Light blue	Electric bluish green	Obviously strong blue changes to an electric bluish green
7	Bicolor: green/violet	1.464	Grayish	n/c	Distinct light blue-green	Green	Electric bluish green	Bicolor disappeared
8	Bicolor: green/violet	2.247	n/c	n/c	Touch to greenish	More toward green	Electric bluish green	Bicolor disappeared
9	Blue-green	2.007	Greenish	n/c	Light green	More electric	Electric green	
10	Blue-gray	1.507	n/c	n/c	Green	Lighter green	Electric green	

[a]Research conducted by Gerhard Becker, of F. A. Becker, Idar-Oberstein, West Germany. In all cases, part of the original rough was retained as an unheated control specimen. Color changes observed happened almost as soon as the specific temperature was reached.
[b]Specimens 1a and 1b were both cut from the same stone.
[c]n/c = No observable change.

Figure 10. Gem zircon (here, 3.00 g and 1.81 ct) is now mined in Tanzania. Photo by Robert Weldon.



taken place. These features should be added to the suite of identifying characteristics previously reported (see Koivula et al., "The Characteristics and Identification of Filled Diamonds," *Gems & Gemology*, Summer 1989).

GIA submitted 66 stones for possible treatment; when all were reexamined following the procedure, 34 showed at least some filling. For research purposes only, all of the diamonds were graded at the GIA Gem Trade Laboratory both before and after the filling procedure. The recorded changes in apparent color and clarity grades for the 34 filled stones are shown in table 2. Eighteen stones improved at least one grade in apparent clarity, with half of these showing no apparent reduction in color. However, 21 stones dropped at least one color grade, 12 of these without any apparent improvement in clarity grade.

One final point worth noting is that the diamonds were submitted for treatment in two batches; all nine

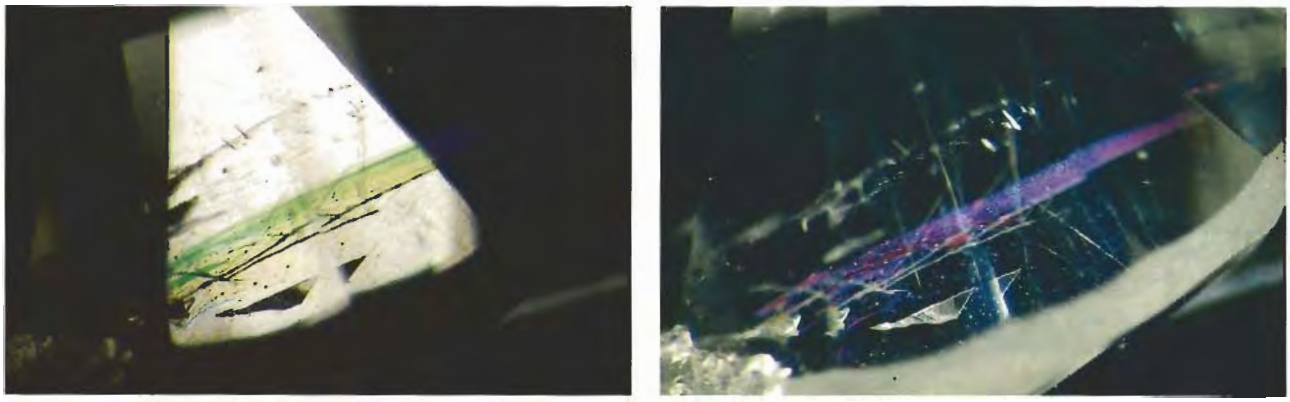


Figure 11. Some diamonds with filled breaks have been observed to exhibit previously unreported pinkish purple (left) and yellowish green (right) "flash effects." Photomicrographs by John I. Koivula; magnified 15×.

stones that showed some apparent clarity improvement with no drop in apparent color grade were in the second group submitted. It is therefore possible that some alteration in the filling material and/or process took place in the interim that at least partially eliminates the negative effect on apparent color grade that has been observed in the past. Such an alteration might also explain the new "flash effect" colors described above. These differences, however, might also be a matter of normal variability within the procedure.

Computer technology enhances new diamond sorter. A new diamond sorter that can accurately sort up to 4,800 ct per hour has been tested by Argyle Diamond Sales in Perth, and is expected to be installed there and at the Argyle sales office in Antwerp.

The machine, developed by CRA's Group Special Equipment (GSE) unit in Melbourne, can perform diamond clarity analysis from three different angles. A solid-state video system, combined with software designed by GSE, determines whether a stone should be accepted or rejected. Rejected stones are shot out of the sorter through high-speed valves.

Dr. Mark Schapper, managing director of CRA's Advanced Technological Development Department, said that while the sorter does not have the discerning eye of a human, it is 50 times faster. And because of its consistency the sorter is ideal for less expensive stones. The GSE also developed the X-ray diamond recovery machine, which was introduced in 1985, and the diamond color classifier, which debuted in Perth in 1987. (*Diamond Intelligence Briefs*, October 16, 1989)

TABLE 2. Color and clarity changes noted in 34 diamonds filled by the "Yehuda" method of cleavage and fracture filling.[a]

Number of specimens	Apparent color change, in number of grades	Apparent clarity change, in number of grades
4	n/c	n/c
11	−1	n/c
1	−2	n/c
8	−1	+1
1	−2	+1
8	n/c	+1
1	n/c	+2

[a]*Stones were graded in the GIA Gem Trade Laboratory (for research purposes only) both before and after treatment by the "Yehuda" process. The numbers represent the number of grades that the stones improved (+) or dropped (−) following treatment. n/c = no change.*

Kimberlites discovered in Canada. Cameco and Uranerz Exploration and Mining reportedly found seven kimberlite pipes on their joint-venture property at La Forge à la Corne, east of Prince Albert, Saskatchewan. One pipe yielded microdiamonds. The companies believe the kimberlite is spread over a much larger area than they originally had estimated, and have staked 170,000 hectares for exploration. Uranerz is seeking permission for additional exploration north of the site. (*Mining Journal*, October 27, 1989)

Israeli-Japanese joint diamond-polishing venture. Dov Riger of Israel and Tasaki Shinju Company Ltd. of Tokyo have formed one of the first Israeli-Japanese joint ventures with the opening of a new plant in Beit Shean, near the Jordan River. The plant, Tasaki Riger Diamond Polishing Israel Ltd., is a computerized cutting facility that is intended to supply the polished-diamond needs of the Japanese company. Moishe Schnitzer, president of the Israeli Diamond Exchange, predicted that the venture would greatly increase Israel's exports to Japan, which now stand at US$600 million per year. (*Diamond Intelligence Briefs*, October 27, 1989)

Ghana considers private mining. Primarily a producer of high-quality industrial diamonds (with 15%–20% of gem quality), Ghana has experienced sharp decreases in diamond production over the past several years. Thus, the government is now considering a return to private

mining, with the hope that an infusion of foreign capital will reverse the trend.

State-owned Ghana Consolidated Diamonds Ltd. currently handles most of the mining operations on the Birim River and in the Bonsa diamond field. However, production along the Birim River declined by 50% in 1988, to 225,105 ct. Even production from individual miners has dropped, to less than 10,000 ct annually. (*Diamond World*, September-October 1989)

Australians develop new technology for diamond exploration. A scanner that can find diamond deposits from the vantage point of an airplane is being developed by Dr. Peter Gregory of Diamond Company N.L., a subsidiary of Carr Boyd Minerals. The device, known as the MkI Airborne Multispectral Scanner, works by bouncing light beams off the earth. By comparing light spectra of different areas, scientists can determine the presence of certain minerals and geologic formations. This system represents a great advance over the "primitive" soil sampling and airborne geophysical methods for locating mineral deposits, and, while airborne scanners are not new in the industry, the MkI is said to be the most sophisticated and accurate.

The MkI is flown in a twin engine light aircraft at altitudes up to 10,000 ft. A real-time image processing capability provides for immediate determination of image quality that is both accurate and clear. The scanner has been used successfully in explorations by Carr Boyd Minerals and in its joint ventures with other companies. De Beers is using the scanner to search for diamonds in its diamond tenements.

Diamond exploration has always been a key interest in Australia. Currently, more than a dozen companies are investigating thousands of leases throughout the country, and it is estimated that US$30 million will be spent on diamond exploration in 1989. (*Mazal U'Bracha*, September 1989)

Figure 12. Fine, large orthoclase feldspar crystals like this 235-ct specimen are being recovered from a new deposit in Madagascar. Photo by Robert Weldon.

COLORED STONES

New amethyst discovery in the eastern United States. Excellent amethyst scepter crystals were uncovered at a road construction site in Salem, Connecticut. Scepters found loose in the topsoil and also in cavities in gneiss measured up to 9 cm long, and showed exceptional transparency as well as clearly displayed phantoms and "flaws." Also found at the site were numerous smaller colorless quartz crystals that exhibited three adjacent, heavily encrusted prism faces opposing a single, very large, rhombohedral face, which suggests the gravitational or current flow of the nutrient solution from which they grew. (*Rocks & Minerals*, November/December 1989)

Beryl discovery in Finland. The Finnish Geological Survey (GSI) has reported the discovery of a completely transparent green beryl ("emerald") crystal weighing 2,250 ct. The GSI plans to lead an intensified search at the 2-hectare site, and two independent mining companies have expressed interest in carrying out exploration. (*Mining Journal*, London, December 1, 1989)

New find of orthoclase. Mr. E. Julius Petsch, Jr., of Idar-Oberstein, West Germany, has advised us of a major new discovery of gem-quality orthoclase feldspar on the island nation of Madagascar. He reported seeing individual facetable pieces of a rich yellow color weighing as much as 500 grams (2,500 ct). Mr. Petsch donated to GIA for study a well-terminated crystal that weighs 47 grams (235 ct) and measures approximately 51.7 × 26.2 × 22.5 mm (figure 12).

The 1987 edition of Arem's *Color Encyclopedia of Gemstones* (Arem, 1987) lists the largest faceted yellow orthoclase in the Smithsonian collection at 249.6 ct. It is reported to have come from Itrongahy, Madagascar, which is the same general area where this new deposit was found.

Figure 13. This 14.98-ct cabochon represents a new find of asteriated quartz from a locality in Plumas County, CA. Photo by Robert Weldon.

California star quartz. David Carl Muster, of Stockton, California, reported to Gem News that he has discovered a deposit of star quartz in a vein in Plumas County. The color ranges from bluish white to white and even pink (figure 13). The largest star cabochon cut to date is bluish white and weighs 73 ct; the largest pink cabochon is 60 ct. All the stones cut thus far display six- to 12-rayed stars of various intensities. Many additional stars can be seen on the sides of cabochons or around spheres of this material.

East African spinels. Mr. Petsch also recently provided several samples of gem-quality spinel from the Umba Valley of Tanzania (figure 14). The spinels occur in a variety of colors that reportedly include pink, colorless, blue, and violet, similar to those in which the fancy-color sapphires from this area occur.

Oregon sunstone update. Larry Gray of One Track Mines, Boise, Idaho, has provided the Gem News editors with an update on activities at the Ponderosa mine, which produces sunstone feldspar (labradorite). The mine is located at 5800 ft. (1763 m) above sea level in the Ochoco National Forest, 40 mi. north-northwest of Burns in eastern Oregon. Weather limits mining to about six months of the year.

During the 1988 mining season, exploration indicated a sizable deposit, and hand-mining techniques produced a significant amount of gem material. Geologic reports

Figure 14. Spinel crystals from the Umba Valley in Tanzania have colors reminiscent of some of the fancy-color sapphires for which this locality is known. The largest shown here weighs 5.12 ct. Photo by Robert Weldon.

indicate that the deposit has excellent long-term potential. The majority of the material is described as being of "cabochon and bead quality" and exhibiting a strong sunstone effect. Body colors range from a light yellow "straw" color, to pink and "salmon," to a darker red-orange and red (figure 15). Rarely, green and bicolored (green with one of the other colors) material is found. The greenish stones exhibit pleochroism in green-green-red or green-red-red. According to Mr. Gray, the pleochroism is so pronounced in some of these stones

Figure 15. Oregon continues to produce fine labradorite sunstone, as exemplified by the cabochon, rough, and 10.76-ct faceted stone shown here. Photo by Robert Weldon.

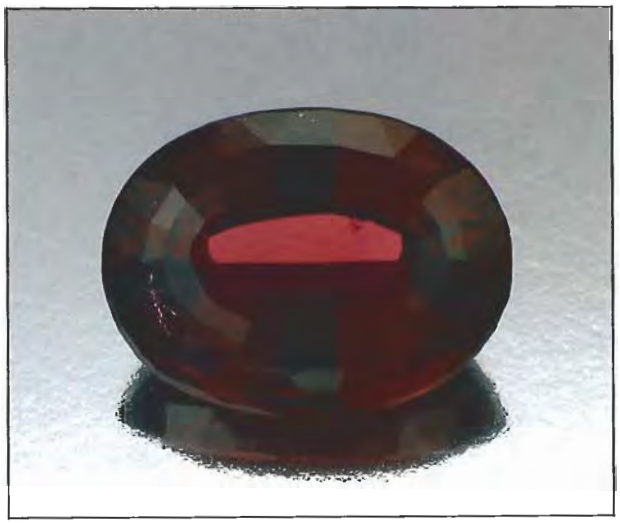


Figure 16. At 20.37 ct, this liddicoatite is believed to be the largest fashioned specimen of this tourmaline species. Photo by Robert Weldon.

that, if properly oriented, a faceted stone may appear uniformly green when viewed from one side and red when examined from the other.

The majority of the rough ranges from 0.5 to 6.0 grams (2.5–30 ct), and will cut beads of 3.5–7 mm and cabochons averaging 2 ct. The largest cabochon fashioned to date weighs 24.67 ct. Facetable material ranges from 0.2 to 1.0 grams (1–5 ct); the largest faceted stone cut to date is dark red and weighs 10.76 ct.

Although much of the 1989 season was spent removing overburden and trees, approximately 100 kg of gem-quality material was still recovered.

Largest known faceted liddicoatite tourmaline reportedly found in Brazil. Great discoveries and important gemstones are often stumbled across by accident, and such was the case with a 20.61-ct liddicoatite that found its way to GIA last October. Staff librarian Robert Weldon, who is in the process of expanding the slide collection of the Richard T. Liddicoat Library and Information Center, was offered the opportunity by dealer Mauro C. Souza to photograph several tourmalines. He noticed among them a large oval-cut gem that the owner said was a rubellite he had purchased in Minas Gerais, Brazil. Mr. Weldon admired the unique dark reddish purple color, and showed the stone to GIA research scientist Emmanuel Fritsch. To check the identification, Dr. Fritsch ran the stone on the recording spectrophotometer and determined that it had an exact spectral match with liddicoatite. On October 24, GIA President William E. Boyajian formally presented the rare tourmaline, recut to 20.37 ct (figure 16) and still believed to be the largest known faceted liddicoatite, to Chairman Richard T. Liddicoat. If the origin can be confirmed, Minas Gerais will represent a new source of this rare gem.

The stone has been set in a large chalice by the GIA Jewelry Manufacturing Arts Department, and is currently on display at GIA headquarters in Santa Monica.

Unusual iridescent zircon. The Gem News editors recently examined an interesting 2.30-ct yellowish green zircon (figure 17) that displayed what at first appeared to be unusually strong dispersion. Closer examination, however, revealed that the spectral color effect was caused by diffraction and interference of light from the finely laminated structure of this metamict stone. Although metamict green zircons from Sri Lanka are relatively common, this is the first such stone we have seen that exhibits this color effect.

SYNTHETICS AND SIMULANTS

Glass imitation emerald crystal. In January of this year, Dr. Gordon Austin, of the U.S. Bureau of Mines, sent a "crystal" that he had received from a group of Zambian emerald dealers to GIA. As described in ICA Alert No. 28, originated by GIA, the "crystal" weighs 82.85 ct and measures 34.00 × 21.69 × 18.33 mm (figure 18). It was accompanied by a 1.01-ct fragment that had obviously been chipped from one edge of the main piece.

The "crystal" is a slightly tapered barrel-shaped prism

Figure 17. The spectral colors seen in this 2.30-ct metamict zircon are caused by diffraction and interference of light. Stone courtesy of Ralph Joseph, Encino, CA; photo by Robert Weldon.

Figure 18. The five-sided symmetry quickly proves that this 34-mm-long fabricated glass specimen is not a natural beryl crystal. Photo by Robert Weldon.

with a rough-textured surface and a rather unconvincing medium-dark yellowish green color. Small patches of a light orangy brown clay-like "matrix" and flakes of biotite mica adhere to all of the prism faces; one apparent termination is coated with mica while the other is somewhat cavernous and coated with the clay-like substance. The prism faces are slightly concave, with some edges appearing molded and/or partially melted. The most unusual feature of this emerald imitation is that in cross-section it is five- rather than six-sided, so a simple count of the external crystal faces shows that it is not a natural beryl crystal.

Standard gemological testing proved that the specimen was constructed of man-made glass. Magnification revealed numerous spherical gas bubbles in both the fragment and the main mass.

Since preparing the original ICA report, the Gem News editors have been made aware of additional glass imitation emeralds that reportedly originated in Africa.

New synthetic ruby. ICA Laboratory Alert No. 30, originated by Dr. Ulrich Henn and Prof. Dr. Hermann Bank, reports on a new synthetic ruby that is believed to come from the USSR. The material is described as dark red and showing an "aggregate-like, grained texture with homogeneous regions" (figure 19). The largest rough specimen examined weighed 30 ct; transparent areas of the crystals cut stones of up to 4 ct.

Gemological properties are listed as follows: R.I., 1.774–1.765; birefringence, 0.009; density, 4.02 gm/cm^3; bright red fluorescence to long-wave U.V. radiation and red to short-wave U.V. Magnification revealed "bubble-like" black inclusions that were believed to be flux residue. Optical absorption spectra showed that the material was colored by chromium, with typical absorption bands at 555 and 410 nm; the absorption minimum in the ultraviolet range was at 330 nm.

Figure 19. These rough clusters (the largest is 30 ct) show the aggregate-like nature of this new synthetic ruby, which is reportedly manufactured in the USSR. Photo courtesy of Dr. Ulrich Henn and Prof. Dr. Hermann Bank, Deutsche Stiftung Edelsteinforschung.

Acknowledgments: The editors would like to thank the following for their help in preparing this section: Emmanuel Fritsch, GIA research scientist; Karin Hurwit, a gem identification supervisor in the GIA Gem Trade Laboratory, Inc.; Loretta Loeb, GIA collection curator; and Maha Smith, archival researcher.

Suggestions for Authors

GEMS & GEMOLOGY is an international publication of original contributions (not previously published in English) concerning the study of gemstones and research in gemology and related fields. Topics covered include (but are not limited to) colored stones, diamonds, gem instruments, gem localities, gem substitutes (synthetics), gemstones for the collector, jewelry arts, and retail management. Manuscripts may be submitted as:

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

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

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

MANUSCRIPT PREPARATION

All material, including tables, legends, and references, should be typed double spaced on 8½ × 11" (21 × 28 cm) sheets. The various components of the manuscript should be prepared and arranged as follows:

Title page. Page 1 should provide: (a) the article title; (b) the full name of each author with his or her affiliation (the institution, city, and state or country where he/she works); and (c) acknowledgments.

Abstract. The abstract (approximately 150 words for a feature article, 75 words for a note) should state the purpose of the article, what was done, and the main conclusions.

Text. Papers should follow a clear outline with appropriate heads. For example, for a research paper, the headings might be: Introduction, Previous Studies, Methods, Results, Discussion, Conclusion. Other heads and subheads should be used as the subject warrants. For general style, see *A Manual of Style* (The University of Chicago Press, Chicago).

References. References should be used for any information that is taken directly from another publication, to document ideas and facts attributed to—or facts discovered by—another writer, and to refer the reader to other sources for additional information on a particular subject. Please cite references in the text by the last name of the author(s) and the year of publication—plus the specific page referred to, if appropriate—in parentheses (e.g., Liddicoat and Copeland, 1967, p. 10). The references listed at the end of the paper should be typed double spaced in alphabetical order by the last name of the senior author. Please list only those references actually cited in the text (or in the tables or figures).

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

Daragh P.J., Sanders J.V. (1976) Opals. *Scientific American,* Vol. 234, pp. 84–95.

Liddicoat R.T. Jr., Copeland L.L. (1967) *The Jewelers' Manual,* 2nd ed. Gemological Institute of America, Santa Monica, CA.

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

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

Submit black-and-white photographs and photomicrographs in the final desired size if possible.

Color photographs—35 mm slides or 4 × 5 transparencies—are encouraged.

All figure legends should be typed double spaced on a separate page. Where a magnification is appropriate and is not inserted on the photo, please include it in the legend.

MANUSCRIPT SUBMISSION

Please send three copies of each manuscript (and three sets of figures and labels) as well as material for all sections to the Editorial Office: *Gems & Gemology,* 1660 Stewart Street, Santa Monica, CA 90404.

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REVIEW PROCESS

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

THE GEMS & GEMOLOGY MOST VALUABLE ARTICLE AWARD

Alice S. Keller, Editor

At *Gems & Gemology,* we continually strive to bring you valuable articles on new enhancements, important localities, and gem identification. To accomplish this, however, we are totally dependent on the support of our authors (many of whom provide several papers a year). They receive no pay for their efforts, yet they work long hours and do tremendous amounts of research. That is why we ask you, our readers, to vote each spring for the articles that have helped you the most during the past year: to honor these people.

This year we received more ballots than ever, with all articles receiving acclaim. The clear winner of first place (it received more votes than any article in the previous years) was "The Characteristics and Identification of Filled Diamonds," written by a team of GIA specialists: John Koivula, Robert Kammerling, Emmanuel Fritsch, C. W. Fryer, David Hargett, and Robert Kane. Second place went to "Polynesian Black Pearls," by Marisa Goebel and Dona Dirlam. "Emerald and Gold Treasures of the Spanish Galleon Nuestra Señora de Atocha" received third place; it, too, was a cooperative effort, by coauthors Robert Kane, Robert Kammerling, Rhyna Moldes, John Koivula, Shane McClure, and Christopher Smith. The authors of these three articles will share cash prizes of $500, $300, and $100, respectively. The three-year subscription to *Gems & Gemology,* chosen at random from the many ballots received, will go to Eva M. Dansereau of Anola, Manitoba, Canada. Congratulations to all! Brief biographies of the winning authors appear below.

C. W. FRYER · ROBERT E. KANE · ROBERT C. KAMMERLING · JOHN I. KOIVULA · EMMANUEL FRITSCH

John Koivula, chief gemologist in GIA's Technical Development Department, is world renowned for his expertise in inclusions and photomicrography. A graduate gemologist, Mr. Koivula also is a fellow of the Gemmological Association of Great Britain and holds bachelor's degrees in chemistry and mineralogy from Eastern Washington State University. As GIA's director of the Technical Development Department, **Robert C. Kammerling** helps coordinate research and development activities between the Institute's Education and Research departments. He is also coeditor—with John Koivula—of the Gem News section of *Gems & Gemology,* as well as a regular contributor to numerous publications worldwide. A native of Chicago, Illinois, Mr. Kammerling has a B.A. from the University of Illinois. **Dr. Emmanuel Fritsch** received his Ph.D. at the Sorbonne. He is now a research scientist at GIA, and specializes in the study of twinned crystals and the origin of color in gem materials. Currently director of West Coast operations and gem identification for the GIA Gem Trade Laboratory, and editor of the Gem Trade Lab Notes section of *Gems & Gemology,* **C. W. ("Chuck") Fryer** has more than 20 years of experience in gem identification. Mr. Fryer is a graduate gemologist and a fellow of the Gemmological Association of Great Britain. **Robert E. Kane** is a supervisor of gem identification at the GIA Gem Trade Laboratory, Santa Monica. He also serves on the editorial review board of *Gems & Gemology* and as a contributing editor for the Gem Trade Lab Notes section. Mr. Kane's specialties include the separation of natural, synthetic, and treated gem materials and the identification of rare collector gems.

DAVID HARGETT

David Hargett, a 13-year veteran of GIA, is manager of gem identification at the GIA Gem Trade Laboratory, New York, and a contributing editor to the Gem Trade Lab Notes section of *Gems & Gemology*. He is also a Certified Gemologist, a member of the Board of Directors of the New York Mineralogical Club, and a graduate of New York University. Mr. Hargett has traveled worldwide giving lectures on gemological topics to various clubs and associations.

MARISA GOEBEL

Marisa Goebel, an independent goldsmith in Beverly Hills, specializes in creating black pearl jewelry. She completed the Graduate Gemology and Jewelry Manufacturing Arts programs at GIA and also worked in the GIA Gem Trade Laboratory. Subsequently, she became a goldsmith apprentice in Munich, West Germany, before attending the Technical School for Design in Pforzheim. Ms. Goebel was born and raised in Mexico City.

DONA MARY DIRLAM

Now senior research librarian at GIA, Ms. Dirlam previously taught earth science for 10 years. In addition to managing the new Richard T. Liddicoat

Library and Information Center, she serves as editor of the Gemological Abstracts section and the Annual Index of *Gems & Gemology*. A native of Redwood Falls, Minnesota, she is a graduate gemologist, holds a fellowship diploma from the Gemmological Association of Great Britain, and has a master's degree in geology/geophysics from the University of Wisconsin-Madison.

CHRISTOPHER P. SMITH · ROBERT E. KANE · ROBERT C. KAMMERLING · SHANE F. McCLURE · JOHN I. KOIVULA

Biographies for Robert E. Kane, Robert C. Kammerling, and John I. Koivula appear above.

Shane McClure, a native Californian, is a senior staff gemologist in the gem identification section of the GIA Gem Trade Laboratory, Santa Monica. Mr. McClure has 12 years of experience in the gem field. He is also an accomplished gem and jewelry photographer.

Christopher P. Smith, originally from the Chicago area, is a graduate of GIA's Graduate Gemology and Jewelry Manufacturing Arts programs. He has worked at the GIA Gem Trade Laboratory for over four years in both the grading and identification sections.

RHYNA MOLDES

Mrs. Moldes is president of International Eximgems, a diamond and colored stone wholesale company. She is a graduate gemologist and a fellow of the Gemmologicial Association of Great Britain and the Writers Guild of Spain. She also has two B.A. degrees, in music and folklore. Mrs. Moldes recently lectured on the Atocha's treasures at the Centro Europeo de Gemología y Joyería in Madrid, Spain. She is currently preparing the first dictionary on gems and gemology written originally in Spanish.

Gems & Gemology

C·H·A·L·L·E·N·G·E

GIA's Continuing Education program was established to provide jeweler-gemologists with the opportunity to fine-tune and expand their skills in this ever-changing field. The 1990 *Gems & Gemology* Challenge will test you on the 1989 issues of the journal—issues that brought you vital information on fracture-filled diamonds, black pearls from Polynesia, and emeralds from Capoeirana, Brazil. They also discussed the latest synthetics and techniques to identify them. Those who get a 75% score or better on the Challenge will receive a GIA Continuing Education Certificate—proof that you care about your profession and keep up with the most current information. Those readers who receive a perfect score (100%) will also be recognized in the Fall issue of *Gems & Gemology.*

The following 25 multiple-choice questions are based on information published in the four 1989 issues of *Gems & Gemology.* We encourage you to refer to those issues to find the *single best answer* as published in the corresponding article or section; then mark the appropriate letter on the card provided in this issue (photocopies or facsimiles of this card will not be accepted). Mail the card with your answers (be sure to include your name and address) by Monday, August 27: Don't forget to put sufficient postage on the card (15¢ in the U.S.). All entries will be acknowledged with a letter and an answer key.

Note: Questions are taken only from the four 1989 issues. Choose the single best answer for each question.

1. Mild radioactivity was observed in spinel-and-glass triplets in which of the following color ranges?
   A. violet-blue to purplish red
   B. blue-green to greenish blue
   C. orange-red to yellowish orange
   D. yellow-green to greenish yellow

2. The Sinkankas Collection at the Richard T. Liddicoat Library and Information Center consists of more than
   A. 8,000 items.
   B. 14,000 items.
   C. 19,000 items.
   D. 25,000 items.

3. The term *gem nodule* refers to a small rounded mass of water-clear gem material that occurs in the central portion of
   A. a geode.
   B. an emerald.
   C. a massive feldspar.
   D. an otherwise included crystal.

4. The largest emerald deposit to date in Pakistan is the
   A. Barang deposit.
   B. Mingora deposit.
   C. Khaltaro deposit.
   D. Gujar Killi deposit.

5. The best means of determining that surface-reaching fractures in a diamond have been filled is
   A. microscopy.
   B. thermal inertia.
   C. chemical analysis.
   D. unaided visual observation.

6. The vast majority of black-pearl culturing occurs in
   A. China.
   B. Japan.
   C. Indonesia.
   D. Polynesia.

7. In addition to twinning, all of the following can aid in the separation of natural from synthetic amethyst except
   A. color zoning.
   B. refractive index.
   C. infrared spectrometry.
   D. distinctive inclusions.

8. The GIA Gem Trade Laboratory graded the clarity of the Hope Diamond as
   A. F_1.
   B. IF.
   C. VS_1.
   D. VVS_1.

9. Reflectance infrared spectroscopy is most useful in gemology
   A. to determine the species of the material.
   B. to separate dyed from natural-color stones.
   C. to detect irradiation-induced color centers.
   D. to detect separation planes in assembled stones.

10. Internal characteristics noted in all of the Capoeirana samples described in this report include
   A. pyrite and calcite crystals.
   B. actinolite and tremolite needles.
   C. two- and three-phase fluid inclusions.
   D. hexagonal color zoning and negative crystals.

11. If no other color zoning is present, green diamonds with a bright blue zone at the culet or keel-line are
   A. probably filled.
   B. probably treated.
   C. proved to be treated.
   D. enhanced with a synthetic diamond thin film.

12. Emeralds from the *Atocha* showed evidence of their long immersion in seawater by
   A. surface etching.
   B. high birefringence.
   C. low specific gravity.
   D. chalky yellow-green fluorescence in fractures.

13. The only consistent internal feature evident in all of the eight Gujar Killi emeralds tested was the presence of
   A. color zoning.
   B. growth zoning.
   C. fluid inclusions.
   D. fine cracks with limonite staining.

14. According to the Central Selling Organization, diamond sales for the first six months of 1989
   A. were slightly up.
   B. were slightly down.
   C. exceeded all previous records.
   D. maintained the level of the previous year.

15. The jewelry examined from the *Atocha* represents several jewelry manufacturing techniques popular in the early 17th century, including
   A. lost-wax casting and filigree.
   B. sand casting and chain drawing.
   C. lost-wax casting and chain drawing.
   D. sand casting and the use of cloisonné.

16. The trade name "Larimar" refers to
   A. petalite.
   B. pectolite.
   C. pollucite.
   D. phosphophyllite.

17. The radioactive decay that occurs in zircon is usually caused by the presence of
   A. uranium and thorium.
   B. hafnium and uranium.
   C. plutonium and thorium.
   D. zirconium and hafnium.

18. The presence of hematite in etched channels in topaz is evidence that the stone is
   A. dyed.
   B. irradiated.
   C. heat treated.
   D. natural color.

19. The red component in chicken-blood stone is
   A. ruby.
   B. cinnabar.
   C. red beryl.
   D. pyrope garnet.

20. Irradiation darkens off-color saltwater cultured pearls by
   A. darkening the bead nucleus.
   B. darkening the conchiolin layer.
   C. altering the structure of the nacre.
   D. releasing organic dyes from the conchiolin.

21. The Capoeirana emerald deposit may be an extension of the
   A. Muzo mine.
   B. Belmont mine.
   C. Paraíba mine.
   D. Santa Terezinha mine.

22. Along with Botswana and the USSR, the country expected to be the major producer of gem-quality diamonds in the 21st century is
   A. China.
   B. Angola.
   C. Australia.
   D. South Africa.

23. One of the most obvious and most common characteristics of filled fractures in diamonds is
   A. a "flash effect."
   B. trapped bubbles.
   C. a crackled texture.
   D. a feathery appearance.

24. One useful indicator in the separation of "Opalite" imitation opal from natural or synthetic opal is
   A. refractive index.
   B. visual appearance.
   C. absorption spectrum.
   D. polariscope reaction.

25. The most identifiable feature of a synthetic diamond thin film is its
   A. granular texture.
   B. electrical conductivity.
   C. ultraviolet luminescence.
   D. reaction to polarized light.